United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/5-83-001d
August 1982

Air

EPA

Benefit Analysis of Alternative Secondary Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates

Volume IV

FINAL ANALYSIS

BENEFITS ANALYSIS OF ALTERNATIVE SECONDARY NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE AND TOTAL SUSPENDED PARTICULATES

VOLUME IV

Benefits Analysis Program
Economic Analysis Branch
Strategies and Air Standards Division
Office of Air Quality Planning and Standards

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August 1982

U.S. Environmental Protection Agency

PREFACE

This report was prepared for the U.S. Environmental Protection Agency by MATHTECH, Inc. The report is organized into six volumes containing a total of 14 sections as follows:

Volume I

- Section 1: Executive Summary
- Section 2: Theory, Methods and Organization
- Section 3: Air Quality and Meteorological Data

Volume II

- Section 4: Household Sector
- Section 5: Residential Property Market
- Section 6: Labor Services Market

Volume III

- Section 7: Manufacturing Sector
- Section 8: Electric Utility Sector

Volume IV

- Section 9: Agricultural Sector

Volume V

- Section 10: Extrapolations
- Section 11: Bibliography

Volume VI

- Section 12: Summary of the Public Meeting
- Section 13: Analysis of Pollutant Correlations
- Section 14: Summary of Manufacturing Sector Review

The analysis and conclusions presented in this report are those of the authors and should not be interpreted as necessarily reflecting the official policies of the U.S. Environmental Protection Agency.

ACKNOWLEDGMENTS

This report and the underlying analyses profited considerably from the efforts of Allen Basala, who served as EPA Project Officer, and V. Kerry Smith, who served as a reviewer for EPA. Allen provided the initiative and on-going support to conduct an applied benefits analysis. Kerry's technical insights and suggestions are reflected in nearly every section of the report.

James Bain and Tom Walton of EPA, and Jan Laarman and Ray Palmquist, who served as reviewers for EPA, also contributed substantially to individual report sections through their advice and comments during the course of the project. Also providing helpful comments and assistance were Don Gillette, Fred Haynie, Neil Frank and Larry Zaragosa, all with EPA.

Several other members of the Mathtech staff contributed to the project during various stages of the work. They included Robert J. Anderson, Jr., Neil Swan, John Keith, Donald Wise, Yaw Ansu, Gary Labovich, and Janet Stotsky.

The production of the report was ably managed by Carol Rossell, whose patience remained intact through countless drafts and deadlines. Carol was assisted by Sally Webb, Gail Gay, and Deborah Piantoni.

Finally, we extend our appreciation to the many dozens of individuals, too numerous to list here, who provided advice, suggestions, and data during the course of the project.

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

SECTION 9

AGRICULTURAL SECTOR

SECTION 9

AGRICULTURAL SECTOR ANALYSIS

INTRODUCTION

Summary of Results

In this section we examine the economic benefits of achieving alternative secondary national ambient air quality standards (SNAAQS) for sulfur dioxide (SO_2) for two economically important crops in the agricultural sector: cotton and soybeans. Economic benefits are measured within the framework of the crop production process. Individual crop yield functions are developed using actual crop production data on a county basis. These functions relate yield to the amount of inputs used in the crop production process. Inputs into this process include both economic and climatological factors, with the ambient level of SO_2 being considered a negative input. These yield functions are estimated in order to test the hypothesis that ambient SO_2 levels have a deleterious effect on the yield of cotton and soybeans. The results of these estimations are then integrated with estimated market supply and demand equations in order to measure the economic benefits of the reductions in SO_2 levels to alternative secondary national ambient air quality standards.

Based on our sample of cotton-producing counties in Alabama, Arizona, California, Mississippi, New Mexico and Texas, a significant negative relationship between SO_2 and cotton yield has not been found. Consequently, the calculation of the economic benefits of meeting the secondary standard for SO_2 for cotton is not warranted.

Our soybean sample consists of a subset of the soybean-producing counties in Alabama, Georgia, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Mississippi, Ohio, Texas and Wisconsin. A significant negative relationship between ambient SO_2 levels and soybean yield has been found to exist for the sample counties in the states of Illinois, Indiana, Iowa and Ohio. Incorporating the results of the soybean yield functions for these states with our estimated demand and supply functions, the economic benefits of the implementation of SNAAQS are calculated based on the SO_2 and soybean production levels existing in the sample counties of these states in 1977. Approximately 40 percent of these sample counties exceeded an alternative secondary standard of 260 $\mu g/m^3$ for the 24-hour maximum in 1977. The discounted present value in 1980 of the economic benefits of the reduction in SO_2 levels in these counties to this alternative secondary standard by 1988 are estimated to be $21.6 million in 1980 dollars. This assumes an infinite time horizon and a 10 percent discount rate.

