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PHYSICAL AND ECONOMIC DAMAGE FUNCTIONS FOR AIR POLLUTANTS BY RECEPTORS

Environmental Research Laboratory
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PHYSICAL AND ECONOMIC DAMAGE FUNCTIONS FOR AIR POLLUTANTS BY RECEPTOR

by

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DISCLAIMER

FOREWORD

The Clean Air Act of 1970 requires substantial reduction in air pollution. Under the authority of this and subsequent Acts, the Environmental Protection Agency has promulgated national ambient air quality standards for several pollutants. In geographic regions where ambient standards are exceeded, the states have been required to undertake action to comply with the standards.

The current energy crisis has resulted in a closer look by society and the Agency at the tradeoffs between energy conservation and improved environmental quality. Specifically, the crisis has resulted in the air quality standards coming under closer scrutiny. The standards in many instances are viewed by industry as impediments to the use of alternative fuels which could alleviate the current energy situation.

In order to effectively evaluate the environmental tradeoffs, the decision maker must have information on the costs and benefits of alternative environmental control strategies. Providing such information involves difficult issues of measuring and evaluating the diverse effects of pollution abatement. One of the results of the energy crisis has been a renewed call for a reevaluation of and increased emphasis on the delineation and quantification of the benefits and costs attributable to air pollution reduction.

As most economists who are familiar with the methodology know, benefit/cost analysis has its limitations in practical application to decision making problems. The primary limitations are the difficulties encountered in placing an economic value on some effect responses, and/or the derivation of adequate effect responses. While dependable, systematic estimates of damages resulting from the effects of air pollution are still quite rare, progress is being made. Within the past decade, several studies have been completed estimating property and material costs of air pollution and the effects of air pollution on property values and human health. However, many of these studies are too specific, and, as a result, do not lend themselves well for use in formulating decisions having national implications. The purpose of this study was to see, using existing studies, whether this limitation could be overcome.

More specifically, the purpose of this study was to examine past economic, and other related environmental studies, to determine whether the results could be utilized in estimating composite parametric damage functions. The functions, while providing ballpark estimates, could be used in evaluating the outcomes of implementing alternative environmental policies. In the meantime it was hoped that additional economic-environmental studies would be undertaken which would mitigate the shortcomings and permit a reestimation of more precise damage functions.

This report estimates economic, parametric damage function by receptor (human health, household soiling, materials, and vegetation) for the stationary source pollutants - sulfur dioxide and suspended particulates. The damage functions are based on existing research results. The socio-economic data used in formulating the damage functions for the different metropolitan areas are derived from the 1970 census.

The research results have been extensively reviewed by environmental economists, whose suggestions and comments have been incorporated into the study. The results should be used with appropriate caution. Some of the assumptions employed in the study, by necessity, are uncertain. Some of the methodological-statistical techniques employed are in their infancy and have not been tested elsewhere. Despite the existence of these difficulties, it is the general consensus of the reviewers that the study represents an important step forward in evaluating alternative pollution control options. Peer review of the study results by other environmental economists are welcome, and should be sent to the project officer at the Corvallis Laboratory.

This study was initiated by the Washington Environmental Research Center, Office of Research and Development, Washington, D.C., and completed at the Corvallis Environmental Research Laboratory (CERL), Office of Research and Development, Corvallis, Oregon.

A. F. Bartsch
Director, CERL

PREFACE

This is the Final Report for the project entitled "Physical and Economic Damage Functions for Air Pollutants by Receptor," for U.S. Environmental Protection Agency, EPA Contract 68-01-2968 and MRI Project No. 4004-D.

The primary objective of this project is to generate some physical and economic damage functions by receptor for sulfur dioxide and suspended particulates for the U.S. urban areas so that marginal benefit and marginal cost principal can be applied to air pollution control decisionmaking. Based on existing literature and available data on U.S. metropolitan areas, 1970, average functions are developed for air pollution damages on human health, household soiling, materials and vegetation. Various types of air pollution damages are also estimated on a cross section basis for the metropolitan areas included. It should be noted that the geographic damage estimates are tentative not only because the assumptions employed in the study are uncertain but also because the methodology used is in its infant stage of development.

This project was completed under the general supervision of Mr. Bruce Macy, Assistant Director of Economics and Management Science Division and the project director was Dr. Ben-chieh Liu, Principal Economist. Research assistance and data process were provided, respectively, by Miss Mary Kies, and Mr. Jim Miller. Valuable assistance and comments from Dr. Chatten Cowherd, Messrs. Paul Gorman and Richard Salmon of MRI, Drs. Donald Gillette, Michael Hay and John Jaksch of EPA, Dr. Fred Able of Energy Research and Development Administration, Dr. William Watson of Resource for the Future and Dr. Eugene Seskin at Urban Institute are gratefully acknowledged. Editorial service was provided by Mrs. Doris Nagel, Mrs. Sharon Wolverton efficiently performed the report typing and computer work was carried out at MRI's Computation Center. Nevertheless, the views expressed in this study are those of the authors. They do not necessarily reflect the opinions of the sponsoring agency.

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EXECUTIVE SUMMARY

The research delineated in this report is primarily concerned with evaluating regional economic damages to human health, material, and vegetation and of property soiling resulting from air pollution. This research also attempts to develop a more plausible exponential physical dose-response function for premature mortality and morbidity. The comparable and consistent damage loss estimates for a variety of receptors developed in this research are expected to provide a data base useful for designing national and regional pollution control strategies.

The report comprises seven sections. A brief summary of the highlights from each section follows:

SECTION I - INTRODUCTION

The project involving the determination of regional air pollution damage losses for mortality, morbidity, household soiling, material and vegetation can be divided into four distinct phases: (1) problem discussion and refinement; (2) information and data gathering; (3) damage loss assessment; and (4) physical and/or economic damage function estimation. Static analyses are performed on the basis of 1970 data for many metropolitan areas and regions in the United States.

SECTION II - MORTALITY AND AIR POLLUTION

A two-step econometric model was developed for estimating a nonlinear mortality physical damage function and net damage costs of premature deaths resulting from excess air pollution for the 40 Standard Metropolitan Statistical Areas (SMSA's) which had a sulfur dioxide level above 25 $\mu g/m^3$ between 1968 and 1970. The model circumvents partially the often recognized but largely ignored econometric problems such as heteroscedasticity and multicolinearity and, hence, gives credence to our damage loss estimate. In addition, an "average" economic damage function was developed which relates premature mortality damage losses in dollar terms to socioeconomic, demographic, climatological and air pollution variables--sulfur dioxide (SO_2) and total suspended particulate (TSP). The estimated mortality damage due to SO_2 for 1970 varies from less than $0.1 million in Charleston, West Virginia to $329 million in New York City, whereas mortality damage attributable to TSP ranges from $1.4 million in Lawrence, Massachusetts to $155 million in New York City. On a per capita basis, the highest damage due to SO_2 and TSP is $28.4 in New York City and $27.6 in Detroit, respectively.

SECTION III - MORBIDITY AND AIR POLLUTION

The damage costs and physical and economic damage functions were developed and estimated. Regional physical damage functions on adult morbidity were derived by resorting to the classical least-squares linear regression. A Monte Carlo technique was then used to derive an "average" nonlinear morbidity physical damage function for adults. Low estimates for total annual morbidity costs due to SO_2 range from less than $1,000 in Cincinnati to a maximum of $22 million in New York City. Low estimates on morbidity damages attributable to TSP, however, range from $152,000 in Bridgeport to more than $21 million in Chicago. On a per capita basis, the highest damage due to SO_2 and TSP is respectively $1.9 in Chicago and $3.7 in Cleveland.

SECTION IV - HOUSEHOLD SOILING AND AIR POLLUTION

A system of soiling physical damage functions relating various types of cleaning frequencies to air pollution was developed. Net and gross soiling damage costs for the 148 SMSA's were estimated. Finally, national "average" economic damage functions for household soiling were developed by relating soiling damages to air pollution, demographic, socioeconomic, and climatological variables. Total net soiling costs for 1970 attributable to air pollution over the 148 SMSA's were estimated to be more than $5 billion, while total gross soiling costs were about $17 billion over the 148 SMSA's.

SECTION V - MATERIAL AND AIR POLLUTION

This section develops economic damage estimates on the two most economically important materials, i.e., zinc and paint, for the 148 SMSA's in the United States. Economic damage functions relating material damages to air pollution and other socioeconomic and climatological variables were derived. The state of the art regarding the physical damage functions on materials was also reviewed and summarized. The soiling damage costs of zinc for 1970 range from less than $0.5 million in Dayton, Ohio to $1.7 billion in Chicago, whereas the deteriorating damage costs of zinc range from less than $0.5 million in Dayton to $57 million in Chicago. The soiling damage costs of paint for 1970 range from $19 million in Fayetteville, North Carolina, to $2.3 billion in New York City, while the deteriorating damage cost of paint is $0.7 million in Fayetteville and $79 million in New York City.

SECTION VI - VEGETATION AND AIR POLLUTION

Dose-response relationships for vegetation were reviewed. A set of national "average" economic damage functions for 10 economically important crops in the United States and regional economic damages to vegetation were derived. The economic damage functions will be useful to policymakers for forecasting possible gains as a result of pollution control programs.

SECTION VII - AGGREGATE DAMAGE LOSSES AND DAMAGE FUNCTIONS: AN OVERALL VIEW

Range estimates of economic damage losses over some broader categories of receptors were derived. A number of aggregate economic damage functions were also developed and summarized for the major pollutants. The aggregate as well as the disaggregate damage functions developed in the previous sections can be useful to national and regional policymakers in their quest for obtaining estimates of possible benefits brought about by various pollution abatement strategies.

The numerically large values of aggregate damage estimates provided by the experts in this area point to the need for effective control of pollutant emissions. The question naturally arises as to what constitutes economically optimal and politically feasible pollution control programs. As an effort in providing some useful clues for understanding the above question, this study attempts to estimate net as well as gross economic damages to human health, material, vegetation and household soiling attributable to and in the presence of air pollution for the urban areas in the United States. Economic and physical damage functions relating economic (physical) damages to air pollution, demographic, socioeconomic, and climatological variables were also developed for the United States urban areas. It is hoped that the generalized economic damage functions in this report are informative and useful for predicting possible marginal (average) benefits resulting from various air pollution abatement programs.

Any study of this nature is bound to have a few inherent limitations. The notable limitations are the uncertainty associated with estimating the physical damage function and in translating it into economic terms, and the uncertainty of selecting the most relevant measure of air pollution and the "correct" form of relating damages to pollution.

To provide the reader an overall view of the economic damages of various receptors due to air pollution, a summary of the damage estimates for the effect categories of human health, material deterioration, and household soiling is presented in Table S-1. The selected 40 SMSA's which had an SO_2 level equal to or greater than the threshold 25 $\mu g/m^3$ are listed in Column 1. The low and high damage estimates of human health are presented, respectively, in Column 2 (HNC1) and Column 3 (HNC2). Column 4 (MDC) presents the material deteriorating damage estimates of both zinc and paint; Column 5 (TNSCO) contains the aggregate net household soiling damages. On the basis of the low and high damage estimates of human health presented, respectively, in Columns 2 and 3, two sets of low and high aggregate damage estimates for the three effect categories, i.e., human health, material deterioration and household soiling, were derived and summarized in Column 6 (TNC1) and Column 7 (TNC2), respectively. The further details on the estimations of the economic damages of each of the effect categories are contained in the subsequent Sections II, III, IV, V and VI. The formulas used for deriving the estimates presented in Table S-1 will be discussed in Section VII.

TABLE S-1 . ECONOMIC DAMAGES DUE TO AIR POLLUTION, BY RECEPTORS FOR SELECTED SMSA's (in $ million, 1970)

(1) SMSA's	(2) HNC1	(3) HNC2	(4) MDC	(5) TNSCO	(6) TNC1	(7) TNC2
1. Akron, OH	10	18	7	16	33	41
2. Allentown, PA	8	15	3	16	27	34
3. Baltimore, MD	48	80	17	137	202	234
4. Boston, MA	49	52	26	117	192	195
5. Bridgeport, CT	3	5	6	3	12	14
6. Canton, OH	6	6	11	14	31	31
7. Charleston, WV	3	3	4	10	17	17
8. Chicago, IL	191	360	105	516	812	981
9. Cincinnati, OH	22	22	12	57	91	91
10. Cleveland, OH	55	93	49	216	320	358
11. Dayton, OH	18	18	9	39	66	66
12. Detroit, MI	129	161	55	294	478	510
13. Evansville, IN	2	2	2	5	9	9
14. Gary, IN	12	24	8	24	44	56
15. Hartford, CT	12	19	5	16	33	40
16. Jersey City, NJ	11	17	8	17	36	42
17. Johnstown, PA	4	4	1	10	15	15
18. Lawrence, MA	3	5	7	3	13	15
19. Los Angeles, CA	123	147	76	388	587	611
20. Minneapolis, MN	21	32	12	37	70	81
21. New Haven, CT	3	5	4	4	11	13
22. New York, NY	352	527	111	418	881	1,056
23. Newark, NJ	39	48	14	112	165	174
24. Norfolk, VA	13	13	3	29	45	45
25. Paterson, NJ	7	7	13	9	29	29
26. Peoria, IL	4	4	9	8	21	21
27. Philadelphia, PA	107	158	33	104	244	295
28. Pittsburgh, PA	45	79	30	147	222	256
29. Portland, OR	13	13	8	30	51	51
30. Providence, RI	16	25	9	20	45	54
31. Reading, PA	5	5	4	15	24	24
32. Rochester, NY	13	15	7	27	47	49
33. St. Louis, MO	44	61	24	119	187	204
34. Scranton, PA	5	5	2	23	30	30
35. Springfield, MA	12	15	3	7	22	25
36. Trenton, NJ	3	3	2	5	10	10
37. Washington, DC	48	88	21	86	155	195
38. Worcester, MA	3	4	8	6	17	18
39. York, PA	4	4	2	9	15	15
40. Youngstown, OH	9	10	8	23	40	41
Total	1,475	2,166	736	3,134	5,349	6,045

Note--individual figure may not add to totals due to rounding.

Table S-1 reveals that the largest aggregate air pollution damage, in the order of $1 billion, occurred in New York and Chicago SMSA's in 1970. The smallest air pollution damage occurred in Evansville and Trenton, both SMSA's damages were in the magnitude of $10 million in 1970. Human health damage estimates (mortality and morbidity) ranged from $1.5 to $2.2 billion for the 40 SMSA's. Total material deterioration damages were about 0.7 billion, and total household soiling costs were about 3 billion for the 40 SMSA's under study.

The implication of our study for pollution abatement strategies is obvious. Any effort to reduce the current pollution level appears to have a varyingly significant impact on the economic damages resulting from the harmful effects of air pollution. Admittedly, the implication of this study must be qualified by several theoretical and empirical factors. The major difficulties often encountered in estimating air pollution damages involve the lack of knowledge regarding the shapes of functions describing the relationship between air pollution and various receptors, and the lack of a satisfactory theoretical model specifying the way air pollution affects various receptors. The impossibility of accounting for all major factors which might affect various receptors, the lack of reliable formulations used for translating physical damages into monetary terms, and the presence of numerous econometric problems have also caused concern to investigators.

Despite the existence of these difficulties, this study represents a step forward in our knowledge of pollution damages. It seems to be the first attempt to construct essential frameworks of the physical and economic damage functions which can be used for calculating comparable regional damage estimates for the several important receptors--human health, material, and household soiling--however tentative the damage estimates may appear to be. More importantly, aggregate economic damage functions instrumental for transforming the multifarious aspects of the pollution problem into a single, homogeneous monetary unit are tentatively derived and illustrated. It is hoped that these results will be of some use to guide policymakers as they make decisions on the implementation of programs to achieve "optimal" pollution levels for this country. Given the experimental nature of the methodological and statistical procedures and the degree of uncertainty associated with the study results, a great deal of caution should be exercised in using the products of this research.

Finally, it should be noted that although the availability of information on average or marginal damages is instrumental in determining the optimal national or regional pollution control strategies, the current problem is far more complex than the question of balancing the benefits to polluters with damages inflicted on the receptors. The issues are pressing and not yet well specified. The basic difficulty in applying the recent research findings to accurately estimate the air pollution damage cost stems from our ignorance about the receptors at risk to air pollution. So far, few attempts have been made to identify who suffers, to what extent, from which sources, and in what regions. At this moment, updating and expansion of the available crude estimates, which are generally restricted to certain regions, are urgently needed. To identify the population at risk to air pollution, and to measure the damage specifically for polluted regions are apparently the most logical steps in the area of future research.

MAJOR NOTATIONS AND VARIABLES

A	Air pollutants
C	Conventional mortality rate
CC	Computed conventional mortality rate
CMR	Computed mortality rate
CRMR	Computed residual mortality rate
CROPL	Economic loss of a particular type of crop
CROPV	The output value of a particular type of crop
DTS	Number of days with thunderstorms
DDCZ	Deteriorating damage cost of zinc
DDCP	Deteriorating damage cost of paint
EXP or e	Exponential
E_{ij}	Elasticity of variable i with respect to variable j
GSCO	Gross household soiling damage cost
MR	Mortality rate
MB	Morbidity rate
MBC	Morbidity cost
MDC	Material deteriorating cost
NSCO	Net household soiling damage cost
OXID	Oxidant relative severity index
PAGE	Percentage of population 65 or older
PYAP	Percentage of population with income above poverty level
PCOL	Percent of persons 25 or older who have completed 4 years of college
PWOP	Percentage of white to total population
POP	Population in the area
PDS	Population density
RHM	Relative humidity
RMR	Residual mortality rate
SDCP	Soiling damage cost of paint
SDCZ	Soiling damage cost of zinc
SMSA	Standard Metropolitan Statistical Areas
SO_2	Sulfur dioxide
SUN	Possible annual sunshine days (percent)
TSP	Total suspended particulates
$TMBCSO_2$	Total morbidity cost due to SO_2
TMBCTSP	Total morbidity cost due to TSP
TEMB	Number of days in a year with temperature below 33° F
TEMA	Number of days in a year with temperature above 89° F
u	The disturbance term

SECTION I

INTRODUCTION

Deterioration in urban air quality constitutes one of the major problems confronting most American cities today. Air pollution has inflicted a multitude of damaging effects on human health, material, vegetation, animals, household and industrial property. In the past decades, numerous research studies have been conducted to ascertain and to quantify, if possible, the physical and monetary damage losses to the various receptors due to the presence of excessive concentration levels of the major air pollutants, e.g., sulfur dioxide, total suspended particulate matter, oxidants, carbon monoxide and other substances in the urban areas.1/

The numerical values of aggregate damage estimates provided by the experts in this area point to the need for effective control of pollutant emissions.2/ The question naturally arises as to what constitutes economically optimal and politically feasible pollution control programs. The issues surrounding the control strategies have been hotly argued and debated. Implementation of some of the proposed control programs has been postponed for either political or economic reasons.

According to estimates prepared by the Bureau of Economic Analysis, (Cremeans and Segel, 1975) a total of $18.7 billion was spent on domestic air, water, solid waste and other pollution abatement and control programs in 1972. The expenditure was about 1.6 percent of our GNP in that year. Of the total figure, 35 percent was accounted for by control and abatement activities of air pollution. This expenditure figure is indicative of the magnitude of sacrifice the society has made for the purpose of reducing the problem of air degradation.

Is this amount of expenditure sufficient, from an economic point of view, to attain optimal air quality for this country? The inquiry into this question is handicapped without information about the corresponding benefit accruable to the society because of the existing pollution control programs.

From economic theory, it is well-known that the control policy is optimal if the marginal benefit due to pollution abatement is matched by the marginal expenditure incurred to implement the control. In the absence of national marginal or "average" damage functions of air pollution by receptors and the marginal (average) damage estimate for each effect category, it is difficult, if not totally impossible, to estimate the marginal (average) benefits stemming from the abatement of the last unit of air pollution in each metropolitan area and the nation as a whole.

1/ For a background information on the cost of air pollution damage, see Barrett and Waddell (1973) and Waddell (1974).

2/ For details on the damage estimates and the references, see the beginning paragraphs of each of the later sections.

For purposes of analysis the effects of air pollution are customarily classified into six broad categories: (1) detrimental effects on human health; (2) damage to vegetation; (3) deterioration of materials; (4) soiling of households and business establishments; (5) injury to animals; and (6) reduction of visibility and other atmospheric effects of an aesthetic nature. Since each of these categories has direct and indirect economic value, whenever one's ability and opportunity to enjoy these benefits is reduced, economic damages result. It is unfortunate that the magnitude and measurement of the resulting economic damages is probably the most controversial point in the entire pollution control issue.

The basic objectives of this study were to estimate net as well as gross economic damages to human health, material, vegetation and household soiling attributable to and in the presence of air pollution for the urban areas in the United States. Economic and physical damage functions relating economic (physical) damages to air pollution, demographic, socioeconomic, and climatological variables were also developed for the United States urban areas. It is hoped that the generalized economic damage functions in this report are informative and useful for predicting possible marginal (average) benefits resulting from various air pollution abatement programs.

Any study of this nature is bound to have a few inherent limitations. The notable limitations are the uncertainty associated with estimating the physical damage function and in translating it into economic terms, and the uncertainty of selecting the most relevant measure of air pollution and the "correct" form of relating damages to pollution.

Since this study is primarily concerned with the estimation of the economic damages of air pollution in the United States urban areas, a brief, but critical, review of the economic effects of air pollution is in order. Accumulating evidence suggests that air pollution results in a number of noticeable and substantial economic effects. Some of the more obvious of these effects include the soiling of materials by dustfall, necessitating additional expenditures for cleaning; corrosion of materials, requiring replacement and application of protective coatings; atmospheric haze, reducing visibility and causing aesthetic blight; and various respiratory and other health problems associated with the inhalation of noxious fumes and particles from the atmosphere.

DAMAGING EFFECTS OF AIR POLLUTION

Effects on Human Health

According to the 1974 National Academy of Sciences reports, two major pollutants, i.e., total suspended particulates and sulfur dioxide, are responsible for the bulk of the deleterious effects on human health. Other pollutants, like carbon monoxide, nitrogen oxides and photochemical oxidants and ozone also exert damaging effects. Exposure to high concentrations of carbon monoxide damages the function of oxygen-dependent tissues and exposure to low concentrations of carbon monoxide results in adverse effects both in normal people and in patients with heart disease. Acute exposure to low concentrations of nitrogen oxide can cause visual and olfactory abnormalities. Tentative evidences indicate that long term exposure to photochemical oxidants can result in eye irritation and a decrease in lung tissue elasticity. At any one time, several pollutants are present in the air. Thus, it is difficult to determine the interaction of pollutants and the specific health damages caused by a single pollutant. Nevertheless, it has been established that air pollutants can accelerate disease and death, even at levels generally considered safe and used as the basis for setting standards. Each of the major air pollutants presents a health hazard in itself, and harmful effects may be greatly amplified when they occur in combination. Unfortunately, the degree of the synergistic effects among the pollutants is not clearly known.

Particulate emissions include a wide variety of pollutants, each of which may exert different effects on human health. Carbon or soot particles are the most commonly emitted kinds of particles. However, even when these are the only particulates emitted--such as in coal combustion--there are indications that the toxic effects of sulfur dioxide (also released in the coal combustion process) are enhanced by their association with the particulate matter. Other contaminants can absorb on the surface of the particles, thereby coming into contact with the inner surfaces of the lungs and mucous membranes in far greater concentrations than would otherwise be possible. The site and extent of particle deposition in the respiratory tract, and therefore its ultimate effect on human health, depend upon both physical and physiological factors.

Sulfur dioxide is highly soluble in body fluids. The principal effect of this gas is irritation of the tissues lining the upper respiratory tract. This results in bronchial constriction which, in turn, produces an increase in respiratory flow resistance. Persons suffering from respiratory or cardiac diseases may be unable to withstand the increased body burden caused by this respiratory flow resistance. Adverse effects on ciliary activity and mucous flow may also result from prolonged exposure to sulfur dioxide. Sulfur dioxide and other oxides of sulfur can, under certain conditions, combine with water, soot particles and other aerosols in the atmosphere to produce toxic acid aerosols and other contaminants far more dangerous than any of the individual ingredients.

The damage to human health depends not only on the concentration level of pollutants, but also on the physical conditions of each individual. There is virtually no single threshold of pollutant concentration below which health damages will not occur. At every level of a pollutant concentration, someone could be adversely affected. In view of a wide range of physical conditions of human beings the threshold of pollutants may be viewed as a symmetrical distribution. The "mean" level of this distribution is used in the present study to calculate the economic damages resulting from air pollution.

While the exact role of air pollution in causing illnesses is not known, there is substantial evidence that air pollution does aggravate existing illnesses, even to the point of causing premature death.1/ While high rates of asthma attacks have been reported on days with high air pollution surface concentrations, greatly increased mortality rates from influenza, bronchitis, and pneumonia have been noted during periods of high sulfur dioxide and particulate levels.

In estimating the damage cost of morbidity, it should be noted that the direct, out-of-pocket cost of treating an illness or disease is probably far less than the value of avoiding the necessity for treatment. When someone suffers from a pollution-related chronic illness, the cost of pollution to him is almost infinite; the value of avoiding the pollution-induced discomfort is, for this person, immeasurably high. For this reason, it should be cautioned that the health damage of air pollution estimated in this study, like other major studies on the basis of the health costs of treating pollution-related illnesses, may understate the true economic costs or benefits of reducing the responsible pollutants. Sections II and III present a thorough analysis of the air pollution effects on human health, i.e., mortality and morbidity, respectively.

Effects on Materials

Many external factors influence the reaction rate between pollutants and materials, with moisture the most important in accelerating corrosion.2/ Inorganic gases are likely to cause tarnishing and corrosion of metals; can attack various building materials such as stone, marble, slate, and mortar; and may deteriorate a variety of natural and synthetic fibers.

The most noticeable effect of particulate pollutants is soiling of the surfaces on which they are deposited. They may also act as catalysts increasing the corrosive reactions between metals and acid gases. Additional damages to surfaces and textiles are incurred by the wear and tear imposed by the extra cleanings made necessary because of particulate soiling.

The true economic damage to materials caused by air pollution is difficult to ascertain. First, it is difficult to scientifically distinguish between natural deterioration and deterioration caused by air pollution. Secondly, it is uncertain regarding indirect costs of early replacement of materials worn out by pollutant soiling.

The most comprehensive analysis of the economic effects of air pollution on materials was conducted by Midwest Research Institute (Salmon 1969). In that study, the damages caused by interactions between specific pollutants and specific materials were identified. The estimated economic loss resulting from the various pollutant-material interactions totaled $3.8 billion in 1968.

1/ For details, see Section III.
2/ See Section V for further details.

Detailed analyses of soiling costs and material damages by region are contained in Sections IV and V, respectively.

Effects on Vegetation

The air pollutants having the greatest deleterious effects on vegetation are sulfur dioxide, hydrogen fluoride, photochemical smog and oxidants, ethylene, and herbicides and fungicides. Sulfur dioxide enters a leaf through the stoma, causing injury to the blade of the leaf in the form of intervenal collapsed areas. Fluorides may be absorbed from the surface of the leaf and can be toxic to some plants at extremely low concentrations. Other pollutants may damage only certain susceptible types of plants.

Based upon a Stanford Research Institute study (Benedict et al., 1973), the national damage cost of air pollution on vegetation is estimated to be $150 million. This damage cost amounts to approximately more than one-half of 1 percent of the total value of crops produced in the United States in 1970. This figure represents mainly the visible damage to agricultural crops, and does not fully recognize the real economic losses due to growth suppression, delayed maturity, reduced yields, and increased costs of crop production.

Section VI describes and estimates the air pollution damages on vegetation on a regional basis for different types of crops.

Other Damaging Effects

Aesthetic damage caused by air pollution is the most difficult to quantify; yet, intuitively at least, it represents one of the important categories of economic loss suffered as a result of degraded air quality. The aesthetic category encompasses a number of different effects ranging from impaired atmospheric visibility to decreased property values resulting from the presence of air pollutants.

Reduction in visibility creates a heavy economic burden on most communities. Some of the community operations which are most affected by pollution-related visibility problems include airports, highways, and homes. When an airport's traffic pattern is slowed due to delays in take-offs and landings caused by reduced atmospheric visibility, operational costs are increased, additional safety hazards are imposed, passengers are inconvenienced, and businesses may be indirectly affected. Similar effects occur on highways where reduced visibility slows traffic, causes congestion, and increases the likelihood of injurious and expensive accidents. Additional lighting--both on the streets and in the home--is required when the sunlight is unable to penetrate a polluted atmosphere.

Aesthetic damage can sometimes be partially measured indirectly, such as by comparing property values in comparable residential neighborhoods having different air pollution levels. In other cases, aesthetic damages may be reflected in the costs that are incurred in connection with their prevention or avoidance, such as special precautions taken to protect certain values from aesthetic damage by air pollutants. Still other cases may require a willingness-to-pay approach, estimating the amount that individuals would be willing to pay in order to prevent or avoid the threatened aesthetic damages due to the soiling effect or, conversely, how much additional they would have to be paid to willingly endure the aesthetic blight.

Due to data deficiency, air pollution effects on aesthetics are not studied.

Considerable damage to animals caused by air pollution has been noted. However, most cases are localized, the sources are easily identified, and the economic consequences are relatively minor. Poisoning of livestock from heavy metals--arsenic, lead, and molybdenum--has been reported on numerous occasions, and cattle and sheep are particularly susceptible to fluorine poisoning. In addition to the direct economic losses resulting from animal mortality, significant losses may come from such effects as decreased reproductivity, decreased growth, and lower output of milk, eggs and wool.

No studies of the economic impact of air pollution on animals have been reported in the literature. The value of all livestock and livestock products produced during 1968 was $21 billion; out of this total, perhaps $10 million could reasonably be attributed to losses of all kinds from air pollution damage (Park, 1974).

Due to data deficiency, air pollution effects on animals are not studied.

In summary, this air pollution damage function project involves four distinct phases common to each of the five studies regarding the damaging effects of air pollution on mortality, morbidity, household soiling, materials and vegetation. The four phases are as follows: (1) problem refinement; (2) data and information gathering; (3) estimation of regional economic damages; and (4) development of physical and economic damage functions.

Data on air pollution, demographic, socioeconomic and climatological variables were collected by a thorough literature search. Most of the data utilized for developing the economic damage functions were attained from a comprehensive quality of life study for the United States Standard Metropolitan Statistical Areas (SMSA's) recently completed by Liu (1975).

Following the selection of the needed data, regression models were developed to determine the physical and economic damage functions for all these major air pollutants as well as the various categories of the damaging effects. Econometric problems and technical difficulties are discussed and dealt with as much as possible during the process of damage estimation. Furthermore, several methodologies were developed to evaluate the economic damages by air pollutants and effect categories for the SMSA's in the United States.

SECTION II

MORTALITY AND AIR POLLUTION

INTRODUCTION: THE PROBLEMS AND THE OBJECTIVES

Two issues in the area of pollution control have attracted much attention recently. The first problem is to evaluate from the control efficiency viewpoint the appropriate governmental policies for handling pollution abatement. While Kneese (1972), Peltzman and Tideman (1972), and Lerner (1974) opted for regional regulation of pollution, Stein (1974) stressed the role of the federal government for controlling various pollution. Another problem involves the determination of the optimal level of pollution abatement at which the marginal benefits are matched by the marginal expenditures incurred to implement the control. Estimation of the marginal benefits of pollution control at regional levels, however, requires information on damage functions and damage estimates for the various regions in the United States.

Empirical works in this area for the United States have been advanced substantially by Ridker (1967), Lave and Seskin (1970, 1973), Jaksch and Stoevener (1974), R. K. and M. Koshal (1974), among others. They confirmed the existence of a close association between health and air pollution.[1,2] The conventional ordinary least squares, linear or log-linear regression method has been employed to quantify the damaging effect of air pollution on mortality. However, often the major difficulties encountered in estimating such a physical damage function involve the problems of errors in variables, nonnormality, heteroscedasticity, and multicolinearity among air pollution and other explanatory socioeconomic, demographic and climatological variables, and the lack of knowledge regarding the shape of the function which depicts the relationship between air pollution and health.

Two major approaches have been suggested in the literature for estimating a pollution damage function.[3] The first approach involves the assumption that consumers are explicitly or implicitly knowledgeable about the potential benefit of pollution control. Therefore, the estimation problem boils down to one of inducing the consumers to reveal their "true" preferences about abatement. Often, unsatisfactory results were obtained in this approach because consumers generally are not willing to pay their share of cost for abatement, and, hence, tend to provide misleading information about the benefit accruable to them if air quality is improved.

1/ These and earlier studies are subject to a number of limitations. For a detailed discussion see, for example, J. R. Goldsmith (1969).

2/ Contrary results have also been obtained, for example, by Toyama (1964) and Petrilli, Agnese and Kanitz (1966). There were no controls for socioeconomic factors in their studies. Hence, their results are subject to bias.

3/ See, for example, Lave (1972), p. 213, for a detailed exposition of the two approaches.

The second method, on the other hand, involves explicit quantification of the physical damage function and translation of the physical damage into monetary terms. The advantage of this explicit approach is that it requires no interpersonal utility comparison and cooperation from the consumers. However, the considerable extent of uncertainty present in estimating the physical damage function and in converting it into an economic damage function casts doubt on the reliability of the damage estimates.

The damaging effects on human health by air pollution in New York City have been well documented by Glasser et al. (1967), Greenburg et al. (1962a, 1962b), Hodgson (1970), and McCarroll and Bradley (1966). Recently, Schimmel and Greenburg (1972) performed a time-series study based on mortality rate and pollution for New York City covering the period between January 1, 1963, to December 31, 1968. The excess mortality rate was regressed on two daily mean pollution variates, SO_2 and smoke shade, for both the same and previous day. They showed that approximately 80 percent of the excess deaths were attributed to the effects of smoke shade while only 20 percent were attributed to SO_2. Again, methodological problems encountered in national estimates are also prevailing in these regional estimates.

Damage costs of premature death and morbidity due to air pollution have been estimated for the whole nation previously. Ridker (1965) estimated the total costs of a specific disease and then attributed 20 percent of these costs to air pollution. Lave and Seskin (1970, 1973) related the amount of mortality for specific diseases to air pollution and some socioeconomic variables. They found that the association between air pollution and mortality is significant and of substantial magnitude; e.g., a 10 percent decrease in the biweekly minimum level of sulfates is associated with a 0.3 percent decrease in mortality rate per 10,000 live births. Koshal (1974) established a quantitative relationship between respiratory mortality rates and the level of air pollution and two climatic variables. They estimated a reduction of about 50 percent in the air pollution would imply a social saving on the order of about \$1.9 to \$2.2 billion per year in terms of respiratory disease alone.

It is noteworthy that although most of these air pollution damage studies draw tentative conclusions, they suffer from a certain inherent difficulty in evaluating their results. Difficulty arises because either the statistical procedures employed are less than perfect or the results obtained are inadequate for generating statistical inferences needed. With the exception, perhaps, of those of Lave and Seskin and the Koshals, most of the studies are time-series analyses with sample observations restricted to a specific area or a small number of areas. As a result, little information can be deduced from the existing studies for designing a general air pollution control policy which requires the knowledge of an "average" damage function expressed in both physical and economic terms and applicable to all metropolitan areas in the nation. From economic theory, it is well known that the control policy is optimal if the marginal benefits resulting from pollution abatement are matched by the marginal expenditures incurred to implement the control. In the absence of national average damage functions by pollutants and the marginal damages for each pollutant, it is difficult to estimate the marginal benefits stemming from the abatement of the last unit of air pollution in each metropolitan area and the nation as a whole.

Lave and Seskin (1973 p. 290) in a well-known article, noted possible specification errors in the empirical estimates of mortality and air pollution relation. They cautioned the reader that "[their] analysis is beset by a vast number of problems including little a priori knowledge of the true specification of the relations, omitted variables, and errors of measurement in the variables." This observation has been recently verified by Smith (1975) by reestimating a set of mortality air pollution relationships with a new data base. The Ramsey tests were utilized with the data on mortality rates and suspended particulates for 50 SMSA's.[1/] The research findings indicate that the errors in specification and heteroscedasticity could constitute technical problems in estimation.

While the multicolinearity problem between air pollution and other independent variables in the damage function makes it difficult, if not totally impossible, to disentangle their influences so as to obtain reasonably precise estimates of their separate independent effects on mortality, the presence of the heteroscedasticity problem violating one of the assumptions used in the normal linear regression model (i.e., the disturbances were independently distributed with constant variances) renders the ordinary least-squares estimates inefficient.[2/] Despite the fact that these specification errors were observed by Lave and Seskin, the econometric problems remain largely unexplored in the prior studies.

This section attempts to achieve two basic objectives. First, a stepwise econometric model will be developed to estimate a dose-response relation for mortality and pollution. Second, "average" economic and physical damage functions for the United States Metropolitan Areas will be constructed by relating mortality economic damages and mortality rates, respectively, to air pollution, demographic, socioeconomic, and climatological variables. Although the methodological and statistical procedures used are experimental, and the statistical results are subject to a great deal of uncertainty, it is hoped that the generalized economic damage function and the cost estimates presented in this section are informative. They can be useful for predicting possible benefits in the urban areas resulting from various air pollution abatement programs and to shed light on the major issues in current and future air pollution research.

Technically, the heteroscedasticity and multicolinearity problems that emerged in estimating the relationships between mortality and pollution damage are partially circumvented via the two-step econometric model. In the first step, observed mortality rates are regressed on several relevant socioeconomic, demographic and climatological variables. In the second step, the residual mortality rates obtained by subtracting the computed mortality rates from the observed

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1/ The logic underlying the Ramsey tests was succinctly outlined in Smith (1975), pp. 341-342. For a detailed discussion on the tests, see Ramsey (1969, 1970, 1974).

2/ See, for example, Johnston (1963), pp. 207-211, and Goldberger (1964), pp. 192-194.

mortality rates are again regressed nonlinearly on air pollution variable only to derive the physical damage function. The estimated dose-response relation is then utilized to derive net damage costs of premature deaths due to excessive air pollution for 40 Standard Metropolitan Statistical Areas (SMSA's) in the United States.

In order to estimate physical and economic damages associated with air pollution the effects of air pollution on human health are classified as: (1) mortality effect; (2) morbidity effect; and (3) combination effect.[1/] The mortality effect refers to the increase in the excess deaths resulting from increased contamination in the air, or the decrease in the survival probability of all ages. The premature mortality affects an individual's probability of being accessible to future earning opportunities and nonmarket leisure activities, but it will not alter the nature of the existing economic and leisure activities. The morbidity effect, which will be dealt with in the next section, however, directly changes the nature of economic and leisure activities. The combination effect can be viewed as earlier mortality because of increased severity in morbidity. In this case, both the survival probability and the nature of activities of the victim are affected. Schrimper (1975) has shown that this interaction effect can be conveniently ignored because of its small magnitude.

It may be worth pointing out, at the outset, that the physical dose-response relation derived in the present study is probably the first of its kind ever estimated in the pollution effect studies. Four distinguishing features in the dose-response relation differentiate our study from the earlier studies, say, Lave and Seskin (1970, 1972, 1973) and Koshals (1974). First, the technique of residualizing the dependent variable (mortality rates) is used in estimating the dose-response function. Second, the pollution variable is the sole explanatory variable included in the dose-response relation. Third, the dose-response function is specified as a nonlinear relation in accord with both *a priori* judgment and empirical results regarding human responses to increased pollution doses. Fourth, a threshold level is adopted before damages are estimated.

This section, which represents a preliminary effort to estimate empirically a nonlinear dose-response function and a linear "average" pollution damage function, is presented in the following subsections: Estimation of Physical Damage Functions, A Linear General Physical Damage Function, Values of Air Pollution Damages and Economic Damage Functions, Premature Mortality Damages and Suspended Particulates, and Implications and Concluding Remarks.

1/ For a detailed discussion on the effect of air pollution on human health, see Schrimper (1975).

ESTIMATION OF PHYSICAL DAMAGE FUNCTIONS

For analytical purposes, two types of physical damage functions can be posited: (1) dose-response or stimulus-effect relations; (2) general physical damage functions which relate mortality not only to pollution, but also to other relevant socioeconomic, demographic and climatological variables.

A long-term, generalized physical damage function has been specified, for example, by Lave and Seskin (1970), Goldsmith (1965), and Ferris and Whittenberger (1966) as

$$MR = F(D, S, E, W, A; e) \qquad \text{(II-1)}$$

where MR is mortality rate per 10,000 population and is related to D (demographic factors such as age, sex, racial and genetic), S (the social factor such as individual's exercise and other habits, nutrition, occupational structure, population density, and housing conditions), E (the economic variables such as income and the level and quality of medical care received), W (weather), A (the air pollutants), and e (the disturbance term). To measure the damage effect of air pollution and other independent variables on mortality, the conventional least-squares linear regression has been the common technique.

If the objective is to estimate a short-term, day-to-day, physical damage function for a given study region, demographic, social and economic factors can then be reasonably assumed to be stable. Hence, the short-term physical damage function can be specified as

$$MR = f(W, A; e) \qquad \text{(II-1')}$$

Lave and Seskin (1972) utilized (II-1') to derive acute, day-to-day mortality-pollution relationships. Lags up to 5 days in the pollution variables were incorporated into the regression equations. Results obtained in their study were generally negative because no discernible, consistent pattern of statistically significant coefficients was observed. One of the several questions examined by Lave and Seskin which has bearing on policymaking is whether deaths are merely shifted by a few days by pollution episodes. Their finding indicates that the reallocation of mortality extends over a period longer than 10 days.

Nonlinear Dose-Response Function

A dose-response relation which includes the pollution variables as the sole explanatory variable can be written as

$$MR = g(A; e) \qquad \text{(II-2)}$$

The dose-response functions may be estimated via controlled laboratory experiments on human bodies. However, ethical and legal considerations prohibit the use of human bodies for experimental purposes. Because of this, epidemiological studies so far have not been fruitful in identifying the true cause-effect relationship underlying mortality and air pollution.

