Appendix A: Cost and Macroeconomic Modeling

Introduction

The purpose of this appendix is to describe in detail the estimation of direct compliance costs associated with the CAA and the effect of those expenditures on U.S. economic conditions from 1970 to 1990. The first section of this appendix describes the dynamic, general equilibrium macroeconomic model used to examine economy-wide effects. Two broad categories of models were considered for use in the assessment: Macroeconomic forecasting models (e.g., the Data Resources Inc. model of the U.S. economy), and general equilibrium models (e.g., Hazilla and Kopp [1990], and Jorgenson and Wilcoxen [1990a]). The project team selected the Jorgenson-Wilcoxen (J/W) general equilibrium model of the United States for this analysis (Jorgenson and Wilcoxen [1990a]). There are two main reasons for choosing a dynamic general equilibrium approach: To capture both the direct and indirect economic effects of environmental regulation, and to capture the long-run dynamics of the adjustment of the economy. The general equilibrium framework enabled the project team to assess shifts in economic activity between industries, including changes in distributions of labor, capital, and other production factors within the economy, and changes in the distribution of goods and services.

The second section describes the data sources for direct compliance expenditures and presents estimates of historical air pollution control expenditures. These estimates are derived primarily from EPA's 1990 report entitled "Environmental Investments: The Cost of a Clean Environment"[1] (hereafter referred to as *Cost of Clean*). Specific adjustments to the *Cost of Clean* stationary source and mobile source O&M data needed to adapt these data for use in the present study are also described. These adjusted expenditure estimates represent the compliance cost data used as inputs to the J/W model to determine macroeconomic effects.

The final section presents a summary of the direct expenditure data, presents direct costs in a form that can be compared to the benefits estimates found elsewhere in the study, and discusses indirect effects arising from compliance expenditures estimated by the macroeconomic model. The indirect effects reported by the model are sectoral impacts and changes in aggregate measures of economic activity such as household consumption and gross national product. These indirect effects are second-order impacts of compliance expenditures — a parallel modeling exercise to estimate second-order economic impacts arising from the benefits of compliance (e.g., increased output as a result of improved longevity or fewer workdays lost as a result of non-fatal heart attacks) has not been attempted.

Macroeconomic Modeling

EPA analyses of the costs of environmental regulations typically quantify the direct costs of pollution abatement equipment and related operating and maintenance expenses. However, this approach does not fully account for all of the broader economic consequences of reallocating resources to the production and use of pollution abatement equipment. A general equilibrium, macroeconomic model could, in theory, capture the complex interactions between sectors in the economy and assess the full economic cost of air pollution control. This would be particularly useful for assessing regulations that may produce significant interaction effects between markets. Another advantage of a general equilibrium, macroeconomic framework is that it is internally consistent. The consistency of sectoral forecasts with realistic projections of U.S. economic growth is ensured since they are estimated within the context of a single model.[2] This contrasts

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[1] Environmental Investments: The Cost of a Clean Environment, Report of the Administrator of the Environmental Protection Agency to the Congress of the United States, EPA-230-11-90-083, November 1990.

[2] In the present study, both benefits and costs are driven by of the same macroeconomic projections from the Jorgenson/Wilcoxen model, to ensure that the estimates are based on a consistent set of economic assumptions.

with typical EPA analyses that compile cost estimates from disparate sectoral and partial equilibrium models.

The economic effects of the CAA may be over- or underestimated, if general equilibrium effects are ignored, to the extent that sectors not directly regulated are affected. For example, it is well known that the CAA imposed significant direct costs on the energy industry. Economic sectors not directly regulated will nonetheless be affected by changes in energy prices. However, an examination of the broader effects of the CAA on the entire economy might reveal that the CAA also led to more rapid technological development and market penetration of environmentally "clean" renewable sources of energy (e.g., photovoltaics). These effects would partially offset adverse effects on the energy industry, and lead to a different estimate of the total economic cost to society of the CAA.

The significance of general equilibrium effects in the context of any particular analysis is an empirical question. Kokoski and Smith (1987) used a computable general equilibrium model to demonstrate that partial-equilibrium welfare measures can offer reasonable approximations of the true welfare changes for large exogenous changes. In contrast, the results of Jorgenson and Wilcoxen (1990a) and Hazilla and Kopp (1990) suggest that total pollution abatement in the U.S. has been a major claimant on productive resources, and the effect on long-run economic growth may be significant. Again, such conclusions must be considered in light of the limitations of general equilibrium models.

Choice of Macroeconomic Model

The adequacy of any model or modeling approach must be judged in light of the policy questions being asked. One goal of the present study is to assess the effects of clean air regulations on macroeconomic activity. Two broad categories of macroeconomic models were considered for use in the assessment: short run, Keynesian models and long-run, general equilibrium models.

Recognizing that structural differences exist between the models, one needs to focus in on the particular questions that should be answered with any particular model. The Congressional Budget Office (1990) noted:

> "Both the [Data Resources Incorporated] DRI and the IPCAEO models show relatively limited possibilities for increasing energy efficiency and substituting other goods for energy in the short run... Both models focus primarily on short-term responses to higher energy prices, and *neither is very good at examining how the structure of the economy could change in response to changing energy prices.* The [Jorgenson-Wilcoxen] model completes this part of the picture..."[3]

One strategy for assessing the macroeconomic effects of the CAA would be to use a DRI-type model in conjunction with the Jorgenson-Wilcoxen model to assess both the long-term effects and the short-run transitions, in much the same way that the Congressional Budget Office used these models to assess the effects of carbon taxes. However, because of significant difficulties in trying to implement the DRI model in a meaningful way, the project team chose to focus on the long-run effects of the CAA. Structural changes (e.g., changes in employment in the coal sector due to the CAA) can be identified with the Jorgenson-Wilcoxen model.

Overview of the Jorgenson-Wilcoxen Model

The discussion below focuses on those characteristics of the Jorgenson-Wilcoxen model that have important implications for its use in the assessment of environmental regulations (see Table A-1). The J/W model is a detailed dynamic general equilibrium model of the U.S. economy designed for medium run analysis of regulatory and tax policy (Jorgenson and Wilcoxen [1990a]). It provides projections of key macroeconomic variables, such as GNP and aggregate consumption, as well as energy flows between economic sectors. As a result, the model is particularly useful for examining how the structure of the economy could change in response to changes in re-

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[3] The Congressional Budget Office report (1990) refers to an older (1981) version of the Jorgenson model, not the current (1988) version. The approach to long-run dynamics differs between the two models. The newer Jorgenson-Wilcoxen model contains both the capital accumulation equation and the capital asset pricing equation. The 1981 version of the model contained only the capital accumulation equation.

Table A-1. Key Distinguishing Characteristics of the Jorgenson-Wilcoxen Model.

- Dynamic, general equilibrium, macroeconomic model of the U.S. economy.
- Econometrically estimated using historic data.
- Free mobility of a single type of capital and labor between industries.
- Detailed treatment of production and consumption.
- Rigorous representation of savings and investment.
- Endogenous model of technical change.
- Does not capture unemployment, underemployment, or the costs of moving capital from one industry to another.

source prices. For the purpose of this study, it has five key features: a detailed treatment of production and consumption, parameters estimated econometrically from historical data, an endogenous model of technical change, a rigorous representation of saving and investment, and free mobility of labor and capital between industries.

The first two features, industry and consumer detail and econometric estimation, allow the model to capture the effects of the CAA at each point in time for given levels of technology and the size of the economy's capital stock. A detailed treatment of production and consumption is important because the principal effects of the Clean Air Act fell most heavily on a handful of industries. The J/W model divides total U.S. production into 35 industries which allows the primary economic effects of the CAA to be captured. Econometric estimation is equally important because it ensures that the behavior of households and firms in the model is consistent with the historical record.

The model's second two features —its representations of technical change and capital accumulation— complement the model's intratemporal features by providing specific information on how the Act affected technical change and the accumulation of capital. Many analyses of environmental regulations overlook or ignore intertemporal effects but these effects can be very important. Jorgenson and Wilcoxen (1990a) suggests that the largest cost of all U.S. environmental regulations together was that the regulations reduced the rate of capital accumulation.

The model's last feature, free mobility of a single type of capital and a single type of labor, is important because it limits the model's ability to measure the short run costs of changes in policy. J/W is a full-employment model that describes the long-run dynamics of transitions from one equilibrium to another. Capital and labor are both assumed to be freely mobile between sectors (that is, they can be moved from one industry to another at zero cost) and to be fully used at all times. Over the medium to long run, this is a reasonable assumption, but in the short run it is too optimistic. In particular, the model will understate the short run costs of a change in policy because it does not capture unemployment, underemployment, or the costs of moving capital from one industry to another. A single rate of return on capital exists that efficiently allocates the capital in each period among sectors. Similarly, a single equilibrium wage rate allocates labor throughout the economy.

Structure of the Jorgenson-Wilcoxen Model

The J/W model assesses a broad array of economic effects of environmental regulations. Direct costs are captured as increased expenditures on factors of production —capital, labor, energy and materials— that the various industries must make to comply with the regulations, as well as additional out-of-pocket expenditures that consumers must make. Indirect costs are captured as general equilibrium effects that occur throughout the economy as the prices of factors of production change (e.g., energy prices). Also, the rate of technological change can respond to changes in the prices of factors of production, causing changes in productivity (Jorgenson and Fraumeni, 1981).

The model is divided into four major sectors: the business, household, government, and rest-of-the-world sectors. The business sector is further subdivided into 35 industries (see Table A-2).[4] Each sector produces a primary product, and some produce secondary products. These outputs serve as inputs to the production processes of the other industries, are used for investment, satisfy final demands by the household and government sectors, and are exported. The model also allows for imports from the rest of the world.

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[4] The 35 industries roughly correspond to a two-digit SIC code classification scheme.

Table A-2. Definitions of Industries Within the J/W Model.

Industry Number	Description
1	Agriculture, forestry, and fisheries
2	Metal mining
3	Coal mining
4	Crude petroleum and natural gas
5	Nonmetallic mineral mining
6	Construction
7	Food and kindred products
8	Tobacco manufacturers
9	Textile mill products
10	Apparel and other textile products
11	Lumber and wood products
12	Furniture and fixtures
13	Paper and allied products
14	Printing and publishing
15	Chemicals and allied products
16	Petroleum refining
17	Rubber and plastic products
18	Leather and leather products
19	Stone, clay, and glass products
20	Primary metals
21	Fabricated metal products
22	Machinery, except electrical
23	Electrical machinery
24	Motor vehicles
25	Other transportation equipment
26	Instruments
27	Miscellaneous manufacturing
28	Transportation and warehousing
29	Communication
30	Electric utilities
31	Gas utilities
32	Trade
33	Finance, insurance, and real estate
34	Other services
35	Government enterprises

The Business Sector

The model of producer behavior allocates the value of output of each industry among the inputs of the 35 commodity groups, capital services, labor services, and noncompeting imports. Output supply and factor demands of each sector are modeled as the results of choices made by wealth maximizing, price taking firms which are subject to technological constraints. Firms have perfect foresight of all future prices and interest rates. Production technologies are represented by econometrically estimated cost functions that fully capture factor substitution possibilities and industry-level biased technological change.

Capital and energy are specified separately in the factor demand functions of each industry. The ability of the model to estimate the degree of substitutability between factor inputs facilitates the assessment of the effect of environmental regulations. A high degree of substitutability between inputs implies that the cost of environmental regulation is low, while a low degree of substitutability implies high costs of environmental regulation. Also, different types of regulations lead to different responses on the part of producers. Some regulations require the use of specific types of equipment. Others regulations restrict the use of particular factor inputs; for example, through restrictions on the combustion of certain types of fuels. Both of these effects can change the rate of productivity growth in an industry through changes in factor prices.

The Household Sector

In the model of consumer behavior, consumer choices between labor and leisure and between consumption and saving are determined. A system of individual, demographically defined household demand functions are also econometrically estimated. Household consumption is modeled as a three stage optimization process. In the first stage households allocate lifetime wealth to full consumption in current and future time periods to maximize intertemporal utility. Lifetime wealth includes financial wealth, discounted labor income, and the imputed value of leisure. Households have perfect foresight of future prices and interest rates. In the second stage, for each time period full consumption is allocated between goods and services and leisure to maximize intratemporal utility. This yields an allocation of a household's time endowment between the labor market (giving rise to labor supply and labor income) and leisure time and demands for goods and services. In the third stage, personal consumption expenditures are allocated among capital, labor, noncompeting imports and the outputs of the 35 production sectors to maximize a subutility function for goods consumption. As with the business sector, substitution possibilities exist in consumption decisions. The model's flexibility enables it to capture the substitution of nonpolluting products for polluting ones that may be induced by environmental regulations. Towards this end, purchases of energy and capital services by households are specified separately within the consumer demand functions for individual commodities.

It is important to be clear regarding the notions of labor supply and demand within the J/W model, and what is meant by "employment" throughout this report. Labor demands and supplies are represented as quality-adjusted hours denominated in constant dollars. The labor market clears in each period; the quantity of labor services offered by households is absorbed fully by the economy's producing sectors. However, inferences regarding the number of persons employed require information on labor quality and work-hours per person over time and across simulations. Neither of these are explicitly modeled.

The Government Sector

The behavior of government is constrained by exogenously specified budget deficits. Government tax revenues are determined by exogenously specified tax rates applied to appropriate transactions in the business and household sectors. Levels of economic activity in these sectors are endogenously determined. Capital income from government enterprises (determined endogenously), and nontax receipts (given exogenously), are added to tax revenues to obtain total government revenues. Government expenditures adjust to satisfy the exogenous budget deficit constraint.

The Rest-of-the-World Sector

The current account balance is exogenous, limiting the usefulness of the model to assess trade competitiveness effects. Imports are treated as imperfect substitutes for similar domestic commodities and compete on price. Export demands are functions of foreign incomes and ratios of commodity prices in U.S. currency to the exchange rate. Import prices, foreign incomes, and tariff policies are exogenously specified. Foreign prices of U.S. exports are determined endogenously by domestic prices and the exchange rate. The exchange rate adjusts to satisfy the exogenous constraint on net exports.

Environmental Regulation, Investment, and Capital Formation

Environmental regulations have several important effects on capital formation. At the most obvious level, regulations often require investment in specific pieces of pollution abatement equipment. If the economy's pool of savings were essentially fixed, the need to invest in abatement equipment would reduce, or crowd out, investment in other kinds of capital on a dollar for dollar basis. On the other hand, if the supply of savings were very elastic then abatement investments might not crowd out other investment at all. In the J/W model, both the current account and government budget deficits are fixed exogenously so any change in the supply of funds for domestic investment must come from a change in domestic savings. Because households choose consumption, and hence savings, to maximize a lifetime utility function, domestic savings will be somewhat elastic. Thus, abatement investment will crowd out other investment, although not on a dollar for dollar basis.

The J/W assumption that the current account does not change as a result of environmental regulation is probably unrealistic, but it is not at all clear that this biases the crowding out effects in any particular direction. By itself, the need to invest in abatement capital would tend to raise U.S. interest rates and draw in foreign savings. To the extent this occurred, crowding out would be reduced. At the same time, however, regulation reduces the profitability of domestic firms. This effect would tend to lower the return on domestic assets, leading to a reduced supply of foreign savings which would exacerbate crowding out. Which effect dominates is an empirical question beyond the scope of this study.

In additional to crowding out ordinary investment, environmental regulation also has a more subtle effect on the rate of capital formation. Regulations raise the prices of intermediate goods used to produce new capital. This leads to a reduction in the number of capital goods which can be purchased with a given pool of savings. This is not crowding out in the usual sense of the term, but it is an important means by which regulation reduces capital formation.[5]

The General Equilibrium

The J/W framework contains intertemporal and intratemporal models (Jorgenson and Wilcoxen [1990c]). In any particular time period, all markets clear. This market clearing process occurs in response to any changes in the levels of variables that are speci-

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[5] Wilcoxen (1988) suggests that environmental regulation may actually lead to a "crowding in" phenomenon. Wilcoxen examined the effects of regulation at the firm level, and introduced costs into the model related to the installation of capital. He found that when firms shut down their plants to install environmental capital, they take account of the adjustment costs and often concurrently replace other older capital equipment. This effect, however, is not captured in the current version of the Jorgenson-Wilcoxen model.

fied exogenously to the model. The interactions among sectors determine, for each period, aggregate domestic output, capital accumulation, employment, the composition of output, the allocation of output across different household types, and other variables.

The model also produces an intertemporal equilibrium path from the initial conditions at the start of the simulation to the stationary state. (A stationary solution for the model is obtained by merging the intertemporal and intratemporal models.) The dynamics of the J/W model have two elements: An accumulation equation for capital, and a capital asset pricing equation. Changes in exogenous variables cause several adjustments to occur within the model. First, the single stock of capital is efficiently allocated among all sectors, including the household sector. Capital is assumed to be perfectly malleable and mobile among sectors, so that the price of capital services in each sector is proportional to a single capital service price for the economy as a whole. The value of capital services is equal to capital income. The supply of capital available in each period is the result of past investment, i.e., capital at the end of each period is a function of investment during the period and capital at the beginning of the period. This capital accumulation equation is backward-looking and captures the effect of investments in all past periods on the capital available in the current period.

The capital asset pricing equation specifies the price of capital services in terms of the price of investment goods at the beginning and end of each period, the rate of return to capital for the economy as a whole, the rate of depreciation, and variables describing the tax structure for income from capital. The current price of investment goods incorporates an assumption of perfect foresight or rational expectations. Under this assumption, the price of investment goods in every period is based on expectations of future capital service prices and discount rates that are fulfilled by the solution of the model. This equation for the investment goods price in each time period is forward-looking.[6]

One way to characterize the J/W model —or any other neoclassical growth model— is that the short-run supply of capital is perfectly inelastic, since it is completely determined by past investment. However, the supply of capital is perfectly elastic in the long run. The capital stock adjusts to the time endowment, while the rate of return depends only on the intertemporal preferences of the household sector.

A predetermined amount of technical progress also takes place that serves to lower the cost of sectoral production. Finally, the quality of labor is enhanced, giving rise to higher productivity and lower costs of production.

Given all of these changes, the model solves for a new price vector and attains a new general equilibrium. Across all time periods, the model solves for the time paths of the capital stock, household consumption, and prices. The outcomes represent a general equilibrium in all time periods and in all markets covered by the J/W model.

Configuration of the No-control Scenario

One of the difficulties in describing the no-control scenario is ascertaining how much environmental regulation would have been initiated by state and local governments in the absence of a federal program. It may reasonably be argued that many state and local governments would have initiated their own control programs in the absence of a federal role. This view is further supported by the fact that many states and localities have, in fact, issued rules and ordinances which are significantly more stringent and encompassing than federal minimum requirements. However, it may also be argued that the federal CAA has motivated a substantial number of stringent state and local control programs.

Specifying the range and stringency of state and local programs that would have occurred in the absence of the federal CAA would be almost entirely speculative. For example, factors which would complicate developing assumptions about stringency and scope of unilateral state and local programs include: (i) the significance of federal funding to support state and local program development; (ii) the influence of more severe air pollution episodes which might be expected in the absence of federally-mandated controls; (iii) the potential emergence of pollution havens, as well as anti-pollution havens, motivated by local

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[6] The price of capital assets is also equal to the cost of production, so that changes in the rate of capital accumulation result in an increase in the cost of producing investment goods. This has to be equilibrated with the discounted value of future rentals in order to produce an intertemporal equilibrium. The rising cost of producing investment is a cost of adjusting to a new intertemporal equilibrium path.

political and economic conditions; (iv) the influence of federally-sponsored research on the development of pollution effects information and control technologies; and (v) the need to make specific assumptions about individual state and local control levels for individual pollutants to allow estimation of incremental reductions attributable to federal control programs.

Another complication associated with the no-control scenario is the treatment of air pollution control requirements among the major trading partners of the U.S. Real-world manifestation of a no-control scenario would imply that public health and environmental goals were not deemed sufficiently compelling by U.S. policy makers. Under these conditions, major trading partners of the U.S. in Japan, Europe, and Canada may well reach similar policy conclusions. Simply put, if the U.S. saw no need for air pollution controls, there is little reason to assume other developed industrial countries would have either. In this case, some of the estimated economic benefits of reducing or eliminating air pollution controls in the U.S. would not materialize because U.S. manufacturers would not necessarily gain a production cost advantage over foreign competitors. However, like the question of state and local programs in the absence of a federal program, foreign government policies under a no-control scenario would be highly speculative.

Given the severity of these confounding factors, the only analytically feasible assumptions with respect to the no-control scenario are that (a) no new control programs would have been initiated after 1970 by the states or local governments in the absence of a federal role, and (b) environmental policies of U.S. trading partners remain constant regardless of U.S. policy.

Elimination of Compliance Costs in the No-Control Case

Industries that are affected by environmental regulations can generally respond in three ways: (i) with process changes (e.g., fluidized bed combustion); (ii) through input substitution (e.g., switching from high sulfur coal to low sulfur coal); and (iii) end-of-pipe abatement (e.g., the use of electrostatic precipitation to reduce the emissions of particulates by combustion equipment).[7] Clean air regulations have typically led to the latter two responses, especially in the short run. End-of-pipe abatement is usually the method of choice for existing facilities, since modifying existing production processes can be costly. This approach is also encouraged by EPA's setting of standards based on the notion of "best available technology" (Freeman, 1978).

All three possible responses may lead to: (i) unanticipated losses to equity owners; (ii) changes in current output; and (iii) changes in long-run profitability. If firms were initially maximizing profits, then any of the above three responses will increase its costs. Fixed costs of investment will be capitalized immediately. This will result in a loss to owners of equity when regulations are introduced. As far as firms are concerned, this is just like a lump sum tax on sunk capital. Such effects will not affect growth or efficiency. However, regulations could also change marginal costs and therefore current output. In addition, they could change profits (i.e., the earnings of capital), and thus affect investment. Both of these effects will reduce the measured output of the economy.

On the consumption side, environmental regulations change consumers' expectations of their lifetime wealth. In the no-control scenario of this assessment, lifetime wealth increases. This causes an increase in consumption. In fact, with perfect foresight, consumption rises more in earlier time periods. This also results in a change in savings.

Capital Costs - Stationary Sources

To appropriately model investment in pollution control requires a recognition that the CAA had two different effects on capital markets. First, CAA regulations led to the retrofitting of existing capital stock in order to meet environmental standards. In the no-control scenario, these expenditures do not occur. Instead, the resources that were invested in pollution abatement equipment to retrofit existing sources are available to go to other competing investments. Thus, at each point in time, these resources might go to investments in capital in the regulated industry, or may go into investments in other industries, depending upon relative rates of return on those investments. This will affect the processes of capital formation and deepening.

Second, the CAA placed restrictions on new sources of emissions. When making investment decisions, firms take into account the additional cost of pollution abatement equipment. Effectively, the

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[7] Regulation may also affect the rate of investment, and change the rate of capital accumulation.

"price" of investment goods is higher because more units of capital are required to produce the same amount of output. In the no-control scenario, there are no restrictions on new sources and hence no requirements for pollution control expenditures. Effectively, the "price" of investment goods is lower. Thus, at each point in time, investors are faced with a lower price of investment goods. This results in a different profile for investment over time.

Operating and Maintenance Costs - Stationary Sources

In addition to purchasing pollution abatement equipment, firms incurred costs to run and maintain the pollution abatement equipment. In the no-control scenario, resources used to pay for these operating and maintenance (O&M) costs are freed up for other uses. The model assumes that the resources required to run and maintain pollution control equipment are in the same proportions as the factor inputs used in the underlying production technology. For example, if 1 unit of labor and 2 units of materials are used to produce 1 unit of output, then one-third of pollution control O&M costs are allocated to labor and two-thirds are allocated to materials. These adjustments were introduced at the sector level. O&M expenditures are exclusive of depreciation charges and offset by any recovered costs.

Capital Costs - Mobile Sources

Capital costs associated with pollution control equipment were represented by changing costs for motor vehicles (sector 24) and other transportation equipment (sector 26). Prices (unit costs) were reduced in proportion to the value of the pollution control devices contained in cars, trucks, motorcycles, and aircraft.

Operating and Maintenance - Mobile Sources

Prices for refined petroleum products (sector 16) were changed to reflect the resource costs associated with producing unleaded and reduced lead gasoline (fuel price penalty), the change in fuel economy for vehicles equipped with pollution control devices (fuel economy penalty), and the change in fuel economy due to the increased fuel density of lower leaded and no lead gasoline (fuel economy credit). Third, inspection and maintenance costs and a maintenance credit associated with the use of unleaded and lower leaded (i.e., unleaded and lower leaded gasoline is less corrosive, and therefore results in fewer muffler replacements, less spark plug corrosion, and less degradation of engine oil) were represented as changes in prices for other services (sector 34).

Direct Compliance Expenditures Data

Sources of Cost Data

Cost data for this study are derived primarily from the 1990 *Cost of Clean* report. EPA publishes cost data in response to requirements of the Clean Air and Clean Water Acts. The following subsections describe *Cost of Clean* data in detail, as well as adjustments made to the data and data from other sources.

Cost of Clean Data

EPA is required to compile and publish public and private costs resulting from enactment of the Clean Air Act and the Clean Water Act. The 1990 *Cost of Clean* report presents estimates of historical pollution control expenditures for the years 1972 through 1988 and projected future costs for the years 1989 through 2000. This includes federal, state, and local governments as well as the private sector. Estimates of capital costs, operation and maintenance (O&M) costs, and total annualized costs for five categories of environmental media, including air, water, land, chemical, and multi-media, are presented. It should be noted that these estimates represent direct regulatory implementation and compliance costs rather than social costs. The *Cost of Clean* relied on data from two governmental sources, the EPA and the U.S. Department of Commerce (Commerce).

EPA Data

EPA expenditures were estimated from EPA budget justification documents.[8] Estimates of capital and operating costs resulting from new and forthcoming regulations were derived from EPA's Regulatory Impact Analyses (RIAs). RIAs have been prepared prior to the issuance of all major regulations since 1981. Finally, special analyses conducted by EPA program offices or contractors were used when other data sources did not provide adequate or reliable data.

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[8] The main source of data for EPA expenditures is the *Justification of Appropriation Estimates for Committee on Appropriations.*

Commerce Data

Data collected by Commerce were used extensively in the *Cost of Clean* for estimates of historical pollution control expenditures made by government agencies other than EPA and by the private sector. Two Commerce agencies, the Bureau of Economic Analysis (BEA) and the Bureau of the Census (Census), have collected capital and operating costs for compliance with environmental regulations since the early 1970's. Commerce is, in fact, the primary source of original survey data for environmental regulation compliance costs. Commerce publishes a number of documents that report responses to surveys and comprise most of the current domain of known pollution abatement and control costs in the United States, including:

- A series of articles entitled "Pollution Abatement and Control Expenditures" published annually in the *Survey of Current Business* by BEA (BEA articles);
- A series of documents entitled "Pollution Abatement Costs and Expenditures" published annually in the *Current Industrial Reports* by Census (PACE reports); and
- A series of documents entitled *Government Finances* published annually by Census (Government Finances).