Background

It is generally accepted that air pollution can have a negative influence on plants. Numerous studies have examined the response of plants to various levels of air pollution concentrations through the use of controlled experiments and have found that air pollution can have a deleterious impact on plant growth and yield. These studies have been extremely useful in identifying the physical effects of air pollution on plants. They are unable, however, to assess the economic impact of ambient air pollution on agricultural crop production. In order to accurately measure the benefits of any air pollution control program, it is the economic effects of air pollution that must be taken into account. Since the purpose of this section is to measure the benefits associated with the implementation of alternative secondary national ambient air quality standards (SNAAQS) in the agricultural sector, it is the economic impacts of these standards that we will address.

In the past, most studies that have evaluated the economic losses in the agricultural sector due to air pollution have relied on the results of controlled laboratory and field studies or field surveys. Their emphasis has been primarily on the categorization and estimation of the physical effects of air pollution on crop production. They are, however, only rudimentary approaches to an accurate assessment of the economic losses in the agricultural sector for several reasons.

The applicability of controlled laboratory studies to actual crop production conditions is questionable due to the differences in the controlled and ambient environment. Both environmental and economic conditions will affect the relationship between the plant and air pollution that is exhibited in a controlled environment. Most laboratory experiments are performed under ideal climatological conditions and are therefore not representative of the conditions under which a crop is grown. Although field experiments replicate the climatological conditions influencing the crop, they do not take into account the economic conditions that influence crop production. For example, a producer, realizing that air pollution affects his crop, may decide to apply more fertilizer to mitigate the effects of air pollution. Using the dose-response relationship exhibited in a field experiment to estimate the effect of a certain level of air pollution will result in an overestimate of damages in this case.

The attempt of field surveys to directly measure the effects of ambient air pollution on crop production is hampered by the difficulty researchers face in isolating the effects of air pollution from all of the other factors that influence crop production. The assessment of crop damages depends, in large part, on the degree of researcher training. Subjective judgments on the part of the researcher are sometimes necessary, thus preventing a standardized methodology from being developed. Reductions in crop production that result from damages that are not visible (e.g., reduced photosynthetic capability that results in reduced crop yield) will probably not be assessed accurately in the field surveys. Unlike the studies utilizing the results of laboratory and field experiments, mitigative actions on the part of the producer may be identified in the field survey.

Economic losses in both of these types of studies are generally calculated by multiplying the estimated reduction in production by an average crop price. Although the researchers are aware of the possible impact that changes in production can have on product price, their methodologies are unable to incorporate this effect into their loss estimates.

In measuring the economic impact of air pollution on agricultural production, it is necessary to couch the analysis within the framework of the agricultural production process. The producer, as the decision maker in this process, is concerned with transforming inputs into agricultural outputs for the purpose of generating a profit. Included as inputs in this production process are factors over which the producer does and does not have control. Clearly, air pollution is a factor over which the producer does not have control.

Assuming for the moment that air pollution enters into the production process as a negative input (i.e., air pollution has a deleterious effect on crop output), the producer has several options open to him:

- He can try to ameliorate the effects of air pollution on his crop through the application of additional amounts of other inputs such as lime. This may enable him to produce the same level of output but at a higher cost.

- He can shift to a cultivar that is more resistant to pollution. If the pollution-resistant cultivar is more expensive than the original cultivar, this will also tend to increase the costs of production.

- He can shift from production of the pollution-sensitive crop to a crop that is less sensitive. This shift is likely to result in revenues that are higher in comparison to the revenues associated with the crop that is pollution-sensitive, but lower in comparison to the revenues associated with the production of the original crop without air pollution.

- He can do nothing. This will result in a lower level of output and a possible decrease in revenue.

Obviously, the adjustments that the producer does or does not make regarding this negative input may influence both the net revenues that the producer receives and the amount of the output produced. These agricultural adjustments may also have an adverse effect on consumers through their impact on crop price. Consequently, an accurate assessment of the economic effects of air pollution on crop production must measure the effects in both the producer and consumer sectors. It is our intent in this section to develop a model that takes both of these factors into account.