The clinical, laboratory, and experimental studies at relatively high concentration levels of sulfur dioxide or other pollutants suggest that tentative dose-response relationships are available. However, information on such relationships is largely lacking at concentration levels in the range of current standards. The best available tentative dose-response function ever produced by epidemiological studies is presented in Buechley (1971). The function can be approximated by a nonlinear, flat "S" shape curve, as shown in Figure II-1. The relation indicates that while the air pollutant SO_2 is a contributing factor of premature mortality, the damaging effect is nonproportional. As the SO_2 concentration level increases, the excess mortality rate increases initially at an increasing rate and continues to increase, but at a decreasing rate after a certain inflection level.

It is generally the opinion of medical experts that the true a priori dose-response is nonlinear. This hypothesis is also recently used by Leung (1974) who studied the exposure-effect relation between human health and mobile source air pollution best described by a nonlinear curve as shown in Figure II-1.

On the basis of a priori judgment of medical experts and the two empirical results produced respectively by Buechley and Leung concerning the human health damage responses to pollutant doses, the exposure-effect function relating mortality rate (MR) to sulfur dioxide (SO_2) in the present study is hypothesized as an exponential function alternatively specified as follows:

$$MR = C + e^{(a-b/SO_2)} \qquad \text{(II-3)}$$

$$MR - C = e^{(a-b/SO_2)} \qquad \text{(II-3')}$$

$$\ln (MR - C) = a - b/SO_2 \qquad \text{(II-4)}$$

where C is the "conventional" mortality rate in that the mortality rate is independent of the pollutants and a and b are parameters determining the shape of the nonlinear function. Since both coefficients a and b can take any real values, the semilog, reciprocal equation (II-3) covers a wide range of nonlinear functions with positive first derivatives.

The conventional mortality rate (C) is determined by a host of socioeconomic, demographic, climatological and personal factors. It is recognized that many of the factors known to affect mortality are not amenable to quantification. Factors such as nutrition, exercise, personal habits, etc., are difficult to measure conceptually, while data on smoking habits have not been collected and on medical care are poorly measured. The exclusion of these relevant factors from the regression equation because of insufficient data may result in specification errors and, hence, biased estimates. Thus, careful interpretation of the regression results is warranted.

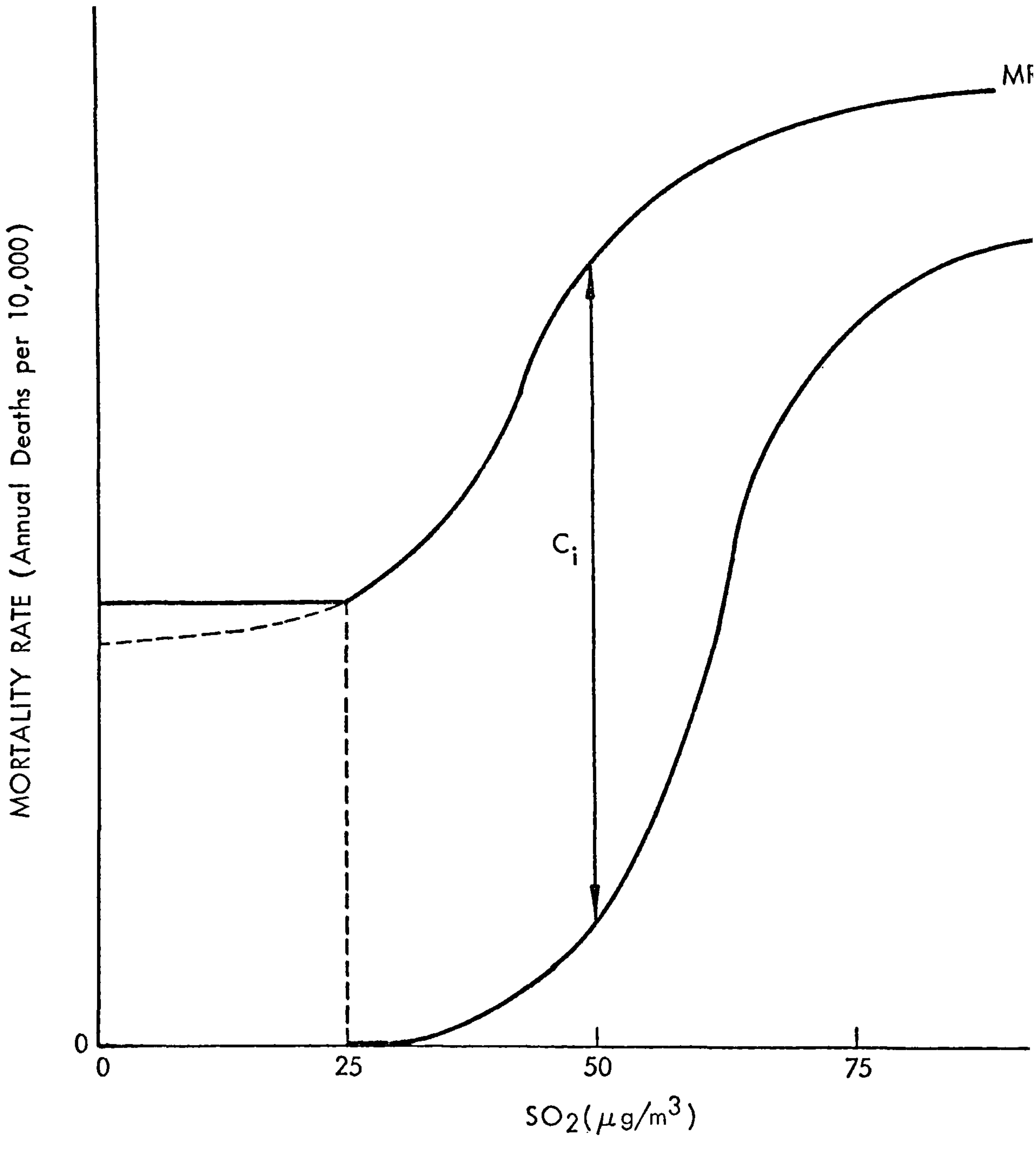

Figure II-1. Hypothetical relationship between mortality rate and SO_2 concentration.

A number of regressions with data on more than 25 potential explanatory variables collected from the 40 SMSA's which had a sulfur dioxide level equal to or greater than 25 $\mu g/m^3$ between 1968 and 1970 were run during the course of this study. The selection of 25 $\mu g/m^3$ as the threshold is based on two considerations: First, this concentration level is the average level prevailing in rural areas. Second, this level is considered to be the "mean" of the tolerable threshold distribution of all individuals in the SMSA. Available evidence suggests that no matter how small the concentration is, adverse health effects may still occur (National Academy of Science, 1974). Thus, threshold in a strict sense should be zero concentration. However, the threshold levels with respect to all individuals in a given region could be reasonably viewed as a symmetrical distribution with a mean level possibly at 25 $\mu g/m^3$. The use of this mean level of thresholds will probably result in more accurate damage estimates than using zero or other threshold levels.

It should be noted that damage estimates cited previously in other pollution studies were derived on the basis of a zero threshold. The use of a zero threshold level tends to overstate the damages.

It is noteworthy that many of the determinants of mortality are difficult to quantify, and data are not readily available for some of the variables.1/ The data for the above mentioned variables for 40 SMSA's which had a sulfur dioxide level equal to or greater than 25 $\mu g/m^3$ between 1968 and 1970 were taken from a comprehensive quality of life study about U.S. SMSA's recently completed by Liu (1975). Variables of no statistical significance or with wrong signs were accordingly eliminated, and the best regression results with the remaining seven independent variables were obtained as follows:

$$\begin{aligned} CC = \underset{(50.5)^*}{229.6} + \underset{(96.4)^*}{741.8}\,PAGE - \underset{(62.8)^{**}}{119.7}\,PYAP - \underset{(0.04)^*}{0.12}\,PCOL - \underset{(21.6)^*}{76.58}\,PWPO \\ - \underset{(0.24)^*}{0.54}\,SUN + \underset{(0.22)}{0.23}\,RHM + \underset{(0.07)}{0.04}\,DTS \end{aligned} \qquad (II\text{-}5)$$

$$R = 0.82$$

1/ In the studies of Lave and Seskin (1970, 1973) and the Koshals (1974), a portion of the explanatory variables was used to estimate a general physical damage. Lave and Seskin regressed mortality rates against air pollutions--particulates and sulfates--population density, proportions of nonwhite, proportions of people over age 64, and proportion of poor families. The Koshals selected the population density, the percentage of relative humidity and the pollutants-suspended particulate matter and benzene soluble organic matter as the explanatory variables in their mortality equation.

where CC denotes the computed conventional mortality rates, PAGE the percentage of population 65 or older, PYAP percentage of population with income above poverty level, PCOL percent of persons 25 or older who have completed 4 years of college, PWPO percentage of white to total population, SUN possible annual sunshine days, RHM relative humidity, and DTS number of days with thunderstorms. The figures in the parentheses are standard errors of the estimates. The estimated coefficients shown in the equation have the correct signs, and with * and ** to indicate that they are statistically significant at the 1 and 5 percent level.

The dose-response function embodying the effect of the threshold level of 25 $\mu g/m^3$ is expressed as:

$$(MR - CC) = EXP\ (a - b/(SO_2 - 25))$$

or

$$RMR = EXP\ (a - b/(SO_2 - 25)) \qquad \text{(II-6)}$$

where CC is the computed value of conventional mortality rate from equation (II-5), and RMR = MR - CC is the residual mortality rate.

The residuals, i.e., MR - CC = RMR, take both positive and negative values. Since the logarithm of a negative number is undefined, RMR was squared prior to its logarithmic transformation. The resultant regression equation was then adjusted by dividing the coefficients by 2. This adjustment is demonstrated as follows:

The regression equation takes the form

$$\text{In}\ (RMR)^2 = 2a - 2b/SO_2$$

By virtue of a property of logarithm, we also obtain

$$2\ \text{In}\ (RMR) = 2a - 2b/SO_2 \qquad \text{(II-7)}$$

or

$$\text{In}\ (RMR) = a - b/SO_2$$

Note that the coefficients in equation (II-7) are twice as large as those in equation (II-4) which is the initially specified nonlinear dose-response function.

The regression result for equation (II-4) is shown as follows:

$$RMR^2 = EXP\ (2.50 - 51.04/SO_2)$$
$$\quad (1.34) \quad (4.22)^*$$

or (II-8)

$$RMR = EXP\ (1.25 - 25.52/SO_2)$$

$$R^2 = 0.03$$

The figures below the coefficients are standard errors with * indicating that the coefficient of SO_2 is significant at the 1 percent level. Though SO_2 explains only 3 percent of the residual mortality rate, the nonlinear fit showed an explanatory power 150 times larger than the linear fit. Generally comparison of R^2 when the dependent variables are different may not be meaningful. However, the purpose of comparing R^2 associated with RMR and In (RMR) equations here is to determine which of the two specifications is more suitable for the estimation of the physical damage function. For comparison purposes, such a linear regression equation is presented as follows:

$$RMR = 29.65 - 0.034\ SO_2 \qquad \text{(II-9)}$$
$$(20.28) \quad (0.35)$$

$$R^2 = 0.0002$$

The linear fit showed not only very low explanatory power, but also an incorrect sign for SO_2. Thus, the nonlinear specification of the dose-response relation seems to be superior and tends to support the *a priori* judgment regarding human responses to pollution dose variations.

To recapitulate, the methodological procedures for estimating the function between mortality rate and SO_2 are summarized as follows:

1. A linear multiple regression model represented by equation (II-5) was developed for estimating the effects of the socioeconomic, demographic, and climatological factors with the exclusion of air pollution on the conventional mortality rate, C, expressed in deaths per 10,000 population.

2. The computed values of C, i.e., CC, were subtracted from the observed gross mortality rate. The residual, RMR = MR - CC, was then regressed on SO_2 alone according to the specification in equation (II-4). The regression result was shown in equation (II-8). The nonlinear, exponential dose-response function was transformed into a linear function with logarithm on RMR and reciprocal on SO_2 for empirical estimation.

The nonlinear physical dose-response function between residual mortality and SO_2 derived from this stepwise econometric technique is characterized by the following features:

1. The nonlinear dose-response function is consistent with the *a priori* judgment about dose-response relationship between air pollution and mortality rate. It can also be easily adjusted with whatever is the threshold level of the SO_2 concentration when estimating the economic damages.

2. For the purpose of predicting and computing the marginal mortality damages due to SO_2, this nonlinear equation has the right sign and higher explanatory power than its counterpart linear equation in view of its goodness of fit.

3. The nonlinear specification circumvents at least partially some of the econometric problems such as multicolinearity and heteroscedasticity which are to be discussed next.

Technical Problems in Estimation--

Although detecting and treating econometric problems which are often encountered in the pollution effect studies are not the main purpose of this study, the problem of multicolinearity and heteroscedasticity are examined during the course of research.

Multicolinearity--[1/]It is well known that multicolinearity problems occur when some or all of the explanatory variables are highly correlated and that it becomes difficult, if not totally impossible, to disentangle their separate influences. Of the nine explanatory variables used in this study, PWPO is correlated with the pollution variables, SO_2 and TSP. RHM is correlated with PAGE, PYAP, PWPO, and SUN. The correlation coefficients are presented in Table II-1. On the basis of this correlation coefficient table, one may be led to conclude that not too "strong" multicolinearity appear to be present in this study. However, it should be noted that the usefulness of partial correlation coefficients as a diagnosis of multicolinearity is questionable. Wichers (1975) has recently shown that a given value of partial correlation coefficient may be compatible with two very different multicolinearity patterns. Less obtusely stated, a simple correlation coefficient may not be the appropriate measure of multicolinearity.

1/ For a detailed discussion on multicolinearity see Johnston (1963), p. 207, Goldberger (1964), pp. 192-193, Farrar and Glauber (1967), and Haitovsky (1969). The three-stage test for the detection of multicolinearity patterns in the classical regression model was criticized by Kumar (1975), Wichers (1975), and O'Hagen and McCabe (1975). Kumar cast doubt on the x^2 test suggested by Farrar and Glauber for the existence of multicolinearity and on the F and t tests to localize the problem. Wichers showed that the third stage of the Farrar-Glauber test is ineffective. O'Hagan and McCabe pointed out a fundamental error which renders meaningless the contribution of Farrar-Glauber to multicolinearity as a sample problem.

TABLE II-1. CORRELATION COEFFICIENTS[a/]

	MR	PAGE	PYAP	PCOL	PWPO	SUN	RHM	DTS	SO_2
PAGE	0.74								
PYAP	-0.26	-0.12							
PCOL	0.61	-0.41	0.25						
PWPO	0.36	0.72	0.33	-0.38					
SUN	-0.25	-0.09	-0.01	0.18	-0.26				
RHM	0.23	0.35	0.45	-0.04	0.42	-0.36			
DTS	0,05	-0.20	-0.19	-0.19	-0.13	-0.17	0.00		
SO_2	0.13	0.05	-0.10	0.08	-0.27	0.08	-0.08	-0.04	
TSP	0.24	-0.09	-0.23	-0.15	-0.33	-0.23	-0.01	0.06	0.04

a/ Correlation coefficients are statistically significant at 5 percent level if $r \geq 0.32$ for 40 observations.

Thus, diagnosis of multicolinearity could be guided by a priori judgment with respect to the interactions among the explanatory variables. Furthermore, the existence of multicolinearity poses little problem if the model is correctly specified, because in such a case least-squares estimates will be unbiased regardless of the extent of multicolinearity. The estimates will be biased if a relevant variable is omitted and inefficient if a nonrelevant variable is included in the regression analysis. The extent of the biases is dependent on the degree of correlation between the misspecified variable and the variables with significant coefficient.

In the presence of multicolinearity, no cut-and-dried technique has been discovered to treat the problem. The residualization technique was first used by Ridker (1965, p. 127-135) in a study of property value and pollution to alleviate the multicolinearity problem by attributing to all the nonpollution variables the covariance between them and the pollution variable. The two-stage estimation procedure is known to bias the pollution coefficients toward zero and reduce their significance in the presence of multicolinearity.

Residualization technique was later employed by Lave and Seskin (1973) to examine the multicolinearity problem. However, the estimated results obtained by Lave and Seskin indicate that the estimated coefficients of the air pollutants retain their significance and the parameter estimates are similar to those in the one-stage regression equation.

Following Ridker and Lave and Seskin, the residuals rather than the gross mortality rates were regressed on the air pollution variables. In doing so, not only the nonlinear dose-response function can be estimated, but also the possible multicolinearity problem existing among the explanatory variables can be alleviated. The low R^2 for the dose-response function is expected from using this two-stage residualization technique. However, the important result is that the nonlinearity of dose-response function represents a better fit than the linear specification as pointed out previously.

Heteroscedasticity- The violation of the condition of a constant variance in the disturbance term in any regression analysis is called heteroscedasticity. The effect of heteroscedasticity is not on the biasness of the estimated regression coefficient itself, but rather on efficiency of the variance of the coefficient estimated. It is recognized that the existence of heteroscedasticity often occurs in the cross-section data. In the present study, heteroscedasticity is detected by using the eyeballing method. In terms of Figure II-2, the residuals are plotted against the dependent variables. The shape of the residual distribution pattern suggests that the variance of the error term is variable, i.e., there is likely a problem of heteroscedasticity. Glejser (1969) and Park (1966) discussed alternative methods for detecting heteroscedasticity. These methods have been applied by Smith and Deyak (1975) for testing heteroscedasticity in estimating air pollution and property value relation.

The common treatment for heteroscedasticity is to use the weighted regression method designed to reduce the nonhomogeneity of the variance. The use of semilog on the dependent variable in this study is a sort of the weighted regression method. The semilog transformation reduces the nonhomogeneous spread of the variance in the error term (e.g., along the mortality rate axis in Figure II-2, on page 27), and, hence, partially alleviates the heteroscedasticity problem.

A LINEAR GENERAL PHYSICAL DAMAGE FUNCTION

As noted earlier, reliable and useful average damage functions on mortality rate and air pollution for the United States metropolitan areas are still lacking. To close this gap in the air pollution damage investigation, a generalized average damage function is developed by regressing jointly, in a linear form, the sum of the estimated mortality rates from both equations (II-5) and (II-8) on the four socioeconomic and demographic variables, the three climatological variables and the SO_2. It should be stressed that the results of this generalized average damage function should only be used for prediction purposes, and any statistical interpretations would be meaningless. Otherwise stated, this damage function so derived serves to yield a more accurate prediction with respect to the changes in the mortality rates in response to a <u>ceretis paribus</u> change in any of its determinants. Based on the data of the 40 SMSA's with SO_2 exceeding 25 $\mu g/m^3$ between 1968 and 1970, the linear regression analysis was conducted to ascertain the generalized average damage function, estimated as:

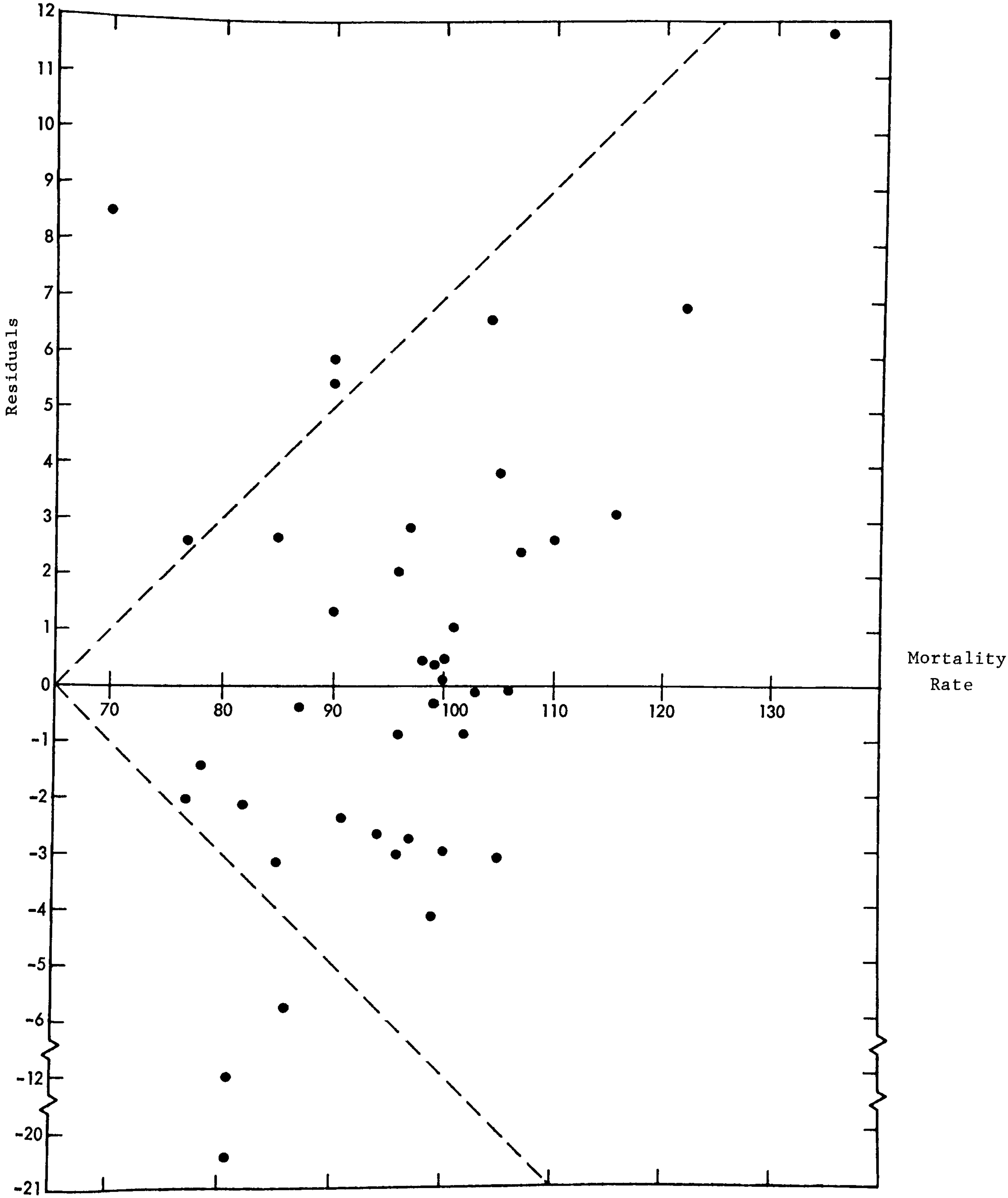

Figure II-2. Heteroscedastic distribution of the residuals.

$$CMR = CC + CRMR$$

$$\begin{aligned} &= \underset{(3.4)^*}{226.2} + \underset{(8.7)^*}{735.4}\ PAGE - \underset{(5.3)^*}{113.8}\ PYAP - \underset{(0.003)^*}{0.12}\ PCOL - \underset{(2.0)^*}{77.5}\ PWPO \\ &\quad - \underset{(0.02)^*}{0.55}\ SUN + \underset{(0.02)^*}{0.23}\ RHM + \underset{(0.006)^*}{0.03}\ DTS + \underset{(0.003)^*}{0.023}\ SO_2 \end{aligned} \qquad \text{(II-10)}$$

where CMR is the computed mortality rate, which is the sum of the computed conventional mortality rate (CC) and the computed residual mortality rate (CRMR) from equations (II-5) and (II-8), respectively. All independent variables on the right-hand side of equation (II-10) were defined previously.

Admittedly, a usual statistical interpretation for the generalized damage function summarized by equation (II-10) is not meaningful. However, the purpose of deriving this equation is to demonstrate that the stepwise econometric model ameliorates some technical problems of estimation. The advantage of this approach is clear if equation (II-10) is compared with the similar physical damage function using the actual rather than computed mortality rates as the dependent variable. Such a physical damage function is summarized as follows:

$$\begin{aligned} MR &= \underset{(51.5)}{230.1} + \underset{(10.59)}{746.4}\ PAGE - \underset{(63.9)}{119.3}\ PYAP - \underset{(0.035)}{0.12}\ PCOL - \underset{(24.3)}{77.7}\ PWPO \\ &\quad - \underset{(0.25)}{0.54}\ SUN + \underset{(0.22)}{0.23}\ RHM + \underset{(0.07)}{0.04}\ DTS - \underset{(0.033)}{0.004}\ SO_2 \end{aligned} \qquad \text{(II-11)}$$

It is noteworthy that the coefficient of SO_2 in equation (II-11) is negative despite the fact that the simple correlation coefficient between MR and SO_2 is positive and equal to 0.13. The negativity of the SO_2 coefficient is probably due to multicolinearity and other econometric problems discussed earlier. The two-step econometric method seems to have partially overcome these technical problems and yields, if not coincidentally, the expected positive coefficient of SO_2 in equation (II-10).

VALUES OF AIR POLLUTION DAMAGES AND ECONOMIC DAMAGE FUNCTIONS

Air pollution damage to human health in this country has been roughly estimated by Ridker (1965), Lave and Seskin (1970, 1973), Jaksch and Stoevener (1974), Koshal and Koshal (1974), Park (1974), and others. However, their estimates vary considerably; from $443 million by Ridker to $2.4 billion by Lave and Seskin, and $6.8 billion by Park, partially because their study scopes and period are not commensurate with each other. In order to estimate an average economic damage function for the United States urban areas, it is not meaningful to borrow the national damages estimated by the above authors not only because of this great disparity but also the different methods of estimation. A method will be developed to quantify regional damage separately for each metropolitan area so that regional control costs and benefits can be evaluated. Since we considered 25 $\mu g/m^3$ as the threshold of SO_2, only those SMSA's with average annual SO_2 levels equal to or greater than 25 $\mu g/m^3$ between 1968 and 1970 and with data on other relevant factors were selected.

Air pollution has caused high morbidity rates in addition to premature mortality in this country. This section, however, is mainly concerned with the mortality damages. The morbidity damages due to air pollution will be discussed in Section III. To estimate the mortality damages of SO_2 and the percentage of pollution-caused damage to total mortality losses, an expected average permanent income method was developed. Specifically, we computed via equations (II-5) and (II-8) the conventional and the residual mortality rate for the selected SMSA's. Assume that each individual in any of the SMSA's is equally affected by air pollution and that the growth in median earnings from 1960 to 1970 represents an expected normal income rate. The expected future income streams are computed by a simple formula computed for the conventional and air pollution victims in the labor force--between 18 and 64 years of age. The present value of the economic damages was derived by discounting the future incomes at a rate of 4 percent which is the long-term bond rate. Finally, we regressed the computed economic losses of both conventional and pollution victims on the demographic, socioeconomic, and weather variables, and SO_2 for the selected SMSA's to derive the so-called "average" economic damage function.

In functional form, this part of the work for each SMSA can be succinctly expressed as follows:1/

$$V = \bar{Y} \cdot \left[\sum_{t=1}^{n} (1 + r)^t / (1 + i)^t \right] \cdot L \cdot [CC + CRMR] \qquad \text{(II-12)}$$

$$V' = \bar{Y} \left[\sum_{t=1}^{n} (1 + r)^t / (1 + i)^t \right] \cdot L \cdot CC \qquad \text{(II-12')}$$

1/ A somewhat different formula was developed and employed by Ridker for estimating damage costs due to premature death. A drawback of his method, as noted by Ridker himself, is the lack of adjustment for increase in labor productivity over time. A similar framework was also used by Schrimper (1975) to calculate mortality costs for Chicago. The expected income formula developed here considers the improvement in labor productivity, though all workers are assumed to live through and be employed until the age of 65. The bias in the resulting estimates is believed to be negligible.

where V and V' are, respectively, the computed value of regional economic damages with or without air pollution;

Y is the weighted median income of 1970 between males and females with the weights being their respective share in the labor force;

r is the expected family income growth rate which partially reflects the growth in labor productivity assumed to be equal to the average from 1960 to 1970;

i is the discount rate, set at 4 percent per year, a rather conservative rate;

L is the labor force or population between 18 and 64 years of age;

CRMR and CC are the computed excess mortality rates and the computed conventional mortality rate, respectively;

n is the difference between regional median age and 64; this assumes that the number of deaths due to air pollution with age younger than the median age is offset by those who fall short of reaching the age of 64.

The damage costs without and with air pollution and the per capita damage costs for 1970 by SMSA are estimated using equations (II-8), (II-12), and (II-12') and are contained in Table II-2. All dollars reported in the table are in 1970 value. Under the heading of mortality damage due to SO_2, total and per capita mortality cost for each SMSA can be found in Columns 1 and 2. Mortality damages in the absence of air pollution is presented in Column 3, and Column 4 presents the ratio or the relative magnitude of total mortality cost attributable to SO_2 and the mortality damage with and without SO_2. The higher the ratio, the more serious is the pollution damage.

It should be noted that the damage estimates presented in the table depend vitally on the assumptions made in this study. The most critical assumptions are the threshold levels of SO_2 the natural mortality rate, the growth in income and the discount rates. Change in any of these assumptions would result in modification in the damage estimate.

As readily revealed in the table, total mortality costs in the presence of SO_2 amounted to \$887 million for the 40 SMSA's which had average annual SO_2 concentration beyond 25 $\mu g/m^3$ between 1968 and 1970. Given that total mortality cost in the absence of air pollution in the 40 SMSA's is \$60.2 billion, as measured, the air pollution damage accounted for 1.4 percent of the total. Among the 40 SMSA's, New York City had the highest total and per capita mortality air pollution damage, about \$329 million and \$28.4 respectively, partially because it had the highest SO_2 concentration level between 1968 and 1970, i.e., 210 $\mu g/m^3$. The highest percentage of air pollution damage was found in Chicago and New York City; 2.7 percent of total gross mortality values in these areas could

TABLE II-2. MORTALITY COSTS WITH SO_2 BY SMSA's, 1970

SMSA	SO_2 ($\mu g/m^3$)	Mortality Damage Due to SO_2: Total (in 10^6) (1)	Mortality Damage Due to SO_2: Per Capita (2)	Mortality Damage Without Air Pollution (in 10^6) (3)	Ratio (1)÷((1)+(3) (4)
1. Akron, OH	51	8.4	12.4	570.6	0.0145
2. Allentown, PA	57	7.5	13.8	462.5	0.0160
3. Baltimore, MD	54	28.4	13.7	1891.6	0.0148
4. Boston, MA	31	1.3	0.5	2398.7	0.0005
5. Bridgeport, CT	40	2.6	6.7	353.4	0.0073
6. Canton, OH	30	0.1	0.3	330.9	0.0003
7. Charleston, WV	27	--	--	159.0	--
8. Chicago, IL	120	178.0	25.5	6292.0	0.0275
9. Cincinnati, OH	25	--	--	1160.0	--
10. Cleveland, OH	64	34.3	16.6	1875.7	0.0180
11. Dayton, OH	25	--	--	398.0	--
12. Detroit, MI	38	26.0	6.2	4884.0	0.0053
13. Evansville, IN	25	--	--	214.0	--
14. Gary, IN	58	10.6	16.7	555.4	0.0187
15. Hartford, CT	57	10.5	15.8	552.5	0.0187
16. Jersey City, NJ	75	9.6	15.8	529.4	0.0178
17. Johnstown, PA	25	--	--	263.0	--
18. Lawrence, MA	52	2.7	11.6	204.3	0.0130
19. Los Angeles, CA	35	15.9	2.3	4964.1	0.0032
20. Minneapolis, MN	38	9.1	5.0	1380.9	0.0065
21. New Haven, CT	40	2.2	6.2	341.8	0.0064
22. New York, NY	210	329.0	28.4	11671.0	0.0274
23. Newark, NJ	37	7.0	3.8	1633.0	0.0043
24. Norfolk, VA	26	--	--	511.0	--
25. Paterson, NJ	28	--	--	1150.0	--
26. Peoria, IL	26	--	--	295.0	--
27. Philadelphia, PA	84	97.9	20.3	4322.1	0.0221
28. Pittsburgh, PA	57	30.0	12.5	2000.0	0.0148
29. Portland, OR	26	--	--	922.0	--
30. Providence, RI	67	14.6	16.0	777.4	0.0184
31. Reading, PA	30	0.1	0.3	257.9	0.0004
32. Rochester, NY	32	0.8	0.9	784.2	0.0010
33. St. Louis, MO	40	13.3	5.6	2156.7	0.0061
34. Scranton, PA	30	--	0.01	185.0	--
35. Springfield, MA	87	10.6	20.0	458.4	0.0226
36. Trenton, NJ	32	0.2	0.7	254.8	0.0008
37. Washington, D.C.	47	35.5	12.4	1194.5	0.0175
38. Worchester, MA	31	0.2	0.6	319.8	0.0006
39. York, PA	31	0.1	0.3	263.9	0.0004
40. Youngstown, OH	30	0.1	0.2	482.9	0.0002
Total		886.6		60,221.4	

Note: -- denotes less than $0.1 million.

Note: -- individual figure may not add to totals due to rounding.

be attributed to SO_2. In order of magnitude, New York City, Chicago, and Philadelphia all had air pollution damages of more than $50 million. In terms of the ratio of net mortality damage to gross mortality damage, i.e., Column 4, again New York and Chicago which had ratio values of 2.7 percent lead all the other SMSA's. As noted earlier, the degree of the pollution damage is partially reflected by the magnitude of this ratio.

Although the economic damage costs derived in this section are more detailed than prior estimates, they are still crude information and should be used with caution under the stated conditions. In order to develop a marginal economic damage function useful for prediction and control purposes, the "total of economic costs of mortality" is related not only to SO_2, but also to various socioeconomic, demographic, and climatological characteristics of different regions. The stepwise regression technique was used with inputs from the 40 sample observations to estimate the economic damage function. The regression results are shown as follows:

$$\begin{aligned} V = \underset{(11{,}023)}{10{,}295} + \underset{(6.97)^*}{47.02\ SO_2} - \underset{(5{,}195.9)}{8{,}128.4\ PWPO} + \underset{(46.9)^*}{98.5\ RHM} + \underset{(53.4)}{72.3\ SUN} \\ - \underset{(15.99)}{15.98\ DTS} - \underset{(13{,}659.9)}{16{,}191.8\ PYAP} + \underset{(7.6)}{7.7\ PCOL} + \underset{(22{,}650)}{3{,}772\ PAGE} \end{aligned} \qquad \text{(II-13)}$$

$$R^2 = 0.74$$

where V is total mortality cost obtained from equation (II-12) and all the explanatory variables are defined earlier.

The coefficients and standard errors in (II-13) are reduced by a factor of 10^6. The values of standard error are presented below the coefficients, with * to indicate that the coefficient is significant at the 1 percent level.

The economic damage function derived can be useful to policymakers in estimating the marginal and average damages (benefits) resulting from a pollution control program. To serve as an illustration, an example involving the computation of the partial elasticity of an explanatory variable and the associated marginal benefit due to the changes in that variable is presented. Suppose the federal government is considering the implementation of a pollution abatement program which is expected to reduce the average SO_2 level in the urban areas by, say, 10 percent. What will then be the dollar worth benefit of the reduced premature mortality rate as a result of the pollution abatement program? Since the average total damage cost due to premature mortality is $1,530.8 million and the average SO_2 level is 47.95 $\mu g/m^3$ among the 40 SMSA's, the partial elasticity of the damage cost with respect to SO_2 is derived by using the formula that

$$E_{c,SO_2} = (\partial c/\partial(SO_2)) \times (\overline{SO_2}/\bar{c}) = 47.02 \times (47.95/1,530.8) = 1.45.$$

Note $(\partial c/\partial(SO_2))$ in the formula denotes the coefficient of SO_2 in the economic damage function; $\overline{SO_2}$ and $\bar{c}$ are, respectively, the mean values of SO_2 and the total damage cost for the 40 SMSA's included in the sample.

The distinguishing property of the concept of elasticity is that it is a unit-free measure of the percentage change in the dependent variable with respect to the percentage change in any of the explanatory variables while holding other things equal. Given the computed elasticity of damage cost with respect to SO_2, $E_{c,SO_2} = 1.45$, it is in general expected that a 10 percent decrease in the SO_2 concentration level will result in a 14.5 percent reduction in the premature mortality damage cost. Since the mean value of the regional damage cost for the 40 SMSA's is $1,531 million, when the SO_2 level decreases from 47.95 $\mu g/m^3$ to 43.15 $\mu g/m^3$, it is expected that on the average the damage cost will be reduced by the amount of $1,530.8 x 14.5 percent = $221.9 million. Likewise, the elasticities for the other explanatory variables can be analogously computed and interpreted.

PREMATURE MORTALITY DAMAGES AND SUSPENDED PARTICULATES

Earlier studies have established a positive qualitative relationship between mortality and suspended particulates. Recently Lave and Seskin (1970, 1973), and the Koshals (1974) further confirmed the existence of a quantitative association between mortality and the particulates. As discussed earlier, the threshold effects of the air pollutant and the heteroscedasticity problems in the empirical estimation of the relation were, by and large, ignored in the prior studies. A two-step residualization technique was, however, developed earlier to cope with these problems in estimating a nonlinear dose-response function. The same methodology is used in this section to establish a dose-response function relating mortality to suspended particulates.

The nonlinear dose-response relation (II-3) was used for regressing the residual mortality rate (MR-C) on total suspended particulates (TSP). To be consistent with earlier SO_2 estimates, the particulate level is also adjusted by a threshold of 25 $\mu g/m^3$ in computing the physical damage. As noted earlier, although 25 $\mu g/m^3$ is a reasonable level for capturing the threshold effect, alternative thresholds may also be considered. Changes in the threshold will cause modifications in the damage estimates. It is conceivable that, other things being equal, a lower threshold level implies higher damage cost.

The least-squares regression yields the following nonlinear physical damage functions for suspended particulates:

$$RMR = EXP\ [1.30 - 65.75/TSP] \qquad (II\text{-}14)$$
$$\qquad (0.83)\ (70.84)$$

$$R^2 = 0.02$$

The values below the coefficients are standard errors. The explanatory variable TSP is not statistically significant. With the availability of the physical damage function, the methodological procedures used earlier for estimating the postulated function relating mortality rate to SO_2 can be employed to estimate the economic damages and the associated economic damage function for suspended particulates.

Economic Damage Functions

For policymakers, economic damage functions may be more relevant than physical damage functions. An economic damage function, or a monetary damage function, relates levels of pollution to the amount of compensation which would be needed in order that the society is not worse off than before the deterioration of the air quality. The economic damage function is useful to decision makers since the multiple dimensions of the decision problem are reduced into one dimension only, i.e., money. It should be noted, however, that transformation of a physical damage function into an economic damage function often involves value judgment on the part of the policymaker. A related question as to the degree of conformity of the values of the policymaker with those of the consumer sovereignty is largely unresolved.

The expected permanent income method delineated earlier was employed to estimate premature mortality damages due to total suspended particulates. The damage costs associated with total suspended particulates are presented in Table II-3. Columns (1) and (2) present total and per capita mortality damage attributable to TSP. Mortality damage without air pollution is presented in Column (3). Column (4) presents ratio of total mortality damage due to TSP to total mortality damage with TSP. This ratio reflects the relative magnitude of the damage attribute TSP to total mortality damage. An examination of the table reveals that the mortality damages range from $1.4 million in Lawrence, Masssachusetts, to $155 million in New York City. The air pollution damage in Lawrence is 0.7 percent of the total gross mortality damage, while in New York City suspended particulate causes about 1.3 percent of total mortality damage. The highest ratio of pollution damage to total mortality damage of the magnitude of 4.0 percent is observed for Dayton, Ohio.

Generalized economic damage functions were derived by regressing the premature mortality damage costs associated with TSP (TMRCT) which is the sum of Columns (1) and (3) in Table II-2 on the demographic, socioeconomic, and

TABLE II-3. MORTALITY COSTS WITH TSP BY SMSA's, 1970
(in dollars)

	SMSA	TSP ($\mu g/m^3$)	Mortality Damage Due to TSP: Total (in 10^6) (1)	Mortality Damage Due to TSP: Per Capita (2)	Mortality Damage Without Air Pollution (in 10^6) (3)	Ratio (1)÷((1)+(3) (4)
1.	Akron, OH	80	7.2	10.6	570.6	0.0125
2.	Allentown, PA	87	6.0	11.0	462.5	0.0128
3.	Baltimore, MD	147	42.0	20.3	1891.6	0.0217
4.	Boston, MA	108	42.9	15.6	2398.7	0.0176
5.	Bridgeport, CT	57	2.0	5.1	353.4	0.0056
6.	Canton, OH	103	5.3	14.2	330.9	0.0158
7.	Charleston, WV	105	2.5	10.9	159.0	0.0155
8.	Chicago, IL	155	147.0	21.1	6292.0	0.0228
9.	Cincinnati, OH	106	18.9	13.6	1160.0	0.0160
10.	Cleveland, OH	201	47.8	23.2	1875.7	0.0249
11.	Dayton, OH	114	16.4	19.3	398.0	0.0396
12.	Detroit, MI	153	116.0	27.6	4884.0	0.0232
13.	Evansville, IN	75	2.0	8.6	214.0	0.0093
14.	Gary, IN	105	10.6	16.7	555.4	0.0187
15.	Hartford, CT	74	6.4	9.6	552.5	0.0115
16.	Jersey City, NJ	83	5.4	8.9	529.4	0.0101
17.	Johnston, PA	103	3.7	14.1	263.0	0.0139
18.	Lawrence, MA	65	1.4	6.0	204.3	0.0068
19.	Los Angeles, CA	118	106.0	15.1	4964.1	0.0209
20.	Minneapolis, MN	76	18.8	10.4	1380.9	0.0134
21.	New Haven, CT	60	1.9	5.3	341.8	0.0055
22.	New York, NY	95	155.0	13.4	11671.0	0.0131
23.	Newark, NJ	134	33.6	18.1	1633.0	0.0202
24.	Norfolk, VA	113	11.2	16.5	511.0	0.0214
25.	Paterson, NJ	56	6.0	4.4	1150.0	0.0052
26.	Peoria, IL	78	3.3	9.6	295.0	0.0111
27.	Philadelphia, PA	78	45.8	9.5	4322.1	0.0105
28.	Pittsburgh, PA	135	38.5	16.0	2000.0	0.0189
29.	Portland, OR	86	11.1	11.0	922.0	0.0119
30.	Providence, RI	77	8.0	8.8	777.4	0.0102
31.	Reading, PA	117	4.3	14.5	257.9	0.0164
32.	Rochester, NY	90	11.7	13.3	784.2	0.0147
33.	St. Louis, MO	120	38.5	16.3	2156.7	0.0175
34.	Scranton, PA	189	3.7	15.8	185.0	0.0196
35.	Springfield, MA	64	3.1	5.9	458.4	0.0067
36.	Trenton, NJ	71	2.4	7.9	254.8	0.0093
37.	Washington, D.C.	90	43.3	15.1	1994.5	0.0212
38.	Worchester, MA	72	2.8	8.1	319.8	0.0087
39.	York, PA	85	3.3	10.0	263.9	0.0124
40.	Youngstown, OH	110	8.2	15.3	482.9	0.0167
	Total		1044.0		60,221.4	

Note: -- individual figure may not add to totals due to rounding.

climatological variables and the suspended particulate level for the 40 SMSA's. The stepwise regression result for the generalized economic damage function is summarized below:

$$\begin{aligned} \text{TMRCT} = {} & \underset{(18{,}034)}{13{,}109} + \underset{(11.68)}{7.63}\ \text{TSP} - \underset{(8{,}339)^{*}}{20{,}225}\ \text{PWPO} + \underset{(72.85)}{85.05}\ \text{RHM} + \underset{(87.49)}{6.85}\ \text{SUN} \\ & - \underset{(24.89)}{14.88}\ \text{DTS} - \underset{(21{,}076)}{10{,}554}\ \text{PYAP} + \underset{(12.25)}{11.39}\ \text{PCOL} + \underset{(33{,}019)}{54{,}606}\ \text{PAGE} \end{aligned}$$

$$R^2 = 0.38 \qquad \text{(II-15)}$$

The values below the coefficients are standard errors. The symbol * indicates that the coefficient is significant at the 1 percent level. The coefficients and standard errors are reduced by a factor of 10^6. The explanatory variables are the same as those appearing in the sulfur dioxide economic damage function and explain about 38 percent of the variations in the dependent variables.