BEA articles contain data derived from a number of sources, including two key agency surveys —the "Pollution Abatement Costs and Expenditures Survey" (PACE Survey) and the "Pollution Abatement Plant and Equipment Survey" (PAPE Survey)— which are conducted annually by Census for BEA. Data have been reported for 1972 through 1987.[9]

PACE reports have been published annually since 1973 with the exception of 1987. Figures for 1987 were estimated on the basis of historical shares within total manufacturing. These reports contain expenditure estimates derived from surveys of about 20,000 manufacturing establishments. Pollution abatement expenditures for air, water and solid waste are reported by state and Standard Industrial Code (SIC) at the four-digit level. According to Census, surveys conducted since 1976 have not included establishments with fewer than 20 employees because early surveys showed that they contributed only about 2 percent to the pollution estimates while constituting more than 10 percent of the sample size.

Each year Census conducts a survey of state, local, and county governments; and survey results are published in *Government Finances.* Census asks government units to report revenue and expenditures, including expenditures for pollution control and abatement.

Non-EPA Federal expenditures were estimated from surveys completed by federal agencies detailing their pollution control expenditures, which are submitted to BEA. Private sector air pollution control expenditures, as well as state and local government air pollution expenditures, were taken from BEA articles.

Stationary Source Cost Data

Capital Expenditures Data

Capital expenditures for stationary air pollution control are made by factories and electric utilities for plant and equipment that abate pollutants through end-of-line (EOL) techniques or that reduce or eliminate the generation of pollutants through changes in production processes (CIPP). For the purposes of this report EOL and CIPP expenditures are aggregated.[10] Table A-3 summarizes capital expenditures for stationary air pollution control, categorized as "nonfarm business" or "government enterprise" expenditures.

Nonfarm business capital expenditures consist of plant and equipment expenditures made by 1) manufacturing companies, 2) privately and cooperatively owned electric utilities, and 3) other nonmanufacturing companies. "Government enterprise" is, according to BEA, an agency of the government whose operating costs, to a substantial extent, are covered by the sale of goods and services. Here, government enterprise means specifically government enterprise electric

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[9] The most recent BEA article used as a source for air pollution control costs in the Cost of Clean was "Pollution Abatement and Control Expenditures, 1984-87" in *Survey of Current Business*, June 1989.

[10] Survey respondents to the Census annual Pollution Abatement Surveys report the difference between expenditures for CIPP and what they would have spent for comparable plant and equipment without pollution abatement features. Disaggregated capital expenditures by private manufacturing establishments can be found in annual issues of Census reports.

Table A-3. Estimated Capital and O&M Expenditures for Stationary Source Air Pollution Control (millions of current dollars).

	Nonfarm Business		Government Enterprise	
Year	Cap.[a]	O&M[b]	Cap.[c]	O&M[d]
1972	2,172		63	
1973	2,968	1,407	82	29
1974	3,328	1,839	104	56
1975	3,914	2,195	102	45
1976	3,798	2,607	156	58
1977	3,811	3,163	197	60
1978	3,977	3,652	205	72
1979	4,613	4,499	285	106
1980	5,051	5,420	398	148
1981	5,135	5,988	451	135
1982	5,086	5,674	508	141
1983	4,155	6,149	422	143
1984	4,282	6,690	416	147
1985	4,141	6,997	328	189
1986	4,090	7,116	312	140
1987	4,179	7,469	277	130
1988	4,267	7,313	243	161
1989	4,760	7,743	235	173
1990	4,169	8,688	226	154

Sources:
a. Non-farm capital expenditures for 1972-87 are from *Cost of Clean*, Table B-1, line 2.
b. Non-farm O&M expenditures for 1973-85 are from *Cost of Clean*, Table B-1, line 8.
c. Government enterprise capital expenditures for 1972-87 are from *Cost of Clean,* Table B-9, line 1.
d. Government enterprise O&M expenditures for 1973-85 are from *Cost of Clean*, Table B-9, line 5.
All other reported expenditures are EPA estimates.

utilities. Government enterprise capital expenditures are pollution abatement expenditures made by publicly owned electric utilities.[11]

Operation and Maintenance Expenditures Data

Stationary source O&M expenditures are made by manufacturing establishments, private and public electric utilities, and other nonmanufacturing businesses to operate air pollution abatement equipment. O&M expenditures for electric utilities are made up of two parts: 1) expenditures for operating air pollution equipment and 2) the additional expenditures associated with switching to alternative fuels that have lower sulfur content (fuel differential). Expenditures to operate air pollution abatement equipment are for the collection and disposal of flyash, bottom ash, sulfur and sulfur products, and other products from flue gases.[12] O&M expenditures are net of depreciation and payments to governmental units, and are summarized in Table A-3. O&M data were disaggregated to the two digit SIC level for use in the macroeconomic model.

For both capital and O&M expenditures, historical survey data were not available for each year through 1990 prior to publication of *Cost of Clean*. For the purpose of the section 812 analysis, EPA projected 1988-1990 capital expenditures and 1986-1990 O&M expenditures. Those projections were used in the macroeconomic simulation, and have been retained as cost estimates to ensure consistency between the macroeconomic results and the direct cost estimates. Since completion of the macroeconomic modeling, however, BEA has published expenditure estimates through 1990. A comparison of more recent BEA estimates with the EPA projections used in the section 812 analysis can be found in the “Uncertainties in the Cost Analysis” section, below.

Recovered Costs

“Recovered costs” are costs recovered (i.e., revenues realized) by private manufacturing establishments through abatement activities. According to instructions provided to survey participants by Census, recovered costs consist of 1) the value of materials or energy reclaimed through abatement activities that were reused in production and 2) revenue that was obtained from the sale of materials or energy reclaimed through abatement activities. Estimates of recovered costs were obtained from the PACE reports and are summarized in Table A-4. In this analysis, recovered costs were removed from total stationary source air pollution control O&M costs — that is, net O&M cost in any year would be O&M expenditures (see Table A-3) less recovered costs. Recovered cost data were disaggregated to the two digit SIC level for use in the macroeconomic model.

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[11] BEA calculates these expenditures using numbers obtained from Energy Information Agency (EIA) Form 767 on steam-electric plant air quality control.

[12] Farber, Kit D. and Gary L. Rutledge, “Pollution Abatement and Control Expenditures: Methods and Sources for Current-Dollar Estimates,” Unpublished paper, Bureau of Economic Analysis, U.S. Department of Commerce, October 1989.

Table A-4. Estimated Recovered Costs for Stationary Source Air Pollution Control (millions of current dollars).

Year	PACE*	Estimated
1972		248
1973		199
1974		296
1975		389
1976		496
1977		557
1978		617
1979	750	750
1980	862	862
1981	1,000	997
1982	858	857
1983	822	822
1984	866	870
1985	767	768
1986	860	867
1987		987
1988	1,103	1,107
1989		1,122
1990		1,256

* Air cost recovered as reported in PACE
Source: "Pollution Abatement Costs and Expenditures" published annually in the Current Industrial Reports by Census.

Mobile Source Cost Data

Costs of controlling pollution emissions from motor vehicles were estimated by calculating the purchase price and O&M cost premiums associated with vehicles equipped with pollution abatement controls over the costs for vehicles not equipped with such controls. These costs were derived using EPA analyses, including EPA RIAs, the *Cost of Clean*, and other EPA reports.[13] This Appendix summarizes the section 812 mobile source compliance cost estimates and provides references to published data sources where possible. Further information on specific methods, analytical steps, and assumptions can be found in McConnell *et al.* (1995),[14] which provides a detailed description of the section 812 mobile source cost estimation exercise and compares the method and results to other similar analyses (including *Cost of Clean* (1990)).

Capital Expenditures Data

Capital expenditures for mobile source emission control are associated primarily with pollution abatement equipment on passenger cars, which comprise the bulk of all mobile sources of pollution. These capital costs reflect increasingly stringent regulatory requirements and improvements in pollution control technologies over time. Each of the following devices have been used at one time or another dating back to the Clean Air Act Amendments of 1965: air pumps, exhaust-gas recirculation valves, high altitude controls, evaporative emissions controls, and catalysts. The cost estimates for each component were computed on a per-vehicle basis by engineering cost analyses commissioned by EPA. The resulting per-vehicle capital costs were multiplied by vehicle production estimates to determine annual capital costs. Table A-5 summarizes mobile source capital costs.

Operation and Maintenance Expenditures Data

Costs for operation and maintenance of emission abatement devices include the costs of maintaining pollution control equipment plus the cost of vehicle inspection/maintenance programs. Operating costs per vehicle were multiplied by total vehicles in use to determine annual cost. Mobile source O&M costs are made up of three factors: 1) fuel price penalty, 2) fuel economy penalty, and 3) inspection and maintenance program costs as described below. These costs are mitigated by cost savings in the form of maintenance economy and fuel density economy. Table A-6 summarizes mobile source O&M expenditures and cost savings by categories, with net O&M costs summarized above in Table A-5. The following sections describe the components of the mobile source O&M cost estimates.

Fuel Price Penalty

Historically, the price of unleaded fuel has been several cents per gallon higher than the price of leaded fuel. CAA costs were calculated as the difference be-

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[13] A complete listing of sources used in calculating mobile source capital and operating expenditures can be found in *Environmental Investments: The Cost of a Clean Environment*, Report of the Administrator of the Environmental Protection Agency to the Congress of the United State, EPA-230-11-90-083, November 1990.

[14] *Evaluating the Cost of Compliance with Mobile Source Emission Control Requirements: Retrospective Analysis*, Resources for the Future Discussion Paper, 1995. Note that McConnell *et al.* refer to the section 812 estimates as: *Cost of Clean* (1993, unpublished).

Table A-5. Estimated Capital and Operation and Maintenance Expenditures for Mobile Source Air Pollution Control (millions of current dollars).

Year	Capital[a]	O&M[b]
1973	276	1,765
1974	242	2,351
1975	1,570	2,282
1976	1,961	2,060
1977	2,248	1,786
1978	2,513	908
1979	2,941	1,229
1980	2,949	1,790
1981	3,534	1,389
1982	3,551	555
1983	4,331	-155
1984	5,679	-326
1985	6,387	337
1986	6,886	-1,394
1987	6,851	-1,302
1988	7,206	-1,575
1989	7,053	-1,636
1990	7,299	-1,816

Sources:
a. Capital exp.: *Cost of Clean*, Tables C-2 to C-9, line 3 on each; Tables C-2A to C-9A, line 10 on each; converted from $1986 to current dollars.
b. O&M exp.: EPA analyses based on sources and methods in: *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*, U.S. Environmental Protection Agency, Office of Policy Analysis, EPA-230-05-85-006, February 1985; and *Cost of Clean*.

tween the cost of making unleaded gasoline and leaded gasoline with lower lead levels and the cost of making only leaded gasoline with a lead content set at pre-regulatory levels. These cost estimates were developed using a linear programming model of the refinery industry. Prices of crude oil and other unfinished oils, along with the prices of refinery outputs, were adjusted annually according to price indices for imported crude oil over the period of analysis. The relative shares of leaded and unleaded gasoline and the average lead content in leaded gasoline also were adjusted annually according to the historical record.

These estimates may tend to understate costs due to a number of biases inherent in the analysis process. For example, the refinery model was allowed to optimize process capacities in each year. This procedure is likely to understate costs because regulatory requirements and market developments cannot be perfectly anticipated over time. This procedure resulted in estimates that are about ten percent less than estimates in other EPA reports.[15] However, new process technologies that were developed in the mid-1980s were not reflected in either the base case or regulatory case runs. It is reasonable to expect that regulatory requirements would have encouraged development of technologies at a faster rate than would have occurred otherwise.

Fuel Economy Penalty

The fuel economy penalty benefit is the cost associated with the increased/decreased amount of fuel used by automobiles with air pollution control devices (all else being equal). An assumption that can be made is that the addition of devices, such as catalytic con-

Table A-6. O&M Costs and Credits (millions of current dollars).

Year	Fuel Price Penalty	Fuel Econ. Penalty	Net I & M*	Total Costs
1973	91	1700	-26	1765
1974	244	2205	-98	2351
1975	358	2213	-289	2282
1976	468	2106	-514	2060
1977	568	1956	-738	1786
1978	766	1669	-1527	908
1979	1187	1868	-1826	1229
1980	1912	1998	-2120	1790
1981	2181	1594	-2386	1389
1982	2071	1026	-2542	555
1983	1956	628	-2739	-155
1984	2012	313	-2651	-326
1985	3057	118	-2838	337
1986	2505	-40	-3859	-1394
1987	2982	-158	-4126	-1302
1988	3127	-210	-4492	-1575
1989	3476	-318	-4794	-1636
1990	3754	-481	-5089	-1816

* Inspection and maintenance costs less fuel density savings and maintenance savings.

Sources: All results are presented in Jorgenson *et al.* (1993), pg. A.17. FPP results are based on a petroleum refinery cost model run for the retrospective analysis. FEP and Net I&M are based on data and methods from *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*, U.S. Environmental Protection Agency, Office of Policy Analysis, EPA-230-05-85-006, February 1985; and *Cost of Clean* (1990). Specific analytic procedures are summarized in McConnell *et al.* (1995).

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[15] Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis, U.S. Environmental Protection Agency, Office of Policy Analysis, EPA-230-05-85-006, February 1985.

verters, decrease automobile fuel efficiency.[16] If this assumption is true, air pollution control devices increase the total fuel cost to consumers. An alternative assumption is that the use of catalytic converters has increased fuel economy. This increase has been attributed in large measure to the feedback mechanism built into three-way catalytic converters.[17] Under this assumption, the decrease in total fuel cost to consumers is considered a benefit of the program.

For the purposes of this study, sensitivity analyses were performed using data presented in the *Cost of Clean* report. These analyses were conducted to evaluate the significance of assumptions about the relationship between mile per gallon (MPG) values for controlled automobiles and MPG values for uncontrolled cars. Based on results of these and other analyses, fuel economy was assumed to be equal for controlled and uncontrolled vehicles from 1976 onward. This may bias the cost estimates although in an unknown direction.

Inspection and Maintenance Programs

Inspection and maintenance programs are administered by a number of states. Although these programs are required by the Clean Air Act, the details of administration were left to the discretion of state or local officials. The primary purpose of inspection and maintenance programs is to identify cars that require maintenance —including cars that 1) have had poor maintenance, 2) have been deliberately tampered with or had pollution control devices removed, or 3) have used leaded gasoline when unleaded is required— and force the owners of those cars to make necessary repairs or adjustments.[18] Expenditures for inspection and maintenance were taken from the *Cost of Clean.*

Beneficial effects of the mobile source control program associated with maintenance and fuel density were also identified. These cost savings were included in this study as credits to be attributed to the mobile source control program. Credits were estimated based on an EPA study,[19] where more detailed explanations may be found.

Maintenance Credits

Catalytic converters require the use of unleaded fuel, which is less corrosive than leaded gasoline. On the basis of fleet trials, the use of unleaded or lower leaded gasoline results in fewer muffler replacements, less spark plug corrosion, and less degradation of engine oil, thus reducing maintenance costs. Maintenance credits account for the majority of the direct (non-health) economic benefits of reducing the lead concentration in gasoline.

Fuel Density Credits

The process of refining unleaded gasoline increases its density. The result is a gasoline that has higher energy content. Furthermore, unleaded gasoline generates more deposits in engine combustion chambers, resulting in slightly increased compression and engine efficiency. Higher energy content of unleaded gasoline and increased engine efficiency from the used of unleaded gasoline yield greater fuel economy and therefore savings in refining, distribution, and retailing costs.

Other Direct Cost Data

The *Cost of Clean* report includes several other categories of cost that are not easily classified as either stationary source or mobile source expenditures. Federal and state governments incur air pollution abatement costs; additionally, federal and state governments incur costs to develop and enforce CAA regulations. Research and development expenditures by the federal government, state and local governments, and (especially) the private sector can be attributed to the CAA. These data are summarized by year in Table A-7.

Unlike the other private sector expenditure data used for this analysis, the survey data used as a source for private sector R&D expenditures cannot be disaggregated into industry-specific expenditure totals. Consequently, private sector R&D expenditures are

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[16] Memo from Joel Schwartz (EPA/OPPE) to Joe Somers and Jim DeMocker dated December 12, 1991, and entitled “Fuel Economy Benefits.” Schwartz states that since this analysis is relative to a no Clean Air Act baseline, not a 1973 baseline, fuel economy benefits are not relevant. In the absence of regulation, tuning of engines for maximum economy would presumably be optimal in the base case as well.

[17] Memo from Joseph H. Somers, EPA Office of Mobile Sources, to Anne Grambsch (EPA/OPPE) and Joel Schwartz (EPA/OPPE) entitled “Fuel Economy Penalties for section 812 Report,” December 23, 1991.

[18] Walsh, Michael P., “Motor Vehicles and Fuels: The Problem,” *EPA Journal*, Vol. 17, No. 1, January/February 1991, p. 12.

[19] Schwartz, J., *et al. Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*, U. S. Environmental Protection Agency, Economic Analysis Division, Office of Policy Analysis, February 1985.

Table A-7. Other Air Pollution Control Expenditures (millions of current dollars).

Year	Abatement		Regulations and Monitoring		Research and Development			Total
	Fed.[a]	State & Local[b]	Fed.[c]	State & Local[d]	Private[e]	Fed.[f]	State & Local[g]	
1973	47	0	50	115	492	126	6	836
1974	56	0	52	131	520	100	7	866
1975	88	1	66	139	487	108	8	897
1976	105	1	69	135	562	131	6	1,009
1977	106	1	80	161	675	144	7	1,174
1978	90	0	93	183	805	146	8	1,325
1979	103	0	100	200	933	105	7	1,448
1980	95	0	122	207	851	130	5	1,410
1981	85	0	108	226	798	131	0	1,348
1982	87	0	93	230	761	126	2	1,229
1983	136	4	88	239	691	133	6	1,297
1984	115	14	101	250	665	165	4	1,314
1985	98	12	103	250	775	247	3	1,488
1986	67	14	106	307	833	217	4	1,548
1987	80	15	110	300	887	200	2	1,594
1988	65	10	120	320	934	220	1	1,670
1989	70	12	130	360	984	230	2	1,788
1990	71	13	133	343	749	231	2	1,542

Sources:

a. Federal government abatement expenditures: 1973-82, "Pollution Abatement and Control Expenditures", Survey of Current Business (BEA) July 1986 Table 9 line 13; 1983-87, BEA June 1989 Table 7 line 13; 1988-90, BEA May 1995 Table 7 line 13.

b. State and local abatement expenditures: 1973-87, *Cost of Clean*, Table B-9 line 2; 1988-90, BEA May 1995 Table 7 line 14.

c. Federal government "regs/monitoring" expenditures: 1973-82, BEA July 1986, Table 9 line 17; 1983-87, BEA June 1989 Table 6 line 17; 1988-90, BEA May 1995 Table 7 line 17.

d. State and local government "regs/monitoring" expenditures: 1973-87, *Cost of Clean*, Table B-9 line 3; 1988-90, BEA May 1995 Table 7 line 18.

e. Private sector R&D expenditures: 1973-86, BEA May 1994 Table 4 (no line #) [total R&D expenditures in $1987 are converted to current dollars using the GDP price deflator series found elsewhere in this Appendix -- netting out public sector R&D leaves private sector expenditures]; 1987-90, BEA May 1995 Table 7 line 20.

f. Federal government R&D expenditures: 1973-82, BEA July 1986 Table 9 line 21; 1983-87, BEA June 1989 Table 6 line 21; 1988-90, BEA May 1995, Table 7 line 21.

g. State and local government R&D expenditures: 1973-87, *Cost of Clean*, Table B-9 line 4; 1988-90, BEA May 1995 Table 7 line 22.

omitted from the macroeconomic modeling exercise (the macro model is industry-specific). The R&D expenditures are, however, included in aggregate cost totals used in the benefit-cost analysis.

The *Cost of Clean* and the series of articles "Pollution Abatement and Control Expenditures" in the Survey of Current Business (various issues) are the data sources for "Other Air Pollution Control Expenditures." State and local expenditures through 1987 are found in *Cost of Clean*; 1988-90 expenditures are from more recent issues of the Survey of Current Business (BEA). Federal government expenditures are from BEA (various issues). Private R&D expenditures were reported in *Cost of Clean*. Since publication of *Cost of Clean*, however, BEA has revised its private sector R&D expenditure series (BEA, 1994 and 1995). Since private R&D expenditures were not included in the macroeconomic modeling exercise, the revised series can be (and has been) used without causing inconsistency with other portions of the section 812 analysis.

Assessment Results

Compliance Expenditures and Costs

Compliance with the CAA imposed direct costs on businesses, consumers, and governmental units, and triggered other expenditures such as governmental regulation and monitoring costs and expenditures for research and development by both government and industry. As shown in Table A-8, annual CAA compliance expenditures – including R&D, etc.– over the period from 1973 to 1990 were remarkably stable[20], ranging from about $20 billion to $25 billion in inflation-adjusted 1990 dollars (expenditures are adjusted to 1990 dollars through application of the GDP Implicit Price Deflator). This is equal to approximately one third of one percent of total domestic output during that period, with the percentage falling from one half of one percent of total output in 1973 to one quarter of one percent in 1990.

Although useful for many purposes, a summary of direct annual expenditures is not the best cost measure to use when comparing costs to benefits. Capital expenditures are investments, generating a stream of benefits (and opportunity cost) over the life of the investment. The appropriate accounting technique to use for capital expenditures in a cost/benefit analysis is to *annualize* the expenditure — i.e., to spread the capital cost over the useful life of the investment, applying a discount rate to account for the time value of money.

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[20] While total expenditures remained relatively constant over the period, the sector-specific data presented in Tables A-3 and A-5 above indicate that capital expenditures for stationary sources fell significantly throughout the period but that this decline was offset by significant increases in mobile source capital expenditures.

Table A-8. Summary of Expenditures and Conversion to 1990 Dollars (millions of dollars).

	CURRENT YEAR DOLLARS								1990 DOLLARS						
	Stationary		Rec.	Mobile Source			TOTAL	GDP price	Stationary		Rec.	Mobile Source			TOTAL
	K	O&M	Costs	K	O&M	Other	EXP	defl.	K	O&M	Costs	K	O&M	Other	EXP
1972	2,235	na	na	na	na	na	na	38.8	6,521						
1973	3,050	1,436	199	276	1,765	836	7,164	41.3	8,360	3,936	545	756	4,838	2,290	19,635
1974	3,432	1,895	296	242	2,351	866	8,490	44.9	8,653	4,778	746	610	5,927	2,184	21,405
1975	4,016	2,240	389	1,570	2,282	897	10,616	49.2	9,240	5,154	895	3,612	5,250	2,063	24,425
1976	3,954	2,665	496	1,961	2,060	1,009	11,153	52.3	8,558	5,768	1,074	4,244	4,459	2,183	24,139
1977	4,008	3,223	557	2,248	1,786	1,174	11,882	55.9	8,116	6,527	1,128	4,552	3,617	2,378	24,062
1978	4,182	3,724	617	2,513	908	1,325	12,035	60.3	7,851	6,991	1,158	4,718	1,705	2,487	22,593
1979	4,898	4,605	750	2,941	1,229	1,448	14,371	65.5	8,465	7,959	1,296	5,083	2,124	2,503	24,837
1980	5,449	5,568	862	2,949	1,790	1,410	16,304	71.7	8,603	8,791	1,361	4,656	2,826	2,226	25,741
1981	5,586	6,123	997	3,534	1,389	1,348	16,983	78.9	8,014	8,785	1,430	5,070	1,993	1,935	24,367
1982	5,594	5,815	857	3,551	555	1,299	15,957	83.8	7,557	7,855	1,158	4,797	750	1,755	21,555
1983	4,577	6,292	822	4,331	(155)	1,297	15,520	87.2	5,942	8,168	1,067	5,622	(201)	1,684	20,148
1984	4,698	6,837	870	5,679	(326)	1,314	17,332	91	5,844	8,505	1,082	7,064	(406)	1,634	21,560
1985	4,469	7,186	768	6,387	337	1,488	19,099	94.4	5,359	8,617	921	7,659	404	1,785	22,903
1986	4,402	7,256	867	6,886	(1,394)	1,548	17,831	96.9	5,142	8,477	1,013	8,044	(1,628)	1,809	20,831
1987	4,456	7,599	987	6,851	(1,302)	1,594	18,211	100	5,044	8,602	1,117	7,755	(1,474)	1,804	20,615
1988	4,510	7,474	1,107	7,206	(1,575)	1,670	18,178	103.9	4,914	8,143	1,206	7,851	(1,716)	1,819	19,805
1989	4,995	7,916	1,122	7,053	(1,636)	1,788	18,994	108.5	5,211	8,259	1,171	7,359	(1,707)	1,865	19,817
1990	4,395	8,842	1,256	7,312	(1,816)	1,542	19,019	113.2	4,395	8,842	1,256	7,312	(1,816)	1,542	19,019

K = Capital expenditures; O&M = Operation and Maintenance expenditures.
Rec. Costs = recovered costs. Total expenditures are the sum of stationary source, mobile source, and "other" expenditures, less recovered costs.
Stationary source expenditures are the sum of "Nonfarm Business" and "Government Enterprise" expenditures (from Table A-3).
To calculate expenditures in 1990 dollars, current year expenditures are multiplied by the ratio of the 1990 price deflator to the current year deflator. For example, 1989 expenditures are multiplied by (113.2/108.5).
Source for price deflator series: Economic Report of the President, February 1995, Table B-3.

Annualization Method

For this cost/benefit analysis, all capital expenditures have been annualized at 3 percent, 5 percent, and 7 percent (real) rates of interest. Therefore, "annualized" costs reported for any given year are equal to O&M expenditures (plus R&D, etc., expenditures, minus recovered costs) plus amortized capital costs (i.e., depreciation plus interest costs associated with the pre-existing capital *stock*) for that year. Stationary source air pollution control capital costs are amortized over twenty years; mobile source air pollution control costs are amortized over ten years. Capital expenditures are amortized using the formula for an annuity [that is, $r/(1-(1+r)^{-t})$, where r is the rate of interest and t is the amortization period].[21] Multiplying the expenditure by the appropriate annuity factor gives a constant annual cost to be incurred for t years, the present value of which is equal to the expenditure.

Due to data limitations, the cost analysis for this CAA retrospective starts in 1973, missing costs incurred in 1970-72. *Cost of Clean*, however, includes stationary source capital expenditures for 1972. In this analysis, amortized costs arising from 1972 capital investments *are included* in the 1973-1990 annualized costs, even though 1972 costs are not otherwise included in the analysis. Conversely, only a portion of the (e.g.) 1989 capital expenditures are reflected in the 1990 annualized costs — the remainder of the costs are spread through the following two decades, which fall outside of the scope of this study (similarly, benefits arising from emission reductions in, e.g., 1995 caused by 1990 capital investments are not captured by the benefits analysis). Table A-9 presents CAA compliance costs from 1973 to 1990, in 1990 dollars, with capital expenditures amortized at a five percent real interest rate. "Total" costs are the sum of stationary source, mobile source, and "other" costs, minus recovered costs.

Tables A-10 and A-11 provide details of the amortization calculation (using a five percent interest rate) for stationary sources and mobile sources, respectively. Similar calculations were performed to derive the annualized cost results using discount rates of three percent and seven percent.