Overview of the Agricultural Model

In simple form, the economic effects of a change in air quality on the production of an agricultural crop can be seen by examining the demand and supply curves for the crop. As can be seen in Figure 9-1,

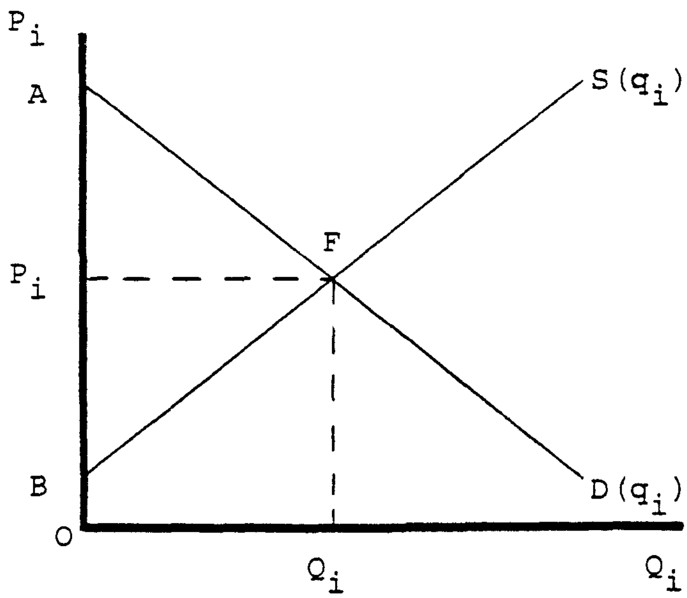

Figure 9-1. Demand and supply curves for crop i.

the supply curve for crop i, $S(q_i)$, reflects the amount of the crop that is supplied at alternative price levels. It is upward sloping, indicating that the supply of the crop increases as price increases. The demand curve $D(q_i)$, which is negatively sloped, shows the amount of the crop that is demanded at alternative price levels. The demand curve indicates that demand for the crop decreases as price increases. Equilibrium price, P_i, and quantity, Q_i, are obtained when sellers are willing to sell and buyers are willing to buy the same quantity at the same price.

The hypothesis that air pollution has a deleterious effect on crop supply will be tested in this analysis. Assuming that such a relationship is found, the improvement in air quality that will result from the implementation of SNAAQS will cause an increase in the amount of the crop that can be supplied at alternative price levels. This increase can be represented by the shift in the supply curve from $S(q_i)$ to $S(q_i)'$ in Figure 9-2.

Given the increase in supply due to the improvement in air quality, price will drop and a new equilibrium price is established at P_i'. Equilibrium quantity increases from Q_i to Q_i'.

The economic benefits of this increase in crop supply can be estimated by comparing the economic surplus that exists with and without the change in air quality. The area above the price of crop i and beneath the demand curve is called "consumer surplus". Consumer

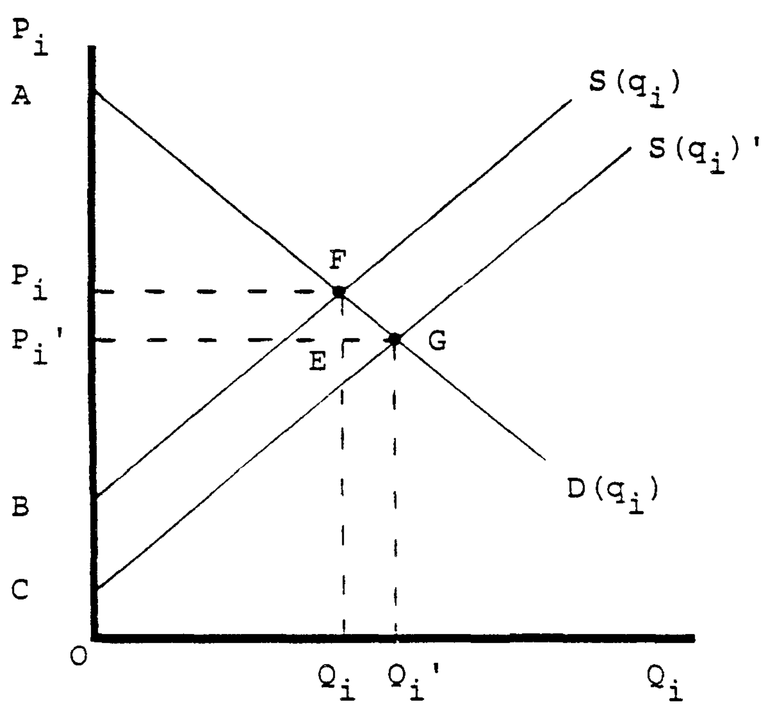

Figure 9-2. Effect of a change in supply on crop price.