Given the mean values of total damage cost and total suspended particulate level are \$1,543.5 million and 100.9 $\mu g/m^3$, respectively, the partial elasticity of damage cost with respect to total suspended particulate is:

$$E_{c,TSP} = 7.63 \times (100.9/1{,}543) = 0.49$$

Thus, a 10 percent decrease in the average TSP level as a result of pollution control programs will cause a reduction of 4.9 percent in the premature mortality damage cost. That is, when the TSP is reduced from 100.9 $\mu g/m^3$ to 89.81 $\mu g/m^3$ the damage cost, on the average, will be reduced by the amount of \$1,543 x 4.9 percent = \$75.6 million.

IMPLICATIONS AND CONCLUDING REMARKS

This study is the first attempt to estimate a physical nonlinear damage function between excess mortality rates and the SO_2 concentration with considerations of circumventing certain econometric problems such as multicolinearity and heteroscedasticity, and accounting for the effects of the threshold levels. Through a two-step adjustment procedure, the average physical mortality function was generalized with a rather complete specification. That is, the generalized average mortality model includes not only the major demographic, socioeconomic, and climatological determinants but also air pollution variables. The two-step econometric model developed here represents a constructive response to the call recently made by Lave and Seskin (1973) and Ferris (1970) in connection with the urgent need to improve on the existing studies in the area of air pollution and human health.

This study is also the first attempt to present comparable estimates for premature mortality damages due to "excessive" air pollution--sulfur dioxide and total suspended particulates--for individual urban areas in the United States. To assist the policymakers in estimating possible marginal damage (benefit) resulting from a given pollution control strategy, "average" economic damage functions which transform the multiaspect of the problems into a single, homogeneous monetary unit were also developed separately for the two major pollutants.

It should be noted that the present federal standards were derived on the assumption that threshold levels for various pollutants exist. These threshold levels are considered to be the safe levels below which essentially no person is hurt. This threshold level concept has been attacked by many medical experts on the grounds that evidence has failed to support a genuine clear-cut lower limit. It is our contention that the threshold model of health effects, however, should not be taken literally, as some experts suggested.

The threshold of 25 $\mu g/m^3$ was used in this study in deriving the damage estimates because it is viewed as the mean level of the underlying distribution of tolerable threshold levels of all the individuals in a given SMSA. Furthermore, it is also the average concentration level in the rural areas where little air pollution damage on human health is observed. Thus, while the annual average concentration level is below the threshold level, the majority of the population in the rural areas is assumed not hurt from the presence of air pollution. In order to derive more accurate "average" damages of pollution in a given region, it is imperative to establish threshold level which is the mean level of the actual threshold distribution. Our model is easily adaptable for any threshold levels that one would like to consider as tolerable.

Another issue which merits discussion is the possible chemical interactions among the pollutants. It is generally recognized that the total effect of several pollutants present at the same time in the air may be greater or less than the sum of their individual effects. In other words, the interaction effect may be additive, synergistic or even antagonistic. Two types of interactions should be noted: (1) physiological, and (2) chemical. Both types of interactions are expected to occur. The crucial question is how and to what extent air pollutants interact with each other. Stated differently, the question is whether the interaction effects are of sufficient magnitude to negate the present method of establishing the air quality standards. All panel experts, according to a recent National Academy of Sciences study (1974), found that synergistic effects are not important enough to invalidate the current methods which set air quality standards for each major pollutant.

Since the synergism occurs when SO_2 and TSP are present at the same time, the independency assumptions employed in this study may result in underestimating the damages. However, it has been well recognized that both SO_2 and TSP may be merely convenient indexes of all major damaging pollutants. This measurement problem of the pollutants contributes to overestimating the damages. In view of these two opposing factors, we are unable to judge whether our procedure tends to result in upward or downward biased estimates.

Other conceptual and empirical problems often encountered in estimating air pollution damage also should be noted. The major difficulties include the lack of knowledge regarding the shape of the function which describes the relationship between air pollution and health, the lack of a theoretical model specifying the way air pollution affects health, the virtual impossibility of accounting for all factors that might affect human health, and errors of observations in the data. Some of these problems, however, have been tackled in the present paper. For example, the nonlinear dose-response relation was specified for the excess mortality rate and the pollutant concentration level. The specification of this more plausible physical dose-response function would partially account for the credibility in our air pollution damage estimates. The semilog transformation reduces the heteroscedasticity while the use of the residuals ameliorates the multicolinearity problem.

Although the income foregone or productivity models have been employed by economists, their application to mortality or deaths in individual metropolitan areas due to SO_2, TSP, and other causes opens up another avenue for air pollution damage quantification which seems to be much more desirable than earlier studies unveiling only some aggregate figures for the nation as a whole. Furthermore, the average air pollution damage functions derived in this study with observations from a selected set of SMSA's with pollution level above the threshold are conceivably more meaningful than prior studies which included all SMSA's as sample observations regardless of the concentration level of air pollution.

This section presents a set of more recent estimates of air pollution damage for each of the 40 SMSA's with concentration levels higher than 25 $\mu g/m^3$. Based on the conservative assumption employed, it is found that while SO_2 alone in 1970 costs approximately $887 million, or about 1.4 percent of total mortality costs in these areas, TSP imposes about $1,047 million damages, or about 1.7 percent on the total mortality costs in the same areas.

The mortality damages due to SO_2 and TSP and the mortality damages without air pollution from Tables II-2 and II-3 are reproduced in Table II-4. Column 4 of Table II-4 presents the total mortality damage costs which are the sum of the three component damages listed in Columns 1, 2, and 3. The SO_2 damage estimates derived in this section should replace the earlier estimates reported by Liu (1975).

The results presented in this section are only suggestive and tentative. Given the tentativeness and experimental nature of the methodological and statistical procedures, and the degree of uncertainty associated with the study results, a great deal of caution should be exercised in using the products of this research. However, the availability of average or marginal damages is instrumental in determining the optimal national or regional pollution control strategies.

The current problem seems far more complex than the question of balancing the benefits to polluters against damages inflicted on the receptors. The issues are pressing and not yet well specified. The basic difficulty in applying the

TABLE II-4. MORTALITY COSTS BY SMSA's, 1970

	SMSA	Total Mortality Damage Due to SO_2 (10^6) (1)	Total Mortality Damage Due to TSP (in 10^6) (2)	Mortality Damage Without Air Pollution (in 10^6) (3)	Total Mortality Damage (in 10^6)
1.	Akron, OH	8.4	7.2	570.6	586.2
2.	Allentown, PA	7.5	6.0	462.5	476.0
3.	Baltimore, MD	28.4	42.0	1891.6	1962.0
4.	Boston, MA	1.3	42.9	2398.7	2442.9
5.	Bridgeport, CT	2.6	2.0	353.4	358.0
6.	Canton, OH	0.1	5.3	330.9	336.3
7.	Charleston, WV	--	2.5	159.0	161.5
8.	Chiçago, IL	178.0	147.0	6292.0	6617.0
9.	Cincinnati, OH	--	18.9	1160.0	1178.9
10.	Cleveland, OH	34.3	47.8	1875.7	1957.8
11.	Dayton, OH	--	16.4	398.0	414.4
12.	Detroit, MI	26.0	116.0	4884.0	5026.0
13.	Evansville, IN	--	2.0	214.0	216.0
14.	Gary, IN	10.6	10.6	555.4	576.6
15.	Hartford, CT	10.5	6.4	552.5	569.4
16.	Jersey City, NJ	9.6	5.4	529.4	544.4
17.	Johnstown, PA	--	3.7	263.0	266.7
18.	Lawrence, MA	2.7	1.4	204.3	208.4
19.	Los Angeles, CA	15.9	106.0	4964.1	5086.0
20.	Minneapolis, MN	9.1	18.8	1380.9	1408.8
21.	New Haven, CT	2.2	1.9	341.8	345.9
22.	New York, NY	329.0	155.0	11671.0	12155.0
23.	Newark, NJ	7.0	33.6	1633.0	1673.6
24.	Norfolk, VA	--	11.2	511.0	522.2
25.	Paterson, NJ	--	6.0	1150.0	1156.0
26.	Peoria, IL	--	3.3	295.0	298.3
27.	Philadelphia, PA	97.9	45.8	4322.1	4465.8
28.	Pittsburgh, PA	30.0	38.5	2000.0	2068.5
29.	Portland, OR	--	11.1	922.0	933.1
30.	Providence, RI	14.6	8.0	777.4	800.0
31.	Reading, PA	0.1	4.3	257.9	262.3
32.	Rochester, NY	0.8	11.7	784.2	796.7
33.	St. Louis, MO	13.3	38.5	2156.7	2208.5
34.	Scranton, PA	--	3.7	185.0	188.7
35.	Springfield, MA	10.6	3.1	458.4	472.1
36.	Trenton, NJ	0.2	2.4	254.8	257.4
37.	Washington, D.C.	35.5	43.3	1994.5	2073.3
38.	Worchester, MA	0.2	2.8	319.8	322.8
39.	York, PA	0.1	3.3	263.9	267.3
40.	Youngstown, OH	0.1	8.2	482.9	491.2
	Total	886.6	1044.0	60,221.4	62,152.0

Note: -- denotes less than $0.1 million.

Note: -- individual figure may not add to totals due to rounding.

recent research findings to accurately estimate the air pollution damage cost stems from our ignorance about the populations at risk to air pollution. So far, few attempts have been made to identify who suffers, to what extent, from which sources, and in what regions. At this moment, updating and expanding the available crude estimates which are generally restricted to certain regions are urgently needed.

SECTION III

MORBIDITY AND AIR POLLUTION

PROBLEMS AND OBJECTIVES

A great number of epidemiological studies have suggested that there is a significant relationship between various morbidity rates and air pollution. Even in the early 17th century it was quite generally suspected that sulfur dioxide in coal smoke was responsible for the high morbidity and mortality associated with the notorious smoke disasters such as those that later occurred in Belgium's Meuse Valley in 1930, in Donora, Pennsylvania in 1948 and in London in 1952.

The relationship between air pollution and health can be acute response--dramatic increases in air pollution concentration exert an immediate adverse effect on human health. However, it is well known that air pollutants continuously react dynamically in the environment. The effect of pollutants on health should also be examined over an extended period. Lave and Seskin (1973b, p. 17) remarked that "a long, or chronic exposure to low concentrations might be just as harmful to health as a short, or episodic exposure to high concentrations."1/

The diseases which are known to be related to air pollution include the following: bronchitis and emphysema; pneumonia, tuberculosis and asthma; total respiratory diseases; lung cancer; nonrespiratory-tract cancers; and cardiovascular diseases. A review of the existing literature on the diseases attributable to air pollution is given in the following paragraphs for better understanding of the problems under study.

Bronchitis and Emphysema

Six specific bronchitis rates have been found by Stocks (1959) to be correlated with a deposit index and smoke. This result was corroborated by Ashley (1969) who found a positive correlation between deaths due to bronchitis and sulfur dioxide and smoke. However, a contrary result was obtained by Burgess and Shaddick (1959) who failed to reveal a significant relationship between bronchitis death and air pollution.

Holland and Reid (1965) and Reid (1968) found that the health status of postmen was inversely affected by fog and air pollution. Cornwall and Raffle (1961) found a positive correlation between sickness absence and fog.

1/ A comprehensive literature review on the effect of air pollution on human health was provided, for example, by Lave and Seskin (1975).

Higgins (1966) found lower peak expiratory flow rate in urban areas than in rural areas. Hammond (1967) confirmed that heavy smokers in cities suffered a much higher morbidity rate than those in the rural areas. Ishikawa et al. (1969) found that the incidence and severity of emphysema was higher in St. Louis than in Winnipeg, which had a lower pollution level than St. Louis.

Petrilli et al. (1966) also discovered that the incidence of bronchitis was signficantly correlated with pollution. Toyama (1964) and Yoshida et al. (1966) confirmed the positive relationship between bronchitis and pollution.

Pneumonia, Tuberculosis, and Asthma

Stocks (1960) discovered a high correlation between smoke index and pneumonia mortality. Mills (1943) found substantial correlation between pneumonia mortality and pollution levels. Significant sample correlations for pneumonia mortality and fuel consumption, and for tuberculosis mortality and fuel consumption were reported by Daly (1969).

Sultz et al. (1969) found a significant relation between air pollution levels and the incidence of asthma and eczema among boys under 5 years of age. Yoshida et al. (1969) found that bronchial asthma among Japanese residents was proportional to the sulfur dioxide levels.

Total Respiratory Disease

Skalpe (1964) found that pulp mill workers under 50 years of age exposed to sulfur dioxide suffered from a significantly lower maximal expiratory flow rate. Speizer and Ferris (1963) reported more prevalent chronic respiratory disease in those working in the tunnel for more than 10 years than for those with shorter employment periods.

Winkelstein and Kantor (1969) discussed a positive reaction between cough with phlegm and suspended particulates. However, the association was not found between cough and sulfur dioxide. Rosenbaum (1961) found that British servicemen from an industrial region exhibited a greater liability to respiratory diseases.

Feidbert et al. (1967) discovered that total respiratory disease mortality in Nashville was directly related to the degree of sulfation and soiling. Lepper et al. (1969) found that total respiratory deaths were related to the levels of sulfur dioxide across areas of Chicago with various socioeconomic variables being controlled.

Lung Cancer

Dean (1966) discovered that lung cancer death rates are higher in urban areas than in rural areas. Gardner et al. (1969) found the lung cancer death rate in males is positively related to air pollution when other social and environmental factors are controlled. Somewhat inconsistent results regarding the relationship between sulfur dioxide and lung cancer were obtained by Buck and Brown (1964).

Stocks (1966) discovered a significant correlation between lung cancer and air pollution. Clemmesen and Nielsen (1951) reported the lung cancer morbidity for males in Copenhagen was about four times greater than in rural areas in Denmark.

Manos and Fisher (1959) and Griswold et al. (1955) found that urban lung cancer rates are significantly higher than rates in rural or nonmetropolitan areas. Greenburg et al. (1967) reported correlation between lung cancer and air pollution. However, negative results were obtained by Zeidberg et al. (1967) and Winkelstein et al. (1967).

Nonrespiratory-Tract Cancers and Cardiovascular Disease

Winkelstein and Kantor (1969) found that stomach cancer mortality was twice as high in high pollution areas as in low pollution areas.

Levin et al. (1960) discovered that the incidence rate for both sexes for each of 16 categories of cancer was higher in urban than in rural areas. Contrary results have also been reported by Greenburg et al. (1967a), among others.

Higher incidence rates of cardiovascular diseases in urban than in rural areas were reported by Enterline et al. (1960). Zeidberg et al. found heart disease rates were correlated with air pollutants in Nashville. Manos and Fisher (1959) also found positive relationships between heart disease and air pollution.

The results of many of the epidemiological studies discussed above indicate that incidence rates of various kinds of diseases are generally much higher in the urban areas than in the rural areas. Many of these disparities in morbidity rates between urban and rural areas can be attributed to air pollution. The ratio of urban incidence to rural incidence of morbidity has been termed the urban factor. This urban factor has been used for estimating health damage due to air pollution. The rationale for the urban factor technique is that if air pollution levels in the urban areas could be reduced to the rural levels, then the differences between the urban and rural morbidity rates adjusted for smoking, age, sex, and race should be eliminated.

The crucial question is what portion of this urban factor is attributable to air pollution. In a pioneering study of air pollution damage, Ridker (1965) assumed that 100 percent of the urban factor is attributable to air pollution and derived a damage value of $2 billion for 1958. Williams and Justus (1974) assumed that a minimum of 10 percent and a maximum of 50 percent of the urban factor is due to air pollution and estimated that the total 1970 nationwide health cost due to air pollution was between $62 million and $311 million. The figures are much lower than the estimate of $6.22 billion for respiratory disease in the United States.[1] The damage estimates derived by using the urban factor of health deterioration due to air pollution are apparently subject to a large margin of error because of the difficult assignment problem of the urban factor. The urban factor method is also replete with several other conceptual and practical difficulties. For example, the distinction between urban and rural pollution levels is hard to define because there exists a continuous scale of pollution intensity instead of a simple dichotomy between urban and rural pollution levels. Thus, after all, the question as to what percentage of this urban factor is actually accounted for by air pollution remains largely unresolved.

A recent study performed by Shy et al. (1974) on the Community Health and Environmental Surveillance System (CHESS) examined the adverse effects of air pollution on acute and chronic respiratory disease. The methodological procedures employed in the CHESS study involve statistical analysis with varying pollutant gradients and concentration levels. Each CHESS set which consists of a group of communities selected to represent an exposure gradient for designated pollutants generally includes High, Intermediate, and Low exposure communities. The community selection is subject to the following criteria: The communities have similar climates and are made up of a predominantly white, middle-class population with as much homogeneity in socioeconomic and other demographic factors as possible. The research findings point to a clear trend toward excess illness in the High exposure community.

Since the national and regional annual damage cost figures greatly assist policymakers in determining optimal pollution control strategies, the effort to derive a set of internally consistent and relatively accurate damage estimates is warranted. The primary purpose of this study is to derive such damage estimates. Specifically, physical and economic damage functions will be derived relating morbidity rate and morbidity costs to air pollution, socioeconomic, demographic, and climatological variables. The morbidity damage costs will be estimated for the 40 SMSA's included in the preceding section on mortality and air pollution.

The balance of this section, which represents an exploratory effort to estimate morbidity dose-response functions for adult morbidity damage costs for the 40 SMSA's selected in our study, discusses the following subjects:

1/ For a detailed discussion on some of the problems in using the urban factor for calculating health costs, see J. R. William and C. F. Justus, "Evaluation of Nationwide Health Costs of Air Pollution and Cigarette Smoking," Journal of the Air Pollution Control Association (November 1974), pp. 1063-1066. The figure $6.22 billion was derived by William and Justus by adjusting Ridker's value of $2 billion for 1958.

Environmental Damage Functions: Some Theoretical Underpinnings, Adult Morbidity and Air Pollution, Adult Morbidity Damage and Sulfur Dioxide, Economic Damages and Economic Damage Functions, and Adult Morbidity Damages and Total Suspended Particulates.

ENVIRONMENTAL DAMAGE FUNCTIONS: SOME THEORETICAL UNDERPINNINGS

An economic damage function, which is usually derived on the basis of a physical damage function, is defined, for example, by Maler (1974) as the compensating variation or the amount the individual (or society) should be compensated so as to maintain his initial preference level in the presence of a deterioration in the environment. This definition is clearly applicable to any situations in which the effect of environmental degradation enters directly into the individual's utility function.

We assume that the consumer's preferences can be represented by a twice differentiable, concave utility function, defined on R^{m+n}

$$U = U(C,H(A)) \qquad \text{(III-1)}$$

where C is an m-vector representing m private commodities and services, with positive components indicating consumption, and negative ones, supply of labor services. H denotes the health status, which is influenced by air pollution; A is an n-vector characterizing environmental quality, which is exogeneously given to the community. H can be viewed as the dose-response function.

Each individual wants to maximize (III-1) subject to the following budget constraint:

$$PC \leq Y \qquad \text{(III-2)}$$

where P is the price vector associated with C, and Y is the individual's income.

The economic damage function as registered in the compensation variations due to changes in the individual's health condition because of changes in A can be derived by minimizing the total expenditures subject to a given utility level, say $\bar{U}$.

The familiar first order necessary conditions are

$$\alpha U_i = P_i, \; i = 1,\ldots,m \tag{III-3}$$

where α is the Langrangean multiplier.

Solving (III-3) yields the following compensated demand functions

$$C = C(P,H(A);\bar{U}) \tag{III-4}$$

The minimum income required to maintain the same utility level when one or several components in A changes is denoted by[1/]

$$I = I(P,A;\; \bar{U}) \tag{III-5}$$

Assuming the individual always exhausts his budget, the economic damage function is simply the difference between (III-5) and the individual's initial income, Y,

$$D = I - Y = (P,H(A);\; \bar{U}) \tag{III-6}$$

Règional economic damages and the economic damage function can be operationally expressed as:

$$MBC_j = MB(A) \times PC_j + HS_j(A) \times HC_j + DU_j(A) \times DC_j \times POP_j \tag{III-7}$$

$$MBC = f(H(E,D,S,W,A;e),P) \tag{III-8}$$

where MBC_j denotes total morbidity cost in the jth urban area, MB is the morbidity rate, HS hospitalization rate, DU drug use rate, PC physician cost, HC hospitalization cost, DC drug cost, and POP is the population in the area. The notations in equation (III-8) were defined in Section II. That is,

1/ Equation 5 was labeled by Maler as the expenditure function. The analytical properties of such expenditure functions are delineated in K. G. Maler, Studies in Environmental Economics, in press.

E for the economic factors, D the demographic factors, S the social factors, W climatological factors, A air pollution, e error term, and P the commodity prices.

ADULT MORBIDITY AND AIR POLLUTION

Physical damage functions on adult morbidity are derived by the classical least-squares linear regression technique and the random sampling, simulation technique. The few aggregated dose-response observations obtained from the CHESS study (1974) form the data base for the regression analysis in this study. The dose-response observation reported in the CHESS study related morbidity prevalence rate to particulates and sulfur dioxide in 1971 for four regions: Salt Lake Basin, Chicago, Rocky Mountain, and New York.1/

The CHESS communities in the Salt Lake Basin are located near the major copper smelter, and the local meteorological pattern provides an area gradient of exposure to sulfur oxides. The selected communities include Magna, Kearns, Salt Lake City, and Ogden. Magna was designated the high exposure area because it had a high sulfur dioxide level due to its proximity to the smelter. Kearns, Salt Lake City, and Ogden were designated as Intermediate II, Intermediate I and Low exposure areas. These three cities had a descending exposure gradient to sulfur oxides.

The CHESS communities in the Chicago area include urban core, suburban areas and the relatively clean area, designated as High I, High II and Low pollution exposure areas for 1969-1970. The five communities selected in the Rocky Mountain area for the CHESS study are Anacenda, Kellogg, East Helena, Bozeman and.Helena, designated, respectively, as High I, High II, Low III, Low I and Low II exposure areas. For the New York City area, Riverhead, Long Island was chosen as a Low exposure community, the Howard Beach section of Queens as the Intermediate exposure community, and the Westchester section of the Bronx as a High exposure community.

The dose-response observations collected from the 15 CHESS communities in the four selected regions are summarized in Table III-I. The adjusted bronchitis prevalence rates expressed in percentages for the selected exposure areas are presented in Column 3 of the table. The annual average sulfur dioxide and total suspended particulates levels for the same set of communities are presented respectively in Column 4 and Column 5. It should be noted that the bronchitis prevalence rates presented in the CHESS report for Utah, Rocky Mountain and New York were adjusted for smoking status (e.g., nonsmoker, ex-smoker and smoker) and sex (e.g., mother and father), while the rates for Chicago were adjusted for education level, race and smoking status.

1/ For a general description about the EPA's CHESS Program, see Shy and Finkles (1973).

TABLE III-1. MORBIDITY DOSE - RESPONSE OBSERVATIONS

Area	Community	Adjusted Bronchitis Prevalence Rate (%)	Pollution Levels ($\mu g/m^3$)	
			SO_2 (1971)	TSP (1971)
Salt Lake Basin	Low	6.71	8	78
	Intermediate I	6.92	15	81
	Intermediate II	8.54	22	45
	High	10.77	62	66
Chicago	Low	25.97	19	71
	High I	25.30	96	155
	High II	21.22	217	103
Rocky Mountain	Low I	1.78	10	50
	Low II	5.10	26	45
	Low III	4.88	67	115
	High I	4.23	177	65
	High II	3.98	374	102
New York	Low	9.17	23	34
	Intermediate I	16.49	51	63
	Intermediate II	13.93	51	86

The adjusted bronchitis prevalence rates were regressed on the two pollutants to derive the dose-response functions for Salt Lake Basin, Chicago, Rocky Mountain and New York separately by the least-squares technique. The regression results are summarized in Table III-2. The regression fit between morbidity and SO_2 for New York, Chicago and Salt Lake Basin is fairly good, with R^2 having the values of 0.50, 0.88 and 0.94, respectively. Furthermore, SO_2 is significant at the 1 percent level for the New York and Salt Lake Basin regression equations. For total suspended particulates, good regression fit was obtained for Chicago and New York. However, TSP is consistently insignificant in expressing the variations in morbidity. These regression equations, coupled with the mean values and standard deviations of the pollutants and the morbidity prevalence rates presented in Table III-3, were used for a random sampling and simulation study to generate a "national" dose-response function which can be used for estimating morbidity damage costs in the various SMSA's.

ADULT MORBIDITY DAMAGES AND SULFUR DIOXIDE

Epidemiological studies have demonstrated that deterioration in air quality results in increased consumption of medical services and, hence, in economic loss to the pollution victims. To estimate such damage loss for the 40 SMSA's and to estimate an average economic damage function on adult morbidity, a random sampling technique for deriving a "representative" dose-response function was employed.

Random Sampling Simulation Study and the Physical Damage Function

"Simulation" is the technique of setting up a stochastic model of a real situation so that sampling experiments can be performed upon the model (Harling, 1958). Simulation study differs from the classical sampling experiment in that the former involves the construction of an abstract model, while the latter involves direct experiment with the new data. The term "simulation" is often used interchangeably with the term "Monte Carlo" technique.

The Monte Carlo technique, which was employed to generate the "average" nonlinear dose-response damage function vis-a-vis existing time series and cross-section studies, involves the study of probability models. As described by Dienemann (1966) the Monte Carlo technique can be defined as follows:

> Assume a system planner can describe each parameter with a probability distribution. This distribution is then treated as a theoretical population from which random samples are obtained. The method of taking such samples, as well as problems which rely on these sampling techniques, are often referred to as Monte Carlo methods.

TABLE III-2. ADULT MORBIDITY LINEAR DAMAGE FUNCTIONS

I. SO_2

(1) Rocky Mountain

$$MB\ (\%) = \underset{(0.94)*}{3.84} + \underset{(0.005)}{0.001}\ SO_2 \qquad R^2 = 0.016$$

(2) Chicago

$$MB\ (\%) = \underset{(2.49)*}{22.14} + \underset{(0.023)}{0.018}\ SO_2 \qquad R^2 = 0.50$$

(3) New York

$$MB\ (\%) = \underset{(3.46)}{4.2} + \underset{(0.08)*}{0.21}\ SO_2 \qquad R^2 = 0.88$$

(4) Salt Lake Basin

$$MB\ (\%) = \underset{(0.46)*}{6.22} + \underset{(0.013)*}{0.075}\ SO_2 \qquad R^2 = 0.94$$

II. TSP

(1) Rocky Mountain

$$MB\ (\%) = \underset{(1.84)}{2.94} + \underset{(0.023)}{0.014}\ TSP \qquad R^2 = 0.109$$

(2) Chicago

$$MB\ (\%) = \underset{(3.52)*}{18.42} + \underset{(0.03)}{0.05}\ TSP \qquad R^2 = 0.74$$

(3) New York

$$MB\ (\%) = \underset{(6.66)}{7.19} + \underset{(0.10)}{0.098}\ TSP \qquad R^2 = 0.47$$

(4) Salt Lake Basin

$$MB\ (\%) = \underset{(4.90)*}{11.97} - \underset{(0.07)}{0.05}\ TSP \qquad R^2 = 0.23$$

TABLE III-3. MEAN VALUES AND STANDARD DEVIATIONS OF THE VARIABLES

	Mean Value ($\bar{X}$)	Standard Deviation (S)
Utah		
Prevalence Rate	8.2	1.9
SO_2	26.8	24.2
TSP	67.5	16.3
Chicago		
Prevalence Rate	24.2	2.6
SO_2	110.6	99.8
TSP	109.6	42.4
Rocky Mountain		
Prevalence Rate	4.0	1.3
SO_2	132.8	150.8
TSP	75.4	31.4
New York		
Prevalence Rate	13.2	3.7
SO_2	41.2	16.2
TSP	61.0	26.1

A random sampling experiment was performed on the four sample regions in this study for deriving an "average" morbidity dose-response function. These four sample regions were constructed in the two dimensional space with the aid of the four regional dose-response functions shown in Part I of Table III-2, coupled with the data on the mean values and the standard deviations of the dependent and independent variable (see Table III-3). The four regional blocks are shown in Figure III-2, the vertical axis represents the morbidity rate expressed in number of incidences per 100 residents, and the horizontal axis denotes SO_2 pollutant concentrations level expressed in $\mu g/m^3$. For each sample block, the height of the block is the difference between the morbidity rate computed from the dose-response function with the coefficient of SO_2 in the function taking the value of (b + s) and (b - s), where b is the coefficient of SO_2 and s the associated standard error. The width of the block is, however, measured by the mean value of SO_2 plus and minus one standard deviation of the mean, i.e., ($\bar{X}$ + S) and ($\bar{X}$ - S) where $\bar{X}$ denotes the mean value of SO_2 and S the associated standard deviation.

Thus, the four sample blocks shown in Figure III-2 were defined on the basis of the four prior studies regarding the morbidity effect of SO_2 in the four different regions. The construction of these four blocks permits us to

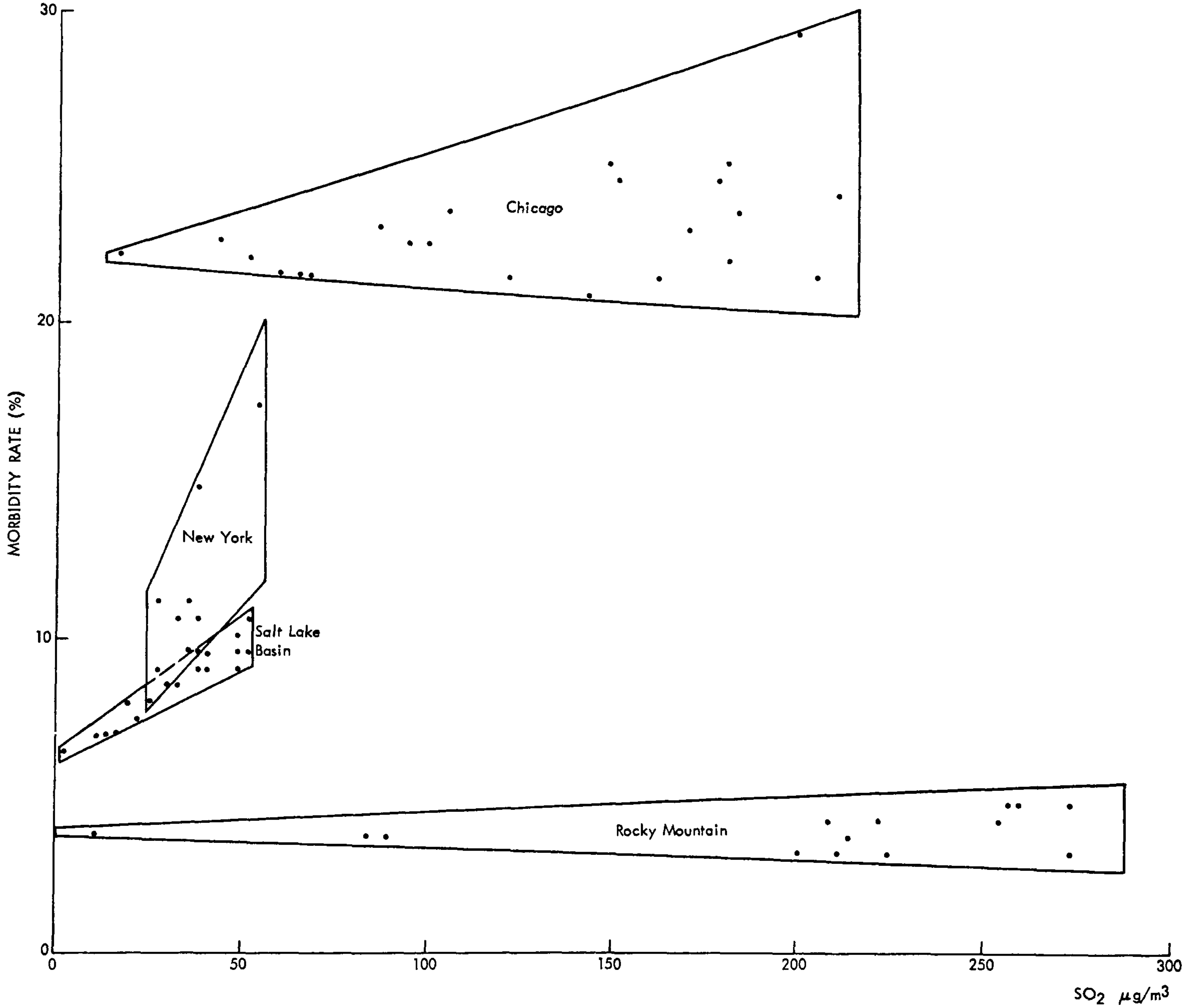

Figure III-1. Sample observation from four morbidity studies with respect to SO_2.

perform random sampling experiments. A random sample of 800 observations with 200 chosen from each block was obtained. To eliminate possible bias in the probability of being randomly selected resulting from the overlapping of the blocks, another random sampling was performed on the basis that two sorting schemes yield better results than one sorting procedure. A smaller sample of 81 observations, i.e., 10 percent of 800, was chosen. These 81 observations were used to develop a nonlinear "average" dose-response function specified alternatively as follows:

$$MB = C + EXP\ (a-b/SO_2) \qquad (III-9)$$

or

$$MB - C = EXP\ (a-b/SO_2)$$

$$(MB-C) = a-b/SO_2 \qquad (III-10)$$

As in the mortality study reported in Section II, the physical dose-response function in this morbidity study is again expressed as an exponential function which is consistent with a priori judgment and empirical results of medical experts regarding plausible human dose-responses to changes in pollution levels. The geometrical counterpart of this exponential relation is a long flat "S" curve, implying that while the air pollutant contributes to the morbidity incidence rate, the damaging effect is not proportional. In the presence of increased SO_2 level, the morbidity rate initially increases at an increasing rate and continues to increase, but at a decreasing rate after a certain inflection level.

Unlike the mortality study in which the intercept term C, conventional mortality, is expressed as a function of a number of socioeconomic, demographic and climatological variables, no such conventional morbidity function was estimated due to the lack of a systematic collection of morbidity data by the various SMSA's. Of necessity, the C term in equation (III-9) above is assumed to take the value of 11 since 11 is the arithmetic mean of the morbidity rates calculated from the four regional dose-response functions with the explanatory variable, SO_2 being at the threshold of 25 $\mu g/m^3$ for the sake of consistency with the earlier mortality study.

In estimating equation (III-9), the classical least-squares technique was applied. Since (MB - 11) may be negative, and the logarithm of a negative number is undefinable, (MB - 11) was therefore squared prior to its logarithm transformation. The resultant regression equation was then adjusted by dividing the coefficients by 2. A detailed discussion on the rationale of this procedure was presented in Section II.

The regression results for equation (III-9) look as follows:

$$MB = 11 + EXP(0.65 - 4.96/SO_2) \qquad (III\text{-}11)$$
$$(0.11)^* \quad (1.99)^*$$
$$R^2 = 0.072$$

The figures below the coefficients are standard errors, with * indicating that the coefficient of SO_2 is significant at the 1 percent level. However, the pollution variable SO_2 explains only about 7 percent of the variations in the residual morbidity rate, i.e., (MB - 11).

A linear morbidity equation was also fitted, with the regression result shown as follows:

$$\acute{M}B = 12.06 - 0.01\ SO_2 \qquad (III\text{-}12)$$
$$(1.28)^* \quad (0.01)$$
$$R^2 = 0.011$$

Comparing the result of equation (III-11) to that of (III-12) the exponential dose-response function is apparently a better fit than the linear one because the former showed an explanatory power seven times larger than the latter equation. Furthermore, the coefficient of SO_2 in the exponential equation is statistically significant, whereas it is insignificant and has a wrong sign in the linear equation. Thus, the empirical results suggest that the nonlinearity in the dose-response relation is more consistent with a priori judgment regarding human health responses to pollution doses.

To recapitulate, the methodological procedures for estimating the dose-response function between morbidity rate and SO_2 are summarized as follows:

a. On the basis of the morbidity - SO_2 observations available for the four regions in the United States, a total of four regional morbidity dose-response functions with respect to SO_2 were derived via the classical least-squares regression technique.

b. Utilizing these four dose-response functions together with the information on the mean and standard deviations of the two variables, four blocks in the two-dimensional morbidity pollution space were constructed for random sampling experiments. A total of 800 random observations was taken in the first round experiment, among which a smaller size of 8 observations were again randomly selected for analytical purposes.

c. These 81 randomly selected observations were fitted to an exponential reciprocal equation to derive an "average" dose-response function for the four regions.

Like the mortality dose-response function, the nonlinear morbidity dose-response function has a number of distinguishing features: (1) the nonlinear dose-response function is not only more in accord with *a priori* judgment regarding human morbidity response to pollution doses, but also it is more amenable to being adjusted with whatever the assumed threshold level of SO_2 is in estimating the economic damages than the linear functions; and (2) for the purpose of predicting and estimating the marginal morbidity damages due to SO_2, the nonlinear equation has shown better fit and hence, will yield more accurate prediction over the linear one.

Economic Damages and Economic Damage Functions

Given the preceding nonlinear physical damage function, the economic costs of diseases related to air pollution can be estimated by transforming the additional morbidity rate into monetary units. Economic damages of morbidity, as discussed earlier, represent the amount that an individual or a society is willing to spend so as to maintain the previous preference level in the presence of the deterioration of air quality.

Morbidity damages generally are comprised of two parts: direct and indirect costs of illness. Included in the direct costs of illnesses are the expenditures for prevention, detection, treatment, rehabilitation, research, training, and capital investment in medical facilities. Indirect costs of illness include the loss of output to the economy because of disability and the imputed costs such as opportunities foregone. A comprehensive framework for calculating the direct and indirect economic costs of illness and disability has been developed by Rice (1966) and others.

Both direct and indirect morbidity costs were estimated in the present study. Direct morbidity costs were computed by summing up the costs of physician visits, hospitalization costs, and drug costs. According to a recent study by Jaksch (1975), the average cost per physician visit for all ages combined in 1970 was $14, and the average cost of a hospital day for all ages combined was $82. To estimate total morbidity costs, further information is needed on the average number of physician visits and the average length of hospital stay per pollution-related disease incidence. A number of assumptions were made to obtain conservative morbidity damage estimates, as follows: (1) each pollution-related morbidity incidence results in one visit to consult a physician; (2) 1 of 8.3 physician visits, i.e., 12 percent, results in hospitalization; (3) drug costs run about 50 percent of the physician costs; (4) if hospitalization is required, each patient stays 1 day in the hospital for treatment.1/

1/ Various information on national data about the number of visits to doctors and the hospital days stayed per treatment can be obtained from Public Health Service (1973).

The conservative nature of both assumptions (1) and (4) leads to underestimations of the morbidity costs. The bias could be partially removed by assuming a greater number of physician visits and a longer hospital stay, however. The estimates presented in this study can be regarded as <u>low</u> estimates for morbidity costs. Assumption (2) is based on the calculated proportion of physician visits resulting in hospital discharge for four categories of diseases related to pollution (Jaksch, 1975). The figure 12 percent is the average of such proportions of physician visits in the four disease categories. Assumption (3) is, however, based on a ratio of total drug costs to total physician costs attributable to the use of oxidation catalyst as estimated by (Jaksch, 1975), i.e., 11.4/23.2 = 0.5.

The direct morbidity costs attributable to SO_2 were estimated with the aid of the following formulas:

$$PCSO_2 = \$14 \times EXP\ [0.65 - 4.96/(SO_2 - 25)] \times POP \times NPV \qquad \text{(III-13)}$$

$$HCSO_2 = \$82 \times EXP\ [0.65 - 4.96/(SO_2 - 25)] \times 0.12 \times POP \times HSD \qquad \text{(III-14)}$$

$$DCSO_2 = 0.5 \times PCSO_2 \qquad \text{(III-15)}$$

where $PCSO_2$ = physician cost atttibutable to SO_2.

$HCSO_2$ = hospitalization cost attributable to SO_2.