The Stationary Source table reports a capital expenditure of $6,521 million for 1972 (in 1990 dollars). The cost is spread over the following twenty years (which is the assumed useful life of the investment) using a discount rate of five percent; thus, the amortization factor to be used is f(20)=0.0802. Multiplying $6,521 million by 0.0802 gives an annuity of $523 million. That annuity is noted on the first data row of the table, signifying that the 1972 expenditure of $6,521 million implies an annual cost of $523 million for the entire twenty-year period of 1973 to 1992 (the years following 1990 are not included on the tables, since costs incurred in those years are not included in this retrospective assessment). The first summary row near the bottom of the table (labeled "SUM") reports aggregate annualized capital costs: for 1973 (the first data column), capital costs are $523 million.

Capital expenditures in 1973 amounted to $8,360 million. Using the amortization technique explained above, one can compute an annualized cost of $671 million, incurred for the twenty-year period of 1974 to 1993. Aggregate annualized capital costs for 1974 include cost flows arising from 1972 and 1973 invest-

Table A-9. Annualized Costs, 1973-1990 (millions of 1990 dollars; capital expenditures annualized at 5 percent).

	Stationary		rec.	Mobile Source			
	K	O&M	costs	K	O&M	other	Total
1973	523	3,936	545	0	4,838	2,290	11,042
1974	1,194	4,778	746	98	5,927	2,184	13,435
1975	1,888	5,154	895	177	5,250	2,063	13,638
1976	2,630	5,768	1,074	645	4,459	2,183	14,611
1977	3,317	6,527	1,128	1,194	3,617	2,378	15,904
1978	3,968	6,991	1,158	1,784	1,705	2,487	15,776
1979	4,598	7,959	1,296	2,395	2,124	2,503	18,282
1980	5,277	8,791	1,361	3,053	2,826	2,226	20,812
1981	5,967	8,785	1,430	3,656	1,993	1,935	20,905
1982	6,610	7,855	1,158	4,313	750	1,755	20,125
1983	7,217	8,168	1,067	4,934	(201)	1,684	20,734
1984	7,694	8,505	1,082	5,564	(406)	1,634	21,909
1985	8,163	8,617	921	6,400	404	1,785	24,447
1986	8,593	8,477	1,013	6,924	(1,628)	1,809	23,161
1987	9,005	8,602	1,117	7,416	(1,474)	1,804	24,237
1988	9,410	8,143	1,206	7,831	(1,716)	1,819	24,281
1989	9,804	8,259	1,171	8,237	(1,707)	1,865	25,288
1990	10,222	8,842	1,256	8,531	(1,816)	1,542	26,066

Source: Stationary source capital costs and mobile source capital costs are from Tables A-10 and A-11, respectively. All other costs and offsets are from Table A-8.

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[21] Using an interest rate of five percent, the factor for a twenty year amortization period is 0.0802; that for a ten year amortization period is 0.1295.

Table A-10. Amortization of Capital Expenditures for Stationary Sources (millions of 1990 dollars).

	EXPEND	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1972	6,521	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523
1973	8,360		671	671	671	671	671	671	671	671	671	671	671	671	671	671	671	671	671
1974	8,653			694	694	694	694	694	694	694	694	694	694	694	694	694	694	694	694
1975	9,240				741	741	741	741	741	741	741	741	741	741	741	741	741	741	741
1976	8,558					687	687	687	687	687	687	687	687	687	687	687	687	687	687
1977	8,116						651	651	651	651	651	651	651	651	651	651	651	651	651
1978	7,851							630	630	630	630	630	630	630	630	630	630	630	630
1979	8,465								679	679	679	679	679	679	679	679	679	679	679
1980	8,603									690	690	690	690	690	690	690	690	690	690
1981	8,014										643	643	643	643	643	643	643	643	643
1982	7,557											606	606	606	606	606	606	606	606
1983	5,942												477	477	477	477	477	477	477
1984	5,844													469	469	469	469	469	469
1985	5,359														430	430	430	430	430
1986	5,142															413	413	413	413
1987	5,044																405	405	405
1988	4,914																	394	394
1989	5,211																		418
1990	4,395																		
SUM		523	1,194	1,888	2,630	3,317	3,968	4,598	5,277	5,967	6,610	7,217	7,694	8,163	8,593	9,005	9,410	9,804	10,222
Expenditures		8,360	8,653	9,240	8,558	8,116	7,851	8,465	8,603	8,014	7,557	5,942	5,844	5,359	5,142	5,044	4,914	5,211	4,395
K stock		6,521	14,880	23,533	32,773	41,331	49,448	57,299	65,763	74,366	82,381	89,937	95,879	101,723	107,082	112,225	117,269	122,182	127,394
K stock net depr.		6,521	14,684	22,876	31,372	38,869	45,612	51,776	58,232	64,469	69,740	74,173	76,606	78,587	79,713	80,249	80,300	79,819	79,217
Int		326	734	1,144	1,569	1,943	2,281	2,589	2,912	3,223	3,487	3,709	3,830	3,929	3,986	4,012	4,015	3,991	3,961
Depr		197	460	745	1,061	1,373	1,687	2,009	2,365	2,744	3,123	3,508	3,863	4,233	4,607	4,993	5,395	5,813	6,262

Capital expenditures for each year are found in the “EXPEND” column. Expenditures are amortized over 20 years (i.e., years (t+1) to (t+20)) using a 5% real interest rate to derive a constant cost per year for the entire amortization period. The present value (in year t) of the cost flow is equal to the expenditure in year t. Annualized CAA compliance capital cost for each year (displayed in row “SUM”) is the sum of the annuities calculated for capital expenditures from previous years. The capital stock (“K stock”) in place at the start of each year is equal to the sum of expenditures from previous years. Subtracting depreciation from the capital stock leaves “K stock net depr.” Annual interest expense is 5% of net capital stock. Annual interest expense plus depreciation equals annualized compliance cost (row “SUM”).

Table A-11. Amortization of Capital Expenditures for Mobile Sources (millions of 1990 dollars).

	EXPEND	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1972	0																	
1973	756	98	98	98	98	98	98	98	98	98	98							
1974	610		79	79	79	79	79	79	79	79	79	79						
1975	3,612			468	468	468	468	468	468	468	468	468	468					
1976	4,244				550	550	550	550	550	550	550	550	550	550				
1977	4,552					590	590	590	590	590	590	590	590	590	590			
1978	4,718						611	611	611	611	611	611	611	611	611	611		
1979	5,083							658	658	658	658	658	658	658	658	658	658	
1980	4,656								603	603	603	603	603	603	603	603	603	603
1981	5,070									657	657	657	657	657	657	657	657	657
1982	4,797										621	621	621	621	621	621	621	621
1983	5,622											728	728	728	728	728	728	728
1984	7,064												915	915	915	915	915	915
1985	7,659													992	992	992	992	992
1986	8,044														1,042	1,042	1,042	1,042
1987	7,755															1,004	1,004	1,004
1988	7,851																1,017	1,017
1989	7,359																	953
1990	7,312																	
SUM		98	177	645	1,194	1,784	2,395	3,053	3,656	4,313	4,934	5,564	6,400	6,924	7,416	7,831	8,237	8,531
Expenditures		610	3,612	4,244	4,552	4,718	5,083	4,656	5,070	4,797	5,622	7,064	7,659	8,044	7,755	7,851	7,359	7,312
K stock		756	1,367	4,979	9,223	13,776	18,493	23,576	28,232	33,302	38,099	42,965	49,419	53,466	57,266	60,469	63,602	65,878
K stock net depr.		756	1,306	4,807	8,647	12,437	15,993	19,480	22,057	24,574	26,287	28,289	31,204	34,023	36,845	39,026	40,997	42,169
Int		38	65	240	432	622	800	974	1,103	1,229	1,314	1,414	1,560	1,701	1,842	1,951	2,050	2,108
Depr		60	112	404	762	1,162	1,595	2,079	2,553	3,084	3,620	4,150	4,840	5,223	5,574	5,880	6,187	6,423

Capital expenditures for each year are found in the “EXPEND” column. Expenditures are amortized over 10 years (i.e., years (t+1) to (t+10)) using a 5% real interest rate to derive a constant cost per year for the entire amortization period. The present value (in year t) of the cost flow is equal to the expenditure in year t. Annualized CAA compliance capital cost for each year (displayed in row “SUM”) is the sum of the annuities calculated for capital expenditures from previous years. The capital stock (“K stock”) in place at the start of each year is equal to the sum of expenditures from the previous ten years. The sum of all previous expenditures less depreciation leaves “K stock net depr.” Annual interest expense is 5% of net capital stock. Annual interest expense plus depreciation equals annualized compliance cost (row “SUM”).

ments: that is, $523 million plus $671 million, or $1,194 million (see the "SUM" row). Similar calculations are conducted for every year through 1990, to derive aggregate annualized capital costs that increase monotonically from 1973 to 1990, even though capital expenditures decline after 1975.[22]

An alternative calculation technique is available that is procedurally simpler but analytically identical to that outlined above. Instead of calculating an annuity for each capital expenditure (by multiplying the expenditure by the annuity factor *f*), then summing the annuities associated with all expenditures in previous years, one can sum all previous expenditures and multiply the sum (i..e., the capital stock at the start of the year) by *f*. The third summary row (labeled "K stock") near the bottom of the amortization summary tables give the pollution control capital stock at the start of each year. For example, the stationary sources capital stock in place at the start of 1975 was $23,533 million (this is the sum of 1972, 1973, and 1974 capital expenditures). Multiplying the capital stock by the annuity factor 0.0802 gives $1,888 million, which is the aggregate annualized stationary source capital cost for 1975.

One can perform further calculations to decompose the annualized capital costs into "interest" and "financial depreciation" components.[23] For example, at the start of 1973, the stationary source capital stock was $6,521 million. A five percent interest rate implies an "interest expense" for 1973 of $326 million. Given a 1973 annualized cost of $523 million, this implies a "depreciation expense" for that year of ($523 million minus $326 million =) $197 million. For 1974, the existing capital stock net of "financial depreciation" was $14,684 million (that is, the $6,521 million in place at the start of 1973, plus the investment of $8,360 million during 1973, minus the depreciation of $197 million during 1973); five percent of $14,684 million is the interest expense of $734 million. Since the annualized capital cost for 1974 is $1,194 million, depreciation expense is $460 million (i.e., the difference between annualized cost and the interest component of annualized cost). This procedure is repeated to determine interest and depreciation for each year through 1990 (see the last three rows of Table A-11).

The three tables above all present costs (and intermediate calculations) assuming a five percent interest rate. As noted above, the Project Team also employed rates of three percent and seven percent to calculate costs. Those calculations and intermediate results are not replicated here. The method employed, however, is identical to that employed to derive the five percent results (with the only difference being the interest rate employed in the annuity factor calculation). Table A-12 presents a summary of expenditures and annualized costs at the three interest rates.

Table A-12. Compliance Expenditures and Annualized Costs, 1973-1990 ($1990 millions).

		Annualized Costs		
Year	Expend.	at 3%	at 5%	at 7%
1973	19,635	10,957	11,042	11,134
1974	21,405	13,231	13,435	13,655
1975	24,425	13,314	13,638	13,988
1976	24,139	14,123	14,611	15,139
1977	24,062	15,253	15,904	16,608
1978	22,593	14,963	15,776	16,653
1979	24,837	17,309	18,282	19,331
1980	25,741	19,666	20,812	22,046
1981	24,367	19,590	20,905	22,321
1982	21,555	18,643	20,125	21,720
1983	20,148	19,095	20,734	22,498
1984	21,560	20,133	21,909	23,819
1985	22,903	22,516	24,447	26,523
1986	20,831	21,109	23,161	25,364
1987	20,615	22,072	24,237	26,562
1988	19,805	22,012	24,281	26,719
1989	19,817	22,916	25,288	27,836
1990	19,019	23,598	26,066	28,717

Discounting Costs and Expenditures

The stream of costs from 1973 to 1990 can be expressed as a single cost number by *discounting* all costs to a common year. In this analysis, all costs and benefits are discounted to 1990 (in addition, all costs and benefits are converted to 1990 dollars, removing the effects of price inflation).[24] There is a broad range

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[22] Similar calculations were performed for mobile source control capital costs, where the assumed amortization period is ten years.

[23] One might, for example, wish to examine the relative importance of the "time value" component of the computed capital costs.

[24] Unlike most cost-benefit analyses, where future expected costs and benefits are discounted back to the present, this exercise brings past costs closer to the present. That is, the discounting procedure used here is actually compounding past costs and benefits.

of opinion in the economics profession regarding the appropriate discount rate to use in analyses such as this. Some economists believe that the appropriate rate is one that approximates the social rate of time preference — three percent, for example (all rates used here are "real", i.e., net of price inflation impacts). Others believe that a rate that approximates the opportunity cost of capital (e.g., seven percent or greater) should be used. A third school of thought holds that some combination of the social rate of time preference and the opportunity cost of capital is appropriate, with the combination effected either by use of an intermediate rate or by use of a multiple-step procedure which uses the social rate of time preference as the "discount rate," but still accounts for the cost of capital. The section 812 Project Team chose to use a range of discount rates (three, five, and seven percent) for the analysis.

Expenditures and annualized costs discounted to 1990 are found on Table A-13. Expenditures are discounted at all three rates; annualized costs are discounted at the rate corresponding to that used in the annualization procedure (i.e., the "annualized at 3%" cost stream is discounted to 1990 at three percent). The final row presents the result of an explicit combination of two rates: Capital costs are annualized at seven percent, then the entire cost stream is discounted to 1990 at three percent.

Table A-13. Costs Discounted to 1990 ($1990 millions).

	3%	5%	7%
Expenditures	520,475	627,621	760,751
Annualized Costs	416,804	522,906	657,003
Annualized at 7%	476,329		

Indirect Economic Effects of the CAA

In addition to imposing direct compliance costs on the economy, the CAA induced indirect economic effects, primarily by changing the size and composition of consumption and investment flows. Although this analysis does not add these indirect effects to the direct costs and include them in the comparison to benefits, they are important to note. This section summarizes the most important indirect economic effects of the CAA, as estimated by the J/W macroeconomic simulation.

GNP and Personal Consumption

Under the no-control scenario, the level of GNP increases by one percent in 1990 relative to the control case (see Table A-14). During the period 1973-1990, the percent change in real GNP rises monotonically from 0.26 percent to 1.0 percent. The increase in the level of GNP is attributable to a rapid accumulation of capital, which is driven by changes in the price of investment goods. The capital accumulation effect is augmented by a decline in energy prices relative to the base case. Lower energy prices that correspond to a world with no CAA regulations decreases costs and increases real household income, thus increasing consumption.

Table A-14. Differences in Gross National Product Between the Control and No-control Scenarios.

Year	Nominal % Change	Real % Change
1973	-0.09	0.26
1974	-0.18	0.27
1975	-0.10	0.44
1976	-0.00	0.49
1977	-0.10	0.54
1978	-0.16	0.56
1979	-0.16	0.63
1980	-0.14	0.69
1981	-0.14	0.73
1982	-0.19	0.74
1983	-0.19	0.78
1984	-0.17	0.84
1985	-0.12	0.95
1986	-0.14	0.98
1987	-0.15	1.01
1988	-0.20	1.00
1989	-0.21	0.99
1990	-0.18	1.00

Removing the pollution control component of new capital is equivalent to lowering the marginal price of investment goods. Combining this with the windfall gain of not having to bring existing capital into compliance leads to an initial surge in the economy's rate of return, raising the level of real investment. The investment effects are summarized in Figure A-1. More rapid (ordinary) capital accumulation leads to a decline in the rental price of capital services which, in turn, stimulates the demand for capital services by producers *and* consumers. The capital rental price reductions also serve to lower the prices of goods and services and, so, the overall price level. Obviously, the more capital intensive sectors exhibit larger price reductions.[25] The price effects from investment changes are compounded by the cost reductions associated with releasing resources from the operation and maintenance of pollution control equipment and by the elimination of higher prices due to regulations on mobile sources.

To households, no-control scenario conditions are manifest as an increase in permanent future real earnings which supports an increase in real consumption in all periods and, generally, an increase in the demand for leisure (see Table A-15). Households marginally reduce their offer of labor services as the income effects of higher real earnings dominate the substitution effects of lower goods prices. The increase in consumption is dampened by an increase in the rate of return that produces greater investment (and personal savings).

Table A-15. Difference in Personal Consumption Between the Control and No-Control Scenarios.

Year	Nominal % Change	Real % Change
1973	-0.02	0.33
1974	-0.01	0.43
1975	-0.10	0.24
1976	-0.10	0.39
1977	-0.10	0.54
1978	-0.09	0.63
1979	-0.11	0.68
1980	-0.12	0.71
1981	-0.13	0.74
1982	-0.12	0.81
1983	-0.13	0.85
1984	-0.15	0.86
1985	-0.19	0.88
1986	-0.19	0.94
1987	-0.19	0.98
1988	-0.17	1.03
1989	-0.17	1.04
1990	-0.18	1.01

Finally, technical change is a very important aspect of the supply-side adjustments under the no-control scenario. Lower factor prices increase the endogenous rates of technical change in those industries that are factor-using. Lower rental prices for capital benefit the capital-using sectors, lower materials prices benefit the materials-using sectors, and lower energy prices benefit the energy-using sectors. On balance, a significant portion of the increase in economic growth is attributable to accelerated productivity growth. Under the no-control scenario, economic growth averages 0.05 percentage points higher over the interval 1973-1990. The increased availability of capital accounts for 60 percent of this increase while faster productivity growth accounts for the remaining 40 percent. Thus, the principal effect arising from the costs associated with CAA initiatives is to slow the economy's rates of capital accumulation and productivity growth. This finding is consistent with recent analyses suggesting a potential association between higher reported air, water, and solid waste pollution abatement costs and lower plant-level productivity in some manufacturing industries (Gray and Shadbegian, 1993 and 1995).

As with the cost and expenditure data presented above, it is possible to present the stream of GNP and consumption changes as single values by discounting the streams to a single year. Table A-16 summarizes the results of the discounting procedure, and also includes discounted expenditure and annualized cost data for reference. Accumulated (and discounted to 1990) losses to GNP over the 1973-1990 period were half again as large as expenditures during the same period, and approximately twice as large as annualized costs. Losses in household consumption were approximately as great as annualized costs.

Table A-16. GNP and Consumption Impacts Discounted to 1990 ($1990 billions).

	3%	5%	7%
Expenditures	520	628	761
Annualized Costs	417	523	657
GNP	880	1005	1151
Household Consumption	500	569	653
HH and Gov't Consumption	676	769	881

Source: Expenditures and annualized costs from above; macroeconomic impacts from Jorgenson et al. (1993), Table 4.1

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[25] Not surprisingly, at the industry level, the principal beneficiaries in the long run of eliminating the costs associated with air pollution abatement are the most heavily regulated industries. The largest changes in industry prices and outputs occur in the motor vehicles industry. Other industries that benefit significantly from the elimination of environmental controls are refined petroleum products, electric utilities, and other transportation equipment. Turning to manufacturing industries, metal mining and the primary metals have the largest gains in output from elimination of air pollution controls.

Figure A-1. Percent Difference in Real Investment Between Control and No-control Scenarios.

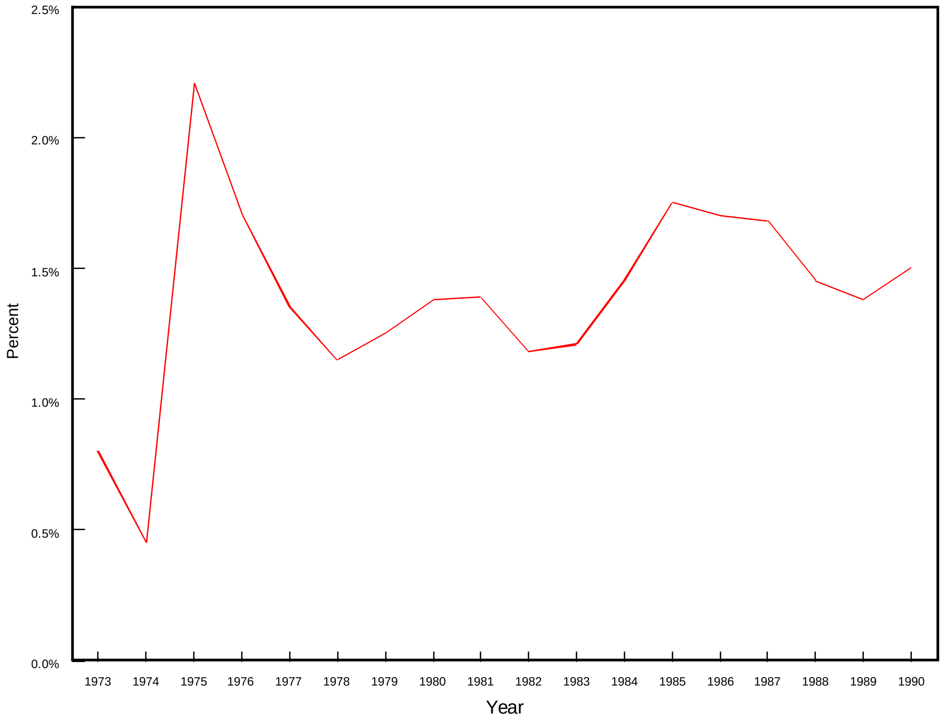
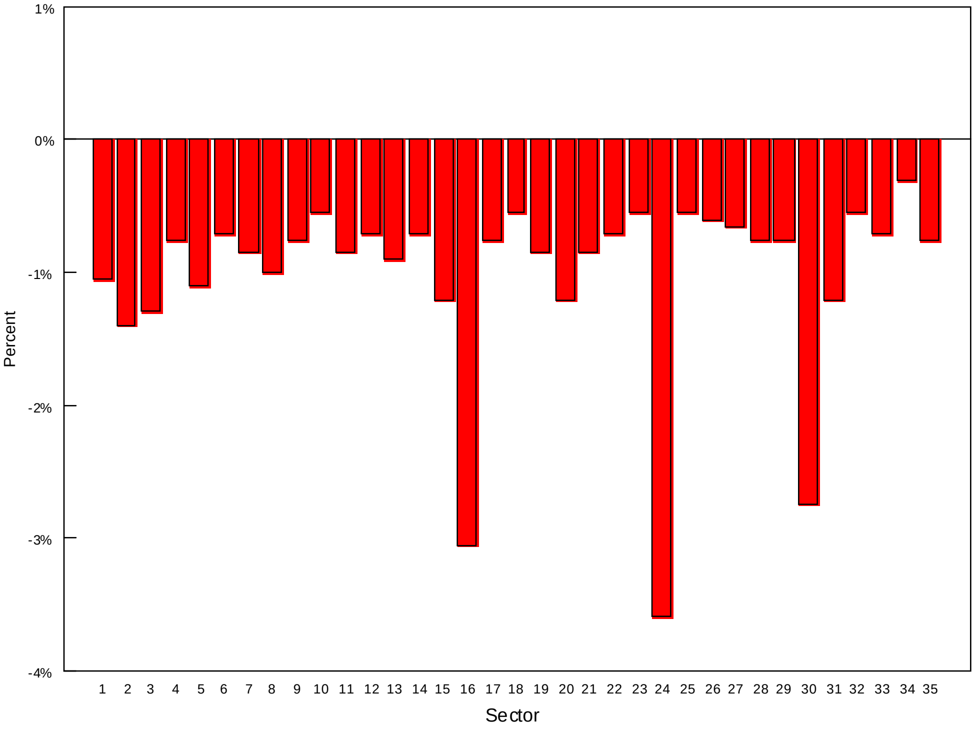


Figure A-2. Percent Difference in Price of Output by Sector Between Control and No-control Scenario for 1990.



Although they have value as descriptors of the magnitude of changes in economic activity, neither GNP nor consumption changes are perfect measures of changes in social welfare. A better measure is Equivalent Variations (EVs), which measure the change in income that is equivalent to the change in (lifetime) welfare due to removal of the CAA. As part of its macroeconomic exercise, EPA measured the EVs associated with removal of the CAA. Elimination of CAA compliance costs (disregarding benefits) represents a welfare gain of $493 billion to $621 billion, depending on assumptions used in the analysis.[26] This result does not differ greatly from the range of results represented by expenditures, anualized costs, and consumption changes.

Prices

One principal consequence of the Clean Air Act is that it changes prices. The largest price reductions accrue to the most heavily regulated industries which are the large energy producers and consumers (see Table A-17). But these are also the most capital intensive sectors and it is the investment effects that are the dominant influences in altering the course of the economy. Focusing on energy prices, under the no-control scenario the price of coal in 1990 declines by 1.3 percent, refined petroleum declines by 3.03 percent, electricity from electric utilities declines by 2.75 percent, and the price of natural gas from gas utilities declines by 1.2 percent. The declining price of fossil fuels induces substitution toward fossil fuel energy sources and toward energy in general. Total Btu consumption also increases.

Table A-17. Percentage Difference in Energy Prices Between the Control and No-control Scenarios.

Year	Coal	Refined Petroleum	Electric Utilities	Gas Utilities
1973	-0.44	-5.99	-2.11	-0.32
1974	-0.47	-4.84	-2.53	-0.44
1975	-0.42	-4.28	-2.19	-0.31
1976	-0.57	-3.83	-2.12	-0.44
1977	-0.74	-3.43	-2.22	-0.59
1978	-0.86	-3.28	-2.39	-0.68
1979	-0.91	-2.92	-2.81	-0.71
1980	-0.94	-2.76	-2.97	-0.69
1981	-0.97	-2.50	-2.76	-0.71
1982	-0.98	-2.42	-2.63	-0.77
1983	-1.09	-2.35	-2.58	-0.85
1984	-1.12	-2.26	-2.49	-0.91
1985	-1.21	-2.89	-2.62	-0.97
1986	-1.27	-3.35	-2.69	-1.12
1987	-1.31	-3.50	-2.78	-1.18
1988	-1.30	-3.61	-2.75	-1.19
1989	-1.31	-3.45	-2.74	-1.19
1990	-1.30	-3.03	-2.75	-1.20

Sectoral Effects: Changes in Prices and Output by Industry

At the commodity level, the effect of the CAA varies considerably. Figure A-2 shows the changes in the supply price of the 35 commodities measured as changes between the no-control case and the control-case for 1990.

In 1990, the largest change occurs in the price of motor vehicles (commodity 24), which declines by 3.8 percent in the no-control case. Other prices showing significant effects are those for refined petroleum products (commodity 16) which declines by 3.0 percent, and electricity (commodity 30) which declines 2.7 percent. Eight of the remaining industries have decreases in prices of 1.0 to 1.4 percent under the no-control scenario. The rest are largely unaffected by environmental regulations, exhibiting price decreases between 0.3 and 0.8 percent.

To assess the intertemporal consequences of the CAA, consider the model's dynamic results and the adjustment of prices between 1975 and 1990. Initially, in 1975, the biggest effect is on the price of output from petroleum refining (sector 16), which declines by 4.3 percent. But by 1990, the price of petroleum refining is about 3.0 percent below control scenario levels. In contrast, the price of motor vehicles (sector 24) is about 2.4 percent below baseline levels in 1975, but falls to about 3.8 percent below baseline levels in 1990.

The price changes affect commodity demands, which in turn determine how industry outputs are affected. Figure A-3 shows percentage changes in quantities produced by the 35 industries for 1990. As noted earlier, the principal beneficiaries under the no-control scenario are the most heavily regulated industries: motor vehicles, petroleum refining, and electric utilities.