surplus represents the amount that consumers would be willing to pay for a particular quantity over and above the market price. It is a measure of the net benefits consumers derive from purchasing the crop. With equilibrium price and quantity at P_i and Q_i, respectively, total expenditure on the crop would be $P_i \cdot Q_i$. Consumer surplus, or the amount consumers would be willing to pay in excess of $P_i \cdot Q_i$, is equal to P_iFA. "Producer surplus," on the other hand, is represented by the area beneath the price of crop i and above the supply curve. It is a measure of the net benefits producers receive from supplying the crop at the market price. At the equilibrium price, P_i, and quantity, Q_i, the producers' gross receipts are equal to $P_i \cdot Q_i$ and are represented by the area P_iFQ_iO. Based on the supply curve $S(q_i)$, producers would be willing to accept receipts equal to the area BFQ_iO for Q_i. Producer surplus, therefore, is equal to the area P_iFB. Economic surplus, or the net benefit of supplying Q_i at a price equal to P_i, is equal to the sum of consumer and producer surpluses. This is equivalent to the area AFB in Figure 9-2.

Given that the implementation of SNAAQS will result in a shift of the supply curve of crop i from $S(q_i)$ to $S(q_i)'$, economic surplus increases to the area AGC. The economic benefits of this increase in supply is equal to the difference in economic surplus with and without the air quality change. In Figure 9-2, this is equivalent to the area BFGC, which can be obtained by integrating over the area:

$$BFGC = \int_0^{Q_i'} [D(q_i) - S(q_i)']dq - \int_0^{Q_i} [D(q_i) - S(q_i)]dq \quad (9.1)$$

From the above discussion, it is clear that in order to measure the economic impact of an improvement in air quality on crop production, the supply and demand curves for the crop must be estimated. A brief discussion of the crop supply and demand curves that are estimated in this section follows.

Supply Equations--

In this analysis, the supply curve of an agricultural crop is obtained from the estimation of two functions: an acreage response function and a yield function. The acreage response function reflects the relationship between the number of acres that are planted in a particular year and the variables affecting that decision. In general, it is of the form:

$$ACPL_i = g(P_i^e, P_s^e, G_i) \quad (9.2)$$

where $ACPL_i$ = the number of acres planted of crop i.

P_i^e = the expected price of the crop.

P_s^e = the expected price of substitute crops in production.

G_i = government support programs for the crop.

The acreage response equation is estimated using annual time series data on the national level from 1955 to 1977.

The number of acres harvested of crop i ($ACHR_i$) is assumed to be a fixed percentage of the number of acres planted of crop i.

The yield function reflects the physical production process that occurs after the crop has been planted. Explicit in this function are factors over which the producer does and does not have control. As such, it is able to examine the impact of air pollution on the crop production process. The yield function for the i^{th} crop in a particular year can be represented by:

$$YLD_i = f(I_i, E_i) \tag{9.3}$$

where YLD_i = the yield or output per acre of the i^{th} crop,

I_i = inputs used in the production process (labor, fertilizer, machinery, etc.), and

E_i = the environmental factor affecting Y_i (temperature, rain, air pollution, etc.).

It is posited that air pollution enters this process as a negative input and therefore has a negative influence on crop production.

The yield equation is designed to be estimated using actual crop production and ambient air quality data on a site-specific basis and therefore avoids the problems associated with extrapolating the results of controlled studies to the ambient environment. By including environmental variables in the yield equation, the possibility that environmental factors may influence the susceptibility of the crop to air pollution is specifically taken into account. The inclusion of economic variables enables the yield equation to reflect the fact that producers can also influence the yield of the crop through the decisions they make regarding the use of labor, machinery, fertilizer, etc.