$DCSO_2$ = drug cost attributable to SO_2.

POP = SMSA population.

NPV = number of physician visits per incidence = 1 (by assumption (1))

HSD = number of hospital stay days = 1 (by assumption (4))

Recall the physical dose-response function for SO_2 as expressed in equation (III-11) which has an intercept value of 11. If the exponential term in equations (III-13) and (III-14) is replaced by the value of the intercept of the dose-response function, then we can derive another set of cost estimates for morbidity in the absence of SO_2.

Another dimension of morbidity health costs is the indirect component regarding the changes in earnings and leisure opportunities because of disability and debility. A shortcut to estimate the indirect morbidity cost attributable to pollution was found by applying to the direct morbidity cost a multiplier of 2.4, which is the ratio of the best estimates of total indirect net costs and the total direct costs of morbidity (Jaksch, 1975). Hence, the following formula was used for estimating the indirect morbidity costs attributable to SO_2:

$$IMBCSO_2 = 2.4 \times (PCSO_2 + HCSO_2 + DCSO_2) \qquad \text{(III-16)}$$

The estimated morbidity costs for the 40 SMSA's with an SO_2 level equal to or greater than 25 $\mu g/m^3$, i.e., the threshold level, are presented in Table III-4. Columns 1, 2, and 3 present, respectively, the physician costs, hospital costs and drug costs attributable to SO_2. Indirect morbidity costs due to SO_2 are presented in Column 4. It should be noted that the figures in Column 4 are 2.4 times the sum of Columns 1, 2, and 3. Total morbidity costs due to SO_2 calculated by summing Columns 1, 2, 3 and 4 are presented in Column 5, and per capita total morbidity costs are in Column 6. Total morbidity costs in the absence of SO_2, direct and indirect, are presented in Column 7. The cost figures in this column were estimated with the aid of equations (III-13) to (III-16) with the modification of replacing the exponential term by the intercept term of the dose-response function. Finally, Column 8 presents the ratio of total morbidity cost attributable to SO_2 to total morbidity cost with and without SO_2, that is, Column 8 = Column 5/(Column 5 + Column 7). The extent of pollution damage to human health is partially reflected by the magnitude of this ratio.

Upon examination of the low estimates of morbidity costs in Table III-4, it is readily revealed that the annual morbidity costs due to SO_2 range from a minimum value of less than $1,000 in Cincinnati, Dayton, Evansville and Johnstown to a maximum of $22 million in New York City. Per capita morbidity costs attributable to SO_2 in 1970 vary between cost of negligible magnitude to $1.96 in New York City. Total morbidity damages attributable to SO_2 over the 40 SMSA's were at least $99 million in 1970.

It should be stressed that the cost figures presented in the table represent <u>low</u> estimates for the morbidity damages due to the two conservative assumptions made for the calculation of the costs. If five instead of one is the average number of doctor visits, and the average number of days in the hospital is 5 days rather than 1 day per pollution-related disease incident, then by assuming the same costs incurred per visit to consult doctors and per hospital day for treatment, the cost figures in Columns 1 to 7 should be revised accordingly. In other words, the direct and indirect morbidity costs and the per capita total morbidity cost attributable to SO_2 should be five times as large as the low cost estimates calculated for the SMSA's.

An "average" economic damage function was derived for the purpose of predicting marginal and average changes in the morbidity costs in response to changes in the pollution or in other variables. The morbidity cost in the presence of SO_2, which is the sum of morbidity costs due to SO_2 and morbidity cost in the absence of pollution, was regressed on a host of socioeconomic, demographic and climatological variables. The stepwise regression results are shown as follows:

TABLE III-4. MORBIDITY COSTS WITH SO_2 BY SMSA's, 1970

SMSA	Direct Morbidity Costs Due to SO_2 (in $\$10^3$)			Indirect Morbidity Costs Due to SO_2 (in $\$10^3$)	Morbidity Cost Due to SO_2		Total Morbidity Cost Without SO_2 (in $\$10^3$)	Ratio (8)=(5)÷((5)+(7))
	$PCSO_2$ (1)	$HCSO_2$ (2)	$DCSO_2$ (3)	$IMBCSO_2$ (4)	Total (5) (in $\$10^3$)	Per Capita (6) ($)	(7)	(8)
1 AKR	151	106	75	796	1127	1.66	7834	0.13
2 ALL	125	88	62	660	935	1.72	6269	0.13
3 BAL	468	329	234	2474	3505	1.69	23883	0.13
4 BOS	323	227	162	1708	2420	0.88	31763	0.07
5 BRI	75	53	38	397	563	1.44	4500	0.11
6 CAN	37	26	19	196	277	0.74	4293	0.06
7 CHA	5	4	3	27	39	0.17	2647	0.01
8 CHI	1775	1248	888	9386	13200	1.91	80240	0.14
9 CIN	--	--	--	--	--	--	15973	--
10 CLE	487	343	244	2577	3651	1.77	23809	0.13
11 DAY	--	--	--	--	--	--	9807	--
12 DET	769	541	385	4066	5760	1.37	48280	0.11
13 EVA	--	--	--	--	--	--	2685	--
14 GAR	146	103	73	773	1095	1.73	7305	0.13
15 HAR	152	107	76	806	1142	1.72	7656	0.13
16 JER	148	104	74	782	1108	1.82	7027	0.14
17 JOH	---	--	--	--	--	--	3031	--
18 LAW	52	36	26	274	389	1.67	2681	0.13
19 LOS	1149	808	575	6075	8607	1.22	80920	0.10
20 MIN	332	233	166	1756	2487	1.37	20919	0.11
21 NHA	69	48	34	362	513	1.44	4120	0.11
22 NYO	3021	2123	1511	15900	22600	1.96	133280	0.14
23 NEW	329	231	165	1741	2467	1.33	21414	0.10
24 NOR	1	1	1	7	10	0.01	7850	---
25 PAT	70	49	35	369	522	0.38	15673	0.03
26 PEO	1	--	--	3	5	0.01	3944	--
27 PHI	1188	835	594	6280	8897	1.85	55420	0.14
28 PTB	551	388	276	2916	4131	1.72	27696	0.13
29 POR	2	1	1	10	14	0.01	11639	--
30 PRO	218	153	109	1150	1629	1.78	10530	0.13
31 REA	29	21	15	156	221	0.74	3419	0.06
32 ROC	117	82	58	616	873	0.99	10181	0.08
33 STL	455	320	228	2407	3410	1.44	27255	0.11
34 SCR	23	16	12	123	174	0.74	2700	0.06
35 SPR	131	92	66	694	982	1.85	6112	0.14
36 TRE	40	28	20	212	301	0.99	3506	0.08
37 WAS	612	430	306	3238	4587	1.60	33001	0.12
38 WOR	40	28	20	214	303	0.88	3975	0.07
39 YOR	39	27	19	204	290	0.88	3801	0.07
40 YOU	53	37	27	282	399	0.74	6182	0.06
Total	13,183	9,266	6,597	69,637	98,633		783,202	

Note: -- denotes less than $1,000.

Note: -- individual figure may not add to totals due to rounding.

$$TMBCSO_2 = \underset{(80.3)}{52.4} + \underset{(0.09)^{*}}{0.60\ SO_2} - \underset{(67.9)^{*}}{135.0\ PWPO} + \underset{(0.7)^{**}}{1.4\ SUN} + \underset{(0.6)^{*}}{1.3\ RHM} -$$

$$\underset{(0.2)}{0.3\ DTS} + \underset{(0.10)}{0.09\ PCOL} + \underset{(310.4)}{34.4\ AGE} \qquad \text{(III-17)}$$

$$R^2 = 0.73$$

where $TMBCSO_2$ denotes the morbidity cost in the presence of SO_2, and all seven explanatory variables are the same as those defined previously in Section II. The values below the coefficients are standard errors, with * and ** to indicate that the coefficients are significant at the 1 and 5 percent level, respectively. All coefficients and the corresponding standard errors are reduced by a factor of 10^6. It should be pointed out that the primary use of equation (III-17) is only for prediction. "Wrong" signs as well as other statistical questions do not constitute a great problem if they are understood and accounted for.

In predicting and estimating the responsiveness of morbidity damages to changes in any one of the explanatory variables, the partial elasticity of the morbidity cost with respect to the variable of interest merits some discussion. Suppose a policymaker would like to estimate what the marginal changes will be in the morbidity cost if the pollution level of SO_2 in the SMSA's is lowered, on the average, by, say, 1 percent. In order to aid this policymaker to make the prediction, the partial elasticity of the morbidity cost with response to SO_2 (E_{MCB,SO_2}) is calculated as follows:

$$E_{MBC,SO_2} = 0.6 \times 10^6 \times (47.95/22.7 \times 10^6) = 1.27 \qquad \text{(III-18)}$$

where (0.6×10^6) is the coefficient of SO_2 in the economic damage function, and 47.95 and (22.7×10^6) are, respectively, the mean level of SO_2 and total morbidity cost.

In view of the SO_2 partial elasticity value of 1.27, the estimated morbidity cost would decrease by 1.27 percent, for every 1 percent reduction in SO_2 level, other things being equal. Stated differently, if the air pollution control program lowers the SO_2 level by 4.7 $\mu g/m^3$ from 47.9 to 43.2 $\mu g/m^3$ (10 percent reduction), adult morbidity costs on the average would decrease by $2.72 million, from $22.7 million to $19.98 million. In a like manner, the coefficients of other variables in equation (III-17) can be used to compute the partial elasticities associated with the variables and can be analogously interpreted as conditional marginal inpact when others are held constant.

ADULT MORBIDITY DAMAGES AND TOTAL SUSPENDED PARTICULATES

Total suspended particulates are directly harmful to human health. The poisonous substances or hydrocarbons contained in the particulates may cause cancer. Other particulates multiply the potential harm of irritant gases. For example, the interaction of sulfur dioxide gas with particulate matter will penetrate deep into the lungs and cause much greater harm. Some particulates expedite chemical reactions in the atmosphere to form harmful substances.

Arsenic, a well-known poison, may also cause cancer. Asbestos fiber is responsible for chronic lung disease. Beryllium has produced malignant tumors in monkeys. Cadmium, a respiratory poison, induces high blood pressure and heart disease. Lead, a cumulative poison, impairs the functioning of the nervous system in adults.

Adult morbidity costs attributable to TSP were estimated by invoking the same methodology delineated above for deriving morbidity costs due to SO_2. The aggregate dose-response observations relating morbidity rate to TSP are presented in Table III-1, page 48. The observations, obtained from the report on the CHESS study, were used to estimate four separate regional, dose-response functions for the four study regions, i.e., Salt Lake Basin, Chicago, Rocky Mountain and New York. The regression results for the regional dose-response relations are shown in the lower half of Table III-2, page 50. The mean values and standard deviations of suspended particulates and the morbidity prevalence rates are presented in Table III-3, page 51.

The random sampling and simulation techniques delineated above were again applied to derive an "average" nonlinear dose-response function relating morbidity rates to suspended particulate levels. A total of 82 observations was randomly selected in the two-round sampling experiments from the four "blocks" defined in the two-dimensional morbidity and suspended particulate space as shown in Figure III-3. Given these 82 observations, least-squares regressions were run and the results are shown as follows:

$$MB = 11 + EXP\ (\underset{(0.22)^*}{1.75} - \underset{(15.7)^*}{(87.7/TSP)}) \qquad (III\text{-}19)$$

$$R^2 = 0.28$$

Again, the values below the coefficients are standard errors with * to indicate that the coefficients are significant at the 1 percent level. It should be noted that the intercept term 11 in equation (III-19) is the arithmetic mean of the morbidity rates calculated from the four regional dose-response functions with the dependent variable TSP being at the threshold level of 25 $\mu g/m^3$.

As in the case of SO_2, (MB - 11) was squared prior to its logarithmic transformation when the regression was run. The coefficients in equation (III-19)

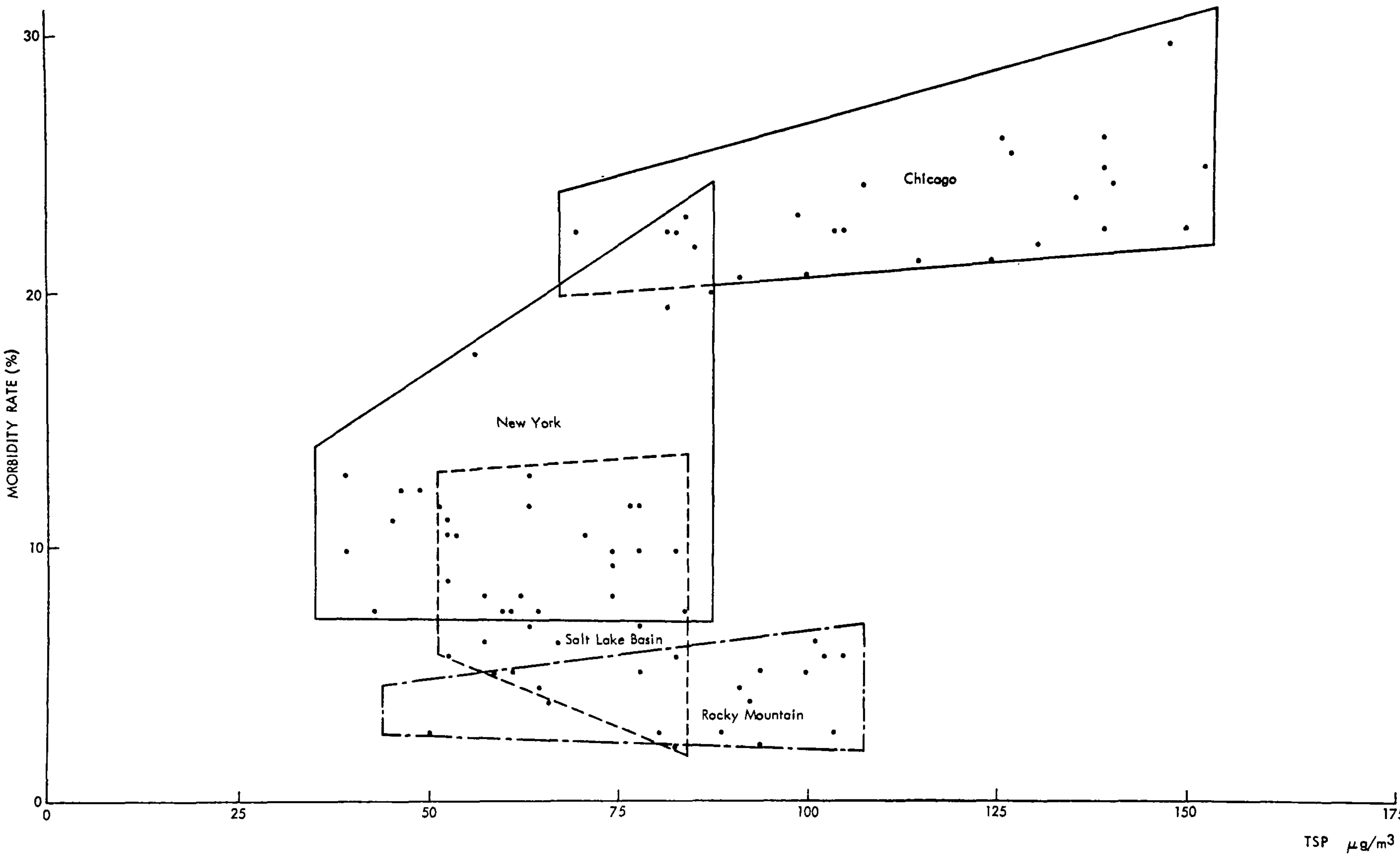

Figure III-2. Sample observations from four morbidity studies with respect to TSP.

were obtained by dividing also the regression coefficients log 2. The coefficient of TSP in this nonlinear dose-response function is also statistically significant at the 1 percent level and has a correct sign.

The direct morbidity costs attributable to TSP were estimated with the aid of the following formulas:

$$PCTSP = \$14 \times EXP\ [1.75 - 87.7/(TSP - 25)] \times POP \times NPV \qquad (III\text{-}20)$$

$$HCTSP = \$82 \times EXP\ [1.75 - 87.7/(TSP - 25] \times POP \times HSD \qquad (III\text{-}21)$$

$$DCTSP = 0.5 \times PCTSP \qquad (III\text{-}22)$$

where PCTSP = physician cost attributable to TSP.

HCTSP = hospitalization cost attributable to TSP.

DCTSP = drug costs attributable to TSP.

POP, NPV and HSD are the same as those defined in (III-13) and (III-14).

Applying the same multiplier of 2.4 used in the case of SO_2, the indirect morbidity costs due to TSP (IMBCTSP) were computed by

$$IMBCTSP = 2.4 \times (PCTSP + HCTSP + DCTSP) \qquad (III\text{-}23)$$

Morbidity costs for the 40 SMSA's with a TSP level equal to or greater than 25 $\mu g/m^3$ are tabulated in Table III-5. Physician costs, hospital costs, and drug costs attributable to TSP are presented in Columns 1 to 3, and indirect morbidity costs due to TSP in Column 4. Total and per capita morbidity costs attributable to TSP are presented in Columns 5 and 6. The ratio of total morbidity cost attributable to TSP to total morbidity cost associated with or without TSP is given in Column 8.

It should be again noted that the cost figures presented in this table, as those in the case of SO_2, are low estimates for the morbidity damage associated with TSP. If each pollution-related incidence results in, on the average, five rather than one visit to doctors, and the patients, if admitted to a hospital, will stay in the hospital for 5 days instead of 1 day, then, by assuming a constant cost for consuming medical services, the morbidity cost estimates in Columns 1 to 7 in Table III-5 will be magnified five times. Consequently, the total morbidity costs over the 40 SMSA's for each category (column) will also increase five times.

TABLE III-5. MORBIDITY COSTS WITH TSP BY SMSA's, 1970

SMSA	Direct Morbidity Cost Due to TSP (in 10^3)			Indirect Morbidity Costs Due to TSP (in 10^3)	Morbidity Cost Due to TSP		Total Morbidity Cost Without TSP (in 10^3)	Ratio (8)=(5)÷((5)+(7))
	PC TSP (1)	HC TSP (2)	DC TSP (3)	IMBCTSP (4)	Total (5) (in 10^3)	Per Capita (6) ($)	(7)	(8)
1 ARK	111	78	56	587	832	1.22	7834	0.10
2 ALL	106	75	53	563	797	1.47	6269	0.11
3 BAL	813	571	406	4298	6089	2.94	23883	0.20
4 BOS	771	542	386	4077	5776	2.10	31763	0.16
5 BRI	20	14	10	107	152	0.39	4500	0.15
6 CAN	97	68	49	515	730	1.96	4293	0.15
7 CHA	62	43	31	327	463	2.02	2647	0.15
8 CHI	2862	2012	1431	15100	21400	3.07	8240	0.21
9 CIN	378	266	189	1998	2830	2.04	15973	0.15
10 CLE	1010	710	505	5342	7567	3.67	23809	0.24
11 DAY	256	180	128	1352	1915	2.25	9807	0.16
12 DET	1705	1199	853	9016	12700	3.04	48280	0.21
13 EVA	32	23	16	172	243	1.04	2685	0.08
14 GAR	170	120	85	901	1277	2.02	7305	0.15
15 HAR	89	63	45	472	669	1.01	7656	0.08
16 JER	108	76	54	572	810	1.33	7027	0.10
17 JOH	69	48	34	364	515	1.96	3031	0.15
18 LAW	21	15	10	111	157	0.67	2681	0.06
19 LOS	2208	1552	1104	11600	16500	2.35	80920	0.17
20 MIN	262	184	131	1384	1960	1.08	20919	0.09
21 NHA	23	16	12	124	175	0.49	4102	0.04
22 NYO	2663	1872	1332	14000	19900	1.72	133280	0.13
23 NEW	669	470	334	3537	5011	2.70	21414	0.19
24 NOR	202	142	101	1070	1516	2.23	7850	0.16
25 PAT	65	45	32	342	484	0.36	15673	0.03
26 PEO	53	37	26	278	394	1.15	3944	0.09
27 PHI	742	521	371	3923	5557	1.15	55420	0.09
28 PTB	872	613	436	4608	6528	2.72	27696	0.19
29 POR	193	136	97	1021	1446	1.43	11639	0.11
30 PRO	136	96	68	720	1020	1.12	10530	0.09
31 REA	92	65	46	487	689	2.33	3419	0.17
32 ROC	184	130	92	975	1382	1.57	10181	0.12
33 STL	756	532	378	3998	5664	2.40	27255	0.17
34 SCR	110	78	55	584	828	3.53	2700	0.24
35 SPR	45	32	23	238	337	0.64	6112	0.05
36 TRE	36	26	18	192	253	0.90	3506	0.07
37 WAS	598	420	299	3162	4479	1.57	33001	0.12
38 WOR	43	30	21	227	322	0.93	3975	0.08
39 YOR	62	43	31	325	461	1.40	3801	0.11
40 YOU	154	108	77	814	1153	2.15	6182	0.16
Total	18,848	13,251	9,425	99,483	140,981		711,202	

Note: -- individual figure may not add to totals due to rounding.

The table reveals that the low estimate for morbidity damages attributable to TSP range from $0.15 million in Bridgeport to more than $21 million in Chicago. On a per capita basis, the low damage estimates for morbidity range from $360 in Paterson, New Jersey to $3,000 in Chicago. Total morbidity damages due to TSP over the 40 SMSA's were estimated to be at least $140 million in 1970.

Comparison of Tables III-4 and III-5 reveals that the morbidity costs associated with TSP are larger than the costs associated with SO_2. The total morbidity cost due to TSP is $141.2 million, while the total morbidity cost attributable to SO_2 is $98.4 million. The ratio between these two costs is 1.43. The larger morbidity cost due to TSP is attributable to the fact that the average TSP level (100.87 $\mu g/m^3$ is larger than the average SO_2 level (47.95 $\mu g/m^3$) and that TSP has a more responsive dose-response function than SO_2.

Note that an important assumption on the independency between SO_2 and TSP is made so that we can estimate the damage cost separately. In reality, the costs of SO_2 and TSP may be larger than the sum of the two component damages because of the possible interaction effects between the two pollutants.

However, another note of caution is warranted in interpreting the cost estimates presented in this study. The effect of SO_2 as indicated in the regression equation may represent the effect of not only the single pollutant SO_2 but also the effect of other pollutants, say TSP, as well. The prior pollution studies suggested that the variable SO_2 may serve as a proxy variable for air pollution. If this is the case, then the pollution damage estimates yielded by summing the two computed damages attributable to SO_2 and TSP may not necessarily be smaller than the actual pollution damages, even if the effect of interaction is accounted for. Whether the sum of the two component damages estimates is larger or smaller than the actual damages attributable to the concomitant presence of the two major pollutants depends on the balance of the magnitudes of the two opposing factors, i.e., the interaction effect versus the double counting effect.

An "average" economic damage function for TSP with respect to the 40 SMSA's was developed by the least-squares technique. Morbidity costs in the presence of TSP, i.e., the sum of the morbidity costs due to TSP, and the morbidity costs in the absence of pollution, were regressed against the same set of socioeconomic, demographic and climatological variables appearing earlier in the SO_2 economic damage function. The regression results are shown as follows:

$$\begin{aligned} \text{TMBCTSP} = & -43 + 0.55\ \text{TSP} - 131.7\ \text{PWPO} + 1.3\ \text{SUN} + 1.2\ \text{RHM} \\ & (74)\quad (0.09)^{*} \quad (63.3)^{*} \quad (0.7)^{**} \quad (0.6)^{**} \\ & - 0.2\ \text{DTS} + 0.07\ \text{PCOL} + 35.0\ \text{AGE} \\ & (0.2) \quad (0.09) \quad (289.7) \end{aligned} \qquad \text{(III-24)}$$

$$R^2 = 0.72$$

where TMBCTSP denotes the total morbidity cost in the presence of TSP, and all seven explanatory variables are identical to those defined previously in Section II. The values below the coefficients are standard errors, with * and ** to denote that the coefficients are significant at the 1 and 5 percent levels. All coefficients and the corresponding standard errors are reduced by a factor of 10^6.

Since equation (III-24) is developed mainly for prediction purposes, the "unexpected" signs and possible colinearity among the independent variables should not present a problem to the use of this equation for estimating TMBCTSP provided that the signs and the multicolinearity will persist in the future. However, the use of partial elasticity between the dependent and the independent variable with wrong signs does cause difficulty in interpreting the results.

This average economic damage function again is useful for forecasting and estimating the changes in adult morbidity costs in response to changes in any of the climatological, demographic, and socioeconomic characteristics, and the suspended particulate variable. The partial elasticity of the morbidity damages with respect to suspended particulates is computed as follows: $E_{MCB,TSP} = 0.55 \times (100.87/708) = 0.08$, as measured from the respective mean levels of total morbidity costs and suspended particulates. Thus, if the suspended particulate level in the air is lowered by 10.1 $\mu g/m^3$ from 100.87 to 90.76 $\mu g/m^3$ (i.e., 10 percent reduction), gross adult morbidity costs on the average would reduce by \$5.66 million from \$708 to \$702.3 million nationwide.

SECTION IV

HOUSEHOLD SOILING AND AIR POLLUTION

THE PROBLEMS AND THE OBJECTIVES

In addition to human health, air pollution has also a multitude of damaging effects on material, vegetation, animals, and residential and commercial establishments, etc. Ronald Ridker (1967) designed a framework for identifying and quantifying these damage costs. He suggested that the effects of air pollution and their costs can be categorized into: (1) cost of direct effects, (2) adjustment costs, and (3) market effect costs. The damage costs of human health derived in the previous two chapters are costs of direct effects of air pollution. The present section is concerned with the second category; i.e., adjustment costs or the cost of individual adjustments to the effects of air pollution.

The best known and the pioneering contribution to the estimation of soiling loss due to air pollution is the Mellon Institute Study of the Pittsburgh smoke nuisance (1913). The $20.00 per capita soiling cost figure of the Mellon Institute Study has been used as a basis for extrapolating to the $11 billion national damage estimate. The validity of this damage estimate, often quoted by public officials, has been questioned by Jones (1969) and others. A serious problem with the national damage estimate arises because of the strong assumption that the air pollution level in Pittsburgh is representative of the entire nation.

The two studies of quantifying the soiling costs in the Upper Ohio River Valley and Washington, D. C. carried out by Michelson and Tourin (1966) have also attracted public attention. Their methodology is based on the hypothesis that significant soiling due to air pollution may be reflected in shortened time intervals between successive cleaning and maintenance operations. Michelson and Tourin established a positive relationship between frequency of cleaning operations and the levels of air pollution in both studies. However, the problems with the sample survey design and the lack of a statistically reliable technique cast doubt on the reliability of their findings. Michelson and Tourin (1968) employed the same methodology and estimated the extra household soiling costs due to air pollution in Connecticut. They found that an average household spent about $600 each year for coping with the effect of suspended particulates, with the range from $230 per year in Fairfield to $725 per year in Bridgeport. These cost estimates are conservative since the cleaning operations studied did not cover the full gamut of operations affected by air pollution.

Ridker (1967) conducted interurban studies to determine the relation between per capita soiling costs and air pollution level for 144 cities in the United States. Soiling damage costs were approximated by per capita expenditures on laundry and dry cleaning services. Ridker found that no discernible patterns between soiling costs and the suspended particulate levels were detected, whether the effects of climate, per capita income, and price differentials were controlled for or not. The problem often encountered in identifying the soiling damages, as noted by Ridker, is that cleaning and maintenance operations are often undertaken on a rigid schedule which is independent of the location of the operation. This is especially true for commercial and industrial buildings. Furthermore, nonpollution factors which could not be controlled for may be important in explaining the cleaning and maintenance procedures.

The primary objectives of this study are threefold: a system of soiling physical damges functions which relate various types of cleaning frequencies to air pollution level are derived. The physical damage functions are then utilized to estimate net and gross soiling damage costs for the 148 SMSA's. Finally, "average" economic damage functions over the United States metropolitan areas are developed by relating soiling damages to air pollution, demographic, socioeconomic, and climatological variables. It is hoped that the generalized economic damage functions presented in this section are informative and useful for predicting possible benefits as a result of the reduction in air pollution when air pollution abatement programs are implemented.

This section, which represents a first exploratory effort to estimate average air pollution soiling damage functions and soiling damage costs for the 148 SMSA's individually, contains subsections: Soiling Physical Damage Function, and Economic Damages and Economic Damage Functions.

SOILING PHYSICAL DAMAGE FUNCTIONS

Soiling as a result of falling total suspended particulates compels households as well as business and industrial establishments to increase cleaning activities. Thus, soiling has resulted in extra economic losses not only to households but to business and industrial firms as well. As noted above, a number of attempts have been undertaken to identify and quantify the soiling damages due to air pollution. However, a recent study by Booz, Allen and Hamilton, Inc. (1970), offers the needed data base for our purpose of developing the soiling physical damage functions.

Sophisticated and rigorous statistical survey techniques were employed by Booz-Allen researchers. The Renjerdel area around Philadelphia, Pennsylvania, was used as the data gathering area. Frequency of cleaning by the residents was determined by a carefully developed questionnaire containing queries regarding cleaning operations and a set of self-referent statements with respect to cleaning attitudes. Among the 27 cleaning and maintenance operations, the study shows that 11 were somewhat sensitive to air-suspended particulate levels. Because of the lack of certain needed information for evaluating the costs, only 9 of these 11 cleaning tasks were considered in this study. A list of these nine pollution-related cleaning tasks together with the information on unit cleaning costs is contained in Table IV-1.

TABLE IV-1. POLLUTION-RELATED TASKS AND THEIR UNIT CLEANING COSTS

Tasks		Unit Market Value ($)
1	Replace air conditioner filter	1.00
2	Wash floor surface	6.00
3	Wash inside window	0.50
4	Clean venetian blinds/shades	3.50
5	Clean/repair screens	0.20
6	Wash outside windows	1.50
7	Clean/repair storm windows	2.00
8	Clean outdoor furniture	10.00
9	Clean gutters	15.00

A set of physical damage functions was derived via the technique delineated in Section III above, which combines the simulation and regression analysis. The areas under study were divided into four zones according to their air pollution levels. This breakdown in the study areas allows one to construct four population "blocks" for each pollution-related cleaning task in the two-dimensional pollution level and cleaning frequency spaces. For ease of description, let X and Y denote respectively the suspended particulate level and cleaning frequency. The vertices of each "block" then consist of the following four combinations: [Max X, Max Y]; [Max X, Min Y]; [Min X, Max Y]; and [Min X, Min Y], where Max and Min denote the upper and lower limits of the two variables. The annual average particulate levels ($\mu g/m^3$) in the four sampling zones were given in the Booz-Allen report as follows:

Zone 1	$X \leq 75$
Zone 2	$75 < X < 100$
Zone 3	$100 < X < 125$
Zone 4	$125 < X$

Thus, the suspended particulate levels, X, vary from 75 $\mu g/m^3$ to 100 $\mu g/m^3$ in Zone 2 and from 100 $\mu g/m^3$ to 125 $\mu g/m^3$ in Zone 3. The upper limit of X in Zone 1 is 75 $\mu g/m^3$ and the lower limit of X in Zone 4 is 125 $\mu g/m^3$. Assuming that 25 $\mu g/m^3$ of suspended particulate is the background concentration level and 175 $\mu g/m^3$ is the upper limit in the study areas then the values of Min X and Max X (in $\mu g/m^3$) for the four study zones are tabulated as follows:

	Min X	Max X
Zone 1	25	75
Zone 2	75	100
Zone 3	100	125
Zone 4	125	175

The minimum and the maximum values for the dependent variable Y (Min Y and Max Y) for each zone were calculated by subtracting and adding one standard error of the mean from the mean value of the cleaning frequency. The computed values for Min Y and Max Y, the mean frequency of cleaning and the standard error of the means are presented in Table IV-2.

The Monte Carlo sampling technique, delineated in Section III, was applied to the four blocks for generating a random sample for the regression analysis. A total of 800 such random observations for each cleaning task were selected. For the sake of computational simplicity, a smaller random sample, about 20 percent of the 800 random observations, was further obtained. The 160 observations included in this sample were fitted via both linear and nonlinear least-squares techniques. The linear fit is more superior than the nonlinear fit in all cases except for Task 8. The linear regression results for Task 1 through 7 and Task 9 and the nonlinear regression result for Task 8 are summarized in Table IV-3.

ECONOMIC DAMAGES AND ECONOMIC DAMAGE FUNCTIONS

Given the preceding nine physical damage functions for the nine pollution-related cleaning tasks and the associated unit cleaning costs which were obtained through telephone conversations with various cleaning firms in Kansas City, the economic costs of soiling or of individual household adjustment to air pollution can be derived by transforming the increased cleaning frequency into monetary units, via the following two formulas:1/

1/ For Task 8, $NSCO_8 = EXP(0.85 - 0.015/(TSP - 45)) \cdot UC \cdot U \cdot HU$ and $GSCO_8 = 2 + EXP(0.85 - 0.015/(TSP - 45)) \cdot UC \cdot U \cdot HU$.

TABLE IV-2. MEAN FREQUENCY, STANDARD ERROR AND UPPER AND LOWER LIMITS OF FREQUENCY AND SUSPENDED PARTICULATES

		Mean Frequency of Cleaning	Standard Error of Means	Min Y	Max Y	Min X	Max X
Task 1							
	Zone 1	0.36	0.06	0.30	0.42	25	75
	Zone 2	0.50	0.08	0.42	0.58	75	100
	Zone 3	0.30	0.07	0.23	0.37	100	125
	Zone 4	0.98	0.34	0.64	1.32	125	175
Task 2							
	Zone 1	40.55	0.84	39.71	41.39	25	75
	Zone 2	42.06	0.84	41.22	42.90	75	100
	Zone 3	42.74	0.98	41.77	43.72	100	125
	Zone 4	45.17	0.93	44.24	46.10	125	175
Task 3							
	Zone 1	10.06	0.61	9.45	10.17	25	75
	Zone 2	11.78	0.70	11.08	12.48	75	100
	Zone 3	12.74	0.82	11.93	13.55	100	125
	Zone 4	18.45	1.10	17.85	20.05	125	175
Task 4							
	Zone 1	4.04	0.53	3.51	4.57	25	75
	Zone 2	6.17	0.66	5.51	6.87	75	100
	Zone 3	9.13	0.91	8.22	10.04	100	125
	Zone 4	9.21	0.49	8.22	10.20	125	175
Task 5							
	Zone 1	0.80	0.07	0.75	0.87	25	75
	Zone 2	0.93	0.16	0.77	1.09	75	100
	Zone 3	0.79	0.10	0.70	0.86	100	125
	Zone 4	1.50	0.32	1.18	1.82	125	175
Task 6							
	Zone 1	4.25	0.35	3.90	4.60	25	75
	Zone 2	4.59	0.38	4.21	4.97	75	100
	Zone 3	6.17	0.60	5.57	6.77	100	125
	Zone 4	10.09	0.88	9.21	10.97	125	175
Task 7							
	Zone 1	2.07	0.28	1.79	2.35	25	75
	Zone 2	1.60	0.23	1.37	1.83	75	100
	Zone 3	2.12	0.39	1.73	2.51	100	125
	Zone 4	3.69	0.63	3.60	4.32	125	175
Task 8							
	Zone 1	2.50	0.45	2.05	2.95	25	75
	Zone 2	4.29	0.65	3.64	4.94	75	100
	Zone 3	3.52	0.71	2.81	4.23	100	125
	Zone 4	1.19	0.47	0.72	1.66	125	175
Task 9							
	Zone 1	1.12	0.22	0.91	1.34	25	75
	Zone 2	1.54	0.33	1.21	1.87	75	100
	Zone 3	1.35	0.44	0.91	1.79	100	125
	Zone 4	2.80	0.69	2.11	3.49	125	175

TABLE IV-3. SOILING PHYSICAL DAMAGE FUNCTIONS[a/]

A. Frequency = a + b TSP

Task	a	b	R^2
1	0.03 (0.05)	0.00510 (0.00048)*	0.43
2	38.6 (0.18)	0.0400 (0.0017)*	0.80
3	5.6 (0.4)	0.078 (0.036)*	0.76
4	2.3 (0.2)	0.048 (0.002)*	0.79
5	0.42 (0.06)	0.0059 (0.0049)*	0.48
6	1.00 (0.28)	0.0530 (0.0025)*	0.74
7	0.85 (0.15)	0.015 (0.001)*	0.48
9	0.27 (0.12)	0.0140 (0.0011)*	0.55
B. Frequency = $c + e^{(a-b/TSP)}$			
8 (c = 2)	0.67 (0.10)	53.2 (7.4)*	0.26

a/ The values below the coefficients are standard errors, with * to indicate that the coefficient is significant at the 1 percent level.

$$NSCO_i = b_i(TSP-45) \cdot UC \cdot U \cdot HU \qquad \text{(IV-1)}$$

$$GSCO_i = a_i + b_i(TSP-45) \cdot UC \cdot U \cdot HU \qquad \text{(IV-2)}$$

where $NSCO_i$ and $GSCO_i$ are, respectively, the net (extra) and gross soiling damage cost for the ith type of cleaning task. Coefficients a_i and b_i are the estimated coefficients in the physical damage functions in Table IV-3. i = 1 through 7, and 9. Variables UC, U and HU stand for the unit market value, number of cleaning objects per household and number of households in a metropolitan area, respectively.

To capture the "real" effect of suspended particulates on soiling damages, the suspended particulate level was adjusted by a threshold level because a low level of suspended particulate might have a negligible effect on the household cleaning activities. A threshold level of 45 $\mu g/m^3$ for suspended particulate was assumed as the background concentration level in this study because the lowest 1970 annual mean level for total suspended particulates was 46.7 $\mu g/m^3$ for Charleston, South Carolina. Alternative reasonable threshold levels can also be considered. Other things being equal, a higher threshold level is generally associated with a lower damage cost, and the marginal changes in the damage cost in response to a unit change in the threshold level is the value of b_i for the ith type of cleaning task.

Given the data collected for the variables in the formula (IV-1) and (IV-2) the net and gross household soiling costs for each of the nine cleaning operations by the 65 large SMSA's (with population greater than 500,000) in the United States were derived and presented in Tables IV-4 and IV-6. Similar damage costs for each of the nine cleaning operations by the 83 medium SMSA's (200,000 to 500,000 people) were presented in Tables IV-6 and IV-7. An examination of the table reveals that Chicago, New York, and Los Angeles, in order of magnitude, suffered the most in terms of total net soiling damages. The net soiling damages in these three SMSA's in 1970 are, respectively, $516 million, $418 million, and $388 million. It is noteworthy that the cleaning activities of Tasks 4 and 6 in response to air pollution had resulted in an economic damage of about $1,956 million and $925.7 million, respectively, in the 40 metropolitan areas. These two tasks constitute the largest damage categories among the nine pollution-related cleaning tasks.

Per capita net and gross soiling damage costs in the presence of air pollution for large SMSA's and medium SMSA's for 1970 are presented, respectively, in Tables IV-8 and IV-9. Per capita net soiling costs (PCNSCO) and per capita gross soiling costs (PCGSCO) are summarized in the second and the third columns of the tables. These cost figures indicate that the soiling damages attributable to air pollution in large SMSA's range from $5 per person in San Antonio, Texas, to $104 per person in Cleveland, Ohio, whereas the net soiling damages in medium SMSA's vary from less than a dollar per person in Charleston, South Carolina, to $67.35 per person in Wichita, Kansas. These estimates for individual SMSA's appear to be compatible with the overall per capita soiling damage estimates of $20.00 by Mellon Institute and of $200 by Michelson and Tourin.

TABLE IV-4. NET SOILING DAMAGE COSTS BY LARGE SMSA's[a/]
(million $)

Large SMSA's	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
1. AKR, OH	--	1.7	1.4	6.3	--	2.9	1.1	0.9	1.5	15.5
2. ALB, NY	0.1	4.0	3.2	14.0	0.1	6.7	2.5	2.2	3.5	36.4
3. ALL, NJ	--	1.8	1.4	6.2	--	2.9	1.1	1.0	1.5	15.9
4. ANA, CA	0.1	6.1	5.0	21.3	0.2	10.1	3.8	3.4	5.3	55.4
5. ATL, GA	0.1	3.8	3.1	13.1	0.1	6.2	2.4	2.0	2.2	34.0
6. BAL, MD	0.3	15.3	12.4	53.6	0.4	25.3	9.6	7.3	13.4	137.0
7. BIR, AL	0.2	7.7	6.2	26.7	0.2	12.6	4.7	3.1	6.7	68.2
8. BOS, MA	0.3	12.9	10.5	45.3	0.3	21.4	8.1	7.2	11.3	117.0
9. BUF, NY	0.2	8.1	6.6	28.3	0.2	12.4	5.1	4.2	7.1	73.1
10. CHI, IL	1.2	57.5	46.7	201.0	1.4	95.2	35.9	26.2	50.3	516.0
11. CIN, OH-KY-IN	0.1	6.3	5.1	21.9	0.2	10.4	3.9	3.5	5.5	57.0
12. CLE, OH	0.5	24.3	19.7	85.0	0.6	40.2	15.1	9.0	21.2	216.0
13. COL, OH	0.1	2.3	1.9	8.2	0.1	3.9	1.5	1.2	2.1	21.1
14. DAL, TX	0.1	6.8	5.5	23.7	0.2	11.2	4.2	3.8	5.9	61.4
15. DAY, OH	0.1	4.4	3.5	15.2	0.1	7.2	2.7	2.4	3.8	39.4
16. DEN, CO	0.2	10.1	8.2	35.3	0.2	16.7	6.3	4.7	8.8	90.7
17. DET, MI	0.7	32.7	26.6	114.0	0.8	54.3	20.4	15.1	28.6	294.0
18. FOR, FL	--	0.9	0.7	3.2	--	1.5	0.6	0.2	0.8	7.8
19. FOR, TX	0.1	2.6	2.1	9.2	0.1	4.3	1.6	1.5	2.3	23.7
20. GAR, IN	0.1	2.7	2.2	9.3	0.1	4.4	1.7	1.5	2.3	24.2
21. GRA, MI	--	1.1	0.9	4.0	--	1.9	0.7	0.5	1.0	10.1
22. GRE, NC	--	1.9	1.5	6.5	--	3.1	1.2	1.0	1.6	16.9
23. HAR, CT	--	1.8	1.4	6.2	--	2.9	1.1	0.8	1.6	15.8
24. HON, HI	--	1.2	1.0	4.1	--	2.0	0.7	0.5	1.0	10.5
25. HOU, TX	0.1	6.4	5.2	22.4	0.2	10.6	4.0	3.5	5.6	58.1
26. IND, IN	0.1	2.5	2.0	8.9	0.1	4.2	1.6	1.2	2.2	22.7
27. JAC, FL	--	1.2	0.9	3.8	--	1.8	0.7	4.7	0.9	9.7
28. JER, NJ	--	1.9	1.5	6.7	--	3.2	1.2	1.0	1.7	17.2
29. KAN, MO-KS	0.1	4.0	3.3	14.1	0.1	6.7	2.5	2.2	3.5	36.6
30. LOS, CA	0.9	42.8	34.8	150.0	1.1	71.0	2.7	2.3	3.8	388.0
31. LOU, KY-IN	0.1	6.3	5.1	21.9	0.2	0.2	10.3	3.9	5.5	56.3
32. MEM, TN-AR	0.1	2.6	2.1	9.2	0.1	4.4	1.6	1.5	2.3	23.8
33. MIA, FL	--	1.7	1.4	6.0	--	2.9	1.1	0.3	1.5	15.0
34. MIL, WI	0.1	4.8	3.9	16.9	0.1	8.0	3.0	2.7	4.2	43.9
35. MINN, MN	0.1	4.1	3.3	14.4	0.1	6.8	2.6	1.9	3.6	36.9

a/ NSCOi stands for the net soiling cost for the ith type of operation, i = 1, 2,. . ., 9.
TOTNETSL is the sum of NESOCOi over i and "--" indicates that the figure is less than 0.05.