In 1990, the motor vehicle sector (sector 24) shows the largest change in output, partly due to the fact that the demand for motor vehicles is price elastic. Recall

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[26] Jorgenson et al., 1993.

Figure A-3. Percent Difference in Quantity of Output by Sector Between Control and No-control Scenario for 1990.

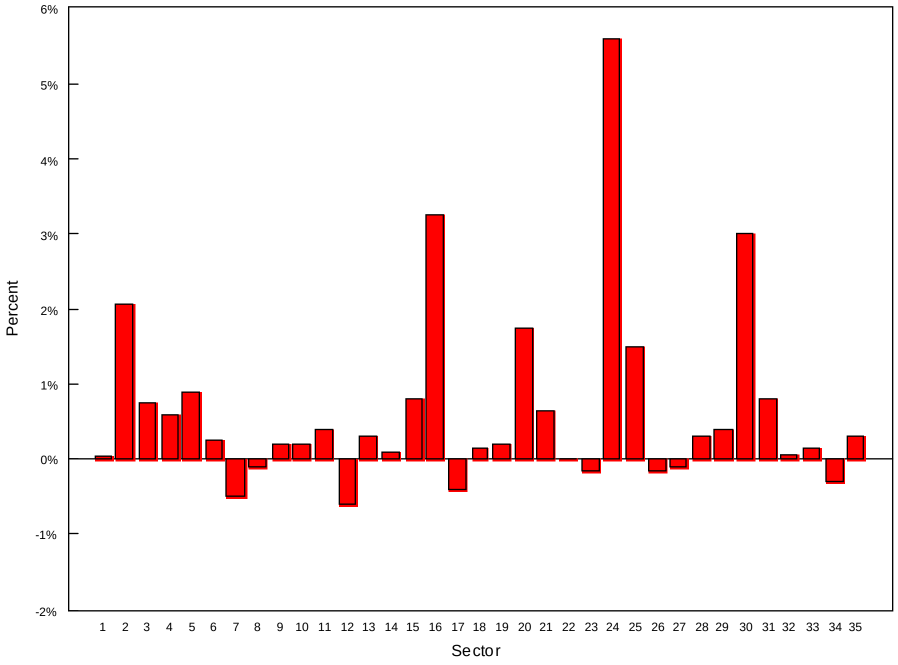
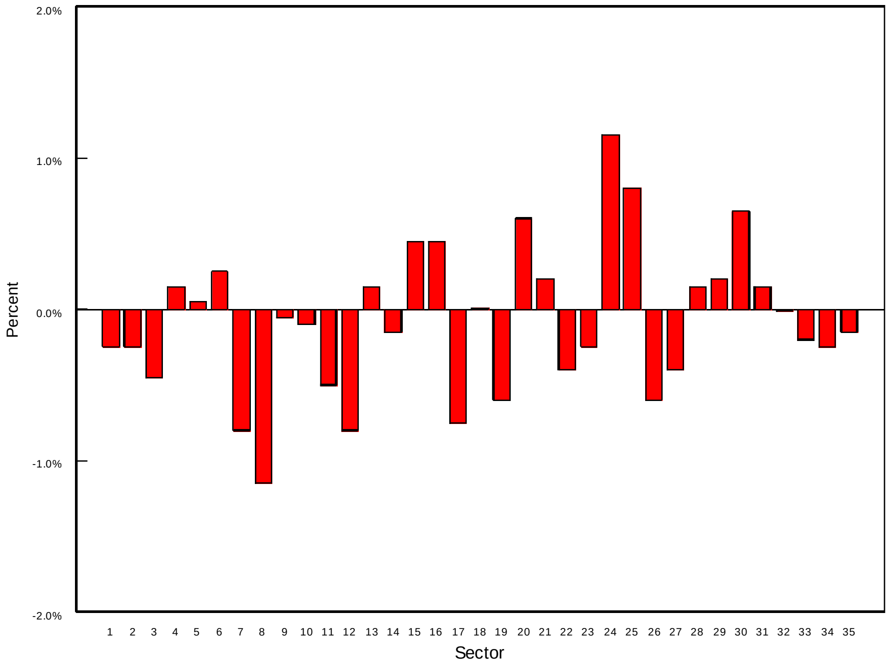


Figure A-4. Percent Difference in Employment by Sector Between Control and No-control Scenario for 1990.



that the largest increase in prices also occurred in the motor vehicles sector. The 3.8 percent reduction in prices produces an increase in output of 5.3 percent relative to the base case.

Significant output effects are also seen in the petroleum refining sector (sector 16) with a 3.2 percent increase, in electricity (sector 30) with a 3.0 percent increase, and in other transportation equipment (sector 25) with a 1.6 percent increase. The large gains in output for these industries are mostly due to the decline in their prices. In manufacturing, the sectors exhibiting the most significant output effects are metal mining (sector 2) with a 2.0 percent increase, and primary metals (sector 20) with a 1.8 percent increase. Twenty of the remaining industries exhibit increase in output of less than 0.9 percent after pollution controls are removed.

While most sectors increase output under the no-control scenario, a few sectors decline in size in the absence of air pollution controls. The most notable of these are food and kindred products (sector 7) which decline by 0.5 percent, furniture and fixtures (sector 12) which decline by 0.6 percent, and rubber and plastic products (sector 17) which decline by 0.3 percent. These sectors are among the least capital intensive, so the fall in the rental price of capital services has little effect on the prices of outputs. Buyers of the commodities produced by these industries face higher relative prices and substitute other commodities in both intermediate and final demand. The rest of the sectors are largely unaffected by environmental regulations.

Changes in Employment Across Industries

The effect of the CAA on employment presents a much more complicated picture. Although Jorgenson-Wilcoxen is a full-employment model and cannot be used to simulate unemployment effects, it is useful for gaining insights about changes in the patterns of employment across industries. Percentage changes in employment by sector for 1990 are presented in Figure A-4.

For 1990, the most significant changes in the level of employment relative to the control scenario occur in motor vehicles (sector 24) which increases 1.2 percent, other transportation equipment (sector 25) which increases 0.8 percent, electric utilities (sector 30) which increases 0.7 percent, and primary metals (sector 20) which increases 0.6 percent. The level of employment is higher relative to the control case in 10 other industries.

For a few sectors, the no-control scenario results in changes in real wages which cause *reductions* in employment. The most notable reductions in employment under the no-control scenario occur in tobacco manufacturing (sector 8) which declines 1.2 percent, furniture and fixtures (sector 12) which declines 0.8 percent, rubber and plastic products (sector 17) which declines 0.8 percent, food and kindred products (sector 7) which declines 0.7 percent, stone, clay and glass products (sector 19) which declines 0.6 percent, and instruments (sector 26) which declines 0.6 percent. These sectors are generally those in which the level of output was lower in 1990 relative to the control scenario, since they are among the least capital intensive and the fall in the rental price of capital services has little effect on the prices of outputs. Buyers of the commodities produced by these industries face higher relative prices and substitute other commodities in both intermediate and final demand. It is interesting to note that several of the least capital intensive sectors experience insignificant employment effects in the short run (1975) under the no-control scenario, but increasingly adverse effects over the 20-year period of analysis. These include food and kindred products, furniture and fixtures, rubber and plastic products, stone, clay and glass products, and instruments.

Examination of the transition of employment in the economy from the initial equilibrium to 1990 reveals that the employment effects of the CAA on motor vehicles, transportation equipment, electric utilities, and primary metals persist over the entire period of analysis. Employment varies from: an increase of 1.7 percent in 1975 to 1.2 percent in 1990 in motor vehicles; an increase of 0.7 in 1975 to 0.8 percent in 1990 in transportation equipment; an increase of 1.2 percent in 1975 to 0.7 percent in 1990 in electric utilities; and an increase of 0.8 percent in 1975 to 0.6 percent in 1990.

Uncertainties in the Cost Analysis

Potential Sources of Error in the Cost Data

Because of the importance of the *Cost of Clean* data for this assessment, the project team investigated potential sources of error due to the use of industry's self-reported costs of compliance with air pollution abatement requirements. Concerns about the accuracy of responses include (1) misreporting by firms in response to federal agency surveys, and (2) omission of important categories of compliance cost from the data collected or reported by these federal agencies.[27] Table A-18 contains a summary of the results of the analysis. This analysis is consistent with the findings of two recent studies comparing combined air, water, and solid waste pollution abatement costs, as reported in federal abatement cost surveys, to their observed effects on productivity levels. These studies suggest that, since observed productivity decreases exceed those expected to result from the reported abatement costs, there may be additional pollution abatement costs not captured or reported in the survey data, and that total abatement costs for the three manufacturing industries studied may be under-reported by as much as a factor of two in the most extreme case (Gray and Shadbegian, 1993 and 1995; Gray, 1996).

The major finding from this analysis indicates that total O&M costs are likely to be under-reported due to exclusion of private research and development

Table A-18. Potential Sources of Error and Their Effect on Total Costs of Compliance.

Source of Error	Effect on Capital Costs	Effect on O&M Costs
Lack of Data at Firm Level	Under-reported Percent Unknown	Under-reported Percent Unknown
Misallocation of Costs:		
Inclusion of OSHA and Other Regulatory Costs	Over-reported Percent Unknown	Over-reported Percent Unknown
Exclusion of Solid Waste Disposal Costs Related to Air Pollution Abatement	—	Under-reported Percent Unknown
Exclusion of Costs:		
Exclusion of Private R&D Expenses	—	Under-reported by 14 to 17% (varies by year)
Exclusion of Energy Use by Pollution Abatement Devices(a)	—	Under-reported by 1 to 3% (varies by year)
Exclusion of Depreciation Expenses(a)	—	Under-reported by 1 to 2% (varies by year)
Exclusion of Recovered Costs	—	Over-reported by 1% Plus
Omission of Small Firms	Under-reported by 1 to 2%	Under-reported by 1 to 2%
NET EFFECT	Under-reported	Under-reported

(a) Energy outlays *are* part of the data on O&M costs and depreciation expenses *are not*. Accordingly, in the J/W model, energy outlays are considered along with other operating expenditures in terms of their impacts on unit costs. Depreciation is represented fully in the capital accumulation process, as the undepreciated capital stock at the beginning of any period gives rise to the flow of capital services available to producers and consumers.

Source: Industrial Economics, Incorporated, memorandum to Jim DeMocker, EPA/OAR, "Sources of Error in Reported Costs of Compliance with Air Pollution Abatement Requirements," October 16, 1991.

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[27] Memorandum from Industrial Economics, Incorporated to Jim DeMocker (EPA/OAR) dated 10/16/91 and entitled "Sources of Error in Reported Costs of Compliance with Air Pollution Abatement Requirements."

(R&D) expenditures. Note, however, that although these costs were excluded from those used for the macroeconomic modeling, they were included in the overall direct cost estimate of the CAA; see “Other Direct Costs,” above. These costs are excluded from the macromodeling because they cannot be disaggregated by industry and, more importantly, because there is no information on what was purchased or obtained as a result of these expenditures.

Based on the need indicated by the IEc review, modifications to the BEA data were made to remedy some of the biases noted above. In particular, recovered costs for stationary source air pollution, e.g. sulfur removed using scrubbers that is then sold in the chemical market, have been accounted for in the data set used in the model runs.

Table A-19. Stationary Source O&M Expenditures as a Percentage of Capital Stock (millions of 1990 dollars).

				O&M divided by	
	K stock	Net K	O&M	K stock	Net K
1973	6,521	6,521	3,936	0.60	0.60
1974	14,880	14,684	4,778	0.32	0.33
1975	23,533	22,876	5,154	0.22	0.23
1976	32,773	31,372	5,768	0.18	0.18
1977	41,331	38,869	6,527	0.16	0.17
1978	49,448	45,612	6,991	0.14	0.15
1979	57,299	51,776	7,959	0.14	0.15
1980	65,763	58,232	8,791	0.13	0.15
1981	74,366	64,469	8,785	0.12	0.14
1982	82,381	69,740	7,855	0.10	0.11
1983	89,937	74,173	8,168	0.09	0.11
1984	95,879	76,606	8,505	0.09	0.11
1985	101,723	78,587	8,617	0.08	0.11
1986	107,082	79,713	8,477	0.08	0.11
1987	112,225	80,249	8,602	0.08	0.11
1988	117,269	80,300	8,143	0.07	0.10
1989	122,182	79,819	8,259	0.07	0.10
1990	127,394	79,217	8,842	0.07	0.11

“K stock” is the accumulated undepreciated stationary source control capital stock available at the beginning of each year, from Table A-10.
“Net K” is the stationary source control capital stock less depreciation implied by amortization at 5%; from Table A-10.
“O&M” is the stationary source control O&M expenditures; from Table A-9.
The final two columns are ratios: O&M divided by capital stock; and O&M divided by net capital.

An additional set of concerns relates directly to reporting of costs by firms. Some have noted an unexpected temporal pattern of stationary source control expenditures in the BEA data that might lead one to question the accuracy of the Census survey responses. One would expect that stationary source O&M expenditures over time would be roughly proportional to the accumulated stationary source control capital stock. Yet, as illustrated in Table A-19, O&M expenditures as a fraction of accumulated capital stock decline over time (even if one discounts the first few years because of the dramatic percentage increases in capital stock during those years). It is true that the ratio of O&M expenditures to the *depreciated* capital stock (in the far right column, labeled “net K”) is reasonably stable after 1981. The depreciation shown here, however, is a *financial* depreciation only, depicting the declining value of a piece of equipment over time, rather than a measure of physical asset shrinkage. Assuming a twenty-year useful lifetime, *all* of the stationary source control capital stock put in place since 1972 could conceivably still be in place in 1990. If anything, one would expect the O&M/K ratio to *increase* as the capital depreciates (i.e., ages), until the equipment is scrapped, because aging equipment requires increasing maintenance. Consequently, one might infer from this information that firms have systematically under-reported O&M expenditures, or have over-reported capital expenditures.

The apparent anomaly might be explained by an examination of the types of O&M expenditures reported. If more than a token percentage of O&M expenditures are unrelated to “operation and maintenance” of pollution control devices, then the observed O&M/K ratio would not appear unusual.

The Census PACE survey[28] required respondents to report air pollution abatement O&M expenses in the following categories: salaries and wages; fuel and electricity; contract work; and materials, leasing, and “miscellaneous.”[29] In later versions of the survey, additional information relating to the types of expenses to report was provided as a guide to respondents. The types of expenses listed that are relevant to air pollution abatement include:

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[28] *Pollution Abatement Costs and Expenditures*, various years.

[29] Census also requested a reporting of “depreciation” expenses as a component of O&M. BEA, however, removed depreciation expense from the reported O&M costs because retaining depreciation would have amounted to double-counting, since BEA also reported capital expenditures.

(1) operating and maintaining pollution abatement equipment;
(2) fuel and power costs for operating pollution abatement equipment;
(3) parts for pollution abatement equipment replacement and repair;
(4) testing and monitoring of emissions;
(5) incremental costs for consumption of environmentally preferable materials and fuels;
(6) conducting environmental studies for development or expansion;
(7) leasing of pollution abatement equipment;
(8) compliance and environmental auditing;
(9) salaries and wages for time spent completing environmental reporting requirements; and
(10) developing pollution abatement operating procedures.[30]

The magnitude of the expenditures associated with the first three items should be correlated with the size of the existing stock of air pollution abatement capital. Expenditures associated with items four through ten, however, should be independent of the size of the existing capital stock (expenditures associated with item seven, leasing of pollution abatement equipment, could be negatively correlated with the size of the capital stock). *If* items four through ten account for a non-negligible proportion of total O&M expenditures, and *if* respondents included these cost categories even though they were not explicitly listed in the survey instructions before 1991, *then* one would expect to see the O&M/K ratio declining during the study period. Thus, even though it is possible that O&M expenditures are underreported (or that capital expenditures are overreported), one cannot be certain.

Mobile Source Costs

For the section 812 analysis, EPA used the best available information on the estimated cost of mobile source air pollution control. Several other sources of cost estimates exist, however, including a cost series produced by the Department of Commerce Bureau of Economic Analysis (BEA). The BEA cost series is summarized in Table A-20. The BEA estimates differ significantly from EPA estimates, particularly with respect to estimates of capital costs and the "fuel price penalty" associated with the use of unleaded gasoline.

Table A-20. Comparison of EPA and BEA Stationary Source Expenditure Estimates (millions of current dollars).

	Private sector		Gov't. Enterprise		Total
Year	capital	O&M	capital	O&M	Expend.
	EPA Estimates				
1986	4,090	7,116	312	140	11,658
1987	4,179	7,469	277	130	12,055
1988	4,267	7,313	243	161	11,984
1989	4,760	7,743	235	173	12,911
1990	4,169	8,688	226	154	13,237
	BEA Estimates				
1986	4,090	7,072	312	182	11,656
1987	3,482	5,843	246	141	9,712
1988	3,120	6,230	121	161	9,632
1989	3,266	6,292	229	152	9,939
1990	4,102	6,799	200	154	11,255

"Recovered Costs" are not included in this table.
Sources for "BEA Estimates": for 1986, "Pollution Abatement and Control Expenditures," Survey of Current Business (BEA) June 1989, Table 7; for 1987-90, BEA May 1995, Table 8.

EPA's capital cost estimates are based on estimates of the cost of equipment required by mobile source regulations. BEA's estimates are based on survey data from the Bureau of Labor Statistics (BLS) that measures the increase in the per-automobile cost (relative to the previous model year) due to pollution control and fuel economy changes for that model year. The difference in approach is significant: BEA's annual capital cost estimates exceed EPA's by a factor of (roughly) two. EPA may underestimate costs to the extent that engineering cost estimates of components exclude design and development costs for those components. The BLS estimates add the incremental annual costs to all past costs to derive total current-year costs. Such an approach overestimates costs to the extent that it fails to account for cost savings due to changes in component mixes over time.

Some mobile source pollution control devices required the use of unleaded fuel. Unleaded gasoline is more costly to produce than is leaded gasoline, and generally has a greater retail price, thus imposing a cost on consumers. EPA estimated the "fuel price penalty" by using a petroleum refinery cost model to determine the expected difference in production cost between leaded and unleaded gasoline. BEA's "fuel price penalty" was the difference between the retail price of unleaded gasoline and that of leaded gasoline.

A detailed description of the data sources, analytic methods, and assumptions that underlie the EPA and BEA mobile source cost estimates can be found in McConnell et al. (1995).

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[30] *Pollution Abatement Costs and Expenditures, 1992*, pg. A-9.

Stationary Source Cost Estimate Revisions

As noted above, the costs used for stationary sources in the macro-modeling (and retained in this cost analysis) were projected for several years in the late 1980s. Since that time, BEA has released historical expenditure estimates for those years based on survey data. A comparison of the expenditure series can be found in Table A-21. Apparently, EPA's projections overestimated stationary source compliance expenditures by approximately $2 billion per year for the period 1987-1990. Since expenditures from all sources are estimated to be $18 billion -$19 billion (current dollars) per year during 1987-1990, this implies that EPA has overestimated compliance expenditures by more than ten percent during this period. Although a substantial overstatement for those years, the $2 billion per year overestimate would have little impact (probably less than two percent) on the discounted present value, in 1990 dollars, of the 1973-1990 expenditure stream.

Table A-21. BEA Estimates of Mobile Source Costs.

Year	Capital Exp.	Net I&M*	Fuel Price Penalty	Fuel Economy Penalty
1973	1,013	1,104		697
1974	1,118	1,380	5	1,180
1975	2,131	1,520	97	1,344
1976	2,802	1,420	309	1,363
1977	3,371	1,289	701	1,408
1978	3,935	1,136	1,209	1,397
1979	4,634	931	1,636	1,792
1980	5,563	726	2,217	2,320
1981	7,529	552	2,996	2,252
1982	7,663	409	3,518	1,876
1983	9,526	274	4,235	1,582
1984	11,900	118	4,427	1,370
1985	13,210	165	4,995	1,133
1986	14,368	(331)	4,522	895
1987	13,725	(453)	3,672	658
1988	16,157	(631)	3,736	420
1989	15,340	(271)	1,972	183
1990	14,521	(719)	1,370	(55)

* Inspection and maintenance costs less fuel density savings and maintenance savings.

Endogenous Productivity Growth in the Macro Model

For each industry in the simulation, the JW model separates price-induced changes in factor use from changes resulting strictly from technical change. Thus, simulated productivity growth for each industry has two components: (a) an exogenous component that varies over time, and (b) an endogenous component that varies with policy changes. Some reviewers have noted that, although not incorrect, use of endogenous productivity growth is uncommon in the economic growth literature. EPA conducted a sensitivity run of the J/W model, setting endogenous growth parameters to zero (i.e., removing endogenous productivity growth from the model).[31]

Endogenous productivity growth is an important factor in the J/W model. For example, for the period 1973-1990, removal of the endogenous productivity growth assumptions reduces household income by 2.9 to 3.0 percent (depending on whether one uses a world with CAA or one without CAA as the baseline). In comparison, removal of CAA compliance costs results in a 0.6 to 0.7 percent change in household income (depending on whether one uses, as a baseline, a world with or one without endgenous productivity growth). That is, use of the endogenous productivity growth assumption has four to five times the impact of that of CAA compliance costs.

Although very important to the simulated growth of the economy within any policy setting, the endogenous productivity growth assumption is less important across policy settings. Under the base (i.e., "with endogenous productivity growth") scenario, the aggregate welfare effect (measured as EVs, see above) of CAA compliance costs and indirect effects is estimated to be 493 billion to 621 billion in 1990 dollars. If one removes the endogenous productivity growth assumption, the aggregate welfare effect declines to the range 391 billion to 494 billion in 1990 dollars (Jorgenson et al., 1993, pg. 6-15), a reduction of about twenty percent.

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[31] For greater detail, see Jorgenson et al., 1993.

Amortization Period for Stationary Source Plant and Equipment

In developing annualized costs, stationary source capital expenditues were amortized over a twenty-year period. That is, it was assumed that plant and equipment would depreciate over twenty years. It is possible that stationary source plant and equipment has, on average, a useful lifetime significantly greater than twenty years. The Project Team tested the sensitivity of the cost analysis results to changes in stationary source capital amortization periods.

Table A-22 presents total annualized compliance costs assuming a 40-year amortization period for stationary source capital expenditures (all other cost components are unchanged from the base analysis). All costs are in 1990-value dollars, ad three alternative discount rates are used in the annualization period. Table A-23 presents the results discounted to 1990, and compared to the base case results (i.e., using a twenty-year amortization period). Doubling the amortization period to 40 years decreases the 1990 present value of the 1973-1990 cost stream by approximately 40 billion dollars. This represents a change of six percent to nine percent, depending on the discount rate employed.

Table A-22. Annualized Costs Assuming 40-Year Stationary Source Capital Amortization Period, 1973-1990 (millions of 1990 dollars).

	Annualized Costs		
Year	at 3%	at 5%	at 7%
1973	10,801	10,899	11,008
1974	12,875	13,108	13,366
1975	12,751	13,121	13,532
1976	13,338	13,891	14,504
1977	14,263	14,996	15,807
1978	13,778	14,690	15,695
1979	15,936	17,024	18,220
1980	18,091	19,368	20,771
1981	17,809	19,272	20,880
1982	16,670	18,316	20,123
1983	16,941	18,759	20,754
1984	17,836	19,803	21,960
1985	20,079	22,213	24,551
1986	18,544	20,809	23,288
1987	19,384	21,772	24,387
1988	19,203	21,706	24,446
1989	19,989	22,604	25,467
1990	20,546	23,268	26,247

Table A-23. Effect of Amortization Periods on Annualized Costs Discounted to 1990 (billions of 1990 dollars).

	Discount rate		
	3%	5%	7%
20-yr amortization period	417	523	657
40-yr amortization period	379	483	617

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Appendix B: Emissions Modeling

Introduction

This appendix provides additional details of the methodologies used to estimate control and no-control scenario emissions and the results obtained by these methods. Methodological information and results are provided for each of the six principal emission sectors: industrial combustion, industrial processes, electric utilities, on-highway vehicles, off-highway vehicles, and commercial/residential sources.

The initial section of this appendix assesses the emissions projections presented in this analysis by (1) comparing the 1970 to 1990 control scenario projections with recent EPA *Trends* report estimates for the same years and (2) comparing the 1970 to 1990 trend in no-control scenario projections with 1950 to 1970 emissions as reported in *Trends*. The first comparison indicates that control scenario emissions projections approximate, but do not precisely match, the EPA *Trends* data. The reason for this mismatch is discussed below. The second comparison is useful for demonstrating that pre-1970 emissions trends would not provide a satisfactory basis for extrapolating emissions trends into the 1970 to 1990 period. The inability to simply extrapolate pre-1970 trends provides further justification for applying the present modeling methodologies to generate no-control scenario emissions projections.

The remainder of the appendix provides further details of the emissions modeling conducted in support of the present analysis, and is largely adapted from the draft report "The Impact of the Clean Air Act on 1970 to 1990 Emissions; section 812 retrospective analysis," March 1, 1995 by Pechan Associates. The draft Pechan report surveys the methodologies and results associated with the sector-specific emission modeling efforts by Argonne National Laboratory (ANL), ICF Resources Incorporated (ICF), Abt Associates (Abt), and the Environmental Law Institute (ELI).

Comparison of Emissions Projections with Other EPA Data

Control Scenario Projections Versus EPA Trends Projections

The control scenario emission results are similar, but not identical, to official EPA historical emission estimates provided by the EPA National Air Pollutant Emission Trends Reports.[1] Comparisons between the current estimates and the *Trends* data for SO_2, NO_x, VOC, CO, and TSP are presented in Figures B-1, B-2, B-3, B-4, and B-5 respectively. More detailed tables providing emission estimates by sector and by target year for TSP, SO_2, NO_x, VOC, CO, and Lead are presented in Tables B-16, B-17, B-18, B-19, B-20, and B-21, respectively, at the end of this appendix.

Though the EPA *Trends* and the present study emission profiles are similar to each other, they should not be expected to match precisely. This is because the emission estimates developed for the present study are based on modeled macroeconomic and emission sector conditions. Even though the macroeconomic and sector models themselves are constructed and calibrated using historical data, modeled replications of historical trends would not be expected to precisely capture actual historical events and conditions which affect emissions. Relying on modeled historical scenarios is considered reasonable for the present analysis since its purpose is to estimate the differences between conditions with and without the CAA. Comparing actual historical emissions with modeled no-control emissions would lead to an inconsistent basis for comparisons between scenarios. Using models for both scenarios allows potential model biases to essentially cancel out.

In general, however, these comparisons show close correspondence between control scenario and *Trends* estimates with the largest differences occur-

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[1] EPA/OAQPS, "National Air Pollutant Emission Trends 1900 - 1994," EPA-454/R-95-011, October 1995.

Figure B-1. Comparison of Control, No-control, and *Trends* SO_2 Emission Estimates.