The total production of crop i can be found by multiplying the number of acres harvested by the average yield per harvested acre:

$$Q_i^S = ACHR_i \cdot \overline{YLD}_i \tag{9.4}$$

The total supply, or quantity available, of the crop in a particular year is equal to the quantity produced in that year (Q_i^S) <u>plus</u> the quantity of the crop left over from the previous year ($Q_i^K(-1)$).

$$SUPPLY_i = Q_i^S + Q_i^K(-1) \tag{9.5}$$

It should be mentioned that this model, as currently developed, is unable to directly reflect the possibility that producers may respond to the effects of air pollution on a particular crop by decreasing the number of acres of the pollution sensitive crop that is planted. In addition, it is unable to reflect the impact that air pollution may have on the quality of the crop.

Demand Equations--

In this section, it is assumed that crop demand consists of three components: domestic demand, export demand, and stock demand.* Like the supply equation, annual time series data from 1955 to 1977 are used to estimate the demand equations. The general form of these three equations are:

Domestic demand--

$$Q_i^M = m(P_i, P_j, Z_i) \qquad (9.6)$$

where Q_i^M = the amount of crop i demanded domestically.

P_i = the price of the crop.

P_j = a vector of prices of other goods that affect the demand for i (e.g., the price of a substitute crop in consumption).

Z_i = a vector of other variables affecting the demand for i (e.g., population, number of livestock).

Export demand--

$$Q_i^X = x(P_i, P_q, XR, Q_i^E, T_i, V_i) \qquad (9.7)$$

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* If a significant portion of the crop is imported into the United States, the export demand equation will be estimated as a net export demand equation (i.e., EXPORTS - IMPORTS).

where Q_i^X = the amount of the crop exported from the United States.

P_i = the price of the crop in the United States.

P_q = a vector of prices of other goods that affect the export demand for i (e.g., the price of a substitute crop in consumption).

XR = the exchange rate between the United States and the importing country.

Q_i^E = the amount of the crop produced outside of the United States.

T_i = the cost of transporting the agricultural crop from the United States to the importing country.

V_i = a vector of other variables affecting the exports of i (e.g., United States foreign aid policy, population of importing counties, number of livestock in importing countries).

Stock demand—

$$Q_i^K = k\ P_i,\ P_i^e,\ Q_i^S,\ Q_i^K(-1),\ C_i,\ G_i \qquad (9.8)$$

where Q_i^K = the amount of the crop held in stock.

P_i = the actual price of the crop.

P_i^e = the expected price of the crop.

Q_i^S = the quantity produced of the crop.

$Q_i^K(-1)$ = the amount of the stock held in the previous year.

C_i = the cost of holding stocks of the crop.

G_i = the capacity constraints of processing the crop into a final good.

Total demand in a particular year is equal to the sum of the components of demand:

$$\text{DEMAND} = Q_i^M + Q_i^X + Q_i^K \qquad (9.9)$$

Market-Clearing Identity

In order to ensure that the market for the crop clears (i.e., SUPPLY = DEMAND), the estimated supply and demand components are subject to the following market-clearing identity:

$$Q_i^S + Q_i^K(-1) = Q_i^M + Q_i^X + Q_i^K \qquad (9.10)$$

Scope of Analysis

Agricultural production is an important part of the United States economy and plays a significant role in the economies of many foreign countries. It is not possible at this time to analyze the effects of air pollution on the entire agricultural sector since the sector is highly complex, composed of the production of many different crops and species whose susceptibility to air pollution vary over a considerable range. For this study, we concentrate on two crops that the literature has shown to be susceptible to air pollution under controlled conditions: cotton and soybeans. In addition to being susceptible to air pollution, these crops are economically important crops, ranking fifth and second, respectively, in terms of crop value within the U.S. in 1977.

Although the alternative secondary standards used in this study are set in terms of total suspended particulate matter (TSP) and sulfur dioxide (SO_2), we will only consider the effects of SO_2 on cotton and soybean production in this analysis. Particulate matter is a generic term for a pollutant whose composition varies significantly. Depending on its composition, this pollutant can have a negative effect on plants (see Literature Review). In general, however, most particulate matter is not considered to be phytotoxic. Since the available particulate matter data are not broken down by composition, and since the generic form of particulate matter is not considered to be harmful to plants, the effect of TSP on crop yield is not examined in this analysis.