TABLE IV-4 (Concluded)

Large SMSA's	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
36. NAS, TN	0.1	3.2	2.6	11.1	0.1	5.3	2.0	1.7	2.8	28.9
37. NEW, LA	0.1	2.7	2.2	9.3	0.1	4.4	1.7	1.3	2.3	23.9
38. NEW, NY	1.0	46.0	37.4	161.0	1.1	76.3	28.7	25.8	40.3	418.0
39. NEW, NJ	0.3	12.4	10.1	43.5	0.3	20.6	7.8	6.3	10.8	112.0
40. NOR, VA	0.1	3.2	0.6	11.0	0.1	5.2	2.0	1.7	2.8	28.5
41. OKL, OK	--	1.2	0.9	3.8	--	1.8	6.8	0.3	1.0	9.6
42. OMA, NE-LA	0.1	3.8	3.1	13.2	0.1	6.3	2.4	1.8	3.3	34.0
43. PAT, NJ	--	1.1	0.9	3.8	--	1.8	0.7	0.1	1.0	9.3
44. PHI, PA-NJ	0.2	11.5	9.4	40.4	0.3	19.1	7.2	5.6	10.1	104.0
45. PHO, AZ	0.2	10.4	8.5	36.4	0.3	17.2	6.5	4.1	9.1	92.8
46. PIT, PA	0.3	16.3	13.2	57.1	0.4	27.0	10.2	8.2	14.2	147.0
47. POR, OR-WA	0.1	3.3	2.7	11.6	0.1	5.5	2.1	1.8	3.0	30.1
48. PRO, RI-MA	--	2.2	1.8	7.7	0.1	3.6	1.4	1.1	1.9	19.7
49. RIC, VA	0.1	2.7	2.2	9.4	0.1	4.4	1.7	1.5	2.3	24.2
50. ROC, NY	0.1	3.1	2.4	10.2	0.1	4.9	1.8	1.6	2.5	26.5
51. SAC, CA	--	1.0	0.8	3.5	--	1.7	0.6	0.2	0.9	8.8
52. SAI, MO-IL	0.3	13.1	10.6	46.0	0.2	21.7	8.2	7.0	11.5	119.0
53. SAL, UT	--	1.9	1.5	6.6	--	3.1	1.2	1.2	1.7	17.2
54. SAN, TX	--	0.5	0.4	1.8	--	0.8	0.3	--	0.4	4.3
55. SAN, CA	0.1	7.9	6.3	27.5	0.2	13.0	4.9	3.9	6.9	70.8
56. SAN, CA	--	1.4	1.1	4.8	--	2.3	0.9	0.2	1.2	11.9
57. SAN, CA	0.1	4.0	3.2	14.0	0.1	6.7	2.5	0.6	3.5	34.8
58. SAN, CA	--	1.2	0.9	4.0	--	1.9	0.7	0.2	1.0	10.0
59. SEA, WA	--	1.4	1.2	5.0	--	2.3	0.9	0.1	1.2	12.1
60. SPR, MC-CT	--	0.8	0.6	2.7	--	1.3	0.5	0.2	0.7	6.7
61. SYR, NY	0.1	3.0	2.5	10.6	0.1	5.0	1.9	1.7	2.7	27.4
62. TAM, FL	0.1	2.7	2.2	9.4	0.1	4.5	1.7	1.3	2.4	24.2
63. TOL, OH-MI	0.1	4.0	3.3	14.1	0.1	6.7	2.5	2.1	3.5	36.4
64. WAS, DC-MD-VA	0.2	9.7	7.8	37.7	0.2	15.9	6.0	5.42	8.4	85.5
65. YOU, OH	0.1	2.5	2.0	8.9	0.1	4.2	1.6	1.4	2.2	23.0
Total	9.9	474.5	382.7	1,662.0	10.6	774.0	284.7	216.8	379.7	2,465.9

Note: -- individual figure may not add to totals due to rounding.

TABLE IV-5. NET SOILING DAMAGE COSTS BY MEDIUM SMSA's
(million $)

Medium SMSA's	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
66. ALB, NM	--	1.1	0.9	3.7	--	1.8	0.7	0.6	0.9	9.7
67. ANN, MI	--	0.5	0.4	1.7	--	0.8	0.3	0.2	0.4	4.3
68. APP, WI	--	0.9	0.7	3.1	--	1.4	0.5	0.5	0.8	7.9
69. AUG, GA-SC	--	0.3	0.3	1.1	--	0.5	0.2	0.1	0.3	2.7
70. AUS, TX	--	0.5	0.4	1.9	--	0.9	0.3	0.2	0.5	4.8
71. BAK, CA	--	2.2	1.8	7.7	0.1	3.7	1.4	1.1	1.9	19.9
72. BAT, LA	--	0.3	0.3	1.1	--	0.5	0.2	0.1	0.3	2.7
73. BEA, TX	--	0.3	0.3	1.2	--	0.6	0.2	0.1	0.3	3.0
74. BIN, NY-PA	--	0.3	0.2	1.0	--	0.4	0.2	--	0.2	2.5
75. BRI, CN	--	0.4	0.3	1.2	--	0.6	0.2	--	0.3	3.0
76. CAN, OH	--	1.6	1.3	5.6	--	2.6	1.0	0.9	1.4	14.4
77. CHA, SC	--	--	--	0.1	--	0.1	--	--	--	0.3
78. CHA, WV	--	1.1	0.9	3.7	--	1.8	0.7	0.6	0.9	9.6
79. CHA, NC	--	1.6	1.3	5.7	--	2.7	1.0	0.9	1.4	14.6
80. CHA, TN-GA	--	1.4	1.2	5.0	--	2.4	0.9	0.8	1.2	12.9
81. COL, CO	--	0.8	0.7	2.9	--	1.4	0.5	0.5	0.7	7.6
82. COL, SC	--	0.4	0.4	1.3	--	0.6	0.2	0.1	0.3	3.2
83. COL, GA-AL	--	0.1	0.1	0.3	--	0.1	--	--	0.1	0.7
84. COR, TX	--	1.1	0.9	4.0	--	1.9	0.7	0.6	1.0	10.2
85. DAV, IA-IL	--	2.3	1.8	8.0	0.1	3.8	1.4	1.1	2.0	20.4
86. DES, IA	--	0.9	0.7	3.1	--	1.5	0.6	0.5	0.8	8.1
87. DUL, MN-WI	--	0.5	0.4	1.9	--	0.9	0.3	0.2	0.5	4.8
88. ELP, TX	--	2.2	1.9	7.9	--	3.8	1.4	1.1	2.0	20.1
89. ERI, PA	--	1.1	0.9	3.9	--	1.9	0.7	0.6	1.0	10.0
90. EUG, OR	--	0.7	0.5	2.3	--	1.1	0.4	0.4	0.6	6.0
91. EVA, IN-KY	--	0.5	0.4	2.0	--	0.9	0.3	0.3	0.5	5.0
92. FAY, NC	--	0.3	0.2	0.9	--	0.4	0.2	0.1	0.2	2.2
93. FLI, MI	0.1	3.0	2.4	10.2	0.1	4.9	1.8	1.5	2.6	26.5
94. FOR, IN	--	0.6	0.5	2.2	00	1.0	0.4	0.3	0.5	5.6
95. FRE, CA	--	2.1	1.7	7.5	0.1	3.5	1.3	1.2	1.9	19.3
96. GRE, SC	--	0.7	0.6	2.4	--	1.1	0.4	0.3	0.6	6.2
97. HAM, OH	--	0.6	0.5	2.0	0.1	1.0	0.4	0.3	0.5	5.3
98. HAR, PA	--	1.0	0.8	3.6	--	1.7	0.6	0.5	0.9	9.2
99. HUN, WV-KY,OH	--	1.0	0.9	3.5	--	1.7	0.6	0.6	0.9	9.1
100. HUN, AL	--	0.3	0.2	1.0	--	0.5	0.2	0.1	0.9	9.7

TABLE IV-5 (Continued)

	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
101. JAC, MS	--	1.1	0.9	3.8	--	1.8	0.7	0.6	0.9	9.7
102. JOH, PA	--	1.1	0.9	4.0	--	1.9	0.7	0.6	1.0	10.1
103. KAL, MI	--	0.2	0.2	0.7	--	0.3	0.1	--	0.2	1.7
104. KNO, TN	--	1.7	1.3	5.8	--	2.7	10.	0.9	1.5	15.0
105. LAN, PA	--	1.5	1.2	5.2	--	2.4	0.9	0.8	1.3	13.3
106. LAN, MI	--	0.9	0.7	3.1	--	1.5	0.5	0.4	0.8	7.9
107. LAS, NV	--	1.2	1.0	4.1	--	1.9	0.7	0.7	1.0	10.6
108. LAW, MA-NH	--	0.4	0.3	1.2	--	0.6	0.2	0.1	0.3	3.1
109. LITT, AK	--	0.7	0.6	2.5	--	1.2	0.4	0.3	0.6	6.4
110. LOR, OH	0.1	2.7	2.2	9.5	0.1	4.5	1.7	1.0	2.4	24.1
111. LOW, MA	--	0.1	0.1	0.3	--	0.1	--	--	0.1	0.7
112. MAC, GA	--	0.5	0.4	1.9	--	0.9	0.3	0.3	0.5	4.9
113. MAD, WI	--	0.6	0.5	2.2	--	1.0	0.4	0.3	0.5	5.5
114. MOB, AL	--	1.6	1.3	5.6	--	2.7	1.0	0.9	1.4	14.5
115. MON, AL	--	0.7	0.6	2.6	--	1.2	0.5	0.4	0.7	6.8
116. NEW, CN	--	0.4	0.4	1.4	--	0.7	0.2	0.1	0.3	3.5
117. NEW, CN	--	0.2	0.2	0.9	--	0.4	0.2	0.1	0.2	2.1
118, NEW, VA	--	0.2	0.1	0.6	--	0.3	0.1	--	0.2	1.5
119. ORL, FL	--	1.0	0.8	3.4	--	1.6	0.6	0.5	0.9	8.8
120. OXN, CA	--	1.9	1.5	6.5	--	3.1	1.2	1.0	1.6	16.9
121. PEN, FL	--	1.0	0.8	3.7	--	1.7	0.7	0.6	0.9	9.5
122. PEO, IL	--	0.8	0.7	3.0	--	1.4	0.5	0.4	0.7	7.6
123. RAL, NC	--	0.2	0.1	0.6	--	0.3	0.1	--	0.1	1.4
124. REA, PA	--	1.7	1.4	6.0	--	2.8	1.0	0.9	1.5	15.3
125. ROC, IL	--	1.2	1.0	4.2	--	2.0	0.8	0.7	1.0	10.9
126. SAG, MI	--	1.3	1.0	4.5	--	2.1	0.8	0.7	1.2	11.6
127. SAL, CA	--	1.2	1.0	4.2	--	2.0	0.7	0.6	1.0	10.8
128. SAN, CA	--	1.5	1.2	5.2	--	2.5	0.9	0.8	1.3	13.4
129. SAN, CA	--	1.2	1.0	4.2	--	2.0	0.7	0.6	1.0	10.8
130. SCR, PA	0.1	2.6	2.1	9.2	0.1	4.3	1.6	1.0	2.3	23.3

TABLE IV-5 (Concluded)

	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
131. SHR, LA	--	1.3	1.1	4.6	--	2.2	0.8	0.7	1.2	11.9
132. SOU, IN	--	0.6	0.5	2.2	--	1.1	0.4	0.3	0.6	5.7
133. SPO, WA	--	1.2	1.0	4.2	--	2.0	0.7	0.7	1.0	10.8
134. STA, CN	--	0.2	0.2	0.7	--	0.3	0.1	--	0.2	1.6
135. STO, CA	--	0.3	0.3	1.1	--	0.5	0.2	--	0.3	2.8
136. TAC, WA	--	1.4	1.2	5.1	--	2.4	0.9	0.8	1.3	13.0
137. TRE, NJ	--	0.6	0.5	2.0	--	1.0	0.4	0.2	0.5	5.2
138. TUC, AZ	--	1.4	1.1	4.9	--	2.3	0.9	0.8	1.2	12.8
139. TUL, OK	--	1.5	1.2	5.1	--	2.4	0.9	0.8	1.3	13.1
140. UTI, NY	--	0.7	0.5	2.3	--	1.1	0.4	0.3	0.6	8.9
141. VAL, CA	--	0.3	0.2	0.9	--	0.4	0.2	--	0.2	2.3
142. WAT, CN	--	0.5	0.4	1.9	--	0.9	0.3	0.3	0.5	4.9
143. WES, FL	--	0.5	0.4	1.7	--	0.8	0.3	0.1	0.4	4.3
144. WIC, KS	0.1	2.9	2.4	10.2	0.1	4.8	1.8	1.4	2.6	26.2
145. WIL, PA	--	2.2	1.8	7.8	0.1	3.7	1.4	1.1	1.9	20.0
146. WIL, DE,NJ,MD	0.1	2.9	2.3	10.0	0.1	4.7	1.8	1.5	2.5	25.9
147. WOR, MA	--	0.7	0.6	2.4	--	1.1	0.4	0.3	0.6	6.2
148. YOR, PA	--	1.0	0.8	3.5	--	1.7	0.6	0.5	0.9	9.0
Total	1.9	84.3	71.4	294.3	1.3	151.7	64.5	58.3	109.2	767.2

Note: -- individual figure may not add to totals due to rounding.

TABLE IV-6. GROSS SOILING DAMAGE COSTS BY LARGE SMSA[a/]
(million $)

Large SMSA's	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
1. AKR, OH	--	49.4	0.9	14.3	0.1	4.4	2.8	5.0	2.3	79.3
2. ALB, NY	0.1	57.2	1.3	23.3	0.2	8.4	4.5	6.8	4.5	106.0
3. ALL, NJ	--	42.2	0.8	13.2	0.1	4.2	2.6	4.5	2.3	69.9
4. ANA, CA	--	107.0	2.2	38.9	0.3	13.3	7.5	12.1	7.1	188.0
5. ATL, GA	0.1	103.0	1.8	20.5	0.3	9.5	6.0	10.5	5.0	166.0
6. BAL, MD	0.3	159.0	4.2	78.8	0.6	30.0	14.8	19.7	15.9	324.0
7. BIR, AL	0.2	61.3	1.2	36.1	0.3	14.4	6.8	7.7	7.6	136.0
8. BOS, MA	0.3	212.0	4.5	80.1	0.7	27.9	15.4	24.4	14.8	380.0
9. BUF, NY	0.2	104.0	2.5	45.2	0.4	16.5	8.6	12.5	8.8	199.0
10. CHI, IL	1.3	563.0	15.4	289.0	2.3	111.0	54.5	69.9	59.1	1160.0
11. CIN, OH-KY-IN	--	106.0	2.2	39.4	0.3	13.6	7.6	12.1	7.2	188.0
12. CLE, OH	0.5	174.0	5.8	111.0	0.9	45.1	20.7	22.0	23.9	405.0
13. COL, OH	0.1	67.8	1.2	19.6	0.2	6.0	3.9	6.8	3.2	108.0
14. DAL, TX	0.2	120.0	2.5	43.5	0.4	14.9	8.4	13.6	7.9	212.0
15. DAY, OH	0.1	65.2	1.4	25.8	0.2	9.2	5.0	7.6	4.9	119.0
16. DEN, CO	0.2	100.0	2.7	51.2	0.4	19.6	9.7	12.5	10.1	207.0
17. DET, MI	0.7	326.0	8.9	166.0	1.3	63.8	31.2	40.4	33.8	672.0
18. FOR, FL	--	52.5	0.8	12.1	0.1	3.2	2.5	4.6	1.7	77.5
19. FOR, TX	0.1	58.4	1.1	18.9	0.2	6.2	3.7	9.6	3.3	98.0
20. GAR, IN	0.1	45.0	1.0	16.8	0.1	5.8	3.2	5.2	3.1	80.8
21. GRA, MI	--	38.1	0.6	10.4	0.1	3.1	2.1	3.7	1.6	59.8
22. GRE, NC	--	45.1	0.8	14.0	0.1	4.5	2.8	4.8	2.4	74.6
23. HAR, CT	--	60.8	4.1	16.5	0.2	4.8	3.3	5.9	2.6	95.1
24. HON, HI	--	39.3	0.7	10.8	0.1	3.2	2.1	3.8	1.7	61.8
25. HOU, TX	0.2	147.0	4.8	47.1	0.4	15.2	9.2	15.7	8.1	246.0
26. IND, IN	0.1	82.8	1.4	22.8	0.2	6.8	4.5	8.1	3.6	130.0
27. JAC, FL	--	38.5	0.6	10.3	0.1	3.0	2.1	3.7	1.6	60.0
28. JER, NJ	--	49.8	0.9	15.0	0.1	4.7	3.0	5.2	2.5	81.2
29. KAN, MO-KS	0.1	98.7	1.8	30.7	0.3	9.8	6.0	10.3	5.2	163.0
30. LOS, CA	1.0	606.0	1.4	248.0	2.1	89.2	4.7	71.6	47.3	1,120.0
31. LOU, KY-IN	--	67.8	1.7	32.3	0.3	12.3	6.1	8.1	6.5	133.0
32. MEM, TN-AR	0.1	55.2	1.1	18.3	0.2	6.1	3.6	6.0	3.2	93.7
33. MIA, FL	--	100.0	1.5	23.3	0.2	6.1	4.7	8.9	3.2	148.0
34. MIL, WI	0.1	105.0	2.0	34.4	0.3	11.2	6.7	11.3	6.0	117.0
35. MINN, MN	0.1	133.0	2.2	36.9	0.3	10.9	7.3	13.0	5.9	209.0

a/ $GSCO_i$ denotes the gross soiling damage cost for the ith type of cleaning operation, i = 1, 2,. . ., 9, TGSCO is the sum of $GSCO_i$ over i.

TABLE IV-6 (Concluded)

Large SMSA's	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
36. NAS, TN	0.1	42.3	1.0	18.0	0.2	6.6	3.4	5.1	3.5	80.1
37. NEW, LA	0.1	76.3	1.3	22.1	0.2	6.8	4.3	7.7	3.6	122.0
38. NEW, NY	0.1	939.0	18.2	317.0	2.8	105.0	61.5	103.0	55.9	1,600.0
39. NEW, NJ	0.3	147.0	3.7	67.1	0.6	25.0	12.7	17.9	13.2	288.0
40. NOR, VA	0.1	47.6	1.1	18.8	0.2	6.7	3.6	5.6	3.5	87.0
41. OKL, OK	--	49.7	0.8	12.3	0.1	3.4	2.5	4.6	1.8	75.1
42. OMA, NE-IA	0.1	42.0	1.1	19.9	0.2	7.5	3.8	5.1	4.0	83.6
43. PAT, NJ	--	99.9	1.4	21.0	0.2	5.0	4.3	8.6	2.7	143.0
44. PHI, PA-NJ	0.3	354.0	6.0	100.0	0.9	30.2	19.8	32.2	16.1	563.0
45. PHO, AZ	0.2	80.5	2.5	48.7	0.4	19.5	9.1	10.1	10.3	181.0
46. PIT, PA	0.4	192.0	4.8	87.8	0.7	32.7	16.6	23.3	17.3	375.0
47. POR, OR-WA	0.1	82.5	1.5	25.4	0.2	8.1	5.0	8.6	4.3	135.0
48. PRO, RI-MA	0.1	67.9	1.2	19.1	0.2	5.7	3.8	6.7	3.1	107.0
49. RIC, VA	0.1	40.4	0.9	15.9	0.1	5.7	3.1	4.7	3.0	73.9
50. ROC, NY	0.1	65.6	1.2	21.1	0.2	6.9	4.1	7.0	3.7	110.0
51. SAC, CA	--	60.3	0.9	13.8	0.1	3.6	2.8	5.3	1.9	88.8
52. SAI, MO-IL	0.3	183.0	4.2	75.8	0.6	27.3	14.4	21.7	14.4	342.0
53. SAL, UT	--	38.7	0.6	13.0	0.1	4.3	2.5	4.2	2.3	66.1
54. SAN, TX	--	57.0	0.8	11.6	0.1	2.7	2.4	4.9	1.4	80.9
55. SAN, CA	0.2	91.9	2.3	42.1	0.3	15.7	8.0	11.1	8.3	180.0
56. SAN, CA	--	99.5	1.4	21.9	0.2	5.5	4.5	8.6	2.9	144.0
57. SAN, CA	0.1	265.0	3.8	59.7	0.6	15.1	12.1	23.1	8.1	388.0
58. SAN, CA	--	75.9	1.1	17.0	0.2	4.3	3.5	6.6	2.3	111.0
59. SEA, WA	--	110.0	1.6	24.0	0.2	5.9	4.9	9.6	3.2	160.0
60. SPR, MC-CT	--	38.9	0.6	9.3	0.1	2.5	1.9	3.5	1.3	58.2
61. SYR, NY	0.1	47.4	1.0	18.3	0.2	6.5	3.4	4.4	3.4	86.0
62. TAM, FL	0.1	88.3	1.5	24.4	0.2	7.2	4.8	8.7	3.9	129.0
63. TOL, OH-MI	0.1	53.3	1.3	22.7	0.2	8.3	4.3	6.4	4.4	101.0
64. WAS, DC-MD-VA	0.2	247.0	4.1	70.1	0.6	22.7	13.6	23.3	12.0	364.0
65. YOU, OH	0.1	40.0	0.9	15.4	0.1	5.4	3.0	4.6	2.9	72.4
Total	9.5	8,063.0	169.8	2,967.8	25.4	1,029.7	531.3	883.8	546.6	14,162.8

Note: -- individual figure may not add to totals due to rounding.

TABLE IV-7. GROSS SOILING DAMAGE COSTS BY MEDIUM SMSA's
(million $)

Medium SMSA's	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
66. ALB, NM	--	22.8	0.4	7.5	0.1	2.5	1.5	2.5	1.3	38.6
67. ANN, MI	--	16.4	0.3	4.5	--	1.3	0.9	1.6	0.7	25.7
68. APP, WI	--	18.9	0.4	6.2	0.1	2.0	1.2	2.0	1.0	31.9
69. AUG, GA-SC	--	16.7	0.2	0.3	--	1.0	0.8	1.5	0.6	24.8
70. AUS, TX	--	21.6	0.3	5.6	0.1	1.6	1.1	2.0	0.8	33.1
71. BAK, CA	--	25.8	0.6	11.8	0.1	4.4	2.2	3.1	2.3	50.6
72. BAT, LA	--	19.0	0.3	4.4	--	1.1	0.9	1.7	0.6	28.0
73. BEA, TX	--	22.8	0.3	5.1	--	1.3	1.0	2.0	0.7	33.3
74. BIN, NY-PA	--	21.8	0.3	4.8	--	1.2	1.0	1.9	0.6	31.5
75. BRI, CN	--	28.1	0.4	6.1	0.1	1.5	1.2	2.4	0.8	40.6
76. CAN, OH	--	28.2	0.6	10.2	0.1	3.5	2.0	3.2	1.9	49.6
77. CHA, SC	--	19.2	0.2	3.5	--	0.7	0.7	1.7	0.4	26.4
78. CHA, WV	--	18.1	0.4	6.7	0.1	2.3	1.3	2.1	1.2	32.2
79. CHA, NC	--	30.5	0.6	10.7	0.1	3.6	201	3.4	1.9	53.0
80. CHA, TN-GA	--	24.1	0.5	8.9	0.1	3.1	1.7	2.8	1.6	42.8
81. COL. CO	--	16.5	0.3	5.7	--	1.9	1.1	1.8	1.0	28.5
82. COL, SC	--	20.2	0.3	4.8	--	1.3	1.0	1.8	0.6	30.1
83. COL, GA-AL	--	15.5	0.2	3.0	--	0.6	0.6	1.3	0.3	21.7
84. COR, TX	--	19.6	0.4	7.1	--	2.5	1.4	2.2	1.3	34.7
85. DAV, IA-IL	--	28.9	0.7	12.5	0.1	4.6	2.4	3.5	2.4	55.2
86. DES, IA	--	22.4	0.4	7.0	--	2.1	1.3	2.3	1.1	36.8
87. DUL, MN-WI	--	19.9	0.3	5.3	--	1.6	1.0	1.9	0.9	30.9
88. ELP, TX	--	24.4	0.6	11.7	0.1	4.4	2.2	3.0	2.4	49.0
89. ERI, PA	--	19.4	0.4	7.1	0.1	2.5	1.4	2.2	1.3	34.4
90. EUG, OR	--	16.4	0.3	5.1	--	1.6	1.0	1.7	0.9	27.0
91. EVA, IN-KY	--	17.9	0.3	5.0	--	1.5	1.0	1.8	0.8	28.1
92. FAY, NC	--	12.2	0.2	3.0	--	0.8	0.6	1.1	0.4	18.4
93. FLI, MI	0.1	36.2	0.9	16.1	0.1	6.0	3.1	4.4	3.2	70.0
94. FOR, IN	--	20.5	0.3	5.7	0.1	1.7	1.1	2.0	0.9	32.3
95. FRE, CA	--	31.5	0.7	12.5	0.1	4.5	2.4	3.7	2.4	57.9
96. GRE, SC	--	21.7	0.4	0.1	1.8	1.2	1.2	2.2	1.0	34.4
97. HAM, OH	--	16.1	0.3	4.8	--	1.5	0.9	1.6	0.8	26.0
98. HAR, PA	--	31.5	0.5	9.0	0.1	2.7	1.8	3.1	1.4	50.2
99. HUN, WV-KY-OH	--	19.7	0.4	6.8	0.1	2.3	1.3	2.2	1.2	33.9
100. HUN, AL	--	15.3	0.2	3.6	--	1.0	0.7	1.4	0.5	22.7

TABLE IV-7 (Continued)

	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
101. JAC, MS	--	18.2	0.4	5.7	0.1	2.3	1.3	2.1	1.2	32.3
102. JOH, PA	--	19.8	0.4	7.2	0.1	2.5	1.4	2.3	1.3	35.0
103. KAL, MI	--	13.8	0.2	5.3	--	0.8	0.6	1.2	0.4	20.1
104. KNO, TN	--	21.0	0.6	10.9	0.1	3.7	2.1	3.5	2.0	54.0
105. LAN, PA	--	24.1	0.5	9.1	0.1	3.2	1.8	2.8	1.7	43.2
106. LAN, MI	--	26.5	0.5	7.6	0.1	2.3	1.5	2.7	1.2	42.3
107. LAS, NV	--	21.5	0.4	7.7	0.1	2.6	1.5	1.4	1.4	37.6
108. LAW, MA, NH	--	17.4	0.3	4.2	--	1.1	0.9	1.6	0.6	26.2
109. LITT, AK	--	24.5	0.4	5.7	0.1	2.0	1.3	2.4	1.1	38.4
110. LOR, OH	0.1	19.6	0.6	12.4	0.1	5.1	2.3	2.5	2.7	45.4
111. LOW, MA	--	13.9	0.3	3.7	--	0.6	0.6	1.2	0.3	19.5
112. MAC, GA	--	14.9	0.3	5.4	0.3	1.4	0.9	1.5	0.7	24.1
113. MAD, WI	--	21.2	0.3	5.8	0.1	1.7	1.1	2.1	0.9	33.1
114. MOB, AL	--	26.8	0.6	10.0	0.1	3.5	1.9	3.1	1.8	47.8
115. MON, AL	--	14.6	0.3	5.0	--	1.7	1.0	1.6	0.9	25.2
116. NEW CN	--	26.5	0.4	6.0	0.1	1.5	1.2	2.3	0.8	38.8
117. NEW, CN	--	14.3	0.2	3.3	--	0.9	0.7	1.3	0.5	21.2
118. NEW, VA	--	19.3	0.3	4.0	--	0.9	0.8	1.7	0.5	27.5
119. ORL, FL	--	32.0	0.5	8.8	0.1	2.6	1.8	3.1	1.4	50.3
120. OXN, CA	--	26.4	0.6	10.8	0.1	3.9	2.1	3.1	2.1	49.1
121. PEN, FL	--	17.4	0.4	6.5	0.1	2.3	1.3	2.0	1.2	31.1
122. PEO, IL	--	25.8	0.4	7.3	0.1	2.2	1.4	2.6	1.2	41.1
123. RAL, NC	--	15.9	0.2	3.3	--	0.8	0.7	1.4	0.4	22.7
124. REA, PA	--	24.3	0.5	9.9	0.1	3.6	1.9	2.9	1.9	45.1
125. ROC, IL	--	20.6	0.4	7.6	0.1	2.5	1.5	2.4	1.4	36.6
126 SAG, MI	--	15.8	0.4	7.1	0.1	2.6	1.3	1.9	1.4	30.6
127. SAL, CA	--	17.6	0.4	7.0	0.1	2.5	1.3	2.1	1.3	32.4
128. SAN, CA	--	20.9	0.5	8.6	0.1	3.1	1.6	2.5	1.6	38.9
129. SAN, CA.	--	16.9	0.4	6.9	0.1	2.5	1.3	2.0	1.3	31.5
130. SCR, PA	0.1	20.2	0.6	12.2	0.1	4.9	2.3	2.5	2.6	45.6

TABLE IV-7. (Concluded)

	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
131. SHR, LA	--	22.3	0.5	8.3	0.1	2.9	1.6	2.6	1.5	39.7
132. SOU, IN	--	20.7	0.3	5.7	0.1	1.7	1.1	2.0	0.9	32.7
133.. SPO, WA	--	22.9	0.5	8.0	0.1	2.7	1.5	2.6	1.4	39.6
134. STA, CN	--	15.0	0.2	3.2	--	0.8	0.7	1.3	0.4	21.6
135. STO, CA	--	21.6	0.3	4.9	--	1.21	1.0	1.9	0.7	31.6
136. TAC, WA	--	29.9	0.6	10.0	0.1	3.3	1.9	3.3	1.8	50.9
137. TRE, NJ	--	22.1	0.4	5.8	0.1	1.7	1.2	2.1	0.9	34.1
138. TUC, AZ	--	27.1	0.5	9.4	0.1	3.2	1.8	3.1	1.7	46.9
139. TUL, OK	--	38.2	0.7	11.5	0.1	3.6	2.3	3.9	1.9	62.3
140. UTI, NY	--	24.5	0.4	6.5	0.1	1.9	1.3	2.3	1.0	37.9
141. VAL, CA	--	17.8	0.3	4.0	--	1.0	0.8	1.6	0.5	26.1
142. WAT, CN	--	15.3	0.3	4.5	--	1.4	0.9	1.6	0.7	24.7
143. WES, FL	--	28.9	0.4	6.7	0.1	1.7	1.4	2.6	0.9	42.7
144. WIC, KS	0.1	31.8	0.8	15.2	0.1	5.8	2.9	3.9	3.1	63.7
145. WIL, PA	--	28.1	0.7	12.2	0.1	4.5	2.3	3.4	2.4	53.8
146 WIL, DE, NJ, MD	0.1	37.3	0.9	16.0	0.1	5.9	3.1	4.5	3.1	71.0
147. WOR, MA	--	25.0	0.4	6.7	0.1	1.9	1.3	2.4	1.0	38.8
148 YOR, PA	--	25.3	0.5	7.7	0.1	2.4	1.5	2.6	1.3	41.4
Total	3.3	1,821.9	34.2	616.3	5.2	198.2	160.3	195.4	105.4	3,204.3

Note: -- individual figure may not add to totals due to rounding.

TABLE IV-8. PER CAPITA NET AND GROSS SOILING DAMAGE COSTS ($) BY LARGE SMSA's, 1970

	SMSA	PCNSCO	PCGSCO
1.	AKR, OH	22.83	116.79
2.	ALB, NY	50.49	147.02
3.	ALL, NJ	29.23	128.49
4.	ANA, CA	39.01	132.39
5.	ATL, GA	24.46	119.42
6.	BAL, MD	66.15	156.45
7.	BIR, AL	92.29	184.03
8.	BOS, MA	42.48	137.98
9.	BUF, NY	54.19	147.52
10.	CHI, IL	73.94	166.21
11.	CIN, OH-KY-IN	41.16	135.74
12.	CLE, OH	104.65	196.22
13.	COL, OH	23.03	117.90
14.	DAL, TX	39.46	136.25
15.	DAY, OH	46.35	140.00
16.	DEN, CO	73.86	168.57
17.	DET, MI	70.00	160.00
18.	FOR, FL	12.58	125.00
19.	FOR, TX	31.10	128.61
20.	GAR, IN	38.23	127.65
21.	GRA, MI	18.74	110.95
22.	GRE, NC	27.98	123.51
23.	HAR, CT	23.80	143.22
24.	HON, HI	16.69	98.25
25.	HOU, TX	29.27	123.98
26.	IND, IN	20.45	117.12
27.	JAC, FL	18.34	113.42
28.	JER, NJ	28.24	133.33
29.	KAN, MO-KS	29.19	129.98
30	LOS, CA	55.18	159.27
31.	LOU, KY-IN	68.08	160.82
32.	MEM, TN-AR	20.91	121.69
33.	MIA, FL	11.83	116.72
34.	MIL, WI	31.27	83.33
35.	MINN, MN	20.34	115.21
36.	NAS, TN	53.42	148.06
37.	NEW, LA	22.85	116.63
38.	NEW, NY	36.26	138.78
39.	NEW, NJ	60.31	155.09
40.	NOR, VA	41.85	127.75

TABLE IV-8 (Concluded)

SMSA's	PCNSCO	PCGSCO
41. OKL, OK	14.98	117.16
42. OMA, NE-LA	62.96	154.81
43. PAT, NJ	6.84	105.22
44. PHI, PA-NJ	21.59	116.85
45. PHO, AZ	95.87	186.98
46. PIT, PA	61.22	156.18
47. POR, OR-WA	29.83	133.80
48. PRO, RI-MA	21.62	117.45
49. RIC, VA	46.72	142.66
50. ROC, NJ	39.01	124.58
51. SAC, CA	10.99	110.86
52. SAI, MO-IL	50.36	144.73
53. SAL, UT	30.82	118.46
54. SAN, TX	4.98	93.63
55. SAN, CA	61.94	157.48
56. SAN, CA	8.76	106.04
57. SAN, CA	11.19	124.76
58. SAN, CA	9.39	104.23
59. SEA, WA	8.51	112.52
60. SPR, MC-CT	12.64	109.81
61. SYR, NY	43.08	135.22
62. TAM, FL	23.89	127.34
63. TOL, OH-MI	52.53	145.74
64. WAS, DC-MD-VA	29.88	127.23
65. YOU, OH	42.91	135.07

TABLE IV-9. PER CAPITA NET AND GROSS SOILING DAMAGE COSTS ($) BY MEDIUM SMSA's, 1970

	SMSA'S	PCNSCO	PCGSCO
66.	ALB, NM	30.70	122.15
67.	ANN, MI	18.38	109.83
68.	APP, WI	28.52	115.16
69.	AUG, GA-SC	10.67	98.02
70.	AUS, TX	16.22	111.82
71.	BAK, CA	60.49	153.80
72.	BAT, LA	9.47	98.25
73.	BEA, TX	9.49	105.38
74.	BIN, NY-PA	8.25	103.96
75.	BRI, CN	7.71	104.37
76.	CAN, OH	38.71	133.33
77.	CHA, SC	0.99	86.84
78.	CHA, WV	41.74	140.00
79.	CHA, NC	35.70	129.58
80.	CHA, TN-GA	42.30	140.33
81.	COL, CO	32.20	120.76
82.	COL, SC	9.91	93.19
83.	COL,GA-AL	2.93	90.79
84.	COR, TX	35.79	121.75
85.	DAV, IA-IL	56.20	152.07
86.	DES, IA	28.32	128.67
87.	DUL, MN-WI	18.11	116.60
88.	ELP, TX	55.99	136.49
89.	ERI, PA	37.88	130.30
90.	EUG, OR	28.17	126.76
91.	EVA, IN-KY	21.46	120.60
92.	FAY, NC	10.38	86.79
93.	FLI, MI	53.32	140.85
94.	FOR, IN	20.00	115.36
95.	FRE, CA	46.73	140.19
96.	GRE, SC	20.67	114.67
97.	HAM, OH	23.45	115.04
98.	HAR, PA	22.38	122.14
99.	HUN, WV-KY,OH	35.83	133.46
100.	HUN, AL	42.54	99.56

TABLE IV-9 (Continued)

SMSA	PCNSCO	PCGSCO
101. JAC, MS	37.45	124.71
102. JOH, PA	38.401	133.08
103. KAL, MI	8.42	99.50
104. KNO, TN	37.50	135.00
105. LAN, PA	41.56	135.00
106. LAN, MI	20.90	111.90
107. LAS, NV	38.83	137.73
108. ALW, MA-NH	13.36	112.93
109. LITT, AK	19.81	118.89
110. LOR, OH	93.77	176.65
111. LOW, MA	3.29	91.55
112. MAC, GA	23.79	116.99
113. MAD, WI	18.97	114.14
114. MOB, AL	38.46	126.79
115. MON, AL	33.83	125.37
116. NEW, CN	9.83	108.99
117. NEW, CN	10.10	101.92
118. NEW, VA	5.14	94.18
119. ORL, FL	20.56	117.52
120. OXN, CA	62.13	180.51
121. PEN, FL	39.09	127.98
122. PEO, IL	22.22	120.18
123. RAL, NC	6.14	99.56
124. REA, PA	51.69	152.36
125. ROC, IL	40.07	134.56
126. SAG, MI	52.73	139.09
127. SAL, CA	43.20	129.60
128. SAN, CA	50.76	147.35
129. SAN, CA	52.68	153.66
130. SCR, PA	99.57	194.87
131. SHR, LA	40.34	134.58
132. SOU, IN	20.36	116.79
133. SPO, WA	37.63	137.98
134. STA, CN	7.77	104.85
135. STO, CA	9.66	108.97
136. TAC, WA	31.63	123.84
137. TRE, NJ	17.11	112.17
138. TUC, AZ	36.36	133.24
139. TUL, OK	27.46	130.61
140. UTI, NY	26.18	111.47

TABLE IV-9 (Concluded)

SMSA	PCNSCO	PCGSCO
141. VAL, CA	9.24	104.82
142. WAT, CN	23.44	118.18
143. WES, FL	12.32	122.35
144. WIC, KS	67.35	163.75
145. WIL, PA	58.48	157.31
146. WIL, DE, NJ, MD	51.90	142.28
147. WOR, MA	18.02	112.79
148. YOR, PA	27.27	125.45

A summary of the net and gross soiling damages by cleaning operations is contained in Table IV-10. The total net soiling damage as a result of falling suspended particulates for the 148 SMSA's in 1970 amounts to $5 billion. This damage figure is far smaller than the $11 billion and $30 billion national estimate extrapolated from the per capita damage figures reported respectively in the Mellon Institute study and the study by Michelson and Tourin. As noted earlier, the validity of the $11 billion and $30 billion estimates is seriously undermined by the assumptions used in the extrapolation technique. Regarding the gross soiling damage costs, New York, Chicago and Los Angeles had the highest damages among the 148 large SMSA's, about $1.6 billion, $12 billion, and $1.1 billion, respectively, partially because of the relatively high suspended particulate levels and a large number of household units in these three cities. Total gross soiling damage which is the sum of soiling damages attributable to air pollution and other factors amounts to $17.4 billion per year for the 148 SMSA's.

TABLE IV-10. NET AND GROSS SOILING DAMAGE COSTS IN 148 SMSA's BY CLEANING OPERATIONS, 1970

Tasks	Net Soiling Damages (million $)	Gross Soiling Damages (million $)	Net/Gross Soiling Damage Cost
1	11.8	12.8	0.91
2	558.8	9,884.9	0.05
3	454.1	204.0	0.45
4	1,956.3	3,584.1	0.55
5	13.6	30.6	0.44
6	925.7	1,227.9	0.75
7	349.2	691.6	0.50
8	275.1	1,079.2	0.25
9	488.9	652.0	0.75
Total	5,033.0	17,367.1	0.28

Note: -- individual figure may not add to totals due to rounding.