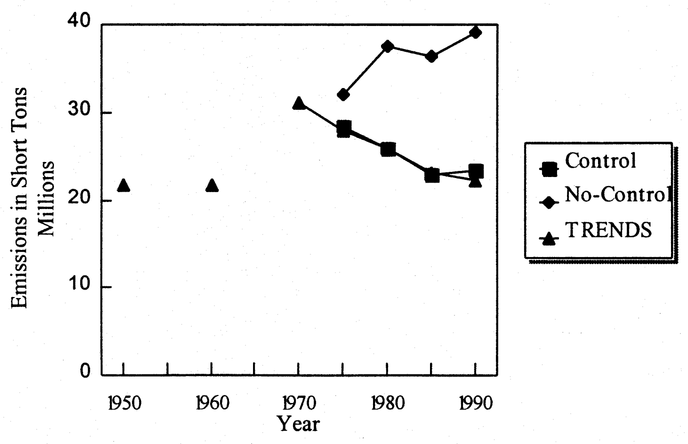


Figure B-2. Comparison of Control, No-control, and *Trends* NO_X Emission Estimates.

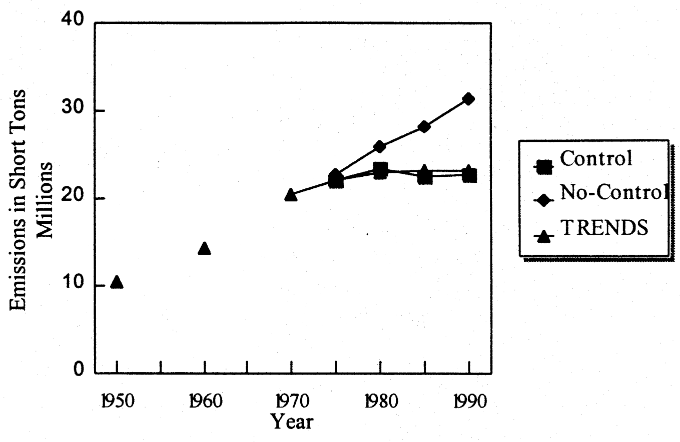


Figure B-3. Comparison of Control, No-control, and *Trends* VOC Emission Estimates.

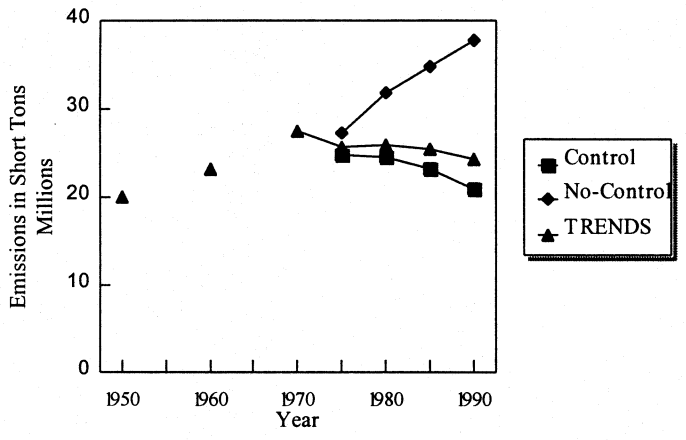


Figure B-4. Comparison of Control, No-control, and *Trends* CO Emission Estimates.

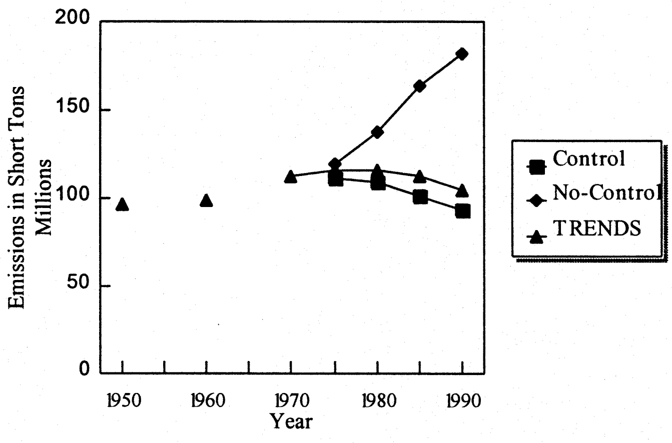
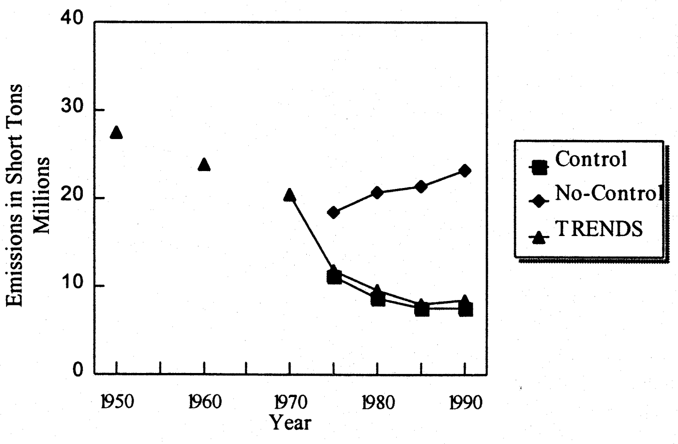


Figure B-5. Comparison of Control, No-control, and *Trends* TSP Emission Estimates.



ring for VOC and CO emissions. The *Trends* report VOC estimates are generally higher than the control scenario estimates due to the inclusion of Waste Disposal and Recycling as a VOC source in the *Trends* report. This inconsistency is of no consequence since Waste Disposal and Recycling sources were essentially uncontrolled by the historical CAA and therefore do not appear as a difference between the control and no-control scenarios. The higher CO emission estimates in the *Trends* Report are primarily associated with higher off-highway vehicle emissions estimates. Again, since off-highway emissions do not change between the control and no-control scenario in the present analysis, this inconsistency is of no consequence.

No-Control Scenario Projections Versus Historical EPA Trends Data

Comparisons between the control scenario emissions estimates generated for the present study and 1970 to 1990 emissions estimates obtained from the *Trends* Report are useful for assessing the reasonableness of the control scenario estimates. As indicated above, there is close correspondence between the control scenario and the *Trends* Report. It may also be useful to compare the pre-1970 historical emissions data from the *Trends* Report[2] with the no-control scenario estimates presented herein to assess whether these pre-1970 trends can be reasonably extrapolated to the 1970 to 1990 period. In addition, examination of any significant changes in emissions trends between the pre-1970 *Trends* data and post-1970 no-control projections might indicate flaws in the emissions modeling conducted for the present study.

For SO_2, the 1950 to 1970 *Trends* data in Figure B-1 demonstrate the effects of the huge increase in fossil fuel combustion between 1960 and 1970. This net increase occurred, despite the obsolescence of coal-fired locomotives and reductions in coal refuse burning, largely because utility emissions nearly doubled between 1950 and 1960, and nearly doubled again between 1960 and 1970.[3] Although no-control scenario projections for the post-1970 period show significant additional increases in SO_2 emissions, the rate of growth is markedly slower than during the 1950 to 1970 period.

The *Trends* data for 1950 to 1970 NO_x shown in Figure B-2 indicate the steady increase in emissions resulting from increased combustion of natural gas and gasoline.[4] The post-1970 emissions estimates derived for the present study reflect a continuation of this trend.

Emissions of VOCs increased steadily over the 1950 to 1970 period, as shown in Figure B-3, primarily due to increases in industrial production and vehicular travel.[5] The no-control scenario emission estimates continue this trend throughout the 1970 to 1990 period, with some acceleration of the rate of change due to the rapid increase in VMT projected under this scenario.

The *Trends* data shown in Figure B-4 for CO indicate an overall increase between 1950 and 1970. This increase occurred despite significant reductions in emissions from stationary source fuel combustion and industrial processes because mobile source emissions nearly doubled during this period.[6] Under the no-control scenario of the present study, additional reductions from stationary sources are not available to offset the transportation-related increases; therefore, the rate of increase in CO emissions after 1970 under the no-control scenario reflects the rapid increase in mobile source emissions caused by increases in vehicle miles traveled.

Finally, Figure B-5 demonstrates a directional shift in emissions of primary particulates between the 1950 to 1970 *Trends* data and the post-1970 no-control scenario. The declining trend from 1950 to 1970 indicated by the *Trends* data, however, is largely due to reductions in use of coal-fired locomotives, reductions in residential coal-burning, coarse (i.e., visible) particle emissions controls installed on fossil fuel combustors and industrial processes, and reductions in forest fires and other open burning.[7] Since the reductions achievable from these sources were largely

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[2] While 1970 to 1990 Trends data were obtained from more recent *Trends* reports, the 1950 to 1970 *data* were obtained from the November 1991 report since this was the last year the *Trends* report series included data for this period.

[3] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, Table 4, p. 16.

[4] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, p. 42.

[5] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, p. 42.

[6] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, Table 7, p. 19.

[7] U.S. EPA, “National Air Pollutant Emission Estimates, 1940 - 1990”, EPA-450/4-91-026, November 1991, Table 3, p. 15.

achieved by 1970, they are no longer available to offset the increases observed from other source categories (e.g., highway vehicles). The no-control scenario therefore shows a steady increase in overall emissions of primary particulates after 1975.

The following sections of this appendix summarize the methodologies used to model control and no-control scenario emissions for each of the six major emission sectors. Additional details can be found in the supporting documents listed in the References section of this appendix.

Industrial Boilers and Processes

For the purposes of the retrospective analysis, the industrial sector was divided into two components: (1) boilers; and (2) industrial processes and process heaters. The factors affecting emissions from these two source types are different, and, as a result, separate methods were used to calculate control and no-control scenario emissions in each of the target years. To analyze the change in emissions from industrial boilers, ANL used the ICE model (Hogan, 1988). This model was developed under the auspices of NAPAP to forecast State-level fuel choice and emissions from conventional, steam raising, industrial boilers. For the retrospective analysis of industrial processes and fuel use emissions from process heaters, ELI used the EPA *Trends* methods and the ANL MSCET data base (EPA, 1991; Kohout et al., 1990). The *Trends* report contains estimates of national emissions for a variety of industrial sources for the time period of interest. The MSCET data base provided the spatial distribution used to calculate State-level emissions.

The distinction between industrial boilers and non-boiler industrial processes was necessitated by the structure of the CAA regulations and by the factors affecting emission levels from these two source types. Boilers are regulated differently from processes and process heaters. Emissions from industrial processes are primarily a function of levels of industrial activity. The emissions from fuel combustion, however, are a function of energy use and fuel choice as well as industrial activity. Fossil fuel emissions in the absence of the CAA are not proportional to industrial output, since the level of energy use is a decision variable for the firm in its production process. Therefore, in the ICE model simulations used to estimate no-control scenario boiler emissions, the level (and type) of energy use were determined first, and then the effects of emission regulation were taken into account.

Overview of Approach

Industrial Boilers

ICE model inputs include fuel prices, total boiler fossil fuel demand by industry type, and environmental control costs. The outputs of the ICE model were SO_2, NO_x, and TSP emissions by State, industry, and boiler size class. The model runs in 5-year increments and has a current base year of 1985.

The model required boiler demand input data at the State level. Seven industry types were included in the ICE model: Standard Industrial Classification (SIC) codes 20, 22, 26, 28, 29, 33, and “other manufacturing.” ANL’s approach assumed that industrial boiler fuel use occurs only in the manufacturing sector. The model also required fuel price data in each of the target years at the Federal Region level. Prices by grade of coal and petroleum product, such as sulfur content and heating value, were used by the model to determine the cost of compliance, and to determine emissions when the regulations are not binding.

Control costs were computed by engineering subroutines in the model. These costs were used by the ICE model’s fuel choice component to determine the effect of CAA-related costs on the market share of a particular fuel. This fuel choice decision only applies to new industrial boilers, since the cost of existing emission controls are not in the ICE data base and fuel choice is not re-evaluated for existing boilers.

Industrial Processes and In-Process Fuel Combustion

The calculation of historical emissions from industrial processes uses EPA *Trends* methods to estimate national emissions for the analysis years, then allocates these emissions to States using the State shares from the MSCET data base.

MSCET uses a variety of methods to estimate historical emissions for the various industrial sectors. For industrial process emissions, MSCET is based on historical data on industrial activity to allocate emissions based on the State level distribution of the polluting activities. The State level distribution and benchmark is based on the 1985 NAPAP Inventory (EPA, 1989). This approach implies that the MSCET data corresponds directly to the 1985 NAPAP Inventory, and that, for any State, the sum of the emissions from Source Classification Codes (SCCs) that comprise the MSCET industry sector are equal to the MSCET data for that State and sector. Data from *Trends* are used by MSCET to provide information on changes in the aggregate level of control for years other than the 1985 benchmark. Since no direct correspondence existed between the *Trends* data and MSCET, a relationship was developed to link MSCET sectors to *Trends* industry categories and to industry categories in the J/W model, which was used to change activity levels for the no-control scenario.

Table B-1 shows the relationship between the sector definition used by MSCET, *Trends*, and the J/W model. The mapping from MSCET to J/W and *Trends* is used to provide the changes in aggregate activity and emission control for the calculation of no-control scenario emissions.

Establishment of Control Scenario Emissions

Energy use and corresponding emissions were broken down between boilers and non-boiler industrial processes. The latter category includes furnaces, kilns, internal combustion engines (e.g., compressors), and other non-steam types of process heat. The focus of this analysis is on boiler emissions, which were subject to increasingly stringent regulations over the 1970 to 1990 period. (Emissions from some types of industrial processes were also regulated, but regulation of non-boiler sources was targeted on the emissions from the industrial process itself, not on its fuel combustion) For this study, ANL assumed that only boiler fuel use is affected by emission regulations. The non-steam boiler portion of industrial fuel use is not directly affected by the CAA. This portion of the emissions may be affected indirectly by changes in industry activity level and fuel consumption. The emissions from non-boiler industrial processes were calculated separately by ELI.

Control Scenario Boiler Emissions

Control scenario boiler SO_2, NO_x, and TSP emissions were calculated by the ICE model. The MSCET data base provided an estimate of historical emissions for total fossil fuel combustion by industry. Since MSCET does not identify the two required components of boiler and non-boiler emissions, ANL defined the residual of the ICE model control scenario and MSCET as the non-boiler or in-process fuel use emissions. For the relevant study period, MSCET provided a control scenario estimate of total boiler and non-boiler emissions, which was used to calculate the control scenario State-level boiler emissions based on a special run of the ICE model.[8]

In order to use ICE to model the historical emissions path, it was necessary to construct a new ICE model base year file and new user input file so that the model could begin its calculations from 1975 conditions. Construction of the base year file was completed in two stages, using two different data sources, as discussed below. The user input file has several elements, including energy prices and historical boiler fuel use; its construction is discussed in the next section. The model base year file provided the energy use in boilers and corresponding emission control regulations (State Implementation Plans –SIPs– for example) by several categories. These categories include:

- State;
- Industry group (one of seven);
- Fuel type (natural gas, distillate or residual fuel oil, and coal);
- Boiler size class (MMBTU/hr, one of eight categories);
- Utilization rate (one of five categories); and
- Air quality control region (AQCR).

For the purposes of ANL’s analysis, only the first three categories were assumed to vary. In other words, for each State, industry, and fuel type combination, the distribution of boiler size, utilization rate, and AQCR was assumed to be constant. Over time, however, changes in the aggregate composition of State, industry, and fuel type would cause corresponding changes in the aggregate composition of the other three characteristics. As mentioned previously, the current base year file was 1985. The retrospective analysis required a 1975 base year. Because of data limitations, the approach to construct a new base year was achieved in the following two steps: the construction of a 1980 interim base year file from the 1985 file, and then the construction of the 1975 file from the interim 1980 file.

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[8] MSCET does not provide State-level estimates of TSP, while ICE does. To estimate total regional TSP from fuel combustion, the *Trends* model was employed. These national emissions estimates were allocated to the States based on the State-level shares of TSP from the NAPAP inventory.

Table B-1. Correspondence Between Process Emissions Categories Used by MSCET, *Trends*, and J/W Industrial Sectors and Identifier Codes.

MSCET Category	MSCET Code	*Trends* Industry Category	J/W Code	J/W Industry Category
Food Proc. and Agric. Operations	FOODAG	Cattle Feed Lots (0211)	1	Agriculture/forestry/fisheries
		Cotton Ginning (0724)		
		Feed and Grain Milling (204)		
		Grain Elevators (4421,5153)		
Mining Operations	MINING	Metallic Ore Mining (10)	2	Metal Mining
		Coal Mining (1211)		
Oil and Gas Extraction	OILGAS	Crude Oil Production, Storage, and Transfer (1211,4463)	3	Oil & Gas Extraction
		Natural Gas Production (1311)		
Mining Operations	MINING	Crushed Stone (142)	5	Nonfuel mining
		Sand and Gravel (144)		
		Clays (145)		
		Potash/Phosphate Rock (1474,1475)		
Degreasing	DEGRS	Degreasing	NA	Manufacturing
Misc. Industrial Processes	MISIND	Adhesives		
Indus. Organic Solvent Use, Misc.	SOLV	Other Organic Solvent Use		
		Solvent Extraction Processes		
Surface Coating	SRFCT	Surface Coating	NA	Durable Goods
Misc. Industrial Processes	MISIND	Lumber and Plywood (24)	11	Lumber & Wood Products
Cement Production	CEMNT	Cement (3241)	19	Stone, Clay, & Glass Products
Glass Manufacturing	GLASS	Glass (321,322)	19	Stone, Clay, & Glass Products
Lime Manufacturing	LIME	Concrete, Lime, Gypsum (327)	19	Stone, Clay, & Glass Products
		Lime (3274)		
Mineral Products Processing	MINRL	Clay Sintering (3295)	19	Stone, Clay, & Glass Products
		Brick and Tile (3251)		
Iron and Steel Production	IRNST	Iron and Steel (3312)	20	Primary Metal Industries
		Ferroalloys (3313)		
		Iron and Steel Foundries (332)		
Other Primary Metals Smelting	OTHMET		20	Primary Metal Industries
Primary Aluminum Smelting	PALUM	Primary Aluminum (3334)	20	Primary Metal Industries
Primary Copper Smelting	PCOPR	Primary Copper (3331)	20	Primary Metal Industries
Primary Lead and Zinc Smelting	PLDZC	Primary Lead and Zinc (3332,3333)	20	Primary Metal Industries
Other Sec. Metal Smelting and Refining	SECMET	Primary Nonferrous Smelters (333)	20	Primary Metal Industries
Other Sec. Metal Smelting and Refining	SECMET	Secondary Nonferrous Smelters (334,336)	20	Primary Metal Industries
Secondary Lead Refining	SLEAD	Secondary Lead (3341)	20	Primary Metal Industries
Food Proc. and Agric. Operations	FOODAG	Food and Beverages (20)	7	Food & Kindred Products
Misc. Industrial Processes	MISIND	Textiles (22)	9	Textile Mill Products
Paper and Pulp Mills Operations	PAPER	Pulp Mills (261,262)	13	Paper & Allied Products
Misc. Industrial Processes	MISIND	Graphic Arts (27)	14	Printing & Publishing
Printing Operations	PRINT		14	Printing & Publishing
Organic Chemicals Manufacture	ORGCM	Organic Chemicals (286)	15	Chemicals & Allied Products
		Carbon Black (2895)		
Other Chemicals Manufacture	OTHCM	Ammonia (2873)	15	Chemicals & Allied Products
		Nitric Acid (2873)		
		Chemicals (28)		
		Sulfuric Acid (2819)		
Petroleum Refining	PTREF	Petroleum Refining (2911)	16	Petroleum & Coal Products
		Asphalt Paving and Roofing (295)	16	Petroleum & Coal Products
Plastics Production	PLAST	Plastics (2821,3079)	17	Rubber and plastic products
Rubber and Misc. Plastics Manufacture	RUBR	Rubber Tires (3011)	17	Rubber and plastic products

Estimates of boiler fossil fuel consumption in 1980 for each State and major fuel type were provided by Hogan (Hogan, 1988). These estimates are based on the assumption that the industry mix, size, utilization, and AQCR distribution within a State are constant. Through assuming this relationship, the 1985 ICE base year was scaled to match the data for 1980, thus forming the 1980 interim base year data.

To construct the 1975 base year file, the assumption of a constant industry mix for a State and fuel type was no longer necessary, since detailed data on each industry for 1980 and 1975 were available from PURchased Heat And Power (PURHAPS) model data files (Werbos, 1983). These PURHAPS data files were derived from the Annual Survey of Manufactures: Fuels and Electric Energy Purchased for Heat and Power (DOC, 1991). The available data in these files were for *total* fuel use not *boiler* fuel use. To make use of these data, it was necessary to assume that the fraction of fuel used in boilers, for any given State and industry, remained constant from 1975 to 1980. To the extent that the fraction of boilers' heat versus process heat applications is a function of the specific industrial production process, this assumption is reasonable.

Based on the assumption of constant boiler fuel fraction of total fuel use, the ratio of 1975 to 1980 energy use for each State, industry, and fuel type was applied to the corresponding record of the 1980 interim base year file to produce 1975 base year files.

Control Scenario Industrial Process Emissions

To estimate boiler emissions of sulfur oxides (SO_x), NO_x, and VOC from industrial processes, data from *Trends* were used. The percentage change in national emissions by *Trends* category was applied to the appropriate sector from MSCET to obtain State-level emissions. In some cases there are several categories in *Trends* that match directly with MSCET categories (see Table B-1). In these cases, the *Trends* sectors were aggregated and the percentage change was computed. It was assumed that the level of control in each industry sector implied by *Trends* was uniform across States. The changes in emissions in each State are not equal to those at the national level, since the industry composition in each State varies.

Development of Economic Driver Data for the Control Scenario - Industrial Boilers and Processes

The results of the J/W model were the primary source of activity in the ICE model driver data. These results were also used by ELI to produce the national results for industrial processes from *Trends*. Both ICE and *Trends* use the forecasted change in industrial activity that results under the no-control scenario. These data were in the form of industry specific changes in energy consumption and industrial output, for boilers and industrial processes.

Economic Driver Data for Industrial Boiler Approach

Using the 1975 base year file as a starting point, the ICE model estimated fuel choice and emissions based on a user input file containing total boiler energy demand and regional energy prices. The 1975, interim 1980, and original 1985 base year files contained the required information on energy demand for each industry group and State, so the data in these three files were aggregated across fuel type, and other boiler characteristics (for example, size). These aggregated data provided the energy demand for three of the target years. Since 1990 State-level data on energy use by industry group were not available at the time of the study, the NAPAP base case forecast for the ICE model for 1990 was used to provide the demand data for this year.

The user input file for ICE also requires a price input for each target year. These prices were input by Federal Region for distillate oil, 4 grades of residual oil (by sulfur content), natural gas, and 11 grades of coal (by sulfur content and coal rank, i.e., bituminous and sub-bituminous). Prices for 1985 and 1990 were obtained from the NAPAP base case user input file. The prices for 1975 and 1980 are from U.S. Department of Energy (DOE) data on State-level industrial energy prices (DOE, 1990). Regional prices of natural gas, distillate oil, steam coal, and residual oil were constructed by aggregating expenditures across States within each region and dividing by total British thermal unit (BTU) consumption for the years 1975, 1980, and 1985. Since prices by sulfur content grade are not reported by this DOE source, ANL assumed that the sulfur premium implied by the 1985 ICE model input file was proportional to the average price. Based on this assumption, the ratio of the regional coal and residual oil price in 1975 and 1980 to the 1985 price was applied to the 1985 price in the ICE model base case file for each grade of fuel. To provide additional consistency between the NAPAP analysis and ANL's study, the distillate oil and natural gas prices were benchmarked to the 1985 ICE model prices as well.

One possible inconsistency arises using this procedure. The residual oil and natural gas markets are closely linked, particularly for industrial customers. These markets, specifically the gas market, underwent tremendous changes over the study period. To model the effect of these structural changes on the sulfur premiums in residual oil would require a detailed oil and gas supply model that was beyond the scope of this project. Moreover, the CAA regulations themselves create the potential for sulfur premiums. This potential effect of the CAA was not captured, though, because of the assumption of proportional fuel sulfur premiums on residual fuel oil. The relationship between market driven sulfur premiums in the coal market and the CAA was given additional consideration in this analysis through the use of an explicit coal supply model.

The J/W data for industrial energy consumptions was supplied in the form of percentage change in cost shares. In order to compute the percentage change in the quantity of energy used, ANL used the following identity:

$$1n\left(\frac{P_E \times E}{P_Q \times Q}\right) = 1n\,(P_E) + 1n\,(E) - 1n\,(P_Q \times Q), \text{ or}(1)$$

$$1n\left(\frac{P_E \times E}{P_Q \times Q}\right) - 1n\,(P_E) + 1n\,(P_Q \times Q) = 1n\,(E), \text{ or}(2)$$

The percentage change in E is the percentage change in cost share, minus the change in price, plus the change in value of shipments. These calculations were performed for each energy type and industry sector in the J/W model. The ICE model requires total fuel use, so the fuel specific percentages were weighted by historical fuel consumption to produce an aggregate change in fuel consumption to apply to the ICE model input data files.[9]

ICE also uses energy prices to simulate boiler fuel choices. The control scenario forecasts of energy prices in ICE were adjusted based on the percentage changes in energy prices, by coal, oil and natural gas. This implicitly assumes that the oil and coal fuel sulfur premiums, by region, are proportional to the average national price. To test this assumption for the coal market, additional modeling of the coal prices was performed using the coal market component of the ARGUS model.

It is possible that in some regions low sulfur coal prices to the industrial sector may be lower than the national average. This was not found to be the case. For example, in 1990, delivered regional industrial coal prices change by less than two-thirds of one percent. In most cases, the percentage change was near zero. This result appears to occur because of the highly regional nature of the coal market. While the artificial demand for low sulfur coal may fall, power plants near low sulfur coal reserves now find it advantageous to buy this local coal, which raises the price back to an equilibrium level near to that of the control scenario. This is even more likely to be true of industrial delivered prices, since industrial prices are more affected by transportation costs than are the utility prices. No additional ICE modeling was performed.

Economic Driver Data for the Industrial Process Approach

The J/W model was also used to account for activity level changes in the calculation of industrial process emissions under the no-control scenario. The correspondence between *Trends*, MSCET, and the J/W model was used to apply changes in industrial activity in each target year to each industrial process.

No-control Scenario Emissions

Industrial Boiler Emissions of SO_2, NO_x, and TSP

The CAA imposed different regulations, SIPs, and New Source Performance Standards (NSPS) that apply to industrial boilers of varying size. The primary effect of CAA regulations on industrial boilers was simulated by defining the Air Quality Control Region (AQCR), the resulting SIPs, and subsequent NSPS for boilers. The industrial boiler SIP regulations were included in the ICE base year file discussed in the previous section. Since the ICE model estimates new boiler emissions for each target year, the boiler NSPS are input through the ICE user files. Industrial NSPS were implemented in two phases. The 1971 regulations are imposed for the study years 1975 and 1980.

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[9] ICE uses six of the manufacturing industries from the J/W model directly. The remaining industries' percentage changes were weighted to produce the "other" category.

The 1984 NSPS revisions are imposed in the study years 1985 and 1990. For the no-control scenario, ANL set the SIPs and NSPS to a flag that indicated “no regulation.”

Industrial Boiler Emissions of CO and VOC

Two of the criteria pollutants emitted by industrial fuel combustors, CO and VOC, were not included as outputs of the ICE model. Therefore, CO and VOC emissions were analyzed separately using *Trends* methods. Control scenario CO and VOC emissions were taken directly from *Trends*.