TABLE IV-11

TABLE IV-11. SOILING ECONOMIC DAMAGE FUNCTIONS[a,b]

Dependent Variable	MANFV	TSP	PCOL	RHM	DTS	PDS	PAGE	a	R^2
GSCO1	66.18 (2.02)*	1,128.83 (147.36)*	2,377.55 (1,288.8)	-995.17 (538.89)	271.69 (193.52)	-1.78 (3.81)	764.7 (1,940.9)	-100,181.3 (46,192.6)	0.92
GSCO2	42.9 (1.45)*	-108.5 (105.5)	2,252.2 (915.7)*	670.6 (383.4)		2.2 (2.7)	2,401.1 (1,392.6)	5,400.0 (32,763.0)	0.89
GSCO3	957.6 (25.9)*	6,802.6 (1,887.5)*	42,426.0 (16,507.0)*	-14,677.0 (6,902.0)*	1,946.0 (2,478.0)	12.4 (48.9)	32,626.0 (24,859.0)	652,046.0 (591,650.0)	0.93
GSCO4	17.2 (0.42)*	160.0 (33.1)*	727.4 (292.3)*	-262.6 (122.4)*	42.577 (43.8)		501.9 (439.4)	14,825.0 (10,445.0)	0.93
GSCO5	144.3 (3.90)*	1,031.6 (284.2)*	6,384.9 (2,485.6)*	-2,210.7 (1,039.3)*	294.6 (373.2)	1.85 (7.36)	4,898.9 (3,743.2)	98,799.0 (89,087.0)	0,93
GSCO6	6.12 (0.17)*	84.0 (12.5)*	236.9 (109.9)*	-92.6 (45.9)*	20.9 (16.5)	-0.083 (0.325)	116.6 (165.6)	-7,565.5 (3,941.2)	0.93
GSCO7	3.29 (0.08)*	27.7 (6.4)*	142.0 (56.3)*	-50.3 (23.5)*	7.6 (8.4)	0.025 (0.166)	102.2 (84.8)	-2,607.0 (2,018.7)	0.93
GSCO8	4.92 (0.15)*	9.07 (10.9)	223.0 (94.9)*	-74.8 (39.7)		0.17 (0.28)	212.9 (144.4)	877.7 (3,396.3)	0.91
GSCO9	3.23 (0.08)*	44.6 (6.5)*	126.9 (579.4)*	-48.9 (24.2)*	11.2 (8.6)		60.4 (87.0)	4,047.7 (2,070.1)	0.93
TGSCO [b]	78.9 (2.3)*	226.4 (166.9)	3,766.0 (1,460.0)*	-1,219.8 (610.7)*	90.9 (219.3)	2.3 (4.3)	3,432.3 (2,199.5)	-25,621.0 (52,347.0)	0.92

a/ All coefficients and standard errors are reduced by a factor of 10^3, except equation GSCO1, GSCO3 and GSCO5. The standard errors are the values below the coefficients, and * indicates that the coefficient is significant at the 1 percent level.

b/ TGSCO denotes the total gross soiling cost for the ith cleaning task, and TGSCO is the sum of GSCOi over i, i = 1, 2,. . .,9.

The regional soiling damage costs and the national damage cost deduced in this study should be used, however, only as crude estimates. There are uncertainties embodied in the two major assumptions: (1) the physical damage functions for the variety of cleaning tasks estimated on the basis of the Philadelphia study are "representative" of the physical damage functions of the 148 SMSA's; (2) the unit market value figures obtained in the Kansas City area are applicable to other SMSA's.

In order to develop "average" soiling economic damage functions for each of the nine cleaning tasks which can be used for prediction and control purposes, the individual metropolitan damage costs were regressed against not only the SO_2, but also to several socioeconomic, demographic, and climatological characteristics of different regions. The independent variables include MANFV (value of manufacturing), PCOL (percentage of persons 25 or older who have completed 4 years of college), RHM (relative humidity), DTS (number of days with thunderstorm), PDS (population density), PAGE (percentage of population 65 or older) and TSP. The inclusion of these variables is to account for the variations in educational level, economic and age structure and density differentials among the study regions. The stepwise regression technique was used with inputs from the 148 sample observations for the purpose of estimating the economic damage functions. The regression results are summarized in Table IV-11. It is noteworthy that all the coefficients of TSP are of correct signs except the one in the second regression equation. Since the partial correlation coefficient between GSCO2 and TSP is positive and equal to 0.18, the negative coefficient obtained for TSP in the regression equation may be attributable to multicolinearity between TSP and other independent variables or other econometric problems or data deficiency.

It is interesting to note that aside from total suspended particulates PCOL, RHM, and MANFV are significant factors in determining the household soiling costs. While the effect of educational level on soiling adjustment cost is ambiguous *a priori*, relative humidity is likely to have a cleansing effect which reduces the soiling costs.

The soiling economic damage functions derived in this study are useful to policymakers at either the local or national level in estimating the marginal and average benefits of implementing a particular pollution abatement program. The responsiveness of gross soiling damages for a particular cleaning task to changes in climatological, demographic, and socioeconomic variables and the concentration level of suspended particulates can be easily estimated. The partial elasticity of the gross soiling costs of, say, cleaning Task 4, i.e., cleaning venetian blinds and shades, with respect to suspended particulate level, can be estimated by

$$E_{SC4,TSP} = \frac{\partial(SC4)}{\partial(TSP)} \cdot \frac{\overline{TSP}}{\overline{SC4}} \qquad \text{(IV-3)}$$

where $\partial(SC4)/\partial(TSP)$ is the coefficient of TSP in the soiling economic damage function with GSCO4 as the dependent variable, and is equal to 160,000. $\overline{TSP}$ and $\overline{SC4}$ are respectively the mean values of total suspended particulates and of soiling damage cost associated with cleaning venetian blinds and shades. Given $\overline{TSP}$ = 94.5 $\mu g/m^3$, and $\overline{SC4}$ = \$24.2 million,

$$E_{SC4,TSP} = 0.16 \times (94.5/24.2) = 0.62$$

Thus, for every 1 percent reduction in suspended particulate level, the soiling damage cost of cleaning venetian blinds would decrease by 0.62 percent, holding other characteristics unchanged. Thus, if the suspended particulate level in the air is lowered by 9.45 $\mu g/m^3$ from 94.5 to 85.5 $\mu g/m^3$ (i.e., 10 percent reduction), gross soiling damage cost associated with cleaning venetian blinds alone, would reduce, on the average, by \$1.5 million from \$24.2 to \$22.7 million nationwide. Of particular policy interest is the estimation of possible benefit in terms of the reduction in the overall soiling damage cost as a result of a pollution control program. Note that the coefficient of TSP in the overall soiling economic damage function is 226,400 and the mean value of overall soiling damage cost is \$117.3 million.

$$E_{SC,TSP} = 226400 \times (94.5/117.300000) = 0.18$$

Thus, if the suspended particulate level is lowered, on the average, by 10 percent, from 94.5 to 85.5 $\mu g/m^3$, overall gross soiling damage cost would reduce by 1.8 percent or by \$2.1 million, from \$117.3 million to \$115.2 million.

SECTION V

MATERIAL AND AIR POLLUTION

PROBLEMS AND OBJECTIVES

The damaging effects of air pollution to materials have been well recognized by the Air Pollution Control Office of the Environmental Protection Agency for some time. Effects of air pollution on materials range from soiling to chemical alteration. Corrosion of metals has attracted the most attention, while many other important areas were found to have been largely neglected. Most materials exhibit a high degree of chemical resistance to oxides of nitrogen, while sulfur dioxides were found to seriously attack about a third of the materials. And while some materials (such as glass) are highly resistant to chemical attack by most air pollutants, certain plastics and metals are highly susceptible to damage by a number of different commonly encountered air pollutants.

Among the adverse effects of air pollution on material included are the corrosion of metals, the deterioration of rubber, the fading of paint and soiling of materials. Many external factors influence the reaction rate between pollutants and materials, with moisture the most important in accelerating corrosion. Inorganic gases are likely to cause tarnishing and corrosion of metals; they can attack various building materials such as stone, marble, slate, and mortar and may deteriorate a variety of natural and synthetic fibers.

The most noticeable effect of particulate pollutants is soiling of the surfaces on which they are deposited. They may also act as catalysts increasing the corrosive reactions between metals and acid gases. Additional damages to surfaces and textiles are incurred by the wear and tear imposed by the extra cleaning made necessary because of particulate soiling. The true economic damage to materials caused by air pollution is difficult to ascertain because of the difficulty of distinguishing between natural deterioration and deterioration caused by air pollution and the uncertainty regarding indirect costs of early replacement of materials worn out by excessive cleaning.

Some of the material damage estimates attributable to air pollution in this country are as follows: In a pilot study by Uhlig (1950), the total corrosion bill was estimated at $5.4 billion, though air pollution was merely implicated as a causal agent of corrosion. Uhlig's estimate was updated and estimated by the Rust-Oleum Corporation (1974) to be $7.5 billion in 1958. Stickney, Mueller and Spence (1971) estimated that the pollution damage cost of rubber to U.S. consumers amounts to at least $398 million. Haynie (1973) estimated a value of $1.4 billion for the cost of corrosion of galvanized steel. The total damage cost due to air pollution inflicted on textiles and fibers was estimated to be $2 billion annually by Salvin (1970).

Robbins (1970) of Stanford Research Institute conducted one of the first major material damage studies and found that the air pollution damage with respect to electric contacts was not as serious as originally estimated. Two types of major costs were investigated. They are the direct cost associated with the plating of contacts with precious metals and the indirect cost incurred because of the preventive measures of air conditioning and air purification. It was estimated that about $65 million is spent annually on electric contacts because of air pollution.

Economic impact of air pollution on electric components was estimated by International Telephone and Telegraph (ITT) Electro-Physics Laboratories (1971). The damage costs to the following electric components were estimated: semiconductor devices, integrated circuits, television picture tubes, connectors, transformers, relays, receiving tubes, and crystals. Total damages to these categories amounted to $15.5 million.

A most comprehensive study on pollution damage on materials was conducted by Midwest Research Institute (Salmon, 1970). The MRI study presented a systematic analysis of all of the physical and chemical interactions between materials, pollutants and environmental parameters. Fifty-three economically important materials which represent about 40 percent of the economic value of all materials exposed to air pollution were identified and selected for the study. An estimated $100 billion in added cleaning costs would be necessary to keep these materials in polluted areas as clean as they would be in a nonpolluted environment, while deterioration of these materials causes yearly direct damage losses of approximately $4 billion. Paint and zinc are the two materials most affected by both soiling and deterioration caused by air pollution, accounting for more than half of the total losses in each category. Based on the MRI estimate, Barrett and Waddell (1974) estimated an annual material deterioration damage in the United States to be $4.75 billion.

Some of the methodological procedures for estimating material effect was critically reviewed by Gillette and Upham (1973). It is generally understood that in order to develop reasonable estimates of pollution damages, the following information is very relevant: (1) geographical and temporal distribution of air quality levels and receptors' exposure to various pollution levels; (2) physical damage functions on important receptors; and (3) data on other socioeconomic, demographic and environmental factors on a regional basis.

Pollution level varies within any given SMSA. In the absence of population-at-risk information, it is usually assumed that the entire SMSA population was exposed to the same pollution level as recorded by the station(s) which in all probability is (are) located in the central city of the SMSA. Cost estimates derived under this assumption tend to overestimate the actual damage due to air pollution, since the pollution concentration level is likely to be higher in the central city than in the suburban areas.

Physical damage functions relating material damage to air pollution have recently been derived in a series of in-house experiments. Haynie and his associates (1974, 1975) obtained such physical dose-response relations separately for different kinds of steels, zinc, oil-base house paint and selected fabrics. Economic damage functions for materials which translate material physical loss into monetary terms, however, are still lacking. Although some damage estimates for certain types of materials at the national level are now available, detailed regional cost estimates on material damages due to air pollution are virtually nonexistent. Since the information on such regional damage costs of air pollution is indispensable for providing guidance for establishing pollution controls, it is imperative to develop a set of comparable damage cost estimates for each as well as a system of economic damage functions on different types of materials.

This section represents a first exploratory effort to estimate not only urban material damages attributable to air pollution for all 148 SMSA's with population greater than 250,000, but also the "average" air pollution damage functions on materials for this country. This section contains the following subsections: A Theoretical Framework, Exposition of Methodology, Regional Material Damage Costs, Economic Damage Functions, and A Summary of Material Physical Damage Functions.

A THEORETICAL FRAMEWORK

A theoretical framework is developed in this section for defining and developing urban economic costs and economic damage functions of materials. The economic costs of a material are defined as the decrease in the values of this particular material as a result of increased contamination in the environment. An economic damage function of material which relates the economic costs to a host of relevant variables including pollution, socioeconomic, demographic and climatological variables is also estimated.

It is noteworthy that materials generally do not directly affect an individual's utility or preferences. Thus, materials can be regarded as "pure" intermediate commodities which are differentiable from the traditional interindustry flows. The pure intermediate commodities utilized the primary inputs, i.e., labor and capital, in their production and are themselves solely utilized as inputs in the production of "final" commodities which enter into one's utility function. Interindustry flows, however, refer to those commodities which are intermediate inputs to be used in other industries as well as final outputs for consumers.

The degree of the effect of air pollution on materials depends on a number of factors: (1) the extent of the reduction in the normal service or use life of material; (2) the frequency of maintenance and preventive measures on the part of users; and (3) the changes in the quality and quantity of the services rendered by the product which contains the materials being affected by air pollution.

Let D_i represent the level of physical deterioration of the ith type of material. SL_i will be the service life, SP_i the service performance, ME_i the maintenance effort of the same ith type of material, and A the air pollution concentration level to which the material is being exposed.

Thus, we can write

$$D_i = D_i \left[SL_i(A),\ SP_i(A),\ ME_i(A);\ e\right] \qquad \text{(V-1)}$$

Equation (V-1) states that the deterioration of the ith type of material is functionally related to SL_i, SP_i and ME_i, directly. Each of the explanatory variables is, however, being influenced by the prevailing pollution levels.

The plausible signs of the partial derivations are as follows:

$$\frac{\partial D}{\partial(SL)} < 0 \ ; \ \frac{d(SL)}{d(A)} < 0$$

$$\frac{\partial D}{\partial(SP)} < 0 \ ; \ \frac{d(SP)}{d(A)} < 0$$

$$\frac{\partial D}{\partial(ME)} > 0 \ ; \ \frac{d(ME)}{d(A)} > 0$$

Thus, $\frac{\partial D}{\partial(SL)} \cdot \frac{d(SL)}{d(A)} > 0$; $\frac{\partial D}{\partial(SP)} \cdot \frac{d(SP)}{d(A)} > 0$; and $\frac{\partial D}{\partial(ME)} \cdot \frac{d(ME)}{d(A)} > 0$.

Assuming noninteractions among the independent variables, total physical damage of material as a result of an increased pollution is expressed as:1/

$$dD = \left[\frac{\partial D}{\partial(SL)} \frac{d(SL)}{d(A)} + \frac{\partial D}{\partial(SP)} \frac{d(SP)}{d(A)} + \frac{\partial D}{\partial(ME)} \cdot \frac{d(ME)}{d(A)}\right] d(A) \qquad \text{(V-2)}$$

Note that changes in SL and SP of the product represent direct damages attributable to pollution, whereas pollution-induced changes in ME are indirect damages due to pollution.

1/ The assumption of noninteraction is made for the sake of simplicity. In the real world, it is observed that service life, performance and maintenance effort are interrelated. Increased maintenance should also increase service life and performance.

A simplified and yet commonly adopted formulation of material physical damage function is written as follows:

$$D_i = D_i(A, RHM; u) \qquad (V-3)$$

where RHM is relative humidity, D and A are the same as in (V-1) and u is the error term.

In order to develop a theoretical framework for estimating economic damage costs of materials, let us assume for the sake of simplicity, but without loss of generality, that there is only one type of material. The initial endowment of this material in a given urban area is M_o. Further, it is assumed that the material stock grows at an exogenously determined rate of r over the planning time horizon.[1/] Thus, total stock of this material in the absence of air pollution in the area at time t is given by:

$$M_g = \int_{t=o}^{t} M_o e^r dt \qquad (V-4)$$

If the area in question is subject to an air pollution level which is above the threshold level, and if the material depreciates at a rate i because of the air pollution, then the net existing material stock at the time t is given by:

$$M_n = \int_{t=o}^{t} M_o e^{(r-i)} dt$$

Note that $i = dD/D$ and $D = D(A; RHM)$ with $\partial D/\partial(A) > 0$. $\partial D/\partial(RHM) \gtrless 0$.

The economic damage of this material (ED) is defined to be that portion of the material loss attributable to air pollution evaluated at the prevailing market prices of the material. Let P_m be the market price of the material, which is determined by the supply and demand conditions for this material.

1/ A more realistic approach is to consider that the growth of stock of a material within an area is endogeneously determined. It is determined by the need for that material within an area and the ability to acquire it. One would expect that the stock growth rate to be a function of population growth rate, per capita income growth rate and the change in demand for that material with respect to replacement material.

Thus,

$$ED = P_m(M_g - M_n) = P_m \int_{t=o}^{t} M_o e^{dD/D(A;RHM)} dt \qquad \text{(V-6)}$$

It may be remarked that (V-6) reflects the economic damage associated with the air pollution level through a change in demand for the material. It does not reflect the economic damage associated with increased flow of the material through the area caused by pollution-induced decreased service life.

It follows from (V-6) that a general economic damage function for material can be expressed as

$$ED = ED(P_m, A, RHM; u) \qquad \text{(V-7)}$$

Those socioeconomic and other variables which influence P_m could be included in the general economic damage function in addition to A and RHM.

EXPOSITION OF METHODOLOGY

Ideally, the information on the distribution of materials, of pollutants, the value of the products made from the materials, the service life of the products in the absence of pollution and the physical dose-response function should be gathered in order to accurately assess economic costs of material deterioration due to excessive air pollution. Empirical data on the distributions of both materials and pollution are unavailable for most urban areas. However, sketchy estimates for product values and the service life have been derived by Fink *et al.* (1971) by resorting to the annual production figures in the Standard Industrial Classification statistics and product useful life statistics issued by Internal Revenue Service. Dose-response functions for a variety of materials have recently been estimated via the technique of in-house controlled experiments.

In the absence of the relevant material and pollution distribution data, an alternative "top-down" method is developed in this section to derive a consistent set of urban economic costs of material damage as a result of air pollution. The existing valuable information on national material damage and the dose-response functions were obtained through literature survey. The national damage estimates were then allocated down to various SMSA's by utilizing the dose-response functions and other relevant regional data.

For the sake of illustration, but without loss of generality, let the physical dose-response function for the ith type of material be written as:

$$D_i = D_i(A, C) \qquad \text{(V-8)}$$

where D, A and C denote, respectively, the physical damage, the air pollution level and climatological conditions.

Given the physical damage function and the national damage estimates, the regional damage costs for the ith type of material can be estimated by using the following formula:

$$RED_{ij} = NED_i \cdot \frac{D_{ij}}{\sum_{j=1}^{n} D_{ij} \Big/ n} \cdot \frac{SE_j}{\sum_{j=1}^{n} SE_j \Big/ n} \qquad \text{(V-9)}$$

where RED_{ij} and NED_i are, respectively, the regional and national economic damage costs for the ith type of material. SE_j stands for the relevant socioeconomic characteristics which are thought to affect material damages, e.g., manufacturing establishments and D_{ij} is the dose-response relation for the ith type of material. The subscript j denotes the jth SMSA.

Substituting (V-8) into (V-9) yields:

$$RED_{ij} = NED_i \cdot \frac{D_{ij}(A_j, C_j)}{\sum_j D_{ij}(A_j, C_j)} \cdot \frac{SE_j}{\sum_j SE_j \; n} \qquad \text{(V-10)}$$

Equation (V-10) can be used to derive the regional economic cost for the ith type of material. The data on NED is available from an earlier material damage study conducted by Salmon (1970) at Midwest Research Institute, and A_j, C_j and SE_j can be respectively secured from the Air Quality Data, published by the Environmental Protection Agency; Local Climatological Data, published by the National Oceanic and Atmospheric Administration; and 1972 County and City Data Book. Substituting the values for NED_i, A_j, C_j, and SE_j into equation (V-10), a series of consistent estimates for material damages for various SMSA's due to air pollution is obtained.

According to the earlier MRI study, material damage as a result of air pollution can be categorized into two major effects: (1) soiling effects attributable to particulate pollutants; and (2) chemical effects attributable to gaseous pollutants. The national soiling cost (SC) and deterioration cost (DC) of various materials were estimated with the aid of the following formulas:

$$SC = SIF \cdot Q \quad (V\text{-}11)$$

$$DC = DIF \cdot Q \quad (V\text{-}12)$$

$$Q = P \cdot N \cdot F \cdot R \quad (V\text{-}13)$$

where SC represents material soiling costs, SIF the soiling interaction factor, Q in-place unprotected material value, DC material deterioration cost, DIF deterioration interaction factor, P annual production value of the material, N economic life of the material based on usage, F weighted average factor for the percentage of the material exposed to air pollution, and R labor factor reflecting the in-place or as-used value of the material.

The rate of soiling interaction factor, SIF, is computed by complex formulas which are different for fibers and nonfibers.1/ The rate of deterioration, DIF, is computed by estimating the difference between the deterioration rate in polluted and unpolluted environments divided by the average thickness of the material.

Finally, it is noted that two methods are generally feasible for estimating regional damage costs. The first method is the "top-down" technique which is to allocate via weighting and adjusting schemes a national damage estimate down to various regions. The second method is the "bottom-up" technqiue which involves direct estimation of the regional damages. The bottom-up method, which incorporates uncertainties of the assumptions into regional estimates generated, was used to derive the damage costs for human health and household soiling adjustment in the preceding three sections. The top-down technique was employed, however, in this study to estimate material damage costs because of the lack of distribution information about materials and pollutants and the technical difficulties encountered in direct estimation of the regional damages.

REGIONAL MATERIAL DAMAGE COSTS

This section is concerned with estimating regional material damages by using the top-down method delineated above. In view of the fact that there are virtually infinite categories of materials, and the fact that zinc and paint are most important from an economic point of view, only these two materials were selected for this study. The damage costs of zinc and paint account for over 50 percent of the total economic damage losses of the 53 economically important materials selected in the earlier MRI study (Salmon, 1970).

1/ The formulas are: $SIF_{fibers} = 0.10\ \Delta f/Rw$ and $SIF_{nonfibers} = 0.10 \Delta f/Rw\rho t$ where Δf is the increased frequency of cleaning due to pollution, R the labor factor, w the material price per pound, ρ the density and t the average thickness.

The soiling and deterioration costs of paint and zinc, and the percentage of these two costs in terms of total costs, are summarized in Table V-1.1/ These figures are admittedly artificial because they were calculated on the assumption that the material would be maintained completely clean at all times. In practice, each individual will have an acceptable level of soiling for each material.

TABLE V-1. SOILING AND DETERIORATING COSTS OF PAINT AND ZINC

	Soiling Cost (SC) (billion \$)	SC/Total SC	Deterioration Cost (DC) (billion \$)	DC/Total DC
Paint	35.0	0.35	1.2	0.31
Zinc	24.0	0.24	0.8	0.20
53 Materials	100.0	0.59	3.8	0.51

The physical dose-response functions for zinc and oil-base house paint are obtained from two recent studies by Haynie and Upham (1970), Spence, Haynie and Upham (1975).

$$\text{Zinc - Corrosion} = 0.001028\ (RH - 48.8)\ SO_2 \qquad \text{(V-14)}$$

$$\text{Paint - Erosion} = 14.32 + 0.01506\ SO_2 + 0.3884\ RH \qquad \text{(V-15)}$$

Recalling equation (V-10), and substituting the above physical dose-response function for zinc, and the relevant socioeconomic data into equation (V-10) yields the estimates of soiling and deterioration cost of zinc for the jth SMSA. Thus,

$$RED^*_{zinc_j} = NED^*_{zinc} \cdot \frac{0.001028(RH_j-48.8)SO_{2_j}}{\sum_{j=1}^{148} (0.001028(RH_j-48.8)SO_{2_j}/148)} \cdot \frac{ME_j}{\sum_j ME_j/148} \qquad \text{(V-16)}$$

$$NED^*_{zinc} = NED_{zinc} \cdot \left(\sum_{j=1}^{148} POP_j/POP_{us} \right) \qquad \text{(V-17)}$$

1/ The estimates are taken from Table XII and Table XIII of the MRI research report, "System Analysis of the Effects of Air Pollution on Materials," Kansas City (January 1970).

where NED^*_{zinc} is the total damage cost of zinc over the 148 SMSA's included for the present study, RH_j and ME_j the relative humidity and manufacturing establishment in the jth SMSA, POP_j and POP_{us} represent, respectively, the population in the jth SMSA and in the whole country.

The earlier MRI study estimated the national soiling and deterioration damage costs of zinc to be $24 billion and $778 million, respectively. Given the ratio of 0.63 which represents the ratio of the 148 SMSA population to the nationwide population in 1974, the soiling and deterioration damage costs of zinc for the 148 SMSA's are calculated as follows:

$24 x 0.63 = $15.12 billion (soiling)

$778 x 0.63 = $496 million (deterioration)

A threshold level of zero $\mu g/m^3$ for SO_2 is implicit in the physical dose-response functions for zinc and paint. Thus, a zero threshold level is used in estimating the regional damage costs of materials. It should be noted that the value of RED^*_{zinc} as calculated from the weighting scheme expressed by (V-16) can be greater than NED^*_{zinc}. Thus, the damage costs for each SMSA are further adjusted by the ratio $(RED_{zinc,\ j} \big/ \sum_{j=1}^{148} RED_{zinc,\ j})$ to preserve the equality between the sum of the regional damage costs obtained via equation (V-16) over the 148 SMSA's and the total damage costs evaluated for the same 148 SMSA's, i.e., NED^*.

Similarly, the soiling or deterioration damage costs of paint for the jth SMSA are computed by using the following formula:

$$RED_{paint,\ j} = NED^*_{paint} \cdot \frac{(14.3 + 0.01506\ SO_{2_j} + 0.3884\ RH_j)}{\sum_{j=1}^{148} (14.3 + 0.01506\ SO_{2_j} + 0.3884\ RH_j)/148} \cdot \frac{HU_j}{\sum_j HU_j/148} \cdot \frac{YP_j}{\sum_j YP_j/148} \qquad (V\text{-}18)$$

$$NED^*_{paint} = NED_{paint} \cdot \left(\sum_{j=1}^{148}\right) POP_j/POP_{us} \qquad (V\text{-}19)$$

where NED^{*}_{paint} is the total cost of zinc over the 148 SMSA's, HU_j and YP_j are housing units and per capita income in the jth SMSA's. POP, SO_2, RH, NED and RED are the same as those in equation (V-15).

The nationwide soiling and deterioration damage costs of paint were estimated in 1970 to be $35 billion and $1.2 billion, respectively. Thus, applying the population ratio of 0.63 to these two estimates, NED* is calculated to be $22 billion and $753 million for soiling and deterioration, respectively. The damage estimates are further adjusted by $RED_{print, j} / (\sum_j RED_{paint, j})$ such that the sum of the damage costs over the 148 SMSA's equals the total damage cost evaluated for these SMSA's by using (V-19).

The soiling and deterioration damage costs of zinc and paint for the 65 large SMSA's and the 83 medium SMSA's are computed by using equations (V-16) through (V-19). The results of the regional damage costs are summarized in Tables V-2 and V-3. Since the national damage figures employed are extremely large because they were estimated on the stringent assumption that the materials would be maintained completely clean at all times, it is not surprising that the top-down method yields relatively large damage figures for the study regions. An examination of the tables reveals that Chicago scores the highest damage costs on zinc among all the 148 SMSA's in both the soiling and deterioration damages (an annual soiling damage of $1.7 billion and deterioration damage of $57 million in 1970). However, regarding the paint damages, New York City, which had an annual soiling and deterioration damage cost of paint of $2.3 billion and $79 million, respectively, surpassed all the SMSA's included in this study.

It should be noted again that the assumptions made in deriving the national damage figures and the physical damage functions in the earlier studies are inherited by this study, especially the theoretically maximum national damage estimates in both categories of soiling and deterioration. Should there be changes in these assumptions, the estimates developed and presented in the table would be modified accordingly. Thus, the results presented in this section are only suggestive and tentative. Given the tentativeness and experimental nature of the methodological and statistical procedures, and the degree of uncertainty associated with the estimates, a great deal of caution should be exercised in using the product of this research.

ECONOMIC DAMAGE FUNCTIONS

In order to develop marginal equivalent economic damage functions which can be used for damage (benefit) prediction and for designing pollution control strategies, the economic costs of material soiling and deterioration are regressed not only against SO_2 and relative humidity, but also against other relevant socioeconomic and climatological variables. The stepwise regression technique was used with inputs from the 148 sample observations for estimating the economic damage functions. The regression results for soiling and deterioration damages of zinc and paint are presented in Table V-4. Consistent with *a priori* expectation, the coefficients of ME, SO_2, TSP, RH, HU and YP are all positive, and the coefficient of SUN has ambiguous signs depending on the type

TABLE V-2. MATERIAL DAMAGE BY LARGE SMSA's, 1970
(in million $)

Large SMSA's	Soiling Damage Cost of Zinc (SDCZ)	Deteriorating Damage Cost of Zinc (DDCZ)	Soiling Damage Cost of Paint (SDCP)	Deteriorating Damage Cost of Paint (DDCP)
1. AKR, OH	108.0	3.533	107.0	3.684
2. ALB, NY	54.0	1.751	121.0	4.141
3. ALL, NJ	16.5	0.537	85.6	2.925
4. ANA, CA	62.6	2.029	279.0	9.542
5. ATL, GA	25.2	0.818	224.0	7.667
6. BAL, MD	190.0	6.166	320.0	10.900
7. BIR, AL	12.9	0.421	98.8	3.374
8. BOS, MA	289.0	9.395	480.0	16.300
9. BUF, NY	32.8	1.064	219.0	7.503
10. CHI, IL	1,770.0	57.600	1,350.0	46.300
11. CIN, OH-KY-IN	134.0	4.372	225.0	7.716
12. CLE, OH	1,110.0	36.000	392.0	13.300
13. COL, OH	91.5	2.969	153.0	5.239
14. DAL, TX	15.3	0.496	273.0	9.343
15. DAY, OH	125.0	4.080	145.0	4.952
16. DEN, CO	--	--	167.0	5.728
17. DET, MI	910.0	29.500	741.0	25.300
18. FOR, FL	8.8	0.284	158.0	5.414
19. FOR, TX	11.9	0.387	127.0	4.352
20. GAR, IN	144.0	4.680	94.0	3.217
21. GRA, MI	29.4	0.955	81.9	2.798
22. GRE, NC	18.8	0.611	86.0	2.937
23. HAR, CT	19.1	0.621	140.0	4.792
24. HON, HI	2.3	0.078	83.7	2.860
25. HOU, TX	28.6	0.929	338.0	11.500
26.. IND, IN	79.3	2.572	192.0	6.563
27. JAC, FL	2.1	0.068	70.8	2.418
28. JER, NJ	128.0	4.152	101.0	3.475
29. KAN, MO-KS	122.0	3.956	229.0	7.824
30. LOS, CA	730.0	23.600	1,530.0	52.300
31. LOU, KY-IN	171.0	5.545	127.0	4.345
32. MEM, TN-AR	17.3	0.563	94.5	3.227
33. MIA, FL	24.6	0.800	239.0	8.164
34. MIL, WI	178.0	5.799	247.0	8.435
35. MINN, MN	32.5	1.054	307.0	10.500
36. NAS, TN	12.6	0.411	80.8	2.759
37. NEW, LA	25.6	0.832	147.0	5.035
38. NEW, NY	1,040.0	34.000	2,310.0	79.100
39. NEW, NJ	94.9	3.077	327.0	11.100
40. NOR, VA	10.3	0.335	81.4	2.781

Note: -- denotes damage of value less than $0.5 million.

TABLE V-2 (Concluded)

Large SMSA's	SDCZ	DDCZ	SDCP	DDCP
41. OKL, OK	2.6	0.083	106.0	3.641
42. OMA, NE-IA	13.3	0.434	85.1	2.907
43. PAT, NJ	101.0	3.292	271.0	9.271
44. PHI, PA-NJ	520.0	16.800	767.0	26.200
45. PHO, AZ	--	--	90.5	3.091
46. PIT, PA	504.0	16.300	386.0	13.200
47. POR, OR-WA	36.3	1.780	179.0	6.116
48. PRO, RI-MA	137.0	4.518	140.0	4.798
49. RIC, VA	18.7	0.061	78.7	2.688
50. ROC, NY	57.1	1.852	151.0	5.516
51. SAC, CA	--	--	114.0	3.900
52. SAI, MO-IL	308.0	10.000	411.0	14.000
53. SAL, UT	--	--	58.8	2.011
54. SAN, TX	1.8	0.060	97.2	3.321
55. SAN, CA	12.1	0.393	198.0	6.760
56. SAN, CA	9.8	0.316	224.0	7.670
57. SAN, CA	57.3	1.858	725.0	24.700
58. SAN, CA	26.7	0.868	199.0	6.826
59. SEA, WA	143.0	4.641	293.0	10.000
60. SPR, MC-CT	15.3	0.498	75.6	2.584
61. SYR, NY	40.4	1.311	104.0	3.557
62. TAM, FL	13.3	0.432	175.0	5.975
63. TOL, OH-MI	28.4	0.922	108.0	3.712
64. WAS, DC-MD-VA	38.4	1.246	578.0	19.700
65. YOU, OH	152.0	4.946	84.9	2.900
Total	10,114.4	328.651	18,272.3	624.854

Note: -- individual figure may not add to totals due to rounding.

TABLE V-3. MATERIAL DAMAGE BY MEDIUM SMSA's, 1970
(in million $)

Medium SMSA's	SDCZ	DDCZ	SDCP	DDCP
66. ALB, NM	--	--	29.6	1.014
67. ANN, MI	572.0	18.500	46.2	1.580
68. APP, WI	0.0	0.000	39.7	1.357
69. AUG, GA-SC	2.3	0.076	26.5	0.905
70. AUS, TX	3.3	0.107	44.8	1.532
71. BAK, CA	-2.9	-0.095	35.9	1.228
72. BAT, LA	75.8	2.459	38.5	1.317
73. BEA, TX	164.0	5.342	49.1	1.678
74. BIN, NY-PA	93.4	3.030	47.9	1.638
75. BRI, CN	155.0	5.041	70.3	2.404
76. CAN, OH	287.0	9.332	59.0	2.016
77. CHA, SC	3.8	0.122	32.1	1.096
78. CHA, WV	76.6	2.485	33.6	1.148
79. CHA, NC	119.0	3.859	65.1	2.224
80. CHA, TN-GA	96.6	3.134	43.9	1.501
81. COL, CO	--	--	24.8	0.849
82. COL, SC	7.7	0.251	34.8	1.189
83. COL, GA-AL	20.5	0.665	26.5	0.905
84. COR, TX	5.9	0.192	112.0	3.831
85. DAV, IA-IL	34.6	1.123	60.3	2.060
86. DES, IA	28.1	0.912	52.0	1.778
87. DUL, MN-WI	31.4	1.020	43.9	1.501
88. ELP, TX	--	--	24.3	0.830
89. ERI, PA	131.0	3.924	37.0	1.264
90. EUG, OR	41.0	1.332	33.2	1.135
91. EVA, IN-KY	104.0	3.389	34.7	1.186
92. FAY, NC	4.6	0.150	19.1	0.653
93. FLI, MI	0.0	0.0	76.4	2.609
94. FOR, IN	67.2	2.180	46.5	1.591
95. FRE, CA	--	--	46.7	1.596
96. GRE, SC	30.2	0.979	37.6	1.287
97. HAM, OH	22.2	0.722	32.3	1.106
98. HAR, PA	6.7	0.218	62.7	2.143
99. HUN, WV-KY,OH	91.4	2.965	34.8	1.190
100. HUN, AL	38.8	1.260	31.1	1.065
101. JAC, MS	2.7	0.086	28.7	0.980
102. JOH, PA	2.4	0.081	32.3	1.104
103. KAL, MI	45.2	1.466	32.3	1.106
104. KNO, TN	46.9	1.523	55.3	1.889
105. LAN, PA	62.6	2.032	45.0	1.539
106. LAN, MI	118.0	3.839	61.0	2.085
107. LAS, NV	--	--	29.7	1.015
108. LAW, MA-NH	162.0	5.270	42.3	1.444
109. LITT, AK	12.3	0.399	46.2	1.579
110. LOR, OH	17.8	5.771	37.9	1.297

TABLE V-3 (Concluded)

Medium SMSA's	SDCZ	DDCZ	SDCP	DDCP
111. LOW-MA	151.0	4.924	31.2	1.067
112. MAC, GA	2.8	0.089	25.5	0.871
113. MAD, WI	18.5	0.602	49.1	1.678
114. MOB, AL	34.7	1.126	42.8	1.464
115. MON, AL	2.9	0.092	24.7	0.845
116. NEW, CN	66.3	2.152	64.4	2.200
117. NEW, CN	42.8	1.388	32.3	1.106
118. NEW, VA	5.3	0.174	39.8	1.359
119. ORL, FL	18.5	0.601	62.4	2.132
120. OXN, CA	22.5	0.732	57.2	1.954
121. PEN, FL	34.6	1.122	30.3	1.037
122. PEO, IL	240.0	7.782	61.4	2.099
123. RAL, NC	10.9	0.355	30.6	1.046
124. REA, PA	90.6	2.939	48.3	1.650
125. ROC, IL	56.8	1.843	48.3	1.651
126. SAG, MI	56.3	1.828	32.1	1.099
127. SAL, CA	5.0	0.164	36.9	1.261
128. SAN, CA	11.6	0.377	44.8	1.531
129. SAN, CA	14.9	0.485	38.9	1.329
130. SCR, PA	25.8	0.838	31.1	1.065
131. SHR, LA	38.5	1.249	38.3	1.310
132. SOU, IN	154.0	4.993	46.4	1.587
133. SPO, WA	--	--	38.6	1.318
134. STA, CN	84.6	2.744	63.0	2.153
135. STO, CA	--	--	37.8	1.292
136. TAC, WA	35.0	1.137	63.7	2.176
137. TRE, NJ	18.6	0.604	48.3	1.651
138. TUC, AZ	--	--	32.9	1.126
139. TUL, OK	473.0	15.300	97.4	3.328
140. UTI, NY	97.7	3.169	50.7	1.733
141. VAL, CA	11.0	0.357	39.3	1.345
142. WAT, CN	8.7	0.282	31.8	1.087
143. WES, FL	3.8	0.122	79.1	2.702
144. WIC, KS	25.4	0.824	62.5	2.136
145. WIL, PA	60.3	1.956	46.0	1.572
146. WIL, DE-NJ-MD	96.1	3.117	78.0	2.663
147. WOR, MA	201.0	6.537	56.1	1.918
148. YOR, PA	9.7	0.313	49.6	1.695
Total	5,005.5	168.309	3,777.8	127.996

Note: -- individual figure may not add to totals due to rounding.

TABLE V-4. ECONOMIC DAMAGE FUNCTIONS ON MATERIALS[a/]

SDCZ $\quad -23{,}328.4 + 43.1\ ME + 943.3\ SO_2 + 148.1\ TSP - 235.0\ SUN$

(19,929) (3.4)* (171.6)* (356.0)* (1820.4)

$+ 2{,}679.3\ RHM + 21.9\ YP \qquad R^2 = 0.64$ (V-20)

(1,750.2) (18.9)

DDCZ $\quad = 7{,}562.2 + 1.4\ ME + 30.5\ SO_2 + 47.9\ TSP - 76.2\ SUN$

(6,460.4) (0.1)* (5.5)* (11.5)* (59.0)

$+ 86.8\ RHM + 712.6\ YP \qquad R^2 = 0.63$ (V-21)

(56.7) (615.5)

SDCP $\quad = -141{,}199.7 + 577.2\ HU + 15.2\ YP + 911.3\ RHM + 69.1\ SO_2$

(259.861.3) (3.4)* (2.6)* (235.3)* (23.2)*

$+ 305.3\ SUN \qquad R^2 = 0.995$ (V-22)

(245.9)

DDCP $\quad = -4{,}820.1 + 19.7\ HU + 0.5\ YP + 31.1\ RHM + 2.3\ SO_2 + 10.4\ SUN$

(887.2)* (0.1)* (0.08)* (8.0)* (0.8)* (8.4)

$R^2 = 0.995$ (V-23)

---

a/ The values below the coefficients are standard errors with * to indicate that the coefficients are significant at the 1 percent level. All coefficients and standard errors are reduced by a factor of 10^3.

of material. The coefficients of ME, SO_2, and TSP are significant at the 1 percent level in equations (V-20) and (V-21), whereas the coefficients of HU, YP, RH and SO_2 are significant at the 1 percent level in equations (V-22) and (V-23).

The economic damage functions on zinc and paint summarized in Table V-4 were estimated simply for national decisionmaking. They offer some short-cut techniques for rough computations and can be used in determining the marginal as well as average damages (benefits) resulting from a pollution control strategy. To serve as an illustration, an example involving the computation of the partial elasticity of SDCZ with respect to SO_2, and the associated marginal benefit due to a reduction in SO_2, is presented. Suppose the federal government is contemplating the implementation of a pollution abatement program which is expected to reduce the average SO_2 level in the urban areas by, say, 10 percent. A question arises as to what the dollar benefit will be for the reduction in soiling damage of zinc as a result of the pollution control program. Since the average gross soiling damage due to SO_2 is \$102 million and the average SO_2 level is 55.73 $\mu g/m^3$ among the 148 SMSA's, the partial elasticity of the damage cost with respect to SO_2 is obtained:

$$E_{c,SO_2} = 0.9433 \times (55.73/102) = 0.52.$$

Thus, it is in general expected that a 10 percent decrease in the SO_2 concentration level will result in a 5.2 percent reduction in the soiling damage cost cost of zinc. Since the mean value of the regional damage cost for the 148 SMSA's included in this study is \$102 million, when the SO_2 level decreases from 55.73 $\mu g/m^3$ to 50.16 $\mu g/m^3$, it is also expected that on the average the damage cost will be reduced by the amount of \$102 million x 5.2% = \$5.73 million. Likewise, the elasticities for the other dependent variables with respect to SO_2 and other explanatory variables can be analogously computed and interpreted.