To estimate CO and VOC emissions from industrial combustion for the no-control scenario, fuel use for industrial manufacturing was adjusted, reflecting fuel consumption changes estimated by the J/W model. These changes in the level of fuel consumption by industrial combustion were also used in ANL’s ICE boiler model. Changes in industrial combustion fuel use by manufacturing between the control and no-control scenarios are reported in Table B-2. These estimates represent an average of several sectors, which were developed by ANL as part of the modeling process for ICE.

No-control scenario emissions were computed using 1970 emission factors. Since there were no add-on controls for industrial combustion VOC and CO emissions, it was not necessary to adjust the no-control scenario for changes in control efficiency.

Table B-2. Fuel Use Changes Between Control and No-control Scenarios.

Year	Fuel Type	Fuel Use Changes
1975	Coal	-.0042
	Oil	+.0311
	Gas	-.0064
1980	Coal	-.0061
	Oil	+.0107
	Gas	-.0095
1985	Coal	-.0061
	Oil	+.0089
	Gas	-.0097
1990	Coal	-.0079
	Oil	+.0091
	Gas	-.0099

Emission estimates were regionalized using State-level emissions data from industrial boilers recorded in MSCET. For the control scenario estimates, VOCs were regionalized using the MSCET State-level shares for industrial fuel combustion. In the no-control scenario, the State-level shares were held constant. The control scenario emissions of CO were regionalized using the control scenario NO_x emissions from the ICE model. This approach assumes that CO emissions are consistent with NO_x emissions. The no-control scenario CO emission estimates from industrial combustion sources were regionalized using no-control NO_x emission estimates from industrial combustion sources.

Industrial Process Emissions

A wide range of controls were imposed on industrial processes. These emission limits are embodied in the assumptions of control efficiencies in the *Trends* model. Data on national no-control scenario emissions from industrial processes were provided by EPA. These data were combined with MSCET to produce regional-level results.

Lead Emissions

Estimates of lead emissions from industrial boilers and industrial processes were completed by Abt Associates. The methods used for calculating lead emissions from industrial processes and industrial boilers were similar. The starting point was the TRI, which provides air toxics emissions data for manufacturing facilities with more than 10 employees. To estimate lead emissions from industrial boilers and processes, 1990 facility-level lead emissions data were extracted from the TRI. These data were then adjusted to create estimates of lead emissions from industrial sources under the control and no-control scenarios for each of the target years. For the control scenario, lead emissions for 1975, 1980, and 1985 were obtained by extracting an emission factor and a control efficiency for each lead-emitting industrial process in the *Trends* data base. These emission factors and control efficiencies were multiplied by the economic activity data for each year for each process as reported in *Trends* to yield estimated control scenario emissions by industrial process. Each industrial process was assigned a code to correspond with energy consumption data by industrial process compiled in the National Energy Accounts (NEA) by the Bureau of Economic Analysis, and emissions were summed over all processes to obtain a total for each target year.

For consistency with the other emission estimates in this analysis, industrial process no-control scenario lead emissions were adjusted for changes in industrial output, and for changes in emissions per unit of output due to control technology applications. Changes in industrial output were accounted for using results from the J/W model. Lead-emitting industrial processes in the *Trends* data base were assigned to a J/W sector. For each sector, the percentage change in economic output was used to adjust the economic activity data for that process from the *Trends* data base. These adjusted economic output figures were used with the 1970 emission factors and control efficiencies to derive the estimated no-control scenario lead emissions for each industrial process in each target year. The process-level emissions were then aggregated to the NEA-code level as in the control scenario.

The lead emission estimates from industrial processes, by NEA code, were used to derive percentage changes in emissions under the control and no-control scenarios by NEA code for application to the TRI emissions data. Since TRI data are reported by SIC code, NEA codes were “mapped” to the appropriate SIC codes, and then the percentage change for each NEA code was used to represent the percentage change for all SIC codes covered by that NEA code.

To calculate lead emissions from industrial boilers, Abt Associates developed estimates of lead emissions from industrial combustion under the CAA for each of the target years. The *Trends* data base contains national aggregate industrial fuel consumption data by fuel type. For each fuel type, the fuel consumption estimate was disaggregated by the share of that fuel used by each NEA industrial category. The *Trends* data base also contains emission factors for industrial fuel use, by fuel type, as well as control efficiencies. The lead emissions from industrial combustion for each NEA category were derived by multiplying the fuel-specific combustion estimate for each NEA category by the emission factor and control efficiency for that fuel type. The result was emissions of lead by NEA code and by fuel type. Emissions from all fuel types were then summed by NEA code. The NEA data were used to disaggregate the industrial fuel consumption figures, based on the assumption that the ICE are the same among all industries covered by a given NEA code.

To estimate no-control scenario lead emissions, the macroeconomic effect of the CAA and the change in emissions per unit of output that resulted from specific pollution control mandates of the CAA were both taken into account. As in the control scenario, the national aggregate industrial fuel consumption estimate by fuel type was disaggregated by the share of that fuel used by each NEA industrial category. The fuel use was then adjusted in two ways: some NEA codes were specifically modeled by the ICE model, and for the remaining NEA codes, J/W percentage changes in fuel use were applied. These fuel use estimates were then combined with the 1970 emission factors and control efficiencies for industrial combustion by fuel type from the *Trends* data base to obtain no-control scenario combustion-related lead emissions from industrial boilers by NEA code. These estimates of total lead emissions by NEA codes were matched to SIC codes, and then to the data in the TRI data base. This approach assumed that an average emission value was assigned to all reporting TRI facilities in a given SIC code.

Off-Highway Vehicles

The off-highway vehicle sector includes all transportation sources that are not counted as highway vehicles. Therefore, this sector includes marine vessels, railroads, aircraft, and off-road internal combustion engines and vehicles. As a whole, off-highway vehicle emissions are a relatively small fraction of total national anthropogenic emissions.

Overview of Approach

The process used by ELI to determine the national level of emissions from the off- highway transportation sector is similar to the procedure outlined above for industrial processes. To estimate the emissions of criteria air pollutants from these sources under the no-control scenario, the historical activity levels were held constant, rather than attempting to calculate a new no-control scenario level of off-highway vehicle activity. This assumption was necessary since the off-highway activity indicators (amount of fuel consumed, and landing and take-off cycles for aircraft) do not have direct correspondence with a given J/W category. The national no-control scenario emissions of criteria air pollutants from these sources were simply derived by recalculating emissions using 1970 emission factors.

Development of Control Scenario

To estimate control scenario emissions, the analysis relied on *Trends* methods, using historical activity indicators, emission factors, and control efficiencies. Essentially, the estimates of off-highway emissions under the control scenario represent the historical estimates from the *Trends* data base.

No-control Scenario Emissions Estimates

The calculation of off-highway emissions for the no-control scenario required the *Trends* data to be adjusted to reflect changes in controls and economic activity in each of the target years. Linking source activity changes with economic activity for this section is not straightforward. The economic activity data for off-highway engines and vehicles are expressed either in terms of amount of fuel consumed, or in terms of landing and take-off cycles for aircraft. Neither of these off-highway activity indicators has a direct correspondence with a given J/W sector, making the sort of direct linkage between *Trends* categories and J/W sectoral outputs that was used for industrial processes inappropriate.

In the absence of a link between the economic factors that are determinants of emissions from this sector and the available economic activity forecasts, the no-control scenario emissions of criteria air pollutants from off-highway mobile sources were estimated based on the same historical activity levels used for the control scenario. Although there were changes in sectoral output and personal income that might have had an effect on off-highway vehicle usage, these changes were deemed to be small and not likely to have a major effect on the emissions from this sector.

Emission factors for each of the off-highway sources were also held constant at 1970 levels to calculate no-control scenario emissions for each target year. The national emissions of criteria air pollutants from these sources were then recalculated using 1970 emission factors.

National and State-Level Off-Highway Emission Estimates

Table B-3 summarizes national-level emission estimates for off-highway sources. The emission estimates derived from using the methodology discussed above yielded results that seem counter-intuitive. The emissions from off-highway sources, in particular the emissions from aircraft, are lower in the no-control scenario than those projected for the control scenario for most pollutants. This is a result of calculating emissions using 1970 emission factors, since the 1970 emission factors for aircraft are lower than the aircraft emission factors in later years.

ELI identified several potential sources of uncertainty in the emission estimates for this sector. First, the assumption that the total level of off-highway vehicle fuel consumption is constant between the two scenarios may be flawed. Second, the use of 1970 emission factors in the no-control scenario may fail to capture significant changes in technology. These technological changes are implicitly captured in the control scenario and it is possible that these technological changes may also have occurred under a no-control scenario.

One possible response to the biases created by the use of 1970 emission factors for all years in the no-control scenario is to test how results might differ if the emission factors used for the control scenario, which would include technological change, were also used for the no-control scenario. However, using this treatment of emission factors, the emissions projections from the adopted methodology from non-highway sources in the no-control scenario would be identical to the emissions projections under the control scenario. The reason for this is that the economic activity levels were not adjusted for the calculation of emissions under the no-control scenario.

In order to disaggregate the national data to a State level, the methodology used the MSCET data base, which is described earlier. Emissions of VOC, SO_x, and NO_x were regionalized using the State-level shares from the MSCET methodology. The emissions of TSP were regionalized by using the State-level shares for SO_x reported by MSCET, and the emissions of CO were regionalized using the State-level shares for NO_x, also reported by MSCET. The potential bias that this introduces is likely to be small, due to the relative homogeneity of off-highway vehicle emission sources.

Table B-3. Difference in Control and No-control Scenario Off-Highway Mobile Source Emissions.

		1975	1980	1985	1990
TSP	Control Scenario:	268.6	281.1	268.7	280.9
	No-Control Scenario:	260.8	268.8	261.2	266.9
	Percentage Increase:	-3%	-4%	-3%	-4%
NO_x	Control Scenario:	1,987.6	2,176.7	2,077.5	2,085.9
	No-Control Scenario:	1,974.6	2,150.5	2,042.7	2,058.9
	Percentage Increase:	-1%	-1%	-2%	-1%
SO_2	Control Scenario:	364.6	531.1	406.4	392.5
	No-Control Scenario:	363.2	528.6	403.0	386.9
	Percentage Increase:	0%	0%	-1%	-1%
CO	Control Scenario:	8,512.8	8,101.4	7,881.9	8,079.0
	No-Control Scenario:	8,511.0	8,071.2	7,880.2	8,077.7
	Percentage Increase:	0%	0%	0%	0%
VOCs	Control Scenario:	1,374.9	1,370.8	1,334.8	1,405.0
	No-Control Scenario:	1,385.9	1,416.1	1,388.6	1,485.8
	Percentage Increase:	1%	3%	4%	6%

Note: Emission estimates are expressed in thousands of short tons. Percentage increase is the differential between scenarios divided by the Control Scenario projection.

As with regionalization of industrial process emissions, the State-level shares are held constant between the two scenarios. To the extent that the distribution of economic activity between States was not constant over the period of the analysis, holding State-level emission shares constant may bias the results, although the direction and magnitude of the potential bias is unknown.

On-Highway

This section addresses the highway vehicle portion of the transportation sector. Highway vehicle emissions depend on fuel type, vehicle type, technology, and extent of travel. Emissions from these vehicles have been regulated through Federal emission standards and enforced through in-use compliance programs, such as State-run emission inspection programs. Vehicle activity levels are related to changes in economic conditions, fuel prices, cost of regulations, and population characteristics. Emissions are a function of vehicle activity levels and emission rates per unit activity.

TEEMS was employed by ANL to analyze the transportation sector. The modeling system links several models, disaggregate and aggregate, to produce State-level estimates of criteria pollutants. The system is subdivided into two modules: an activity/energy module and an emissions module. Each module contains multiple models. TEEMS has been documented in several reports and papers (Mintz and Vyas, 1991; Vyas and Saricks, 1986; Saricks, 1985). It has been used for several policy analyses and assessment studies for DOE and NAPAP. This section presents an overview of the approach used to conduct the analysis of the transportation sector. Also included in this section is a summary of the methodology used by Abt Associates to estimate changes in lead emissions from highway vehicles in each target year.

Overview of Approach

TEEMS has two modules: an activity/energy module and an emissions module. The activity/energy module calculates emissions based on: (1) personal travel; (2) goods movement; and (3) other transportation activity inputs.

Personal Travel

Personal travel activity and resulting fuel consumption were calculated for each target year using procedures that disaggregate households by demographic and economic attributes. Economic driver data, developed from U.S. Government data and macroeconomic model(s) of the domestic economy, formed the basis for household disaggregation. Modeling procedures were employed by ANL to project movement of households between various attribute classes, and vehicle holdings were projected in terms of the number and type of vehicles held by each household type. National totals were then developed by aggregating the vehicle holding estimates for each household type, accounting for the number of households of that type. Travel estimates, in terms of VMT, were calculated using the same approach, and based on the VMT of each household type. The basis for household transportation activity projection has been empirically established through analysis of the 1983-84 Nationwide Personal Transportation Survey (NPTS) (FHWA, 1986; Mintz and Vyas, 1991). VMT are projected using this empirical relationship, and estimates of the elasticity of VMT to vehicle operating cost are then made. Energy consumption was estimated in each target year using VMT, shares of VMT by vehicle type, and exogenously developed vehicle characteristics.

The following three models and an accounting procedure were employed to develop target year personal travel activity projections:

1. The first model projected the target year distribution of households by their attributes. This model employed an iterative proportional fitting (IPF) technique and projected the number of households in each cell of the household matrix - each of which is defined by various categories within six household attributes.

2. The second model projected changes in vehicle ownership resulting from changes in income and cost of vehicle operation. The model applied estimated ownership changes to each target year household matrix such that the control values within each of the household attributes, excepting vehicle ownership, remained unchanged.

3. The third model estimated the composition of household vehicle fleet by type (cars and trucks), size, technology, and fuel.

4. An accounting procedure applied VMT per vehicle to vehicle ownership in each combination of household attributes. VMT and energy consumption were accumulated by vehicle type, size, and fuel.

Each of these models is described separately in the following subsections.

Iterative Proportional Fitting (IPF)

This IPF model modified a control scenario matrix of household counts. A household matrix was developed from the 1983 NPTS data and upgraded to the year 1985 using published aggregate data. The procedure used in constructing the 1985 household matrix has been documented elsewhere (Appendix B of Mintz and Vyas, 1991). The matrix is defined by six attributes: (1) residential location (central city, suburb, rural); (2) household income; (3) age of householder; (4) household size; (5) number of drivers; and (6) number of vehicles. The household matrix has 3,072 cells, some of which are illogical (such as 1 person, 2 drivers). Illogical cells were replaced with zeros.

Household shares within each attribute in each target year were developed exogenously using data from the Bureau of the Census and selected macroeconomic model runs. The projected total of households and shares of households in each category of an attribute were supplied to the IPF model. The model modified the control scenario household matrix to match the specified shares and total number of households.

The IPF model treated household distribution within each attribute as a set of vectors. These vectors were scaled to match the specified shares and household total. Following the initial scaling, a gradual scaling technique was used to move in the direction of the target shares. The scaling process was repeated until closure was achieved for all attribute classes. Since vehicle ownership levels were estimated by the vehicle ownership model (described in the next section), shares within the sixth household attribute (number of vehicles held) were not specified, leaving it uncontrolled. This flexibility of an uncontrolled attribute helped to facilitate the model operation. The number of households in each class of vehicle ownership within the output matrix represents distribution of households using the control scenario (1985) relationship of vehicle ownership to other household attributes.

Vehicle Ownership Projection (VOP)

The VOP model projected the changes in vehicle ownership resulting from changes in the number of licensed drivers, disposable personal income, and annual fuel cost of vehicle operation. The model is based on historical household ownership rates. A target per-driver ownership rate was computed using disposable income and fuel cost. This target rate represented desired ownership if income and fuel cost were the only determinants. A parameter representing ownership responsibilities such as acquisition effort, disposal effort, parking requirements, and other indirect aspects was applied to adjust this target. The new ownership rate was used to estimate the number of household vehicles.

The household matrix created by the IPF model was revised to match the projected household vehicle ownership. Household shares within the first five attributes remain constant while those within the sixth attribute (i.e., number of vehicles) were variable. A deviation measure was defined and its value for each class within the first five attributes was minimized. A set of simultaneous equations was solved using Lagrangian multipliers.

Projection of Vehicle Fleet Composition

The composition of household vehicles was projected for each household matrix cell using a vehicle choice model called the Disaggregate Vehicle Stock Allocation Model (DVSAM). Vehicles are defined by type (auto, light truck), size (small, mid-size, full-size auto; small pickup, small utility/minivan, standard pickup, large utility/standard van; or any other size classification), fuel (gasoline, diesel, methanol, ethanol, or compressed natural gas), and technology (stratified charge, direct injection, electric, fuel cell, or Brayton).

The model computed vehicle composition based on an individual vehicle's utility to households and household needs. A menu of vehicles classified by the previously mentioned vehicle attributes was supplied to the model. The menu specified characteristics of each vehicle available to households. Vehicles were characterized by price, operating cost, seating capacity, curb weight, and horsepower. These variables formed the basis for computing "utility" (analogous to consumer satisfaction). The household matrix provided demographic and economic attributes which, when combined with vehicle usage in miles, define household needs. Vehicle usage (VMT) was computed as a function of income, number of drivers, and number of vehicles. A logit model was applied to compute vehicle ownership shares. Several model enhancements facilitated modeling of limited range vehicles, and representation of supply constraints and/or regulated market penetration.

Activity/Energy Computation

An accounting procedure was applied to compute personal travel activity in terms of VMT by vehicle type. Control scenario VMT per vehicle estimates for each cell in the household matrix were developed from the 1983 NPTS. These rates were adjusted within the procedure on the basis of changes in average vehicle operating cost per mile for each cell. The vehicle composition projection model computes ownership shares and share-weighted change in vehicle operating cost. Elasticity values were applied to this change.

ANL assumed that VMT per vehicle remained nearly unchanged for a household matrix cell over time (with the exception of the effect of changes in vehicle operating cost). In other words, variation of VMT across household types is far greater than within household types. VMT per household vehicle remained stable during the period from 1977 to 1984 (Klinger and Kuzmyak, 1986). Some increases were observed in recent years, which were attributed to lower fuel prices and increased household income (DOC, 1991; FHWA, 1992). (A portion of the increase could be attributed to the method of computing average VMT per vehicle.) The assumption that VMT per vehicle for each cell remained nearly constant and was elastic relative to vehicle operating cost is reasonable. As households move from one cell of the matrix to another, they "acquire" the VMT per vehicle rate of that cell. Thus, this approach accounted for changes in VMT per vehicle due to increased household affluence, increased rate of driver licensing, changes in fuel price, and changes in vehicle technology.

Goods Movement

Energy and activity demand resulting from movement of 24 aggregate categories of commodities is estimated by this subcomponent of the TEEMS activity module. Changes in commodity demand/production were provided by growth indexes by two-digit SIC generated by a macro model. A model that projects shifts in mode shares among truck, rail, marine, air, and pipeline modes was used, followed by a procedure to compute ton miles of travel for each mode, VMT by fuel type for trucks, and energy consumption by operation type for non-highway modes. The model used 1985 control scenario data, which were compiled from railroad waybill sample and publications, waterborne commerce publications, transportation statistics, and other sources. The procedure used in developing the 1985 control scenario freight data has been documented in an ANL report (Appendix A of Mintz and Vyas, 1991).

This goods movement model was not used for this retrospective analysis because of funding and time constraints. A procedure to estimate truck VMT by fuel type was employed in its place. Published historical VMT values (FHWA, 1988; 1992) were used along with VMT shares by fuel and truck type from Truck Inventory and Use Surveys (TIUS) (DOC, 1981; 1984; 1990).

Other Transportation Activities

The activity/energy module also has other models for developing activity and energy use projections for air, fleet automobiles, and bus modes. Fleet automobile activity estimates from an earlier study (Mintz and Vyas, 1991) were used while other modes were not analyzed.

Lead Emissions

Estimates of lead emissions in the transportation sector were developed by Abt Associates based on changes in reductions of lead in gasoline. This estimation required the estimates of lead in gasoline consumed over the period from 1970 to 1990 and the amount of lead content in gasoline that would have been consumed in the absence of the CAA. These values were calculated using the quantity of both leaded and unleaded gasoline sold each year and the lead concentration in leaded gasoline in each target year. Data on annual gasoline sales were taken from a report by ANL that presented gasoline sales for each State in each target year. For the control scenario, data on the fraction of gasoline sales represented by leaded gasoline were used. For the no-control scenario, all of the gasoline sold was assumed to be leaded. Data on the lead content of gasoline was obtained from ANL for 1975 through 1990. For 1970 through 1975, the analysis assumed that the 1974 lead content was used.

Estimation of No-control Scenario Emissions

TEEMS emissions projections were carried out by ANL in the following three steps:

1. Development of emission factors;
2. Allocation of highway activity to States; and
3. Development of highway pollutant estimates.

The following subsections describe the procedures used for computing highway vehicle emissions.

Development of Emission Factors

EPA's MOBILE5a Mobile Source Emission Factor model was used to provide all of the highway vehicle emission factors used to estimate 1975 to 1990 emission rates (EPA, 1994b). Documentation of the MOBILE5a model is found in the User's Guide for the MOBILE5 model.[10]

Although the actual emission factors used by ANL are not documented in either the original ANL TEEMS model report or in the Pechan summary report, the Project Team provided direction that defined the emission factors to be used. For the control scenario, ANL was directed to use the official EPA emission factors prevailing at the time for each target year. For example, the official EPA emission factor being used in 1980 for on-highway vehicle NO_x was to be used to estimate 1980 control scenario on-highway vehicle NO_x emissions. For the no-control scenario, the official EPA emission factors used to estimate emissions in 1970 were to be used throughout the 1970 to 1990 period.

It is important to note that using the 1970 on-highway vehicle emission factors to estimate no-control scenario emissions for the entire 1970 to 1990 period may bias scenario emission differentials upward. This is because it is possible that technological changes to on-highway vehicles unrelated to CAA compliance

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[10] EPA/OAR/OMS, "User's Guide to MOBILE5," EPA-AA-AQAB-94-01, May 1994; see also 58 FR 29409, May 20, 1993.

strategies may have yielded incidental reductions in emissions. However, EPA Office of Mobile Sources (EPA/OMS) experts indicate that the two major technological changes in vehicles occurring during the period of the analysis –electronic ignition and electronic fuel injection– would have yielded negligible emission reductions in the absence of catalytic converters.[11]

Another potential bias is introduced by assuming the CAA had no substantial effect on vehicle turnover. However, two factors render this potential bias negligible. First and foremost, under the no-control scenario retired vehicles would be replaced by new but equally uncontrolled vehicles. Second, no-control scenario vehicle use is greater in terms of VMT per year. This means no-control scenario vehicles would reach the end of their service lives earlier, offsetting to some extent the alleged incentive to retire vehicles later due to costs imposed by CAA control requirements.

Allocation of Highway Activity to States

TEEMS' activity module generated national activity and energy estimates. These activity totals were allocated to States through a regionalization algorithm that used time series data on historical highway activity shares by State. A trend extrapolation methodology was used that stabilizes shifts after 5 years in the future. For the retrospective analysis, historical highway activity shares for each target year were developed using data published by the Federal Highway Administration (FHWA) (FHWA, 1988; 1992).

Development of Highway Pollutant Estimates

Highway emission estimates were calculated in both scenarios for each target year using VMT estimates generated by TEEMS and emission factors from MOBILE5a. Control scenario activity levels were adjusted for the no-control scenario using economic forecasts and historical data.

Control Scenario Emissions Calculation

Control scenario data for the transportation sector were compiled from several sources. Household counts and shares of households by six attributes were obtained from various editions of the *Statistical Abstracts* of the United States. Household income information was obtained from the control scenario run of the J/W model. Fuel prices were obtained from the *Annual Energy Review* (DOE, 1992) while vehicle fuel economy and aggregate VMT per vehicle were obtained from *Highway Statistics* (FHWA, 1988; 1992). B-4 lists data sources for the control scenario run.

Table B-5 shows household shares prepared for the IPF model. The total number of households increased from 63.4 million in 1970 to 93.3 million in 1990. A gradual shift from rural to urban was observed with movement to suburbs within urban areas. The effect of economic downturns in 1975 and 1980 was an increase in share for the lowest income category; more households moved to the highest income group from 1970 to 1990, while the lower middle income group share expanded and the upper middle income share declined. The rate of household formation was high during the 1970's, which resulted in increases in smaller and younger households. The trend in younger households reversed after 1980 as household formation slowed. Average household size dropped from 3.2 in 1970 to 2.67 in 1990. The number of licensed drivers increased throughout the analysis period as more and more young people were licensed to drive.

Data for the VOP model included disposable income per capita, fuel price, overall personal vehicle fuel economy, and annual usage in terms of VMT. Table B-6 shows these data for each year in the analysis period.

Data preparation for the model that projected household vehicle composition was limited to characterization of existing technology vehicles. Seven vehicle size and type combinations were characterized for 1975 and 1980 while one vehicle, minivan/small utility, was added for 1985 and 1990. Control scenario vehicle characteristics are tabulated in Table B-7. TEEMS' activity and energy computation procedure was executed to produce personal vehicle travel and energy consumption estimates.

Commercial truck travel was not modeled but, historical data published by the FHWA (FHWA, 1987; 1991) were used. FHWA publishes truck travel by three categories: 1) 2-axle, 4-tire trucks; 2) single unit

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[11] Telephone conversation between Jim DeMocker, EPA/OAR and EPA/OMS/Ann Arbor Laboratory staff (date unknown). Nevertheless, the Project Team did consider reviewing emission factors for European automobiles to attempt to estimate no-control scenario emission factors for 1975 through 1990 reflecting the use of electronic fuel injection and electronic ignition but no catalytic converter. However, the Project Team concluded that differences in fuel/air mix ratios used in Europe would probably obscure any differences in emission rates attributable to the use of electronic fuel injection and electronic ignition.

trucks; and 3) combination trucks. All 2-axle, 4-tire trucks were treated as light-duty trucks. VMT by personal light trucks were subtracted from the published totals to arrive at commercial light truck VMT. Diesel truck VMT shares of total VMT were obtained from TIUS (DOC, 1981; 1984; 1990). TIUS data were also used to split VMT by single unit and combination trucks. All combination trucks were assumed to be the heaviest, class 7 and class 8, while single unit trucks could be of any size class 3 through 8. Gasoline and diesel VMT totals were developed for these heavy-duty trucks and were kept constant for the control and no-control scenarios.

Table B-4. Sources of Data for Transportation Sector Control Scenario Activity Projection.

Data Item	Model	Source
Household total, population, household shares by four attributes (location, income, age of head, and household size).	IPF	Statistical Abstract of the United States, editions 96th, 98th, 103rd, 104th, 108th, and 113th.
Household shares by number of drivers.	IPF	Statistical Abstracts and FHWA Highway Statistics provided total drivers. The *with CAA* distribution of households trended.
Personal and Disposable income.	VOP	J/W model output and Statistical Abstracts.
Vehicle fleet on-road fuel economy.	VOP DVSAM	FHWA Highway Statistics.
Fuel Prices	VOP DVSAM	Energy Information Administration's (EIA) Annual Energy Review.
Vehicle Price	DVSAM	Ward's Automotive Yearbooks 1975-1983, Automotive News Market Data Book 1985.

IPF - Iterative Proportional Fitting
VOP - Vehicle Ownership Projection
DVSAM - Disaggregate Vehicle Stock Allocation Model
FHWA - Federal Highway Administration
EIA - Energy Information Administration

Table B-5. Distribution of Households by Demographic Attributes for Control Scenario.

Household (Million)	63.4	71.1	80.8	86.8	93.3
Population (Million)	204.0	215.5	227.2	237.9	249.5
Attribute	**Household Percentage, by Year**				
	1970	1975	1980	1985	1990
Location					
Central City	33.2	32.0	31.9	31.6	31.4
Suburbs	33.6	36.0	37.0	38.1	38.3
Rural	33.2	32.0	31.1	30.3	30.3
Income (1990 $)*					
<$13,000	25.9	26.5	26.6	25.9	25.5
$13,000 - $33,000	34.0	37.2	37.4	37.7	38.0
$33,000 - $52,500	27.6	22.7	22.4	22.2	22.2
>$52,500	12.5	13.6	13.6	14.2	14.3
Age of Householder (YR)					
<35	25.4	29.1	31.1	29.3	27.4
35 - 44	18.6	16.7	17.3	20.1	22.1
45 - 64	36.3	34.0	31.2	29.6	29.0
> = 65	19.7	20.2	20.4	21.0	21.5
Household Size					
1	17.2	19.5	22.7	23.7	24.6
2	29.0	30.7	31.3	31.6	32.2
3 - 4	33.0	33.0	33.2	33.5	32.8
> = 5	20.8	16.8	12.8	11.2	10.4
Licensed Drivers					
0	9.1	8.5	8.1	7.2	6.6
1	27.8	27.3	27.0	26.2	26.0
2	48.1	49.2	50.5	52.5	53.5
> = 3	15.0	15.0	14.4	14.1	13.9

Note: *Approximated to 1990 dollars.

Table B-6. Economic and Vehicle Usage Data for Vehicle Ownership Projection – Control Scenario.

Year	Disposable Income per Capita (84 $)	Fuel Price (84 $)/Gallon	Miles/Gallon	VMT/Vehicle
1970	7,597	0.92	13.5	10,143
1971	7,769	0.88	13.5	10,246
1972	7,990	0.84	13.4	10,350
1973	8,436	0.84	13.3	10,184
1974	8,270	1.06	13.4	9,563
1975	8,340	1.03	13.5	9,729
1976	8,553	1.02	13.5	9,833
1977	8,742	1.01	13.8	9,936
1978	9,070	0.97	14.0	10,143
1979	9,154	1.21	14.4	9,522
1980	9,052	1.53	15.5	9,212
1981	9,093	1.55	15.9	9,212
1982	9,050	1.38	16.7	9,419
1983	9,239	1.27	17.1	9,419
1984	9,691	1.20	17.8	9,550
1985	9,881	1.09	18.2	9,568
1986	10,139	0.88	18.3	9,672
1987	10,174	0.88	19.2	10,090
1988	10,564	0.86	19.9	10,100
1989	10,713	0.90	20.3	9,819
1990	10,903	1.00	20.8	9,780

Table B-7. Control Scenario Personal Characteristics.*

Vehicle Type and Size (Seats)	1975 Curb Weight (lb)	1975 Engine Power (hp)	1975 Fuel Economy (mpg)	1980 Curb Weight (lb)	1980 Engine Power (hp)	1980 Fuel Economy (mpg)
Automobile						
Small (2-4)	2,770	91	17.2	2,535	83	19.6
Compact (4)	3,625	115	14.6	3,335	105	16.9
Mid-size (5)	4,140	128	13.3	3,730	116	15.1
Large (6)	4,900	155	12.2	4,840	153	13.3
Light truck						
Std. truck	4,530	141	11.2	4,455	143	12.6
Compact	3,745	108	14.2	3,580	99	15.9
Std. Van/Std.	5,010	145	9.9	4,975	144	11.4
Utility (11-15)						
Minivan/Small Utility (7-8)						

Vehicle Type and Size (Seats)	1985 Curb Weight (lb)	1985 Engine Power (hp)	1985 Fuel Economy (mpg)	1990 Curb Weight (lb)	1990 Engine Power (hp)	1990 Fuel Economy (mpg)
Automobile						
Small (2-4)	2,225	75	22.7	2,135	75	24.9
Compact (4)	2,775	90	19.3	2,595	90	22.0
Mid-size (5)	3,180	108	16.8	3,050	108	19.5
Large (6)	3,975	135	14.6	3,705	130	17.1
Light truck						
Std. truck	4,160	132	13.1	4,000	128	14.1
Compact	3,495	90	17.2	3,360	90	18.9
Std. Van/Std.	4,920	142	12.4	4,765	138	12.9
Utility (11-15)						
Minivan/Small Utility (7-8)	4,125	101	16.7	3,910	108	18.2

Note: *Average for all vehicles of each type and size.

Table B-8. Distribution of Households by Income Class for No-control Scenario.

	Household Shares (%), by Year			
Attribute	**1975**	**1980**	**1985**	**1990**
Income (1990 $)*				
<$13,000	26.3	26.2	25.3	24.7
$13,000-33,000	37.3	37.6	38.4	38.4
$33,000-52,000	22.8	22.6	22.0	22.6
>$52,000	13.6	13.6	14.3	14.3

Note: *Approximated to 1990 dollars.

No-control Scenario Emissions

The control scenario data were modified to reflect no-control scenario emissions using economic changes predicted by the J/W model, EPA, and ANL. The J/W model predicted a slight loss of employment and drop in GNP in terms of nominal dollars. However, the lower rate of inflation coincided with a real GNP rise. ANL's information from the model did not include any indexes for converting nominal income to real income. ANL assumed real income changes to be similar to those of real GNP and modified household shares by income classes accordingly. The model also predicted a slight drop in refined petroleum price beginning in 1973. The predicted drop was the largest (5.35 percent) in 1973, reached the lowest level (2.16 percent) in 1984, then increased to a second peak (3.44 percent) in 1988, and dropped again from 1989 to 1990. Since these changes were inconsistent with historical patterns of leaded and unleaded gasoline price change, ANL developed an estimate of changes in fuel price resulting from the cost of removal of lead from gasoline and other infrastructure costs involved with distributing a new grade of fuel. Subsequently, EPA provided a set of fuel costs for use in the analysis. Both ANL and EPA fuel prices followed a similar pattern, although their magnitudes differed. The no-control scenario was analyzed with EPA fuel prices. ANL also established a relationship with cost of regulation/emission control technology, and the effect of costs on vehicle price and fuel economy directly from the EPA publication *Cost of A Clean Environment* (EPA, 1990). These changes were used in the analysis.

The IPF model was executed for target years 1975, 1980, 1985, and 1990 using a set of revised household shares by income class. Table B-8 shows the revised shares. Comparing Table B-8 no-control scenario shares with those in Table B-5 for the control scenario, there seems to be a slight shift away from travel by the lowest income group and toward the middle income groups.

The vehicle ownership projection model was executed for the above four target years using the data listed in Table B-9. Changes in fleet characteristics are summarized in Table B-10.

Table B-9. Economic and Vehicle Usage Data for Vehicle Ownership Projection – No-control Scenario.

Year	**Disposable Income per Capita (84 $)**	**Fuel Price (84 $)/Gallon**	**Miles/ Gallon**	**VMT/Vehicle**
1970	7,597	0.91	13.5	10,143
1971	7,769	0.88	13.5	10,247
1972	7,990	0.83	13.4	10,353
1973	8,463	0.84	13.3	10,189
1974	8,297	1.06	13.4	9,569
1975	8,406	1.02	13.5	9,736
1976	8,600	1.01	13.5	9,854
1977	8,795	1.01	13.8	9,963
1978	9,126	0.96	14.0	10,174
1979	9,216	1.19	14.4	9,557
1980	9,114	1.51	15.5	9,234
1981	9,158	1.53	16.0	9,234
1982	9,116	1.36	16.8	9,447
1983	9,312	1.25	17.2	9,450
1984	9,775	1.18	17.9	9,582
1985	9,976	1.06	18.3	9,607
1986	10,244	0.84	18.4	9,738
1987	10,282	0.86	19.4	10,201
1988	10,676	0.83	20.1	10,214
1989	10,827	0.88	20.5	9,902
1990	11,019	0.97	21.0	9,849

Note: The effect of reductions in vehicle price and vehicle operating cost, and increases in fuel economy and horsepower were reflected in the menu of the vehicle choice model (DVSAM). Vehicle weight and seating capacity were kept unchanged from the *with CAA* run. Table IV-7 shows the changes in various vehicle attributes.

Table B-10. Percent Changes in Key Vehicle Characteristics Between the Control and No-control Scenarios.

	1975			1980		
Vehicle	**Price**	**mpg**	**HP**	**Price**	**mpg**	**HP**
Small Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Compact Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Midsize Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Large Auto	-2.35	0.01	0.59	-2.76	0.22	1.81
Small Truck	-1.30	0.01	0.59	-2.71	0.22	1.81
Std Truck	-1.30	0.01	0.59	-2.71	0.22	1.81
Std Van/Util	-1.30	0.01	0.59	-2.71	0.22	1.81
M Vn/Sm Utility						

	1985			1990		
Vehicle	**Price**	**mpg**	**HP**	**Price**	**mpg**	**HP**
Small Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Compact Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Midsize Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Large Auto	-3.25	0.62	2.20	-2.94	0.95	2.77
Small Truck	-2.53	0.62	2.20	-2.58	0.95	2.77
Std Truck	-2.53	0.62	2.20	-2.58	0.95	2.77
Std Van/Util	-2.53	0.62	2.20	-2.58	0.95	2.77
M Vn/Sm Utility	-2.53	0.62	2.20	-2.58	0.95	2.77

<u>Note:</u> *Average change for each vehicle size and type combination.

Utilities

The electric utility industry retrospective analysis was prepared using two different utility simulation models. ICF utilized its CEUM to estimate control and no-control scenario emissions for SO_2, TSP, and NO_x in each of the target years. ANL's ARGUS model was used to estimate electric utility CO and VOC emissions for the same period. This mix of modeling approaches was used because, while CEUM was determined to be a better tool for examining fuel shifts that were affected by the CAA than ARGUS, the CEUM model was not initially set-up to evaluate CO or VOC emissions. Although CEUM can be (and eventually was) configured to provide emission estimates for pollutants other than SO_2, NO_x, and PM, ARGUS was already configured to provide VOC and CO emissions. However, it should also be noted that VOC and CO emissions from utilities are quite low, as efficient fuel combustion reduces both pollutants. Thus, for this sector, the presence or absence of the CAA would not produce any different VOC or CO control techniques. VOC and CO emission rates for this sector differ primarily based on the fuel and boiler type. Therefore, a simpler modeling approach was judged to be acceptable and appropriate for these two pollutants. This chapter presents the methodology used to estimate utility emissions under the control and no-control scenario using the CEUM and ARGUS models. The method used by Abt Associates to estimate lead emissions from utilities is also presented.

Overview of Approach

The CEUM model uses industry capacity data and specific unit-by-unit characteristics, operating costs data, electricity demand estimates under the control and no-control scenario, and historical fuel prices to estimate SO_2, TSP, and NO_x emissions for 1980, 1985, and 1990. Changes in electric utility emissions, costs, and regional coal production were developed using ICF's CEUM with a calibration to historical electricity generation, fuel use, and emissions. The ARGUS model, which was used by ANL to estimate utility VOC and CO emissions, is driven by operating costs, industry capacity and generation data, demand for coal, and unit-level operating characteristics. The J/W model is used to incorporate predicted changes in electricity demand under the no-control scenario. Finally, Abt Associates relied upon energy use data, the *Trends* data base, and the Interim 1990 Inventory to calculate utility lead emissions based on coal consumption. The approaches used by each of these three contractors are discussed individually in the following sections.

Establishment of Control Scenario Emissions

A common feature of the approaches taken by ICF and ANL was to identify conditions that are inputs to the CEUM and ARGUS models, respectively, in the control scenario. Later in the analysis, these variables were revised to reflect no-control scenario conditions. The next section discusses the specific assumptions used in the CEUM analysis.

Key Assumptions in the Development of the ICF Analysis

At EPA's direction, ICF made several assumptions in conducting this analysis for purposes of consistency with other ongoing EPA efforts assessing the effects of the CAA. These include the macroeconomic assumptions regarding the effects of the CAA on economic growth, or more specifically, electricity demand, developed from other EPA commissioned efforts. Each is described briefly below.

Pollution Control Equipment Costs

Only limited actual data were available for this analysis on the historical capital and operating costs of pollution control equipment. Accordingly, for this analysis, the actual capital and operating costs of scrubbers were estimated using EPA scrubber cost assumptions adjusted to reflect actual data from a survey of scrubbed power plants with scrubbers installed during the 1970s and early 1980s. For those power plants with actual survey data, actual capital costs were used. For other pre-1985 scrubbers, ICF relied on the average costs from the survey data. For particulate control equipment (primarily electrostatic precipitators, or ESPs), costs were estimated based on limited actual data, and a 1980 Electric Power Research Institute (EPRI) study of ESP and baghouse costs. Based on this information, ESPs were estimated to cost an average of $50 per kilowatt (in 1991 dollars). The development of more detailed data on actual power plant pollution control costs was beyond the scope of ICF's analysis. ICF concluded that such an effort would not significantly change the national or regional cost estimates developed by its approach.

Electricity Demand and Fuel Prices

Consistent with other EPA ongoing analyses, ICF assumed that the CAA resulted in a reduction in electricity demand of 3.27 percent in 1980, 2.77 percent in 1985, and 2.97 percent in 1990. Also consistent with these studies, ICF assumed that natural gas prices and oil prices would not be affected by the CAA. Coal prices were estimated to change in line with increases and decreases in demand for specific coal supplies (and consistent with ICF's detailed modeling of coal supply and demand). The average prices of all residual oils consumed were also estimated to change due to a greater use of more expensive lower sulfur residual oils under the CAA.

Coal, Nuclear, Hydro, and Oil/Gas Capacity

At EPA's direction, ICF's approach was based on the assumption that no changes in the amount of nuclear, coal, hydro, or oil/gas stream or combined cycle capacity would be built or in place in 1980, 1985, or 1990. Given that the driving factors associated with the actual decisions to build new baseload capacity were not based solely on economics but entailed financial, regulatory, and political factors as well, the actual effect of the CAA on these build decisions is very uncertain. To the extent that more coal-fired power plants would be built and fewer oil/gas-fired power plants constructed, the actual emissions reductions associated with the CAA would be greater than those estimated by ICF, while the estimated costs of the CAA would be greater (because fewer, lower-cost, coal-fired power plants would be on line under the CAA). However, the CAA had virtually no effect on the costs of constructing new coal-fired power plants that came on line prior to about 1975 and a relatively moderate cost effect on coal-fired power plants that came on line through the early 1980s (since these power plants were not required to install scrubbers). Since a large majority of coal-fired power plant capacity came on line prior to 1975, ICF concluded that the effect of the CAA on the amount of total coal-fired capacity was not expected to be very large.

Natural Gas Consumption

The analysis assumed that the amount of natural gas consumed under the no-control scenario could not exceed the actual amount of consumption in 1980, 1985, and 1990. In part, because of natural gas price regulation and the oil price shocks of the 1970s, natural gas was often unavailable to electric utilities in the early 1980s. Since the CAA is relatively unrelated to the questions of supply availability and price regulation of natural gas, ICF assumed that no additional gas supplies would be available if the CAA had never been adopted. It is possible, however, that in the absence of the CAA, industrial and commercial users of natural gas would have used more oil or coal. To the extent that this would have occurred, there would have been more natural gas supplies available to the electric utility sector. This increase in supply would have resulted in an increase in the estimated costs of the CAA, and a corresponding decrease in the estimated emission reductions. ICF concluded, however, that this effect would not be very significant.

State and Local Environmental Regulations

At EPA's direction, ICF assumed that there would be no State and local emission limits or other emission control requirements under the no-control scenario. Accordingly, ICF assumed that there would be no SO_2, NO_x, or TSP emission limits under the no-control scenario and that all scrubbers, NO_x controls, and ESPs/baghouses (at coal-fired power plants) were installed as a result of the CAA. (The more limited amount of particulate control equipment installed at oil-fired plants was assumed to have been installed prior to the passage of the CAA.) In the case of particulate control equipment, some ESPs and other equipment were installed at coal plants prior to the 1970 CAA. To the extent that this is the case, the estimates of the costs of meeting the CAA have been overstated. ICF concluded, however, that the amount of such capacity was not substantial.

Retirement Age

The analysis assumed that unit retirement age was constant between the control and no-controls scenarios. Adoption of this assumption might bias the emission reduction estimates upward to the extent turnover rates of older (and presumably higher-emitting) units may be slower under the control scenarios, because more significant CAA control requirements focused on new units. However the vast majority of existing coal and oil capacity was built after 1950 and it is generally acknowledged that a relatively short technical plant lifetime would be about 40 years. As such, even if the no-control scenarios resulted in no life-extension activity, there would be virtually no effect over the 1970 to 1990 timeframe of the analysis.

ICF 1975 Control Scenario Emissions

The 1975 emissions under both scenarios were calculated differently than emissions in 1980, 1985, and 1990. In calculating or estimating 1975 SO_2 emissions for the control scenario (i.e., “actual” 1975), the weighted average emission rates at the State level, in the year 1975 were estimated, based on plant level average sulfur content of fuel deliveries from Federal Energy Regulatory Commission (FERC) Form 423 and assumed AP-42 sulfur retention in ash. These weighted average emission rates were then applied to actual State-level electric utility fuel consumption in the year 1975 (DOE, 1991). In the case of NO_x emissions, first, an estimate of Statewide NO_x emissions in the year 1975 was derived based on the use of the same NO_x emission rates, by fuel type, as developed for the 1980 no-control scenario modeling runs. These emission rates were specific to the fuel type (coal, oil, or natural gas). These Statewide NO_x emission rates or factors were then applied to actual fuel consumed by electric utilities in the year 1975, in order to obtain estimated “actual” 1975 emissions. As before, the fuel consumption at a State level was derived from the *State Energy Data Report* (DOE, 1991). ICF calculated the weighted average heat content (BTU/lb) by State from the 1975 FERC Form 423 data and used these figures with the TSP emission factors (lbs/ton) to derive emission rates by State (lbs/MMBTU). These emission rates were then applied to 1975 fuel consumption estimates obtained from the *State Energy Data Report*. For the control scenario 1975 estimates, ICF used the 1975 factors.

For the remaining target years, ICF used the results of CEUM runs that provided fuel consumption figures in 1980, 1985, and 1990, respectively. Emissions were then calculated using the appropriate emission factors for each year.

ARGUS Modeling Assumptions

The portion of the electric utility sector analysis conducted by ANL with the ARGUS model is described in this subsection. ARGUS contains four major components: BUILD, DISPATCH, the Emissions and Cost Model, and the Coal Supply and Transportation Model (CSTM). An overview of ARGUS can be found in Veselka *et al* (1990). Only the DISPATCH and CSTM modules were used for the present analysis. A brief description of the ARGUS components used in this analysis is found in the following subsections.

DISPATCH Module

The DISPATCH module contains a probabilistic production-cost model called the Investigation of Costs and Reliability in Utility Systems (ICARUS). This module calculates reliability and cost information for a utility system. ICARUS represents detailed, unit-by-unit operating characteristics such as fuel cost, forced outage rate, scheduled maintenance, heat rate, and fixed and variable operating and maintenance (O&M) costs. These components are used to efficiently compute system reliability (such as loss-of-load probability and unserved energy) and production costs.

The input data required by ICARUS include monthly load duration curves, annual peak demands, and, for both new and existing units, unit sizes, capital costs, fixed and variable O&M costs, fuel types and costs, heat rates, scheduled maintenance, and equivalent forced outage rates. The output from ICARUS includes annual summaries of capacity, generation, cost, and reliability for the entire generating system.

CSTM Module

The CSTM module determines the least-cost combination, on a per BTU basis, of coal supply sources and transportation routes for each demand source. First, it estimates coal market prices based on regional demands for coal from all economic sectors. To generate market prices, CSTM estimates regional coal production patterns and coal transportation routes. The CSTM input data are grouped into three major categories: demand, supply, and transportation. CSTM uses supply curves from the Resource Allocation and Mine Costing (RAMC) Model (DOE, 1982). Every region has a separate curve for one or more of the 60 different coal types that may be produced in that region. CSTM modifies the original RAMC supply curve by dividing the single RAMC curve into two curves, one representing deep mines and the other representing surface mines, but still uses the same ranges for heating values and mine prices that define the supply curves in RAMC. Prices fluctuate as a result of different mining methods, size of mining operations, reserve characteristics, and depletion effects.

The transportation data defines the network that connects 32 coal supply origins with 48 demand centers. Transportation cost is affected by distance, terrain, congestion, variable fuel costs, cost escalators for fuels and facility upgrades, and competition. CSTM first computes the production cost for each coal supply region and coal type. It then matches supply sources with transportation routes to find the lowest delivered costs.

Coal demand for a particular region is based on the amount, geographic region, economic sector, and range of coal types. There are 44 domestic demand regions. CSTM allows demand to be met by one, or a combination of, different supply regions.

The ARGUS input data for existing units are based on the Argonne Power Plant Inventory (APPI). APPI is a data base of operating and planned generating units in the United States that was current through 1988 at the time of ANL's analysis. This data base is updated annually based on information in the regional North American Electric Reliability Council (NERC) reports, reports from the Energy Information Administration (EIA), and other sources. Unit operating characteristics (fixed O&M, variable O&M, heat rate, forced outage rate, and scheduled maintenance) are based on regional data as defined in the EPRI report on regional systems and other historic data (EPRI, 1981).

ANL used the 1988 inventory to generate a 1990 inventory. The 1990 inventory was then used to generate a separate unit inventory for the target years 1975, 1980 and 1985. The target year inventories were generated by removing units whose on-line year was greater than the target year, from their respective inventory. The regional capacity totals in these preliminary inventories were tabulated by major fuel category (nuclear, coal, oil and gas steam) and compared to the regional historic NERC totals. This review identified capacity differences, especially in 1975 and 1980 inventories. The original plan was to add phantom units to match the regional historic totals. However, based on the need for State-level emissions, it was decided that a more thorough review of the unit inventories was required.

ANL's detailed review included an examination of the nuclear and coal units greater than 100 megawatt equivalent (MWe) in each target year. Missing units, with the appropriate unit size and State code, were added so that the regional totals were comparable. The availability of coal units was based on the on-line year of the unit as reported in the EIA report *Inventory of Power Plants in the United States* (DOE, 1986). The coal units were also checked against the EIA Cost and Quality Report (EIA, 1985) to verify the existence of flue gas desulfurization (FGD) systems in each of the target years. The nuclear unit inventories were verified with the EIA report *An Analysis of Nuclear Power Plant Operating Costs* (DOE, 1988). The review also included oil and gas steam units greater than 100 MWe. The total capacity of the oil and gas steam units were compared because many units switched primary fuel from oil to gas during the relevant time period. The oil and gas units were compared to historic inventories based on information provided by Applied Economic Research. In addition to thermal generation, the hydro and exchange energy was reviewed. For each target year, the hydro generation and firm purchase and sale capacity data was adjusted to reflect the historic levels. These two components, hydro and firm purchase and sales, are accounted for first in the loading order. If these variables are overestimated, there will be less generation from coal units. Likewise, if they are underestimated, there will be too much coal generation. The hydro and firm purchases and sales can vary significantly from year to year because of weather conditions and other variables. Therefore, it was important that they be accurately represented.

No-control Scenario Emissions

In order to calculate utility emissions under the no-control scenario, inputs to both the CEUM and ARGUS models were adjusted to reflect no-control scenario conditions. The changes made to each model's base year input files are discussed separately in the following sections.

ICF Estimates of SO_2, TSP, and NO_x Emissions in the No-control Scenario

As described earlier, ICF utilized a different methodology to calculate 1975 emission estimates. Rather than relying on the use of detailed modeling runs, ICF based the 1975 emission estimation on historic fuel consumption and sulfur content data in 1975. This subsection first outlines the process used to calculate no-control scenario emissions in 1975 and then presents the methods used for the remaining target years.

1975 Utility SO_2, NO_x, and TSP Emissions

To develop State-level no-control scenario utility SO_2 emissions, ICF developed no-control scenario SO_2 emission rates. A reasonable surrogate for these emission rates is SO_2 rates just prior to the implementation of the SIPs under the CAA. ICF developed 1972 rates (based on the earliest year available for FERC Form 423) and compared these with 1975 rates. In each State, the greater of 1972 or 1975 rates was used in the calculation of SO_2 emissions in the absence of the CAA. To develop State-level no-control scenario SO_2 emissions, no-control scenario fuel consumption data were needed. ICF assumed that the demand for electricity in 1975 would be 2.73 percent higher than the actual energy sales in 1975. This assumption is identical to the no-control scenario electricity demand projections derived from the J/W projections. For the purpose of this analysis, it was further assumed that this increment in demand would have been met in 1975 from the oil and coal-fired plants in each State. The increase in consumption of these fuels was assumed to be in the same proportion as their share in the 1975 total energy mix for electricity generation in that State. It was assumed that the generation of nuclear, gas-fired, and other electricity generation would not change. A sensitivity case without an assumed electricity demand change was also calculated. (The sensitivity analysis results are presented later in this appendix.)

For NO_x emissions under the no-control scenario, it was also assumed that the 1975 electricity sales would have been 2.73 percent higher than was the case in 1975. No-control scenario TSP emissions in 1975 were based on national emission rate numbers from EPA that were converted to pounds per million BTU using the average energy content of fuels in each State. No-control scenario TSP emissions were calculated based on 1970 emission factors (Braine, Kohli, and Kim, 1993).

1980, 1985, and 1990 Utility Emissions

For 1980, 1985, and 1990, ICF calculated no-control scenario emissions based on fuel consumption figures from the CEUM runs, and 1970 emission factors from EPA.

Electric utility SO_2 emission estimates are approximately 10 million tons (or about 38 percent) lower by 1990 under the control scenario than under the no-control scenario. Most of this estimated difference results from the imposition of emission limits at existing power plants through the SIPs under the 1970 CAA. Most of these SIPs were effective by 1980 (with some not fully effective until 1985). Most of the additional reductions that occurred during the 1980s were the result of the electric utility NSPS, which required the installation of 70 to 90 percent SO_2 removal control equipment.

By contrast, electric utility NO_x emission estimates under the control scenario are only about 1.2 million tons, or 14 percent, lower than under the no-control scenario by 1990. This occurs because, under the implementation of the 1970 CAA, only a few existing power plants were subject to NO_x emission limits. Virtually all of the estimated reductions are the result of NO_x NSPS, which generally required moderate reductions at power plants relative to uncontrolled levels. In addition, electricity demand is estimated to be about 3 percent lower under the control scenario. This decrease reduces the utilization of existing power plants and also contributes to lower NO_x emissions (and other pollutants as well).

Electric utility annualized costs (levelized capital, fuel, and O&M) are estimated to be $0.2 billion lower in 1980, $1.5 billion higher in 1985, and $1.9 billion higher in 1990 under the control scenario. Note, however, that this reflects the effects of two offsetting factors: (1) the *higher* utility compliance costs associated with using lower sulfur fuels, and the increased O&M and capital costs associated with scrubbers and particulate control equipment; and (2) *lower* utility generating costs (fuel, operating and capital costs) associated with lower electricity demand requirements. In 1980, the increase in fuel costs due to higher generation requirements (under the no-control scenario), was larger than the decrease in capital and O&M costs and thus yielded a cost increase over the control case.