A SUMMARY OF MATERIAL PHYSICAL DAMAGE FUNCTIONS

After a careful review of the literature, some recent publications as well as many unpublished manuscripts were identified as major sources providing useful information for our future on material damage. The damage resulting from air pollution includes corrosion of metals, deterioration of paints and materials, fading of fabric dyes, etc. It is also worth noting that the physical damage functions expressed in equations (V-30) and (V-32) below were utilized in deriving the economic damage estimates in the preceding section.

Major Pollution and Material Interactions

Fred H. Haynie (1974), based on an MRI study, summarized in Table V-5 the relative extent to which effects of pollutants on materials are known. Haynie considered an effect (1) "well established" when evidence was corroborated by several high quality references; (2) "some evidence" in the presence of one or two references; and (3) "suspected" when interactions are based on behavior of material at pollutant level much higher than the ambient level.

TABLE V-5. MAJOR POLLUTANT - MATERIAL INTERACTIONS

Pollutants	Material				
	Metals	Paints	Textile	Elastomers	Plastics
Sulfur dioxide	1	2	1	--	3
Particulate	2	1	2	--	--
Ozone	2	2	1	1	3
Nitrogen dioxide	2	3	1	3	3
Hydrocarbons	--	3	--	--	--

Metals--

Steel, SO2 and Photochemical Oxidant--Haynie and Upham (1971) conducted an in-house field study of the effect of atmospheric pollutants on steel corrosion, Good dose-response relationships were estimated as follows:

Carbon steel

$$y = A.013 \left[e^{0.00161\, SO_2} (4.768t)^{0.7512 - 0.00582\, OX} \right] \quad (V\text{-}24)$$

Copper bearing steel

$$y = 8.341 \left[e^{0.00171\, SO_2} (4.351t)^{0.8151 - 0.00642\, OX} \right] \quad (V\text{-}25)$$

Weathering steel

$$y = 8.876 \left[e^{0.0045\, SO_2} (3.389t)^{0.6695 - 0.00544\, OX} \right] \quad (V\text{-}26)$$

Y is the depth of corrosion in microns (m); SO_2 and OX are expressed in $\mu g/m^3$; t is time.

Enameling Steel, Sulfate in Suspended Particulate--Haynie and Upham (1974) in a companion paper examined correlation between erosion behavior of steel and gaseous SO_2, total suspended particulate, sulfate in suspended particulate, and nitrate in suspended particulate. Multiple linear regression and nonlinear curve fitting techniques were used to analyze the relationship between corrosion of enameling steel and the atmospheric data. The resulting best empirical function has the form:

$$\text{Corrosion} = 183.5 \sqrt{t}\ \text{EXP}\ [0.06421\ \text{Sul} - 163.21/\text{RH}] \qquad \text{(V-27)}$$

where

corrosion = depth of corrosion, μm

t = time, years

Sul = average level of sulfate in suspended particulate ($\mu g/m^3$) or average level of sulfur dioxide ($\mu g/m^3$)

RH = average relative humidity

The statistical analysis shows that differences in average temperature, average total suspended particulate, and average nitrate in suspended particulate exert insignificant effects on steel's corrosion behavior. Covariance between sulfate and SO_2 and the relative accuracies of the two sets of data make it impossible to statistically identify the causative agent. Laboratory experiments suggest that SO_2 is the major cause.

Galvanized Steel and SO_2--In an unpublished paper, Spence, Upham, and Haynie (1975) derived a dose-response relation for galvanized steel, SO_2, NO_2 and Ozone in controlled environmental chambers. Of the three pollutants, SO_2 was shown to be a major factor in determining the corrosion rate of galvanized steel. The corrosion of the galvanized panels fits the relationship:

$$\text{Corr} = (d_0\ SO_2 + e^{b - E/RT})\sqrt{t_w} \qquad \text{(V-28)}$$

where Corr = corrosion in micrometer (μm)

$d_0 = 0.0187$, $b = 41.85$, $E = 23{,}240$

t_w = time of wetness

Weathering Steel, SO_2, Relative Humidity and Temperature--A similar chamber study for weathering steel was conducted by Spence, Haynie, and Upham (1975b) who developed a corrosion function that accounts for 99 percent of the variability for the clean air and pollutant experimental data.

$$\text{Corr} = \left[5.64 \sqrt{SO_2} + e^{(55.44 - \frac{31,150}{RT})}\right]\sqrt{t_w} \qquad \text{(V-28)}$$

where

SO_2 is $\mu g/m^3$

R is 1.9872 cal/g - mole °K

T is the goemetric mean temperature of the specimen when wet in ^{o}K

t_w is time of wetness in years

This chamber has shown that SO_2 is a major factor determining the corrosion of weathering steel.

Zinc and SO_2--Haynie and Upham (1970) have shown that the amount of SO_2 in the air is the major factor in determining the rate of corrosion of zinc. They found that little zinc corrosion would occur in an environment in which SO_2 was not present.

The dose-response relationship between zinc corrosion rate and SO_2 was estimated as follows:

$$Y = 0.00104\ (RH - 49.4)\ SO_2 - 0.00664\ (RH - 76.5) \qquad (V\text{-}30)$$

or alternatively, $Y = 0.001028\ (RH - 48.8)\ SO_2$

where

Y = zinc corrosion rate, μm/year

RH = average relative humidity, percentage

SO_2 = average sulfur dioxide concentration, $\mu g/m^3$

Pitting of Galvanized Steel--J. W. Spence and F. H. Haynie (1974) exposed specimens of galvanized steel to polluted and clean air in controlled environmental chambers. They found that corrosion of the zinc films was essentially a linear function of time for polluted and clean air condition. Uniform corrosion of the zinc occurred in the polluted exposures, whereas pitting corrosion of the zinc was observed in the clean air exposures.

The pitting corrosion, expressed as a uniform thickness loss, fits the relationship:

$$Corr = t_w \exp\left[30.53 - (16{,}020/RT_m)\right] \qquad (V\text{-}31)$$

where

Corr = amount of pitting corrosion (μm)

t_w = time of wetness, years

T_m = geometric mean specimen temperature when wet, ^oK

Catastrophic Failure of Metals--Air pollution has contributed to the catastrophic failure of metal structure. John Gerhard and Fred H. Haynie (1974) estimated the loss of metal failure to be between $50 million and $100 million annually for the United States. The dose-response relationship between air pollution and the occurrence of catastrophic failure of metals has not been established in the literature.

Three types of catastrophic failure of metals that are associated with environmental corrosion were identified: (1) stress-corrosion cracking, (2) corrosion fatigue, and (3) hydrogen embrittlement. Notable examples of problem areas involve failure of essential structures, aircraft and aerospace components, and communication equipment.

In the case of a 40 percent reduction in pollution, the per capita cost would drop from the present level of $7.10 to $4.36 by 1980. Assuming a 60 percent reduction in pollution, the per capita cost will drop from $7.10 to $2.20 in 1980.

Air Pollution Corrosion Costs on Metals--Fink, Buttner and Boyd (1971) examined air pollution corrosion costs on metals in the United States from both technical and economic viewpoints. They calculated corrosion costs for the nine major categories which were most sensitive to and most damaged by air pollution corrosion. The grand total cost was estimated at $1.45 billion, or approximately $7.10 per person per year.

Fink, Buttner and Boyd considered SO_2 as the most important pollutant from a corrosion point of view. They projected the damage costs of metals due to SO_2 under a variety of SO_2 concentration levels for 1980. The annual loss would increase from the present $1.45 billion to $2.1 billion by 1980 if there is a 55 percent increase in pollution. A 10 percent increase in SO_2 level would result in an increase in annual loss by $0.3 billion to $1.73 billion in 1980.

Paint

Paint Technology and Air Pollution--

J. W. Spence and F. H. Haynie (1972a) in their recent survey on paint technology and air pollution, identified the characteristics of pollutant attacks on exterior paints, and estimated the annual cost of air pollutant damage to such paints. They assessed the chemical damage of air pollutants for four classes of exterior paints: (1) household, (2) automotive refinishing, (3) coil coating, and (4) maintenance. The cost at the consumer level is more than $0.7 billion annually. Household paints sustain damage representing 75 percent of the total annual dollar loss.

Exterior Paint, SO_2, and Particulates--

Spence and Haynie (1972b) investigated the deterioration of exterior paints due to SO_2 and particulate matter, and the associated potential economic loss to manufacturers and consumers. A breakdown of the damage loss of exterior paints is summarized as follows:

	Loss at Consumer Level (million $)
Coil coating	16
Automotive refinishing	88
Maintenance	60
Household	540
Total	704

Oil Base House Paint, Acrylic Latex House Paint, Vinyl Coil Coating and Acrylic Coil Coating--

A chamber study of the effects of gaseous pollutants on paints was carried out by J. Spence, F. Haynie, and J. Upham (1975c). Regression analysis showed that SO_2 concentration and relative humidity accounted for 61 percent of the variability in the case of oil base house paint which experienced the highest erosion rates. Vinyl and acrylic coil coatings experienced very low erosion rates.

The multiple linear regression of oil base house paint on SO_2 concentration and relative humidity gave the relationship:

$$\text{erosion rate} = 14.323 + 0.01506\ SO_2 + 0.3884\ RH \qquad \text{(V-32)}$$

where erosion rate is μm/year

SO_2 is $\mu g/m^3$

RH is percent relative humidity

In the case of vinyl and acrylic coil coating, the regression equations are respectively given by:

$$\text{erosion rate} = 2.511 \pm 1.597 \times 10^{-5}\ RH \times SO_2 \qquad \text{(V-33)}$$

and

$$\text{erosion rate} = 0.159 + 0.000714\ O_3 \qquad \text{(V-34)}$$

where O_3 is in $\mu g/m^3$.

Fabric Fading

Selected Drapery Fabrics and NO_2--

Upham, Haynie and Spence (1975) have studied and assessed the fading characteristics of three drapery fabrics after exposure to air pollutants and other environmental factors in the chamber. The experimental results indicated that NO_2 is a major factor in determining the fading rate for one of the fabrics, a plum-colored cotton duck material. The other two fabrics did not fade significantly in the presence of the air pollutants.

The dose-response relationship for the plum fabric was estimated as follows:

$$\Delta E = 30 \left[1 - EXP(-(257 + 3.38 \times 10^{-5} M \times NO_2)t)\right] \qquad \text{(V-35)}$$

where

ΔE = amount of fading, fading units

M = amount of moisture, $\mu g/m^3$, at $25^\circ C$ and one atmosphere

NO_2 = $\mu g/m^3$

t = exposure time, year

$R^2 = 0.70$

Dyed Fabrics, NO_2, Ozone, SO_2 and Nitric Oxide--

Beloin (1973) assessed 20 dye-fabric combinations which were exposed to two levels each of NO_2, ozone, SO_2 and nitric oxide, at four combinations of temperature and humidity for a period of 12 weeks. The study showed that NO_2, ozone and, to a lesser extent, SO_2, can cause appreciable dye fading, and that nitric oxide has little or no effect. In an earlier article, Beloin (1972) evaluated the color fastness of 67 dye-fabric combinations exposed to atmospheric gases. Multiple regression analysis of pollutant concentrations indicated that SO_2, NO_2 and ozone are major factors determining fabric fading.

Rubber, Ozone, Nitrogen

Stickney, Mueller and Spence (1971) estimated the yearly cost of air pollution damage to rubber industry. The total estimated cost at the consumer level is at least \$500 million yearly. Of this, \$398 million can be accounted for in detail. Mueller and Stickney (1970) identified ozone as the only major pollutant to shorten the life of rubber products. SO_2 is not known to have harmful effects on rubber products.

Soiling and Suspended Particulates

Beloin and Haynie (1975) studied the soiling of building materials. Six building materials were exposed at five sites in Birmingham, Alabama, to determine the rate of soiling by different levels of suspended particulate. Excellent dose-response relationships were obtained for the white-surfaced painted cedar siding and asphalt shingles. Similar regressions for brick can account for 34 to 50 percent of variability. Poor correlations were obtained for concrete, limestone, and window glass. The regression results are summarized in Table V-6.

Material Damage

Material Damage From SO_2--

An overall assessment of material damage from SO_2 was made by Gillette and Upham (1973) and is summarized as follows:

Metals--Corrosion of metals by acids derived from airborne SO_2 is most important. Zinc and steel are particularly vulnerable to attack by atmospheric SO_2.

Cotton Fabrics--Not significant since most cotton fabrics are not exposed continuously to the external environment.

Synthetic Fabrics and Blends--Not significant with the exception of nylon hosiery.

Dye Fading--Unimportant at present SO_2 concentrations.

Paper and Leather Products--Strongly influenced by SO_2, tend to disintegrate or discolor after prolonged exposure to relatively high levels of SO_2.

Plastics--Little is known about the effects of SO_2 on plastics.

Concrete, Marble, Roofing Slate, Mortar and Other Limestone--Subject to attack from acids derived from SO_2. Most of the concrete and limestone used in the construction of highways and buildings in the United States is not seriously affected by the present level of atmospheric SO_2.

In assessing the damage loss resulting from SO_2, the following observations are noteworthy:

- Most materials are not substantilly damaged when pollution levels are less than 250 $\mu g/m^3$.

TABLE V-6. RESULTS OF REGRESSION ANALYSIS FOR SOILING OF BUILDING MATERIALS AS A FUNCTION OF SUSPENDED PARTICULATE DOSE

Material	Independent variable	N	A	B	S^2_A	S^2_B	S^2_E	R^2	Remarks
Oil Base Paint	$\sqrt{SP(\mu g/m^3) \times t(months)}$	400	89.43	-0.2768	0.0641	0.000069	7.6510	0.745	Excludes all data beyond 12 months
Tint Base Paint	Ditto	400	86.13	-0.2618	0.0571	0.000061	6.8265	0.738	Ditto
Sheltered Acrylic Emulsion Paint	"	400	91.54	-0.593	0.1156	0.000123	13.8143	0.880	"
Acrylic Emulsion Paint	"	720	90.79	-0.4131	0.0497	0.000026	8.3791	0.902	
Shingles	$\frac{SP(\mu g/m^3) \times t(years)}{10}$	48	41.69	-0.331	0.1895	0.000312	3.8685	0.884	Excludes 2 24 month Tarrant readings
Shingles	$\sqrt{SP(\mu g/m^3) \times t(months)}$	48	43.50	-0.199	0.5771	0.000258	7.6992	0.769	Ditto
Concrete	Ditto	160	41.45	-0.0458	0.1338	0.000080	7.5011	0.143	
Coated Limestone	"	80	44.57	+0.0779	0.2464	0.000164	6.9046	0.347	
Uncoated Limestone	"	80	46.99	-0.0503	0.1500	0.000089	4.2035	0.266	
Coated Red Brick	"	80	12.95	-0.0296	0.0223	0.000013	0.6255	0.459	
Uncoated Red Brick	"	80	14.88	-0.0374	0.0331	0.000020	0.9274	0.477	
Coated Yellow Brick	"	80	45.05	-0.1133	0.5337	0.000317	14.9533	0.342	
Uncoated Yellow Brick	"	80	43.21	-0.1133	0.2740	0.000168	7.6773	0.503	
Glass	"	45	0.2806	+0.0314	0.008077	0.000007	0.6851	0.340	Haze readings including 3 periods for right panes prior to 12 months

N Number of data sets (dependent upon the number of controlled variables in the factorial experiment)
A Intercept of linear regression
B Slope of linear regression
S^2_A Estimated variance of intercept
S^2_B Estimated variance of slope
S^2_E Residual variance (error)
R^2 Correlation index (fraction of variability accounted for by regression)
SP Suspended particulate

- Given the present SO_2 levels, damage to most materials other than certain ferrous and nonferrous metals is probably not significant.

- The only important materials adversely affected by SO_2 are iron, steel and zinc products.

- There are two important factors determining the corrosion rate for galvanized products: (1) relative humidity, and (2) SO_2 level.

- The relationship between SO_2 and damage to paint is not as clear as it is between SO_2 and corrosion to galvanized products.

- The threshold or minimum level of SO_2 required to produce an economic loss ≥ (10 $\mu g/m^3$). For lack of better data, it is reasonable to assume a threshold level of 20 $\mu g/m^3$ before any loss is achieved.

Finally, to recapitulate, the various physical dose-response relationships for metals, paints, fabrics, and building materials are summarized in Table V-7.

TABLE V-7. PHYSICAL DAMAGE FUNCTIONS FOR MATERIALS

Material	Dose - Response Relationships	R^2
1. Metals		
A. Steel - Carbon steel	$Y = 9.013 \left[e^{0.00161\ SO_2}\right]\left[(4.768t)^{0.7512\ -\ 0.00582\ OX}\right]$	0.91
Copper-bearing steel	$Y = 8.341 \left[e^{0.00171\ SO_2}\right]\left[(4.351t)^{0.8151\ -\ 0.00642\ OX}\right]$	0.91
Weathering steel A	$Y = 8.876 \left[e^{0.0045\ SO_2}\right]\left[(3.389t)^{0.6695\ -\ 0.00544\ OX}\right]$	0.91
Weathering steel B	$corr = \left[5.64 \sqrt{SO_2} + e^{(55.44\ -\ 31,150/RT)}\right]\sqrt{t_w}$	0.91
Enameling steel A	$corr = 183.5 \sqrt{t}\, e^{[0.06421\ Sul - 163.21/RH]}$	
Enameling steel B	$corr = 325 \sqrt{t}\, e^{[0.00275\ SO_2\ -\ (163.2/RH)]}$	
Galvanized steel	$corr = \left[0.0187\ SO_2 + e^{41.85\ -\ 23,240/RT}\right]\sqrt{t_w}$	0.9[illegible]
B. Zinc	$Y^* = 0.001028\ (RH - 48.8)\ SO_2$	0.9[illegible]
2. Paints		
A. Oil base house paint	erosion rate = 14.323 + 0.01506 SO_2 + 0.3884 RH	0.6

B. Vinyl coil coating	erosion rate = $2.511 \pm 1.597 \times 10^{-5}$ RH x SO_2	0.34
C. Acrylic coil coating	erosion rate = 0.159 + 0.000714 O_3	
3. Fabrics - Plain fabric	$\Delta E = 30 \left[1-e^{-(2.57 + 3.38 \times 10^{-5} M \times NO_2)t}\right]$	0.70
4. Soiling of Building Material		
A. Oil base paint	Reflectance = 89.43 - 0.2768 $\sqrt{SP \times t^*}$	0.74
B. Tint base paint	Reflectance = 86.13 - 0.2618 $\sqrt{SP \times t^*}$	$R^2 = 0.738$
C. Sheltered acrylic emulsion paint	Reflectance = 91.54 - 0.593 $\sqrt{SP \times t^*}$	$R^2 = 0.88$
D. Acrylic emulsion paint	Reflectance = 90.79 - 0.4131 $\sqrt{SP \times t^*}$	$R^2 = 0.902$
E. Shingles	Reflectance = 43.50 - 0.199 $\sqrt{SP \times t^*}$	$R^2 = 0.769$
F. Coated yellow brick	Reflectance = 43.21 - 0.1133 $\sqrt{SP \times t^*}$	$R^2 = 0.503$

where
Y = depth of corrosion in microns (μ)
SO_2 = μg/m³
OX = μg/m³
t = time, years
corr = depth of corrosion in micrometer (μm)
sul = average level of sulfate in suspended particulate (μg/m³)
RH = average relative humidity, percent
tw = time of wetness
R = 1.9872 cal/g - mole °K
T = geometric mean temperature of the specimen when wet in °K
Y* = Zinc corrosion rate, μm/year
Erosion rate = μm/year
O_3 = Ozone, μg/m³
ΔE = amount of fading, fading units
M = amount of moisture, μg/m³ at 25°c and one atmosphere
NO_2 = μg/m³
Reflectance = a measure of soiling, percent
SP = suspended particulate (μg/m³)
t* = time, months

SECTION VI

VEGETATION AND AIR POLLUTION

PROBLEMS AND OBJECTIVES

Air pollution is a fact of contemporary life. It is not only deleterious to human health, material, and household and commercial establishments as discussed in the preceding sections, but it is also recognized as a causal agent of damage to vegetation. Urban expansion and industrialization have resulted in deteriorated air quality in many major cities in the United States. Though social concern with the problem of contaminated air can be dated back to as early as the 13th century, the biological effects of degraded air are not thoroughly understood even now. Some progress has been made, however, in recent years. According to Naegele (1973), laboratory and chamber studies of individual plants under somewhat controlled environments have contributed to the awareness of the complexity of plant response to toxicants. Acute and even chronic responses of plants to deteriorated air are being studied and documented.

There are three principal air pollutants of major interest to agricultural plants; namely, sulfur dioxide, fluorine compounds and smog. Regarding smog, there are two distinct types, with numerous intermediate grades: the London type, which is a mixture of coal smoke, fog and sulfur dioxide, and the Los Angeles type which is a mixture of ozone and peroxidized organic compounds.1/

Studies on the effect of sulfur dioxide (SO_2) on vegetation are voluminous. Stoeckhard (1871) reported SO_2 injury to plants as early as 1871. Since then more than 700 articles have been published regarding the effects of SO_2 upon vegetation. The documents point to a great variation in plant responses to the pollutant. This variation in plant responses can be accounted for by such factors as genetic composition, stage of development, climatic factors, interactions between pollutants, the time of day of exposure, and soil moisture.

The effects of air pollution are customarily classified into two categories: (1) visible effects, which are identifiable pigmented foliar patterns as a result of major physiological disturbances to plant cells, and (2) subtle effects, which are not visibly identifiable, and may be identified when physiological change occurs in the plant. The disturbance of biochemical processes at the molecular level is the cause of both the visible and subtle effects. Within the category of visible effects, acute and chronic injury can be identified. Acute injury is a severe injury as a result of a short-term, but high concentration of the pollutant. Chronic injury is light to severe injury; it develops from exposure to long-term, low pollutant concentration.

1/ For a detailed discussion on the types of air pollutants causing damage to vegetation, see Thomas (1961).

The effects of oxidant on vegetation have been studied since the early part of this century. Oxidant or smog type symptoms were identified with the reaction product of ozone and reactive hydrocarbons. The symptoms were also associated with a new toxicant, peroxiyacetyl nitrate (PAN), which was generated experimentally by photochemical reaction of a mixture of nitrogen dioxide and reactive hydrocarbon (Stephen et al., 1960). Nitrogen dioxide is also a phototoxicant at high concentration levels. Benedict and Breen (1955) found tissue collapse with nitrogen dioxide concentration above 20 ppm.

Generally speaking, agricultural plants are adversely affected by air pollution vis-a-vis reductions in the quantity of output and/or degradation of the quality of the product. With the information on the determinants of the biological response of a plant to contaminated air, a reasonable, physical dose-response relationship could be constructed. In translating the physical damage function into a monetary damage function, the following factors should be considered: time and growing season, market value and price of the plant, the possibility of growing a different crop and the opportunity cost of the site for growing the plant.

Waddell (1974) identified two general approaches to assess the economic loss of plants due to air pollution.1/ One approach is to survey the damage loss on a statewide basis. Included in this category are the studies by Middleton and Paulus (1956), Weidensaul and Lacasse (1970), Feliciano (1972), Pell (1973), Naegele et al. (1972), and Millecan (1971).

Another approach is to construct predictive models by relating data on crop losses to crop values, pollution emission and meteorological parameters. The landmark study by Benedict and his associates (1971, 1973) at Stanford Research Institute (SRI) is probably the only study undertaken so far which provided some essential background material for further investigation. The SRI study estimated plant losses caused by air pollution in those U.S. counties where major pollutants (oxidants, SO_2, and fluorides) are expected to produce adverse effects on plants.

The major contribution of the SRI study is the provision of a wealth of data for the development of economic damage functions or of more sophisticated predictive models when better dose-response data are available. However, the study also contains the following weaknesses: (1) the damage factors were at best educated guesses and are subject to criticism; (2) yearly variations in climate and meteorology were not allowed for; (3) ornamentals were undervalued since only replacement costs were used as a proxy for aesthetic values; and (4) the subtle effects of air pollution which causes no visible injury were ignored. However, some subtle injuries were indeed included, contrary to most critics. The amount was a rough guess and, with the exception of citrus and grapes, could

1/ See Waddell (1974) for a detailed discussion.

have been much larger or much smaller depending on the plant species. Latest information shows that such losses to forests and perhaps cotton in California are much greater than previously realized.[1/]

A review of some previous damage estimates at both the national and state levels would give us a rough idea as to how serious the damage loss is because of air pollution. Benedict and his associates estimated the national total damage of visible injury to vegetation to be $132 million each year. Lacasse-Weidensaul estimated the amount of direct losses uncovered in the survey to be more than $3.5 million in Pennsylvania in 1969. Indirect losses were estimated to be $8 million. Feliciano reported the losses to agriculture in New Jersey due to air pollution were about $1.19 million in 1971. Naegele estimated direct economic losses for the 1971-72 season at $1.1 million. Finally, Millecan estimated a monetary loss of $26 million in crops in California in 1970.

In summary, the problems in the field of vegetation and air pollution are similar to those delineated previously in other categories, i.e., the lack of reliable scientific damage functions and the presence of a wide range of damage estimates. The primary objective of this section is to review the state of the art and derive, through existing documentation and data, an integrated economic damage function of air pollution on vegetation for purpose of prediction. The remaining part of this section contains the following subsections: Dose-Response Relationships, Economic Damage Functions, and Concluding Remarks.

DOSE-RESPONSE RELATIONSHIPS

Some crude dose-response relationships for various types of crops have been derived. O'Gara (1972) estimated the first such function for alfalfa under conditions of maximum sensitivity, as follows:

$$(C-0.33t) = 0.92 \qquad \text{(VI-1)}$$

where C is the concentration level to be estimated with respect to time t in hours. The constant 0.33 ppm represents a concentration that presumably can be endured indefinitely, i.e., the threshold level, without prolonged fumigation. That is to say that $C = 1.25$ ppm for $t = 1.0$.

The O'Gara equation was generalized by Thomas and Hill (1935) for any degree of leaf destruction and any degree of susceptibility. The generalized equation can be specified as:

$$t(c-a) = b \qquad \text{(VI-2)}$$

1/ Personal correspondence with Dr. H. M. Benedict.

where t = time, hours, c = pollutant concentrations above a, a = threshold concentration below which no injury occurs, and b = constant.

With maximum susceptibility, the generalized equations were shown as follows:

$$t(c-0.24) = 0.94 \quad \text{traces of leaf destruction}$$

$$t(c-1.4) = 2.1 \quad \text{50 percent leaf destruction}$$

$$t(c-2.6) = 3.2 \quad \text{100 percent leaf destruction}$$

Zahn (1963) developed an equation which modified the O'Gara equation and provides better fit over a longer period of time. The equation is shown as follows:

$$t = b\frac{1 + 0.5C}{C(C-a)} \qquad \text{(VI-3)}$$

The threshold level a was given as 0.1 for alfalfa; b is the dimensional resistance factor which incorporates the influence of environmental conditions.

An alternative experimental formula was suggested by Guderian, Van Haut (1960) and Stratmann (1963). The formula gives best fit to their observations for either short- or long-term exposures.

$$t = Ke^{-b(C - a)} \qquad \text{(VI-4)}$$

where K = vegetation life time, in hours, t; a, b, and C are the same as in (VI-3). These parameters may vary with species, environmental conditions, and degree of injury.1/

Although several physical dose-response relationships have been determined, economic damage functions for vegetations are largely nonexistent. The economic damage functions described in the following section employed input data on vegetation losses obtained from the Benedict study (1971,1973).

1/ The dose-response equations developed by Zahn, and Guderian, Van Haut and Stratmann were summarized in Environmental Protection Agency, Effect of Sulfur Oxides in the Atmosphere on Vegetation, op cit. The references were contained therein.

Benedict et al. derives crop loss estimates by using the product of three factors, i.e.,

$$\text{Crop Loss} = \text{crop value} \cdot \text{crop sensitivity to the pollutant} \cdot \text{regional pollution potential} \qquad \text{(VI-5)}$$

The regional pollution potential is a relative severity index of pollution, estimated for each county selected in the Benedict study on the basis of emission rates which are, in turn, derived from fuel consumption data. The relative sensitivity of various plant species to the pollutants was determined from a literature review. Each crop or ornamental was classified as to whether the part of the plant directly affected by the pollutants had high, medium or no economic value.

Despite the fact that the ceteris paribus type of dose-response functions has been developed and refined for certain types of vegetation, such functions are still unavailable for a majority of vegetations even now. Furthermore, the multivariate physical damage functions relating plant damage to several relevant explanatory factors are yet to be developed. In the absence of reliable plant dose-response functions, only rough estimates of economic damages for various plants can be derived.

ECONOMIC DAMAGE FUNCTIONS

Of more relevance to policymakers at both the national and local levels, however, are the monetary or economic damage functions which transform all aspects of dose-response relationships into one common unit of measurement, i.e., money. An attempt was made in this study to estimate such economic damage functions which relate economic losses of a variety of crops to air pollution concentration levels and climatological variables.

The crops and agricultural products for which the economic damage functions were estimated include corn grain, soybean, cotton, vegetable, other vegetable, nursery, floral, forestry, field crop, fruit and nuts, total crops, total ornamentals, and all plants. The selection of the crops is based mainly on the economic importances of these crops to the United States. However, it is understood that different cultivating procedures and methods as well as relocation of crop growing patterns in the United States will result in reduction in air pollution damage to crops.

A stepwise linear multivariate regression model was developed for determining the economic damage functions for the selected crops and plants, as follows:

$$\begin{aligned} CROPL_i &= a + b\ CROPV_i + c\ TEMB + d\ TEMA + e\ SUN + f\ RHM + g\ DTS \\ &\quad + h\ SO_2 + j\ OXID \end{aligned} \qquad \text{(VI-6)}$$

where CROP denotes the economic loss (in $1,000) of the ith type of crops by county from the Benedict study; $CROPV_i$ the output value (in $1,000) of the ith type of crops by county; TEMB and TEMA stand for, respectively, the number of days in a year with temperature below 33°F and above 89°F; SUN represents possible annual sunshine days; RHM, relative humidity; DTS number of days with thunderstorm; SO_2 sulfur dioxide concentration or relative severity index; and OXID the oxidant relative severity index.

Data used for the regression analysis were obtained from prior studies on vegetation losses and the official publication on climatological data. As noted earlier, the disaggregated data on the vegetation losses and the values of the crops by county were obtained from the Benedict study. It should be pointed out that only the aggregate data on vegetation by regions are presented in Benedict et al. (1973). The crop data in the published form were integrated so as to preserve some anonymity about certain single sources of pollution. The data for CSO_2 and OXID were taken from Table 7 of Benedict et al. (1973), and the data for TEMB, TEMA, SUN, RHM, DTS were secured from the U.S. Department of Commerce, Local Climatological Data. Since the climatological data were not available for all counties or cities, data for a nearby city were, hence, substituted for the missing information for a number of counties. Finally, the annual mean level for SO_2 was taken from the U.S. Environmental Protection Agency, Air Quality Data - 1972 Annual Statistics.

Although estimates on crop values and crop losses are available for a total of 679 counties in the United States, a thorough examination of the data reveals that some counties have zero crop damage estimates and, hence, are not suitable for inclusion in the study sample. In addition, both climatological and pollution data are unavailable for a number of counties, but for which positive crop loss estimates were available. Only 74 counties have both positive crop loss estimates and data on climate and pollution levels. Thus they were selected for this study for deriving the vegetation economic damage functions.

The dependent and explanatory variables used in the regression analysis are described in Table VI-1. It should be noted that for sulfur dioxide two alternative measures were available: the first measure is the relative severity index constructed on the basis of pollutant emissions, concentration rate factor and episode days by Benedict et al. (1971), i.e., CSO_2..The second alternative measure, SO_2, is the annual mean level for sulfur dioxide ($\mu g/m^3$). Both measures were used in the regression analysis, and the regression results are separately reported in Tables VI-2 and VI-3. With regard to oxidants, the relative severity index for oxidants was also provided by Benedict et al. (1971). However, data on the annual mean level of oxidants are insufficient for this study. Thus, only the former measure was used in the regression analysis. The regression results containing oxidants are presented in Tables VI-2 and VI-4.

Some remarks on the regression results are in order. The values below the regression coefficients are standard errors with * indicating that they are significant at the 1 percent level. The signs of the regression coefficients

TABLE VI-1. VARIABLES USED IN ECONOMIC DAMAGE FUNCTIONS

A. Dependent variables - vegetation loss (in $1,000)

CORNL	Corn grain loss.
SOYBL	Soybean loss.
COTNL	Cotton loss.
OVGTL	Other vegetable loss.
NUSRL	Nursery loss.
FLORL	Floral loss.
FRSTL	Forestry loss.
FCROL	Field crops loss.
FRNTL	Fruit and nuts loss.
VEGTL	Vegetable loss.
TOCRL	Total crop loss.
TOORL	Total ornamentals loss.
ALPLL	All plant loss.

B. Explanatory Variables

CROPV	The value of the vegetation in question (in $1,000)
TEMB	Number of days with temperature 32°F or below.
TEMA	Number of days with temperature 90°F or above.
SUN	Possible annual sunshine days.
RHM	Relative humidity.
DTS	Number of days with thunderstorm.
SO_2	Annual mean level for sulfur dioxide ($\mu g/m^3$).
OXID	The relative plant-damaging oxidant pollution potential index.
CSO_2	The relative plant-damaging sulfur dioxide pollution potential index.

TABLE VI-2. ECONOMIC DAMAGE FUNCTIONS ON VEGETATION WITH POLLUTION RELATIVE SEVERITY INDICES (in $1,000)

	a	CROPV	TEMB	TEMA	SUN	RHM	DTS	CSO_2	OXID	R_2
(1) CORNL	4.4	0.001	0.02	0.09	-0.13	0.16	-0.041	6.73	-0.85	0.28
	(32.1)	(0.001)	(0.04)	(0.10)	(0.35)	(0.34)	(0.10)	(1.84)*	(2.18)	
(2) SOYBL	-2.2	0.003	0.01	0.04	-0.04		0.05	3.58	0.24	0.26
	(0.3)	(0.001)*	(0.03)	(0.07)	(0.28)		(0.74)	(1.49)*	(1.65)	
(3) COTNL	-5.8	0.0063	0.0006	-0.054	0.067	0.03	0.03	0.05	0.57	0.98
	(6.9)	(0.0002)*	(0.0094)	(0.028)	(0.077)	(0.07)	(0.02)	(0.40)	(0.48)	
(4) OVGTL	133.6	0.006	-0.03	-0.44	2.02	0.10	0.06		97.73	0.96
	(58.5)*	(0.001)*	(0.08)	(0.22)	(0.63)*	(0.65)	(0.21)		(3.71)*	
(5) NUSRL	-113.1	0.11	1.12	-0.19	0.35	-2.95	2.34		191.51	0.90
	(300.2)	(0.02)*	(0.42)*	(1.03)	(3.27)	(3.26)	(1.02)*		(33.09)*	
(6) FLORL	-616.4	0.10	0.93	-0.30	-0.79	-6.7	3.03		356.3	0.93
	(485.2)	(0.01)*	(0.57)	(1.41)	(4.37)	(4.4)	(1.37)*		(30.8)*	
(7) FRSTL	-616.4	0.071	1.93	-2.33	5.20	-1.88	4.77		370.52	0.96
	(485.2)	(0.003)*	(0.70)*	(1.63)	(5.34)	(5.23)	(1.71)*		(30.71)*	
(8) FCROL	520.5	0.003	0.28	1.17	-5.61	-3.26	-1.20		54.07	0.35
	(222.3)*	(0.002)	(0.32)	(0.82)	(2.44)*	(2.44)	(0.77)		(14.20)*	

TABLE VI-2 (Concluded)

(9) FRNTL	-90.9 (281.2)	0.061 (0.006)*	0.83 (0.43)*	0.43 (1.00)	-2.28 (3.18)	0.28 (3.09)	1.74 (0.98)	121.3 (18.02)*	0.82
(10) VEGTL	-308.8 (168.4)	0.011 (0.002)*	-0.33 (0.23)	-1.66 (0.64)*	4.92 (1.80)*	1.05 (1.85)	0.08 (0.60)	136.02 (10.69)*	0.89

TABLE VI-3. ECONOMIC DAMAGE FUNCTIONS OF VEGETATION, WITH SULFUR DIOXIDE ANNUAL MEAN LEVEL (In $1,000)a/

	a	CROPV	TEMB	TEMA	SUN	RHM	DTS	SO_2 ($\mu g/m^3$)	R_2
(1) CORNL	10.6	0.0013	0.015	0.11	0.38	0.21		0.0008	0.10
	(31.0)	(0.0007)	(0.045)	(0.09)	(0.32)	(0.30)		(0.0960)	
(2) COTNL	-9.4	0.0063	-0.0004	-0.05	0.11	0.07	0.02	0.0005	0.98
	(6.2)	(0.0002)*	(0.0089)	(0.03)	(0.66)	(0.07)	(0.02)	(0.0195)	
(3) OVGTL	-803.0	0.009	-0.72	-1.05	9.44	6.82	-1.58	0.27	0.60
	(181.1)*	(0.003)*	(0.27)*	(0.77)	(1.95)*	(2.00)*	(0.67)*	(0.57)	
(4) NUSRL	-780.2	0.20	0.77	-0.98	7.79	1.19	1.87	0.40	0.85
	(350.6)*	(0.01)*	(0.51)	(1.25)	(3.81)*	(3.86)	(1.25)	(1.06)	
(5) FRSTL	-3,315.6	0.065	-3.52	-1.29	36.53	24.3	-3.05	2.30	0.87
	(785.0)*	(0.005)*	(2.90)	(1.17)	(8.57)*	(8.63)*	(2.82)	(2.44)	

a/ For the 10 types of vegetations, the economic damage functions for CORNL COTNL OVGTL NUSRL and FRSTC yields a positive SO_2, while the remaining regression equations contain a negative SO2. Only those five damage functions with a positive SO_2 are reported here.

TABLE VI-4. ECONOMIC DAMAGE FUNCTIONS ON TOTAL CROPS, TOTAL ORNAMENTALS AND ALL PLANTS (in $1,000)[a/]

	a	CROPV	TEMB	TEMA	SUN	RHM	DTS	OXID	SO_2 ($\mu g/m^3$)	R^2
(1) TOCRL	-375.7	0.011	-0.66	-6.81	12.93	-8.12	1.25	1,262.5		0.96
	(762.8)	(0.003)*	(1.07)	(2.80)*	(8.45)	(8.40)	(2.77)	(50.26)*		
(2) TOORL	-519.7	0.074	3.18	-1.61	-0.91	-6.36	9.09	769.31		0.92
	(965.5)	(0.004)	(1.38)	(3.28)	(10.59)	(10.63)	(3.42)	(60.87)		
(3) ALPLL	-2,251.3	0.039	0.50	-16.02	18.02	7.84	9.34	1,892.46		0.92
	(1,908.9)	(0.006)*	(2.73)	(6.76)*	(21.49)	(20.83)	(7.21)	(121.58)*		
(4) TOCRL	-8,247.2	0.032	-9.07	-16.40	93.30	74.72	-15.44		3.15	0.59
	(2,302.4)	(0.011)*	(3.38)	(9.03)	(26.04)*	(25.07)*	(8.76)		(7.19)	
(5) TOORL	-5,927.4	0.069	-3.039	-4.03	61.38	46.27	-6.23		4.29	0.74
	(1,630.8)*	(0.008)*	(2.41)	(6.03)	(17.82)*	(17.97)*	(5.89)		(5.07)	
(6) ALPLL	-14,350.5	0.05	θ12.53	-24.98	150.45	128.37	-20.13		6.87	0.6
	(3,835.7)*	(0.01)*	(5.69)*	(14.52)	(43.62)*	(41.68)*	(15.06		(11.84)	

a/ Equations (1) through (3) are economic damage functions of total crops, total ornamentals and all plants with OXID as the sole pollution variable, while equations (4) to (6) are similar economic damage functions with SO_2 rather than OXID as the sole pollution variable.

are mostly compatible with a priori expectations. Specifically, the signs of the pollution variables are mostly correct except in equation (1) of Table VI-2 in which a negative sign for OXID appears. The negativity of OXID may be substantially attributable to the multicolinearity between the two pollution variables, CSO_2 and OXID ($r = 0.31$) because OXID changes sign from positive to negative immediately when CSO_2 was picked up by the regression equation.1/

Utilizing pollution severity indexes in the regression, a wide range of R^2 is obtained, ranging from 0.25 for soybeans to 0.98 for cotton. However, when the annual mean level of SO_2 was included as the sole pollution variable, the independent variables explain a minimum of about 10 percent of the variations in corn losses and a maximum of 98 percent of the variations in cotton losses. The coefficients for the pollution severity indexes, i.e., CSO_2 which were constructed on the basis of pollutant emissions, concentration rate factor and episode days and OXID, are mostly significant at the 1 percent level whereas no coefficients for SO_2 are significant even at the 10 percent level. This result lends support to the hypothesis that it may not be appropriate to use pollution measures mostly recorded in the central city to represent countywide pollution level. Furthermore, it should be noted that the variable DTS was intentionally excluded from equation (1) of Table VI-3 to preserve the positive sign of SO_2.2/

Using Equation (4), (5) and (6) in Table VI-4, economic damages of total crops, total ornamentals and all plants were estimated for the 74 counties. The results are presented in Table VI-5. The table reveals that while total crop damages reached about $4 million in Los Angeles, Orange and San Diego counties all in California, San Bernadino suffered the largest ornamental damages and all plant damages in the order of $8.5 million and $10.6 million, respectively.

Intercorrelation among explanatory variables may not constitute a serious problem if prediction is the primary objective, provided, of course, the intercorrelation is expected to persist in the future. However, if multicolinearity results in an incorrect sign of the key variable, SO_2, a statistical interpretation of the SO_2 coefficient would be meaningless, and the exclusion of DTS is, hence, warranted.