However, lower electricity demand for the utility sector would translate into higher costs in other sectors (as electricity substitutes are used). This effect was captured to some extent by the original J/W macroeconomic modeling conducted for the present analysis.

Average levelized U.S. electricity rate estimates are approximately 3 percent higher under the control scenario during the 1980s. Note that year by year, electric utility revenue requirements and capital expenditures (not estimated by ICF) would be estimated to have increased by a greater percentage particularly in the 1970s and early 1980s as incremental capital expenditures for scrubbers and ESPs were brought into the rate base.

Significant shifts in regional coal production are estimated to have occurred between the control and no-control scenarios. High sulfur coal producing regions such as Northern Appalachia and the Midwest/ Central West are estimated to have lower production under the control scenario, while lower sulfur coal producing regions such as Central and Southern Appalachia are estimated to have higher coal production.[12]

ARGUS No-control Scenario

Regional fuel prices, for the thermal units, were based on historic information from the EIA Form 423 data for the year 1977, 1980 and 1985. The 1977 data was used for 1975. Fixed and variable O&M costs were adjusted from the 1988 level, and all cost data were converted to 1985 dollars.

The load data were based on regional historic NERC data for each of the target years. The shapes of the monthly load duration curves are the result of modifications based on the data in the EPRI report on regional systems (EPRI, 1981). The shapes were modified to match the projected 1988 monthly load factors for the NERC regions. These load shapes were held constant for all years.

The actual peak-loads were selected from historic information and used with the existing load duration curves. The system was dispatched so that the calculated generation could be compared with historic data. Discrepancies were resolved by adjusting the peak load so that the annual generation was on target. This procedure was repeated for each of the target years.

The electric utilities were expected to have an increase in generation as identified by the J/W data. Table B-11 identifies the increase in national level generation by year. The national level increase in generation was applied to each power pool.

Table B-11. J/W Estimates of Percentage Increases in National Electricity Generation Under No-control Scenario.

Year	Percentage Increase
1975	2.7%
1980	3.3%
1985	2.8%
1990	3.0%

In addition to load changes, coal units with FGD equipment were modified. These units had their FGD equipment removed along with a 3 percent decrease in heat rate, a 2 percentage point decrease in forced outage rate, and a 50 percent decrease in their fixed and variable O&M costs. These changes were incorporated into the ARGUS model for each of the target years. Model runs were then conducted to arrive at estimates of VOC and CO emissions in the no-control scenario.

Estimation of Lead Emissions from Utilities

In order to estimate lead emissions from electric utilities in each of the target years, data from three different sources were used. Energy use data for the control and no-control scenarios were obtained from the national coal use estimates prepared for the section 812 analysis by ICF (Braine and Kim, 1993). The *Trends* data base provided emission factors and control efficiencies, and the Interim 1990 Inventory identified utility characteristics. The ICF data bases provided the amount of coal consumed for both the control and no-control scenarios in each of the target years. A correspondence between the Interim Inventory and the ICF data base was achieved through the plant name variable. Using emission factors for lead and control efficiencies for electric utilities, estimates of lead emissions per plant per year were calculated. These factors were obtained from the *Trends* data base. It was assumed that pollution control on coal-burning power plants under the no-control scenario would be the same as the pollution control level in 1970. Therefore, the control efficiency from 1970 is used as the basis for the no-control case.

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[12] At EPA's direction, ICF's analysis did not estimate the effect of shifts in non-utility coal consumption on regional coal production, nor did it consider the possibility that fewer new coal powerplants might have been built due to the CAA as discussed earlier. Both of these factors could result in a greater estimated change in total U.S. coal production than estimated herein although the difference is not likely to be very significant.

CEUM Sensitivity Case

In addition to comparing actual (control scenario) historical costs and emissions with the higher electricity demand under the no-control scenario, ICF also evaluated emissions in a sensitivity case without the CAA (i.e., under the no-control scenario) with the same electricity demand (versus the no-control scenario with higher demand). The purpose of this sensitivity analysis was to isolate the incremental electric utility compliance costs and reductions in emissions associated with the CAA from the lower resulting generation costs and emissions due to lower estimated electricity demand under the CAA. The incremental effects of the CAA when compared with this case indicate:

- Estimated reductions in emissions due to the CAA are somewhat lower if measured against the sensitivity case without the CAA with the same electricity demand than the emissions without the CAA with lower demand. This occurs because lower electricity demand under the no-control scenario sensitivity results in lower utilization of existing coal and oil plants which, in turn, results in lower emissions. As noted above, in some sense, the changes in emissions represent the effects of electric utility compliance actions under the CAA, absent the effect of lower resultant demand for electricity.

- When measured against the sensitivity case without the CAA (with the same electricity demand), electric utility annualized costs are estimated to have increased by about $5 to $6 billion during the 1980 to 1990 period. This reflects the following cost factors: (1) higher annualized capital costs associated primarily with scrubbers and ESPs installed by electric utilities to comply with the CAA; (2) higher O&M costs associated with the additional air pollution control equipment; and (3) higher fuel costs associated with using lower sulfur coal and oil in order to meet the emission limit requirements of the CAA.

Commercial/Residential

The Commercial and Residential Simulation System (CRESS) model was developed by ANL as part of the Emissions and Control Costs Integrated Model Set and used in the NAPAP assessment (*Methods for Modeling Future Emissions and Control Costs, State of Science and Technology, Report 26*) (McDonald and South, 1984). CRESS is designed to project emissions for five pollutants: SO_x, NO_x, VOC, TSP, and CO. The CRESS output is aggregated into residential and commercial subsectors related to both economic activity and fuel use. The introductory material provided in this appendix about CRESS describes the base year as being 1985. It appears in this way because CRESS was originally developed to operate using the 1985 NAPAP Emission Inventory as its base year data set. For the five pollutants reported by CRESS, emission estimates are provided for the following sectors:

- ♦ Commercial/institutional
  - coal, including point and area categories of anthracite and bituminous boilers;
  - liquid fuel, including boiler and space heating uses of residual, distillate, LPG, and other fuels;
  - natural gas boilers, space heaters, and internal combustion engines;
  - wood used in boilers and space heaters; and
  - other mixed or unclassified fuel use.

- ♦ Residential
  - coal, including area sources of anthracite and bituminous;
  - liquid fuel, composed of distillate and residual oil;
  - natural gas; and
  - wood.

- ♦ Miscellaneous
  - waste disposal, incineration, and open burning; and
  - other, including forest fires, managed and agricultural burning, structural fires, cutback asphalt paving, and internal combustion engine testing.

In addition, VOC emissions are projected for these source categories:

- ♦ Service stations and gasoline marketing;

- ♦ Dry-cleaning point and area sources; and

- Other solvents, including architectural surface coating, auto-body refinishing, and consumer/commercial solvent use.

This section describes the use of CRESS to estimate control and no-control scenario emissions from the commercial/residential sector.

Control Scenario Emissions

For the NAPAP assessment, 1985 CRESS output corresponded to the 1985 NAPAP Inventory (EPA, 1989), which served as the benchmark for any projections. The design of CRESS is such that emissions by NAPAP SCC are input for each State, then projected to future years by scaling them to economic data such as energy demand. In estimating emissions, differences in emission controls associated with new, replacement, and existing equipment are taken into account where such differences are considered significant. The basic modeling approach is shown in the following equation:

$$Q_{t,b} = \left(\frac{Q_0}{E_0}\right), b \times \left(\frac{D_T}{D_0}\right) \times \sum^{j} (f_{t,j} \times E_{t,j}) \qquad (3)$$

where:

Q = emissions in year t or the base year, year 0

E = emission factor for the source category b in the base year, or for a subcategory j subject to controls in year t (this takes into account changes in emission rates that may occur as a result of emission regulations or technology changes)

D = driver data indicating activity levels in the base and future years

f = fraction of total activity in year t differentially affected by emission controls

The calculations are carried out in two subroutines, one for SO_2, NO_x, TSP and CO, and one for VOC.

Typically SO_2, NO_x, TSP, and CO emissions are projected by multiplying the 1985 NAPAP SCC data or base year data by the ratio of the driver data (activity level) value in the projection year to its value in the base year. Because there are few controls on SO_x or NO_x emissions from the sources covered by CRESS, projected emissions for most sectors are proportional to the expected activity levels. Thus,

$$Q_t = Q_0 \times \left(\frac{D_t}{D_0}\right) \qquad (4)$$

There are a few source types, such as commercial/institutional boilers, for which emission controls are mandated. These are modeled by multiplying the 1985 emission data by the ratio of the controlled emission factor to the base-year emission factor. Emission factors for each source type are weighted by the proportion of base year activity in each subsector to which controls are expected to apply.

$$Q_{t,b} = Q_0\, [g_{t,b} + \left(\frac{E_{t,n}}{E_{0,b}}\right) \times (g_{t,r} + g_{t,n})] \qquad (5)$$

where:

g = the fraction of base-year activity accounted for by existing source b, replacement source r, or new source n in year t

The effective emission factor (Et,n) for the sector is calculated by weighing the portions of sectoral emissions subject to NSPS controls and those likely to continue at existing levels. An appropriate Internal Revenue Service-based rate at which new equipment replaces existing sources is applied to each sector in the model. This is done to estimate how emissions might change as older sources are retired and replaced by new sources that emit at lower rates.

The SO_x/NO_x/TSP/CO subroutine varies in new and replacement emission-source fractions subject to NSPS controls. These fractions are applied to the emission-source replacement rates. In addition, ratios for new source emission factors are varied by State. However, emission ratios for any pollutant/source type combination do not vary over the projection period.

The VOC estimation methodology is similar, but allows variation in emission factors over time. Emission ratios are calculated from files of replacement and existing source emission factors weighted by the replacement rate for each sector and new source factors by State. These are input for each 5-year projection interval. For most source categories, VOC controls are not envisioned, and the 1985 NAPAP emissions for the category are simply scaled proportionally to changes in the driver (activity level) data.

For sources to which controls apply, a variation on the following equation is employed:

$$Q_{t,b} = (\frac{Q_0}{E_0}, b) \times (E_{t,b} + g_{t,n} \times E_{t,n})] \qquad (6)$$

In equation 6, the emission factors for new and existing sources are effectively weighted by the proportion of total activity in year t to which controls apply.

In using CRESS for the CAA retrospective analysis, the base year was 1975. CRESS requires emissions information by State and NAPAP source category as input. Since detailed information on emission levels for 1975 by NAPAP source category were not available, the data were developed from a combination of sources. The procedure for calculating 1975 emissions based on the 1985 NAPAP inventory is described below. The emissions module uses these initial values in conjunction with activity estimates to project control and no-control scenario emissions.

Emissions Data

Since the starting point for the analysis was 1975, emissions data by State and SCC for SO_2, NO_x, VOC, TSP, and CO were required. Available emissions information for this year was not at the level of detail needed by CRESS. The 1985 NAPAP Inventory, which contains the necessary level of detail, in conjunction with information from EPA's *National Air Pollutant Emission Estimates, 1940-1990* (*Trends*) and ANL's MSCET, was used to construct an emissions inventory for 1975. The model then uses these emissions as a benchmark for the analysis.

The method for constructing the 1975 emissions data base was consistent for all pollutants; however, two different sources of emissions data were necessary in order to obtain time series information on all pollutants. MSCET contains monthly State-level emission estimates from 1975 to 1985 by emission source group for SO_2, NO_x, and VOC. Therefore, MSCET information was used for SO_2, NO_x, and VOC, while *Trends* data were used for TSP and CO. Emission source groups from MSCET were matched with 1985 NAPAP Inventory SCCs. The MSCET methodology is benchmarked to the 1985 NAPAP Inventory and uses time series information from *Trends* in conjunction with activity information to estimate State-level emissions for SO_2, NO_x, and VOC. Although the level of detail contained in the NAPAP Inventory could not be preserved because of the aggregation needed to match with MSCET emissions sources, MSCET provided the State-level spatial detail required by CRESS.

Once the 1985 emissions by SCC and State from the 1985 NAPAP Inventory were matched with emission source groups and States from the MSCET data base, an estimate of 1975 emissions was computed by multiplying the 1985 NAPAP Inventory emissions value by the ratio of 1975 MSCET emissions to 1985 MSCET emissions. Ratios were computed and applied for each combination of State, pollutant, and MSCET emission source group.

This method of constructing an emissions inventory for 1975 utilizes the State estimates from MSCET, thus capturing the spatial shifts that occurred over the analysis period. It is assumed that NAPAP provides the most reliable point and area source information in terms of the level of 1985 emissions (which is also the assumption of the MSCET methodology). Note that if there were a 1-to-1 correspondence between MSCET and NAPAP, this method would be equivalent to using the MSCET methodology directly for constructing 1975 emission levels.

A similar method was used for TSP and CO, but since these pollutants are not included in MSCET, the *Trends* ratio of 1975 to 1985 emissions for these two pollutants was used. Thus, for TSP and CO, all States were assumed to have experienced the same change in emissions as indicated by the national figures.

It should be noted that in addition to the loss in spatial detail, the *Trends* source groups generally spanned several NAPAP source categories. The strength in the *Trends* information is the consistency of emissions estimates over time. It is considered to be the most reliable data for tracking changes in emissions over the time period of the analysis, and was therefore chosen for developing 1975 estimates for TSP and CO.

The 15 source categories reported in *Trends* were matched with those in the 1985 NAPAP Inventory. The ratios of 1975 emissions to 1985 emissions by source category that were applied to the 1985 NAPAP emissions data are shown in B-12. The 1975 emis-

Table B-12. *Trends* Source Categories and (1975 to 1985) Scaling Factors for TSP and CO.

Trends **Source Category**	**TSP***	**CO***
Commercial/Institutional Fuel Combustion:		
Coal	2.11	0.59
Natural Gas	1.00	0.91
Fuel Oil	2.35	1.43
Other	1.83	0.67
Residential Fuel Combustion:		
Coal	1.33	1.47
Natural Gas	1.17	1.00
Fuel Oil	1.11	1.76
Wood	0.49	0.49
Miscellaneous: Forest Fires	0.67	0.62
Solid Waste Disposal:		
Incineration	3.00	0.64
Open Burning	1.50	1.44
Miscellaneous Other Burning	1.00	1.33
Industrial Processes: Paving	2.71	0.56
Asphalt Paving and Roofing	2.71	0.56
Miscellaneous Other	1.83	0.67

Note: *These values are the ratios of 1985 *Trends* emissions to 1975 *Trends* emissions for each source category. For example, the commercial/ institutional fuel combustion: coal emission ratio of 2.11 is computed as the ratio of the 1975 TSP emissions of 40 gigagrams per year to the corresponding 1985 emissions of 19 gigagrams per year.

sions data estimated from the above procedure served as the benchmark and initial value for the CRESS emissions module for both scenarios.

CAA regulation of commercial/ residential emissions was limited and largely confined to fuel combustion sources (SO_2, NO_x, TSP), gasoline marketing (VOC), dry cleaning (VOC), and surface coating (VOC). NSPS regulations of small (over 29 MW capacity) fuel combustors were promulgated in 1984 and 1986. For purposes of emissions calculations, the stipulated NSPS for SO_2, NO_x, and TSP were incorporated into the control scenario for 1985 and 1990. Emission rates for source categories subject to VOC regulation were similarly adjusted.

Energy Data

Nearly 75 percent of the source categories in CRESS use energy consumption by State and sector as the driver for the emissions calculation. State-level energy consumption statistics are published by EIA in *State Energy Data Report, Consumption Estimates, 1960-1989,* and are electronically available as part of the State Energy Data System (SEDS) (DOE, 1991). The SEDS data base contains annual energy consumption estimates by sector for the various end-use sectors: residential, commercial, industrial and transportation, and electric utilities.

Seven fuel-type categories are used in CRESS: coal, distillate oil, residual oil, natural gas, liquid petroleum gas, wood, and electricity. The model assumes zero consumption of residual fuel oil in the residential sector and zero consumption of wood in the commercial sector. Energy consumption for each fuel-type was expressed in BTUs for purposes of model calculations. With the exception of wood consumption, all of the energy consumption statistics used in CRESS were obtained from SEDS.

Residential wood consumption estimates were derived from two data sources. State-level residential sector wood consumption estimates for 1975 and 1980 were obtained from *Estimates of U.S. Wood Energy Consumption from 1949 to 1981* (EIA, 1982). State-level wood consumption, however, was not available for 1985 and 1990, therefore, regional information from an alternative publication, *Estimates of U.S. Biofuels Consumption 1990* (EIA, 1990), was used to derive State-level residential wood use figures. Regional 1985 and 1990 wood consumption was distributed among States using 1981 State shares. All wood consumption figures were converted to BTU's using an average value of 17.2 million BTU per short ton.

Economic/Demographic Data

Emissions from slightly more than 25 percent of the CRESS source categories follow State-level economic and demographic activity variables. The demographic variables used by CRESS include State-level population, rural population, and forest acreage. State population is the activity indicator for six emissions source categories for SO_2, NO_x, TSP, and CO, and 13 VOC source categories. State population data were assembled from the SEDS data base. Rural population, which is the indicator of residential open burning activity, is computed as a fraction of total State population. Forest wildfires and managed open burning activity are related to 1977 State-level forest acreage. The demographic information is assumed to be invariant to CAA regulations and thus is the same in the control and no-control scenarios.

Car stock (or vehicle population), the driver variable for the auto body refinishing, is approximated by State motor vehicle registrations. *Highway Statistics*, an annual publication by the FHWA, was the source for data on State motor vehicle registrations. The three source categories connected with gasoline marketing are driven by State-level gasoline sales in gallons. State gasoline consumption was obtained from the SEDS data base. Housing starts and 10 percent of the existing housing stock were combined to form the activity indicator for architectural surface coating emissions. Housing data compiled by the U.S. Bureau of the Census were available in the *Statistical Abstract of the United States* (DOC, 1975; 1977; 1982; 1983; 1987; 1993). Regional-level data for 1975 was allocated to the States based on the 1980 State distribution.

No-control Scenario Emissions

Adjustments to control scenario emissions in each of the target years to reflect conditions under the no-control scenario were achieved through emission factors, energy input data, and economic/demographic data. The adjustments made to each of these variables to generate no-control scenario emissions are discussed individually in the following subsections.

Emissions Data

CAA regulation of the commercial/residential sector was minimal. For regulated source categories, emission factors were revised to reflect pre-regulation emission rates. Six commercial/residential source categories were regulated for VOC emissions: Service Stations Stage I Emissions, Service Stations Stage II Emissions, Dry Cleaning (perchloroethylene), Gasoline Marketed, Dry Cleaning (solvent), and Cutback Asphalt Paving. Commercial-Institutional boilers were regulated for SO_2 and TSP and internal combustion sources were regulated for NO_x emissions. All NSPS were removed for these sources to estimate no-control scenario emissions levels.

Energy Data

State-level energy demand for the residential and commercial sectors for the no-control scenario was estimated from the J/W model forecast. Final energy demand estimates for the household sector were calculated by an EPA contractor for the purposes of the no-control scenario analysis. State allocation of the national-level estimates was based on historic State shares, i.e., this assumes that there is no change in the distribution of energy demand across States as a result of removing regulations. In addition, the J/W model estimates an aggregate refined petroleum category and does not distinguish among liquid petroleum gas, distillate oil, and residual oil. The relative shares among these three categories of petroleum products remained constant between the control and no-control scenarios. The information on percentage change in energy demand by fuel type as provided by the J/W model is listed in Table B-13.

The differential for commercial sector final energy demand was calculated from the combination of four intermediate product flow categories from the J/W forecast. The National Income and Product Accounts (NIPA) for the commercial sector correspond to J/W SIC categories 32 through 35:

Table B-13. Percentage Change in Real Energy Demand by Households from Control to No-control Scenario.

Year	Coal	Refined Petroleum	Electric	Natural Gas
1975	1.48	4.76	3.62	2.42
1980	1.50	3.84	4.26	2.12
1985	1.98	3.90	3.88	2.41
1990	2.23	4.33	4.18	2.77

(32) Wholesale and Retail Trade;
(33) Finance, Insurance, and Real Estate;
(34) Other Services; and
(35) Government Services.

Percentage change information from the J/W forecast for energy cost shares, value of output, and energy prices was used to calculate the differential in commercial sector energy demand for the no-control scenario. The energy cost share is defined as the cost of energy input divided by the value of the output. In order to calculate the percentage change in commercial sector energy demand, the change in energy price was subtracted from the percentage change in energy cost, and added to the change in the value of output. Each of these variables was available from the J/W model results. This calculation was performed for each of the four energy types, and each of the four NIPA categories. The change in commercial sector energy demand was obtained by taking the weighted average of the four NIPA categories. Since data on relative energy demand for NIPA categories were not readily available, square footage was used as a proxy for calculating the weights. These data were taken from the *Nonresidential Buildings Energy Consumption Survey, Commercial Buildings Consumption and Expenditure 1986* (EIA, 1989). The resulting estimate for commercial sector changes in energy demand is provided in Table B-14.

Table B-14. Percentage Change in Commercial Energy Demand from Control to No-control Scenario.

Year	Coal	Refined Petroleum	Electric	Natural Gas
1975	-0.13	3.36	1.30	-0.80
1980	0.31	1.90	2.06	-0.82
1985	0.48	1.98	1.72	-0.40
1990	0.39	2.26	1.74	-0.22

The national-level change in commercial sector energy demand was allocated to the States using historic shares. Implicit is the assumption that removal of CAA regulations does not alter the State distribution of energy use.

Economic/Demographic Data

State population was assumed not to vary as a result of CAA regulations, thus only the economic variables were revised for the no-control scenario. No-control scenario housing starts and car stock were derived from J/W forecast information on construction and motor vehicles. The differential for categories 6 (construction) and 24 (motor vehicles and equipment) was applied to control scenario values to obtain no-control scenario levels. The percentage change from the J/W forecast is given in Table B-15.

State-level gasoline sales is one of the activities forecasted by the transportation sector model. The percentage change in gasoline sales calculated by the TEEMS model was used in the no-control scenario as a CRESS model input.

Table B-15. J/W Percent Differential in Economic Variables Used in CRESS.

Year	Construction	Motor Vehicles
1975	0.70	5.04
1980	0.14	4.79
1985	0.41	6.07
1990	0.29	6.25

Table B-16. TSP Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990 Emissions
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	
Transportation:									
Highway Vehicles	700	760	770	820	770	910	1,030	1,180	(30%)
Off-Highway Vehicles	270	280	270	280	260	270	260	270	5%
Stationary Sources:									
Electric Utilities	1,720	880	450	430	3,460	4,480	5,180	5,860	(93%)
Industrial Processes	5,620	3,650	3,040	3,080	11,120	12,000	11,710	12,960	(76%)
Industrial Boilers	740	480	250	240	780	550	360	400	(41%)
Commercial/Residential	2,020	2,510	2,680	2,550	2,020	2,520	2,700	2,560	(1%)
TOTAL*	11,070	8,550	7,460	7,390	18,410	20,730	21,250	23,230	(68%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-17. SO_2 Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990 Emissions
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	
Transportation:									
Highway Vehicles	380	450	500	570	380	450	500	560	1%
Off-Highway Vehicles	370	530	410	390	360	530	400	390	1%
Stationary Sources:									
Electric Utilities	18,670	17,480	16,050	16,510	20,690	25,620	25,140	26,730	(38%)
Industrial Processes	4,530	3,420	2,730	2,460	5,560	5,940	5,630	6,130	(60%)
Industrial Boilers	3,440	3,180	2,660	2,820	3,910	4,110	4,020	4,610	(39%)
Commercial/Residential	1,000	800	590	690	1,000	810	610	710	(3%)
TOTAL*	28,380	25,860	22,950	23,440	31,900	37,460	36,310	39,140	(40%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-18. NO_x Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				**Without the CAA**				**Difference in 1990 Emissions**
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	
Transportation:									
Highway Vehicles	8,640	9,340	8,610	8,140	9,020	11,060	13,160	15,390	(47%)
Off-Highway Vehicles	1,990	2,180	2,080	2,090	1,980	2,150	2,040	2,060	1%
Stationary Sources:									
Electric Utilities	5,540	6,450	6,660	7,060	5,740	7,150	7,780	8,300	(15%)
Industrial Processes	750	760	690	710	760	830	790	1,090	(35%)
Industrial Boilers	4,090	3,680	3,540	3,710	4,120	3,660	3,680	3,900	(5%)
Commercial/Residential	1,060	960	880	930	1,060	970	890	950	(2%)
TOTAL*	22,060	23,370	22,460	22,640	22,680	25,830	28,350	31,680	(29%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-19. VOC Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				**Without the CAA**				**Difference in 1990 Emissions**
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	
Transportation:									
Highway Vehicles	12,220	10,770	9,470	7,740	14,620	16,460	19,800	23,010	(66%)
Off-Highway Vehicles	1,380	1,370	1,340	1,410	1,390	1,420	1,390	1,490	(5%)
Stationary Sources:									
Electric Utilities	20	30	30	40	20	30	30	40	(7%)
Industrial Processes	5,910	6,780	6,230	5,630	6,130	7,930	7,290	6,810	(17%)
Industrial Boilers	150	150	150	150	150	150	140	150	0%
Commercial/Residential	4,980	5,480	5,820	5,870	4,980	5,700	6,080	6,130	(4%)
TOTAL*	24,660	24,580	23,030	20,840	27,290	31,680	34,730	37,630	(45%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-20. CO Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990 Emissions
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	
Transportation:									
Highway Vehicles	83,580	79,970	72,490	65,430	90,460	105,530	131,420	149,280	(56%)
Off-Highway Vehicles	8,510	8,100	7,880	8,080	8,510	8,070	7,880	8,080	0%
Stationary Sources:									
Electric Utilities	240	280	290	370	250	290	300	380	(3%)
Industrial Processes	7,580	6,990	4,840	5,140	9,240	9,120	8,860	10,180	(49%)
Industrial Boilers	720	710	670	740	720	710	620	740	0%
Commercial/Residential	10,250	13,130	14,140	13,150	10,250	13,170	14,200	13,210	0%
TOTAL*	110,880	109,170	100,300	92,900	119,430	136,880	163,280	181,860	(49%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

Table B-21. Lead (Pb) Emissions Under the Control and No-control Scenarios by Target Year (in thousands of short tons).

	With the CAA				Without the CAA				Difference in 1990 Emissions
Sector	**1975**	**1980**	**1985**	**1990**	**1975**	**1980**	**1985**	**1990**	
Transportation:									
Highway Vehicles	180	86	22	2	203	207	214	223	(99%)
Stationary Source:									
Industrial Processes	3	1	1	1	7	7	6	5	(87%)
Industrial Combustion	4	2	0	0	5	5	5	5	(96%)
Utilities	1	1	0	0	2	3	4	4	(95%)
TOTAL*	190	90	23	3	217	221	228	237	(99%)

Notes: The estimates of emission levels *with and without the CAA* were developed specifically for this section 812 analysis using models designed to simulate conditions in the absence of the CAA. These numbers should not be interpreted as actual historical emission estimates.

*Totals may differ slightly from sums due to rounding.

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