1/ It should be noted that RHM was intentionally excluded from equation 2 in Table VI-2 because the inclusion of RHM resulted in a negative OXID.

2/ When DTS is included, the regression equation, however, changes to read as follows:

$$\underset{(31.3)}{\text{CORNL} = 9.6} + \underset{(0.0007)}{0.0013\ \text{CROPV}} + \underset{(0.05)}{0.02\ \text{TEMB}} + \underset{(0.12)}{0.14\ \text{TEMA}} - \underset{(0.33)}{0.41\ \text{SUN}}$$

$$+ \underset{(0.35)}{0.27\ \text{RHM}} + \underset{(0.10)}{0.05\ \text{DTS}} - \underset{(0.097)}{0.004\ SO_2}$$

$$R^2 = 0.10$$

TABLE VI-5. ESTIMATED ECONOMIC DAMAGES OF TOTAL CROPS, TOTAL ORNAMENTALS AND ALL PLANTS[a/]
(in $1,000)

(1) Counties	(2) Estimated Total Crop Damages[b/]	(3) Estimated Total Ornamental Damages[c/]	(4) Estimated All Plant Damages[d/]
Jefferson, Alabama	--	--	--
Maricopa, Arizona	1,947	605	3,214
Alameda, California	3,708	1,527	5,677
Los Angeles, California	4,591	3,658	8,350
Orange, California	4,330	1,249	6,675
San Bernadino, California	3,780	8,481	10,606
San Diego, California	4,008	2,434	6,908
Fairfield, Connecticut	703	530	1,140
New Haven, Connecticut	847	423	1,290
New Castle, Delaware	136	2	89
Santa Rosa, Florida	--	--	--
Chatham, Georgia	--	28	--
Fulton Georgia	139	185	250
Honolulu, Hawaii	3,178	885	4,596
Cook, Illinois	149	766	888
Lake, Indiana	161	82	335
Marion, Indiana	356	144	602
St. Joseph, Indiana	442	106	692
Vanderburgh, Indiana	407	277	633
Polk, Iowa	522	58	841
Sedgwick, Kansas	159	103	301
Shawnee, Kansas	122	38	222
Wyandotte, Kansas	375	231	565
Boone, Kentucky	--	--	--
McCracken, Kentucky	281	217	407
Cumberland, Maine	381	209	549
Anne Arundel, Maryland	144	139	177
Baltimore, Maryland	281	1,257	1,192
Harford, Maryland	148	--	83
Howard, Maryland	84	--	--
Montgomery, Maryland	--	--	--
Prince Georges, Maryland	--	--	--
Berkshire, Massachusetts	--	--	--
Bristol, Massachusetts	280	87	311
Middlesex, Massachusetts	894	444	1,359
Worcester, Massachusetts	185	423	533
St. Louis, Missouri	196	230	405
Douglas, Nebraska	327	227	527
Lancaster, Nebraska	563	265	990
Rockingham, New Hampshire	117	333	286
Mercer, New Jersey	--	--	--
Bernalillo, New Mexico	--	--	--
Albany, New York	--	--	--
Erie, New York	294	389	835
Monroe, New York	--	--	--
Niagara, New York	257	--	405
Oneida, New York	--	--	--
Forsyth, North Carolina	114	51	142
Clark, Ohio	187	--	266
Cuyahoga, Ohio	151	322	458
Franklin, Ohio	--	--	--
Hamilton, Ohio	--	--	--
Jefferson, Ohio	--	--	--
Mahoning, Ohio	281	124	494
Montgomery, Ohio	72	42	180
Stark, Ohio	--	--	--
Summit, Ohio	--	--	--
Multnomah, Oregon	102	--	--
Indiana, Pennsylvania	--	--	--
Washington, Rhode Island	175	--	21
Greenville, South Carolina	--	--	--
Davidson, Tennessee	--	--	--
Hamilton, Tennessee	--	--	--
Knox, Tennessee	267	77	393
Shelby, Tennessee	303	387	595
Tom Green, Texas	--	--	--
Nansemond, Virginia	995	224	1,364
York, Virginia	803	327	1,079
King, Washington	834	1,249	1,876
Pierce, Washington	711	837	1,407
Spokane, Washington	--	286	--
Dane, Wisconsin	1,070	132	1,759
Milwaukee, Wisconsin	340	147	517
Natrona, Wyoming	--	--	--

a/ "--" denotes that the estimates are either insignificant or unreliable.
b/ Estimates based on equation (4) in Table VI-4.
c/ Estimates based on equation (5) in Table VI-4.
d/ Estimates based on equation (6) in Table VI-4.

Utilizing the "average" economic damage functions presented in this section, the changes in crop losses brought about by changes in the pollution or climatological variables can be easily estimated. For the sake of illustration; but without loss of generality, consider equation (6) of Table VI-4. The partial elasticity of ALPLL with respect to SO_2 evaluated at their mean values (see Table VI-6) is

$$E_{PLSO_2} = 6.87 \times (20.5/790) = 0.18.$$

Thus, if the SO_2 level in the air is lowered on the average by 2 $\mu g/m^3$ from 20.5 $\mu g/m^3$ to 18.5 $\mu g/m^3$ (i.e., 10 percent reduction), then economic damage to all plants, on the average, could reduce by \$14,220, \$790,00 x 1.8 percent from \$790,000 to \$775,780. The partial elasticities for other variables of interest in the economic damage functions can be similarly computed, and the results are amenable to analogous interpretation. It should be noted, however, that the estimates are based on the assumption that the presence of any SO_2 is harmful to vegetation regardless of its level of concentration. Although California has been reported to have very low SO_2, Equations (4) to (6) do indicate the positive, though not statistically significant, damaging effect of SO_2 on crop losses.

CONCLUDING REMARKS

Economic damage functions estimated in this section are replete with conceptual difficulties. The task of translating physical damage functions into monetary damage functions involves a rather anthropocentric-egocentric evaluation procedure. This is generally the case because the evaluation, and subsequently adoption, of the physical damage functions by Benedict et al. is mainly based on our own value judgments rather than on any scientific substance. Furthermore, the damages suffered or anticipated by the receptors may well lead to changes in the market behavior, and hence, the market prices may not correctly reflect the welfare loss associated with the physical damages.[1/]

In spite of the various conceptual difficulties associated with translating physical damages into dollar worth equivalents, economic damage functions were estimated for a variety of vegetation in this study. In view of the numerous inherent weaknesses in the prior study and other conceptual and empirical difficulties associated with the estimation of economic damage functions, the damage functions presented in this section, though useful for estimating possible damage reductions brought about by pollution abatement programs, should be interpreted and employed with proper caution.

Finally, it is widely recognized that the best way to determine the occurrence and severity of an air pollution episode is to install a network of recorders to measure the daily and hourly concentration of various pollutants and the physical effects simultaneously. Although such nationwide networks have been

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1/ For a detailed discussion on some conceptual difficulties with economic damage functions, see Hans Opschoor, "Damage Functions, Some Theoretical and Practical Problems," in Environmental Damage Costs, Paris, OECD (1974).

TABLE VI-6. MEAN AND STANDARD DEVIATIONS OF VARIABLES IN VEGETATION DAMAGE FUNCTIONS[a]

Variable	Mean	Standard Deviation
CORNL	6.3000	13.5973
SOYBL	3.8838	11.0622
COTNL	2.8176	18.7760
OVGTL	32.3865	120.5110
NUSRL	72.2946	370.8508
FLORL	150.8000	622.7670
FRSTL	208.3392	894.3120
FCROL	48.7608	106.6920
FRNTL	56.2486	257.2594
VEGTL	58.2176	197.5723
TOCRL	436.6257	1502.4422
TOORL	353.8257	1334.1816
ALPLL	790.4486	2651.6519
CORNV	1199.6392	2347.7278
SOYBV	562.8405	1330.7283
COTNV	439.0622	3088.3767
OVGTV	992.6432	4300.7229
NUSRV	728.7108	1755.0623
FLORV	1441.2243	3055.6803
FRSTV	2734.4284	10586.1798
FCROV	6435.3541	8530.7033
FRNTV	1154.7284	3037.2926
VEGTV	1660.6703	5341.7627
TOCRV	11905.0000	16015.2235
TOORV	5576.9757	12421.3958
ALPLV	17473.4527	22764.5429
SO2	20.4595	17.7148
SUN	59.5135	6.6647
DTS	34.5811	18.8999
TEMA	26.2027	24.2735
TEMB	82.4595	40.6061
OXID	0.4586	1.0726
SCO2	0.7927	0.9200
RHM	58.8108	6.9394

a/ The values of crop losses and crop values are expressed in $1,000.

set up, the individual stations are unfortunately mostly located in the center of large metropolitan areas or industrialized areas. Few stations have been located in agricultural areas or in suburban areas where most of the vegetation is grown. Furthermore, a substantial amount of SO_2 is produced by power plants and various smelter operations which are generally located outside of SMSA's. This difficulty of a lack of meaningful information on pollution levels in suburban or rural areas has motivated earlier investigators to resort to fuel consumption, number of pollution episodes, and the tendency of atmospheric conditions to derive the air pollution damaging potential estimates. After all, it is imperative to conduct research directed at obtaining information on vegetation-at-risk isopleths for various counties in the United States, so that more reliable economic damage estimates for vegetation can be derived for policy decisions.

SECTION VII

AGGREGATE ECONOMIC DAMAGE COSTS AND FUNCTIONS: AN OVERALL VIEW

Air pollution constitutes a modern problem which goes beyond the technology of simply controlling the pollutants. The need for effective control is generally recognized, but arguments against control proposals also prevail. These arguments are mainly based on economic grounds--whether or not the cost of attaining a specified level of ambient air quality exceeds the economic benefit that would be realized from a control program. The regional damage estimates developed in the preceding six sections provide some of this much needed information, however crude it may be, for evaluating the economic feasibility of a specific air pollution control program.

This final section presents an overall view of the economic damages and damage functions of various receptors that were derived in the preceding six sections. Further, "aggregate" economic damage functions defined with respect to several effect categories are developed by regressing the aggregate damages to the same set of explanatory variables used earlier in the development of the "individual" effect economic damage functions. Aggregate damage estimates for selected categories of damaging effects are also computed and presented.

The economic damage estimates for the effect categories of human health, material, and household soiling are summarized in Table VII-1, for the 40 SMSA's having an SO_2 level equal or greater than 25 $\mu g/m^3$. These 40 SMSA's are listed in Column 1. Column 2 (HNC1) and Column 3 (HNC2) present, respectively, the <u>low</u> and the <u>high</u> damage estimates of human health; the material deterioration damage estimates of both paint and zinc as derived in Section V are summarized in Column 4 (MDC). Column 5 (TNSCO) contains the total net household soiling damages as described in Section IV. Based upon the low and high damage estimates of human health presented in Columns 2 and 3, respectively, two sets of low and high aggregate damage estimates for the three effect categories were estimated and presented in Column 6 (TNC1) and Column 7 (TNC2).

Specifically, the following two equations were used for computing HNC1 and HNC2 for the 40 SMSA's.

$$HNC1 = \text{Maximum of } (HNCSO_2, HNCTSP) \qquad \text{(VII-1)}$$

$$HNC2 = HNCSO_2 + HNCTSP \qquad \text{(VII-2)}$$

where $HNCSO_2$ and HNCTSP are, respectively, the net health damages attributable to SO_2 and TSP. These two aggregate damage estimates were computed by summing the mortality and morbidity costs due to SO_2 and TSP derived in Sections II and III; namely,

TABLE VII-1. ECONOMIC DAMAGES DUE TO AIR POLLUTION, BY RECEPTORS FOR SELECTED SMSA's
(in $ million, 1970)

(1) SMSA's	(2) HNC1	(3) HNC2	(4) MDC	(5) TNSCO	(6) TNC1	(7) TNC2
1. Akron, OH	10	18	7	16	33	41
2. Allentown, PA	8	15	3	16	27	34
3. Baltimore, MD	48	80	17	137	202	234
4. Boston, MA	49	52	26	117	192	195
5. Bridgeport, CT	3	5	6	3	12	14
6. Canton, OH	6	6	11	14	31	31
7. Charleston, WV	3	3	4	10	17	17
8. Chicago, IL	191	360	105	516	812	981
9. Cincinnati, OH	22	22	12	57	91	91
10. Cleveland, OH	55	93	49	216	320	358
11. Dayton, OH	18	18	9	39	66	66
12. Detroit, MI	129	161	55	294	478	510
13. Evansville, IN	2	2	2	5	9	9
14. Gary, IN	12	24	8	24	44	56
15. Hartford, CT	12	19	5	16	33	40
16. Jersey City, NJ	11	17	8	17	36	42
17. Johnstown, PA	4	4	1	10	15	15
18. Lawrence, MA	3	5	7	3	13	15
19. Los Angeles, CA	123	147	76	388	587	611
20. Minneapolis, MN	21	32	12	37	70	81
21. New Haven, CT	3	5	4	4	11	13
22. New York, NY	352	527	111	418	881	1,056
23. Newark, NJ	39	48	14	112	165	174
24. Norfolk, VA	13	13	3	29	45	45
25. Paterson, NJ	7	7	13	9	29	29
26. Peoria, IL	4	4	9	8	21	21
27. Philadelphia, PA	107	158	33	104	244	295
28. Pittsburgh, PA	45	79	30	147	222	256
29. Portland, OR	13	13	8	30	51	51
30. Providence, RI	16	25	9	20	45	54
31. Reading, PA	5	5	4	15	24	24
32. Rochester, NY	13	15	7	27	47	49
33. St. Louis, MO	44	61	24	119	187	204
34. Scranton, PA	5	5	2	23	30	30
35. Springfield, MA	12	15	3	7	22	25
36. Trenton, NJ	3	3	2	5	10	10
37. Washington, DC	48	88	21	86	155	195
38. Worcester, MA	3	4	8	6	17	18
39. York, PA	4	4	2	9	15	15
40. Youngstown, OH	9	10	8	23	40	41
Total	1,475	2,166	736	3,134	5,349	6,045

Note--individual figure may not add to totals due to rounding.

$HNCSO_2$ = Mortality cost due to SO_2 + morbidity cost due to SO_2

HNCTSP = Mortality cost due to TSP + morbidity cost due to TSP

Total material damages (MDC) in Column 4 is the sum of deterioration damages on both materials, zinc and paint. Specifically, it was calculated as follows:

$$MDC = DDCZ + DDCP \qquad \text{(VII-3)}$$

with DDCZ, and DDCP defined and computed previously in Section V.

Finally, Column 6 (TNC1) and Column 7 (TNC2), which represent the low and high human health damages, respectively, plus other damages, were calculated as follows:

$$TNC1 = HNC1 + MDC + TNSCO \qquad \text{(VII-4)}$$

$$TNC2 = HNC2 + MDC + TNSCO \qquad \text{(VII-5)}$$

An inspection of Table VII-1 reveals that while New York and Chicago SMSA's had the largest aggregate air pollution damages, in the order of $1 billion, the smallest air pollution damages occurred in Johnstown and York, Pennsylvania, in the magnitude of $15 million in 1970.

Total material deterioration damage, including deterioration for zinc and paint, amounted to $0.7 billion for the selected 48 SMSA's under study. The corresponding figures for net household soiling was estimated at $3 billion, respectively. The damage on vegetation for this nation was estimated, according to Benedict, to be $132 million. These damage figures employed in this study were taken from earlier studies which were completed under various stringent assumptions.

AGGREGATE ECONOMIC DAMAGE FUNCTIONS

In order to develop marginal equivalent economic damage functions for the purpose of predicting damage or benefit, and for designing pollution control strategies, the overall economic costs of human health in the presence of SO_2 ($HCSO_2$) and that in the presence of TSP (HCTSP) were respectively regressed not only against pollution and relative humidity, but also against other relevant socioeconomic and climatological variables, e.g., PWPO, PAGE, PCOL, PDS, DTS, SUN, etc. The least-squares regression technique was used with input from the 40 sample observations for estimating the economic damage functions. The regression results pertaining to overall human health damage are presented in Column 1 to Column 4 in Table VII-2. The overall economic damage functions for zinc and paint, for household soiling and for plants derived in the previous sections are also presented in the table in Columns 5, 6, 7, 8, 9, and 10.

The existence of an economic damage function does not in itself provide us with sufficient information to make any policy recommendations. Quantitative estimates of the magnitudes of the relationship are required. As discussed earlier, this information can be obtained directly from the estimated regression coefficients. The coefficients in the regression equation indicate the changes in the dependent variable in response to a one unit change in the associated explanatory variable ceteris paribus. The coefficients can be used for computing the elasticities under given conditions. A distinguishing feature of the concept of elasticity is that it is a unit free measure of the percentage change in the dependent variable with respect to the percentage change in the independent variable. Given the elasticity estimates, we are able to answer the question, "What would the effect of a reduction in the pollution level be, ceteris paribus, on the level of economic damages of various receptors?"

Table VII-3 contains estimates of a hypothetical reduction in the air pollution concentration level for the several pollution receptors analyzed and presented in Table VII-2. The first column in this table presents the dependent variables. Column 2 shows the estimated values of the coefficients of the SO_2 or TSP variables. The next two columns list the mean values of SO_2, TSP, and the economic damages of the various receptors. The estimated elasticity of economic damages of a particular receptor with respect to SO_2 or TSP, evaluated at the means of both variables, is found in Column 5. These elasticities indicate the percentage change in the economic damages that would result, on an average, from a 1 percent change in SO_2 or TSP.

Of particular interest to the policymaker is the effect of a given discrete change in the pollution level on the economic damages of a particular receptor. Assuming that the federal government is considering the implementation of a pollution control program which is expected to lower the pollution level, on the average, by 10 percent, the average benefit of a receptor can be calculated by multiplying the coefficient of SO_2 or TSP by 0.10 times the mean value of SO_2 and TSP. These estimates can be found in Column 6.

The study of Table VII-3 reveals that the partial elasticities of gross economic damages of the receptors included in our study vary from 0.004 to 1.28. Furthermore, a 10 percent reduction of the air pollution level would result in a decrease in the annual economic damages in the range of \$0.01 million for plants (ALPLL) to \$5.26 million for the soiling effect of zinc (SDCZ).

The implication of our study for pollution abatement strategies is obvious. Any effort to reduce the current pollution level appears to have a varyingly significant impact on the economic damages resulting from the harmful effects of air pollution. Admittedly, the implication of this study must be qualified

TABLE VII-2. ECONOMIC DAMAGE FUNCTIONS[a,b,c]

Dependent Variables	HCSO2	HCTSP	HCAP1	HCAP2	SDCZ	DDCZ	SDCP	DDCP	GRSOC	ALPLL
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Intercept	37,775	-9,939	-54,687	-46,751	-23,328.4	7,562.2	-141,199.7	-4,820.1	-25,621.0	-14,350.5
	(35,512)	(10,525)	(42,107)	(57,923)	(19,929)	(6,640.4)	(259.8)*	*887.2	*(52,347.0	(3,835.7)*
PWPO	0.02									
	(0.14)									
PAGE	189,112	74,828	100,580	146,324					3,432.3	
	(207,266)	(36,937)*	(179,860)	(204,915)					(2,199.5)	
COL	70	5	70	70					3,766.0	
	(89)	(16)	(83)	(89)					(1,460.0)*	
PD									2.3	
									(4.3)	
DTS	94	39	54	75					90.9	-20.13
	(196)	(35)	(156)	(195)					(219.3)	(15.06)
RHM	222	156	120	120	2,679.3	86.8	911.3	31.1	-1,219.8	128.37
	(489)	(94)		(518)	(1,750.2)	(56.7)	(235.3)*	(8.0)*	(610.7)*	(41.68)*
SUN		179	242	139	-235.0	-76.0	305.3	10.4		150.45
		(114)	(563)	(632)	(1,820.4)	(59.0)	(245.9)	(8.4)		(43.62)*
SO2	593		611	601	943.3	30.5	69.1	2.3		6.87
	(78)*		(74)*	(77)*	(171.6)*	(5.5)*	(23.2)*	(0.8)*		(11.84)
TSP		0.0003	0.00006	0.00004	148.1	47.9			226.4	
		(0.002)	(0.00009)	(0.00012)	(356.0)*	(11.5)*			(166.9)	
MANFV									78.9	
									(2.3)*	
ME					43.1	1.4				
					(3.4)*	(0.1)*				
YP					21.9	712.6	15.2	0.50		
					(18.9)	(615.5)	(2.6)*	(0.08)*		
HU							577.2	19.7		
							(3.4)*	(0.1)*		
CROPV										0.05
										(0.01)*
TEMA										-24.98
										(14.52)
TEMB										12.53
										(5.69)*
R^2	0.66	0.25	0.69	0.68	0.64	0.63	0.99	0.099	0.92	0.64

a/ The values in the brackets are standard errors of the coefficients, with * to indicate that the coefficient is significant at the 1 percent level. The coefficients and standard errors in equations (5), (6), (7), (8) (9) and (10) are reduced by a factor of 10^3

b/ HCSO2 = Overall health cost in the presence of SO_2, HCTSP = overall health cost in the presence of TSP.
HCAP1 = HCSO2 + HCTSP = high health damage estimates.
HCAP2 = Maximum (HCSO2, HCTSP) = low health damage estimates, SDCZ, DDCZ, SDCP, DDCP, GRSOC and ALPLL are defined previously in Chapters IV, V, and VI.

c/ The sample observations for HCSO2, HCTSP, HCAP1 and HCAP2 are the 40 SMSA's with SO_2 level equal or greater than 25 g/m^3, whereas the sample observations for SDCZ, DDCZ, SDCP, DDCP and GRSOC are the 148 SMSA's with population greater than 250,000. In the case of ALPLL, 74 counties were selected in the sample observation.

TABLE VII-3. GROSS ECONOMIC DAMAGES CHANGES RESULTING FROM A 10 PERCENT REDUCTION IN THE POLLUTION LEVEL[a,b]

(1) Dependent Variables	(2) Coefficients SO_2, TSP (10^3)		(3) Mean Values of SO_2, TSP ($\mu g/m^3$)		(4) Mean Value of Economic Damages ($ million)	(5) Partial Elasticity E = (2)·(3)/(4)	(6) Economic Damage Reduction = 0.1·(2)·(3) ($ million)
	SO_2	TSP	SO_2	TSP			
HCSO2	593		47.25		5,575.7	0.050	2.80
HCTSP		0.0003		100.87	2,431.7	--	--
HCAP1 (a)	611		47.25		8,007.4	0.004	2.89
(b)		0.00006		100.87	8,007.4	--	--
HCAP2 (a)	601		47.25		6,789.2	0.004	2.83
(b)		0.00004		100.87	6,789.2	--	--
SDCZ (a)	943.3		55.73		107.3	0.480	5.26
(b)		148.1		93.81	107.3	0.130	1.39
DDCZ (a)	30.5		55.73		3.5	0.480	0.17
(b)		47.9		93.81	3.5	1.280	0.45
SDCP	69.1		55.73		150.0	0.026	0.39
DDCP	2.3		55.73		3.3	0.039	0.01
GRSOC		226.4		93.81	434.2	0.049	2.12
ALPLL	6.87		20.45		0.8	0.180	0.01

a/ This table is calculated on the basis of the 10 economic damage equations presented in Table VII-2.
b/ "--" denotes value smaller than $10,000.

by several theoretical and empirical factors. As discussed in the previous sections, the major difficulties often encountered in estimating air pollution damages include the lack of knowledge regarding the shapes of functions describing the relationship between air pollution and various receptors, and the lack of a satisfactory theoretical model specifying the way air pollution affects various receptors. The impossibility of accounting for all major factors which might affect various receptors, the lack of reliable formulations used for translating physical damages into monetary terms, and the presence of numerous econometric problems have also caused concern to investigators.

Despite the existence of these difficulties, this study represents a major step forward in our knowledge of pollution damages in that it seems to be the first attempt to construct essential frameworks of the physical and economic damage functions to calculate comparable regional damage estimates for the several important receptors--human health, material, and household soiling, however tentative they may be. More importantly, various aggregate economic damage functions instrumental for transforming the multifarious aspects of the pollution problem into a single, homogeneous monetary unit are tentatively derived and illustrated. It is hoped that these will be useful to policymakers as they make decisions on the implementation of programs to achieve "optimal" (where social MR = social MC) pollution levels for this country, although proper caution must be exercised in interpreting and employing the various economic damage functions presented in this study.

Finally, it should be noted that although the availability of information on average or marginal damages is instrumental in determining the optimal national or regional pollution control strategies, the current problem is far more complex than the question of balancing the benefits to polluters against damages inflicted on the receptors. The issues are pressing and not yet well specified. The basic difficulty in applying the recent research findings to accurately estimate the air pollution damage cost stems from our ignorance about the receptors at risk to air pollution. So far, few attempts have been made to identify who suffers, to what extent, from which sources, and in what regions.1/ At this moment, updating and expansion of the available crude estimates, which are generally restricted to certain regions, are urgently needed. To identify the population at risk to air pollution, and to measure the damage specifically for polluted regions are apparently the most logical steps in the area of future research.

1/ We are aware of only one study in the area of estimating population at risk. Namely, Istvan Jakaces and G. Bradford Shea, Estimation of Human Population-at-Risk to Existing Levels of Air Quality, Enviro Control, Inc., Rockville, Maryland (February 1975). This study reports the number of people within each major social and economic classification who were exposed to 1973 levels of various air pollutants within each standard metropolitan statistical area and EPA regions. Estimates of the population at risk for other major receptors, e.g., material and vegetation, have not been derived to date.

SECTION VIII

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APPENDIX A

OPTIMAL POLICIES IN THE PRESENCE OF ENVIRONMENTAL POLLUTION: A THEORETICAL FRAMEWORK

Before we systematically present the economic damage and damage function of air pollution for a variety of receptors, a general equilibrium framework explicitly incorporating the effect of environmental pollution is described in this section. Optimal intervention policies are also derived in this framework for policy consideration. More importantly, optimal policy prescriptions are suggested for meeting the acceptable pollution levels predetermined by the authority.

For analytical purposes, the following assumptions are made:[1/]

1. Air pollution adversely affects social welfare.

2. There are two types of industries; pollution emitting and pollution nonemitting, and air pollution is a joint product of the commodities produced by the pollution emitting industry.

3. Air pollution adversely affects the productivity of the labor input used in other industries.

4. By holding capital constant, labor is the only variable factor of production in all industries in the short run.

The social utility function for the economy under consideration is written as

$$U = U(X_1, X_2, A) \qquad \text{(A-1)}$$

where X_1 and X_2 denote, respectively, the vectors of commodities produced by the first and the second industries. The first industry refers to one in which the labor productivity is adversely affected by air pollution, and the second industry consists of those firms which, in the process of producing commodities X_2, emit pollution into the air. A represents a vector of n pollutants existing in the air, i.e.,$\{A = \{a_1, \ldots a_j, \ldots, a_n\}$.

The partial derivatives of U are subject to the following sign restrictions:

1/ The assumptions are made mainly for facilitating the exposition. Relaxation of any of the postulates will not affect the conclusions.

$$U_1 = \partial U/\partial X_1 > 0; \qquad U_{11} = \partial^2 U/\partial X_1^{\,2} < 0$$

$$U_2 = \partial U/\partial X_2 > 0; \qquad U_{22} = \partial^2 U/\partial X_2^{\,2} < 0$$

$$U_A = \partial U/\partial A < 0$$

In view of assumption (2), the amount of air pollution emitted to the air, A_e is proportional to X_2.

$$A_e = aX_2 \tag{A-2}$$

where a is a matrix with elements showing the quantity of each type of pollutant being emitted per unit of the commodities produced by the industry 2.

Assumption (3) permits the production function of the first industry to be represented by

$$X_1 = F_1 \left[L_1 - bAL_1\right] \tag{A-3}$$

where L_1 is the amount of labor employed in industry 1, and b is the vector with elements indicating the loss of efficiency in L_1 due to a unit of the jth pollutant produced by industry 2, $j = 1,\ldots,n$. To ensure that net labor input is positive, it is imposed that $bA < 1$.

Since industry 2 is assumed to be unaffected by, or at least compensated for, air pollution, an externality or by-product, its production function is represented by

$$X_2 = F_2\ (L_2) \tag{A-4}$$

where L_2 is the amount of labor utilized in industry 2.

Also assume that there is a pollution control sector with the following production function

$$A_c = A_c\ (L_3) \tag{A-5}$$

where A_c is the quantity of air pollution abated and L_3 the amount of labor utilized in the pollution control activities.

Thus, the pollution existing in the air at any point of time is simply the difference between the quantity of pollution emitted and quantity of pollution abated.

$$A = A_e - A_c = aX_2 - A_c(L_3) \tag{A-6}$$

Finally, the economy is subject to a labor availability constraint

$$L_1 + L_2 + L_3 \leq L \tag{A-7}$$

The first order optimality conditions for this economy which is subject to an environmental externality are derived by maximizing (A-1) subject to the constraints (A-2), through (A-7) and

$$L_1, L_2, L_3, X_1, X_2, A \geq 0 \tag{A-8}$$

Form the Lagrangean:

$$\emptyset = U(X_1, X_2, A) - \lambda [X_1 - F_1(L_1 - bAL_1)] - \beta [X_2 - F_2(L_2)]$$

$$- \gamma [aX_2 - aF_2(L_2)] - u [A - aX_2 + A_c(L_3)] - w (L_1 + L_2 + L_3 - \bar{L}) \tag{A-9}$$

Partially differentiating (A-9) with respect to X_1, X_2, A, L_1, L_2 and L_3 yields:

$$\frac{\partial \emptyset}{\partial X_1} = U_1 - \lambda = 0 \tag{A-10}$$

$$\frac{\partial \emptyset}{\partial X_2} = U_2 - \beta - \gamma a + ua = 0 \tag{A-11}$$

$$\frac{\partial \emptyset}{\partial A} = U_A - \lambda \frac{\partial F_1}{\partial L_1^*} - bL_1 - u = 0 \tag{A-12}$$

$$\frac{\partial \emptyset}{\partial L_1} = \lambda \frac{\partial F_1}{\partial L_1^*} (1-bA) - w = 0 \quad \text{(A-13)}$$

$$\frac{\partial \emptyset}{\partial L_2} = (\beta + \gamma a) \frac{\partial F_2}{\partial L_2} - w = 0 \quad \text{(A-14)}$$

$$\frac{\partial \emptyset}{\partial L_3} = -u \frac{\partial A_c}{\partial L_3} - w = 0 \quad \text{(A-15)}$$

Note that the shadow prices of X , X and A are, respectively, λ, β and μ. Both λ and μ are positive by assuming nonsatiation in consumption of both X and X . μ is negative since $\partial U/\partial A < 0$. The interpretation of equations (A-10) through (A-15) is straightforward. The optimality in the presence of the pollution externality requires that $U_1/U_2 = \lambda/[\beta + a(\gamma - u)]$;

$U_1/U_A = \lambda/(u + bL_1 + \lambda\frac{\partial F_1}{\partial L_1^*})$ and $w = \lambda(1-bA)\frac{\partial F_1}{\partial L_1^*} = -u\frac{\partial Ac}{\partial L_3} = (\beta + \gamma a)\frac{\partial F_2}{\partial L_2}$.

In view of (A-11), and remembering $a > 0$ the optimal policy is to impose a consumption tax of $a(\mu + \gamma)$ per unit of X_2. From (A-12), it is clear that a subsidy of $\mu + bL_1 + \lambda\frac{\partial F}{\partial L_1^*}$ should be given to consumers who suffer from the air pollution. In view of (A-13), a production subsidy of λbA per unit of X_1 is required for efficient production. Also in view of (A-14), a production tax of γa per unit of X_2 should be imposed. In short, the optimal policies in the presence of the environmental pollution involve a consumption and production tax on X_2, a consumption subsidy on A and a production subsidy on X_1.

ACCEPTABLE POLLUTION LEVEL

Suppose the pollution level is constrained by the authority not to exceed the statutory acceptable level. This problem amounts to introducing an additional constraint in the model.

$$A \leq A^* \quad \text{or} \quad aF_2(L_2) - A_c(L_3) \leq A^*$$

In this case, the first order conditions (A-14) and (A-15) should alter to

$$\frac{\partial \emptyset}{\partial L_2} = (\beta + \gamma a + \alpha a)\frac{\partial F_2}{\partial L_2} - w = o \qquad \text{(A-14')}$$

$$\frac{\alpha \emptyset}{\alpha L_3} = (-\mu - \alpha)\frac{\partial A_c}{\partial L_3} - w = o \qquad \text{(A-15')}$$

where α is the shadow price associated with the acceptable pollution constraint. The constraint will be binding because otherwise the objective can be attained without statutory regulation. This means $\alpha > 0$. It is clear, in view of (A-14') and (A-15') that the optimal interventions to constrain the pollution in the air not to exceed the acceptable level are to apply an additional tax of αa per unit of X_2 and a subsidy of α per unit of A_c to the pollution control sector of the economy. Thus, a penalty on the pollution producing industry coupled with a subsidy on the pollution abatement industry is the second best optimal combination of policies to achieve the objective of reducing the pollution concentration below the "threshold" level.

APPENDIX B

LIST A

SMSA'S WITH POPULATION OVER 500,000 (L)

	SMSA	Code	Population, 1970 (in 1,000)
1	Akron, Ohio	AKR	679
2	Albany-Schenectady-Troy, N.Y.	ALB	721
3	Allentown-Bethlehem-Easton, Pa.-N.J.	ALL	544
4	Anaheim-Santa Ana-Garden Grove, Calif.	ANA	1,420
5	Atlanta, Ga.	ATL	1,390
6	Baltimore, Md.	BAL	2,071
7	Birmingham, Ala.	BIR	739
8	Boston, Mass.	BOS	2,754
9	Buffalo, N.Y.	BUF	1,349
10	Chicago, Ill.	CHI	6,979
11	Cincinnati, Ohio-Ky.-Ind.	CIN	1,385
12	Cleveland, Ohio	CLE	2,064
13	Columbus, Ohio	COL	916
14	Dallas, Texas	DAL	1,556
15	Dayton, Ohio	DAY	850
16	Denver, Colo.	DEN	1,228
17	Detroit, Mich.	DET	4,200
18	Fort Lauderdale-Hollywood, Fla.	FOR	620
19	Fort Worth, Texas	FOR	762
20	Gary-Hammond-East Chicago, Ind.	GAR	633
21	Grand Rapids, Mich.	GRA	539
22	Greensboro-Winston-Salem-High Point, N.C.	GRE	604
23	Hartford, Conn.	HAR	664
24	Honolulu, Hawaii	HON	629
25	Houston, Texas	HOU	1,985
26	Indianapolis, Ind.	IND	1,110
27	Jacksonville, Fla.	JAC	529
28	Jersey City, N.J.	JER	609
29	Kansas City, Mo.-Kans.	KAN	1,254
30	Los Angeles-Long Beach, Calif.	LOS	7,032
31	Louisville, Ky.-Ind.	LOU	827
32	Memphis, Tenn.-Ark.	MEM	770
33	Miami, Fla.	MIA	1,268
34	Milwaukee, Wis.	MIL	1,404
35	Minneapolis-St. Paul, Minn.	MIN	1,814
36	Nashville-Davidson, Tenn.	NAS	541
37	New Orleans, La.	NEW	1,046
38	New York, N.Y.	NEW	11,529
39	Newark, N.J.	NEW	1,857
40	Norfolk-Portsmouth, Va.	NOR	681
41	Oklahoma City, Okla.	OKL	641
42	Omaha, Nebraska-Iowa	OMA	540
43	Paterson-Clifton-Passaic, N.J.	PAT	1,359
44	Philadelphia, Pa.-N.J.	PHI	4,818
45	Phoenix, Ariz.	PHO	968
46	Pittsburgh, Pa.	PIT	2,401
47	Portland, Oreg.-Wash.	POR	1,009
48	Providence-Pawtucket-Warwick, R.I.-Mass.	PRO	911
49	Richmond, Va.	RIC	518
50	Rochester, N.Y.	ROC	883
51	Sacramento, Calif.	SAC	801
52	St. Louis, Mo.-Ill.	STL	2,363
53	Salt Lake City, Utah	SAL	558
54	San Antonio, Texas	SAN	864
55	San Bernadino-Riverside-Ontario, Calif.	SAN	1,143
56	San Diego, Calif.	SAN	1,358
57	San Francisco-Oakland, Calif.	SAN	3,110
58	San Jose, Calif.	SAN	1,065
59	Seattle-Everett, Wash.	SEA	1,422
60	Springfield-Chicopee-Holyoke, Mass.-Conn.	SPR	530
61	Syracuse, N.Y.	SYR	636
62	Tampa-St. Petersburg, Fla.	TAM	1,013
63	Toledo, Ohio-Mich.	TOL	693
64	Washington, D.C.-Md.-Va.	WAS	2,861
65	Youngstown-Warren, Ohio	YOU	536

LIST B

SMSA'S WITH POPULATION 200,000-500,000 (M)

	SMSA	Code	Population, 1970 (in 1,000)
66	Albuquerque, N. Mex.	ALB	316
67	Ann Arbor, Mich.	ANN	234
68	Appleton-Oshkosh, Wis.	APP	277
69	Augusta, Ga.-S.C.	AUG	253
70	Austin, Texas	AUS	296
71	Bakersfield, Calif.	BAK	329
72	Baton Rouge, La.	BAT	285
73	Beaumont-Port Authur-Orange, Texas	BEA	316
74	Binghamton, N.Y.-Pa.	BIN	303
75	Bridgeport, Conn.	BRI	389
76	Canton, Ohio	CAN	372
77	Charleston, S.C.	CHA	304
78	Charleston, W. Va.	CHA	230
79	Charlotte, N.C.	CHA	409
80	Chattanooga, Tenn.-Ga.	CHA	305
81	Colorado Springs, Colo.	COL	236
82	Columbia, S.C.	COL	323
83	Columbus, Ga.-Ala.	COL	239
84	Corpus Christi, Texas	COR	285
85	Davenport-Rock Island-Moline, Iowa-Ill.	DAV	363
86	Des Moines, Iowa	DES	286
87	Duluth-Superior, Minn.-Wis.	DUL	265
88	El Paso, Tex.	ELP	359
89	Erie, Pa.	ERI	264
90	Eugene, Oreg.	EUG	213
91	Evansville, Ind.-Ky.	EVA	233
92	Fayetteville, N.C.	FAY	212
93	Flint, Mich.	FLI	497
94	Fort Wayne, Ind.	FOR	280
95	Fresno, Calif.	FRE	413
96	Greenville, S.C.	GRE	300
97	Hamilton-Middleton, Ohio	HAM	226
98	Harrisburg, Pa.	HAR	411
99	Huntington-Ashland, W. Va.-Ky.-Ohio	HUN	254
100	Huntsville, Ala.	HUN	228
101	Jackson, Miss.	JAC	259
102	Johnstown, Pa.	JOH	263
103	Kalamazoo, Mich.	KAL	202
104	Knoxville, Tenn.	KNO	400
105	Lancaster, Pa.	LAN	320

	SMSA	Code	Population, 1970 (in 1,000)
106	Lansing, Mich.	LAN	378
107	Las Vegas, Nev.	LAS	273
108	Lawrence-Haverhill, Mass.-N.H.	LAW	232
109	Little Rock-North Little Rock, Ark.	LIT	323
110	Lorain-Elyria, Ohio	LOR	257
111	Lowell, Mass.	LOW	213
112	Macon, Ga.	MAC	206
113	Madison, Wis.	MAD	290
114	Mobile, Ala.	MOB	377
115	Montgomery, Ala.	MON	201
116	New Haven, Conn.	NEW	356
117	New London-Groton-Norwich, Conn.	NEW	208
118	Newport News-Hampton, Va.	NEW	292
119	Orlando, Fla.	ORL	428
120	Oxnard-Ventura, Calif.	OXN	376
121	Pensacola, Fla.	PEN	243
122	Peoria, Ill.	PED	342
123	Raleigh, N.C.	RAL	228
124	Reading, Pa.	REA	296
125	Rockford, Ill.	ROC	272
126	Saginaw, Mich.	SAG	220
127	Salinas-Monterey, Calif.	SAL	250
128	Santa Barbara, Calif.	SAN	264
129	Santa Rosa, Calif.	SAN	205
130	Scranton, Pa.	SCR	234
131	Shreveport, La.	SHR	295
132	South Bend, Ind.	SOU	280
133	Spokane, Wash.	SPO	287
134	Stamford, Conn.	STA	206
135	Stockton, Calif.	STO	290
136	Tacoma, Wash.	TAC	411
137	Trenton, N.J.	TRE	304
138	Tucson, Ariz.	TUC	352
139	Tulsa, Okla.	TUL	477
140	Utica-Rome, N.Y.	UTI	340
141	Vallejo-Napa, Calif.	VAL	249
142	Waterbury, Conn.	WAT	209
143	West Palm Beach, Fla.	WES	349
144	Wichita, Kans.	WIC	389
145	Wilkes-Barre-Hazleton, Pa.	WIL	342
146	Wilmington, Del.-N.J.-Md.	WIL	499
147	Worcester, Mass.	WOR	344
148	York, Pa.	YOR	330

TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This study is primarily concerned with evaluating regional economic damages to human health, material, and vegetation and of property soiling resulting from air pollution. This study represents a step forward in methodological development of air pollution damage estimation. It attempts to construct essential frameworks of the physical and economic damage functions which can be used for calculating comparable regional damage estimates for the several important receptors--human health, material, and household soiling--however,tentative the damage estimates may appear to be. More importantly, aggregate economic damage functions instrumental for transforming the multifarious aspects of the pollution problem into a single, homogeneous monetary unit are tentatively derived and illustrated. It is hoped that these results will be of some use to guide policymakers as they make decisions on the implementation of programs to achieve "optimal" pollution levels for this country. Given the experimental nature of the methodological and statistical procedures and the degree of uncertainty associated with the study results, a great deal of caution should be exercised in using the products of this research.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Physical Damage Functions Economic Damage Functions Air Pollutants - SO_2, Suspended Particulates Receptors - Health, Materials, Household Soiling, Vegetations Standard Metropolitan Statistical Areas Regions		

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