To enable us to capture the effect of year-to-year variations in SO_2 on crop yield, our yield equations are estimated using county air pollution and crop production data from 1975 to 1977.

The analysis will include all areas producing cotton and soybeans for which adequate air quality and farm production data are available. Our cotton sample includes counties in the states of Alabama, Arizona, California, Mississippi, New Mexico, and Texas. These states accounted for approximately 80 percent of the U.S. cotton production in 1977. The soybean sample includes counties in the states of Alabama, Georgia, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Mississippi, Ohio, Texas, and Wisconsin. These states accounted for approximately 69 percent of the U.S. soybean production in 1977.

Plan of Presentation

The subsections of the remainder of the Agricultural section are organized in the following manner:

- Literature Review
- Methodology
- Data
- Yield Equation Results
- Benefit Estimation
- Conclusions

LITERATURE REVIEW

The effects of air pollution on vegetation have been the subject of extensive study by plant pathologists and biologists for a number of years. In general, these studies have found that various types and levels of air pollution can have a deleterious effect on plants. The purpose of this subsection is to highlight some of the findings of the studies which investigate the effects of TSP and SO_2 on vegetation and to illustrate briefly the confounding factors implicit in the measurement of these effects. In addition, special attention will be given to those studies that have quantified, in dollar terms, the effects of air pollution on vegetation. For a comprehensive review of the literature on the physical effects of air pollution on vegetation, the interested reader is directed to the studies by Jacobson and Hill (1), Treshow (2), Naegele (3), and Mudd and Kozlowski (4).

Before reviewing the studies which examine the effects of TSP and SO_2 on vegetation, it is helpful to understand the types of injuries plants may sustain as a result of air pollution exposure.

The deleterious effects of air pollution can be broadly classified into two groups: (1) visible and (2) subtle injury. Plant injury evidenced by discoloration and/or lesions of the leaves, stems, or roots are examples of visible injury. Subtle injury, on the other hand, tends to be more difficult to detect. Examples of subtle injury are reductions in photosynthetic capability, growth, weight, flowering, and the amount or quality of yield. Increased susceptibility to insects and disease is another form of subtle injury. The fact that injury is not always apparent does not indicate that it is unimportant. In evaluating the economic damages of the effects of air pollution on agricultural crops, subtle injury that results in a reduction in yield may comprise a significant portion of economic damages.*

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* One facet of potential pollution effects not encompassed by yield reduction is the change in the taste or other quality attributes of the crop.

Laboratory and Field Studies*

Particulate Matter--

Relatively few studies have been done that examine the effects of particulate matter on plants. The pollutant called "particulate matter" is composed of many different elements whose distribution varies, depending on the source of the pollutant. At the present time, particulate matter is generally not considered to be harmful to plants and is therefore not considered to be a phytotoxic pollutant of major importance.

Studies that have examined the effects of particulate matter on plants have concentrated on the effects of dust accumulation on the plant itself rather than the accumulation of dust in the soil. In some cases, plant injury has been shown to occur from the deposition of particulate matter which is contained in waste gases of cement kilns. It has been found that the stomata of a number of plants may become clogged, resulting in a reduction in photosynthesis (7,3). The conclusions that can be drawn from such studies are limited, however, because the composition of the dusts in these studies varies significantly.

Heavy metals such as lead, manganese, zinc, nickel, boron, beryllium, and cadmium are phytotoxic elements that may be found in

* This summary relies on information contained in References (1), (2), (3), (4), (5), and (6).

particulate matter. Some studies that have examined the effects of these metals on plants have found that plant injury may occur where accumulated amounts of these metals are found in the soil where the plant is grown (8,9).

Sulfur Dioxide--

Sulfur dioxide (SO_2) enters the plant through the stomata. Once inside the plant, SO_2 reacts with water to form a sulfite ion which is oxidized by the plant to produce a sulfate ion. This ion can then be used by the plant for its sulfur requirements. Injury from SO_2 will occur if the amount of the sulfite and sulfate ions present in the plant cells exceed that which can be oxidized and assimilated. Injury may appear as chlorosis or necrosis of the leaves (10). Chronic injury may resemble senescence (1).

Invisible injury from SO_2 has also been found to occur. Thomas and Hill (11) found a reduction in the uptake of CO_2 by the plant as the result of SO_2 exposure. Changes in stomatal resistance, and therefore photosynthetic capabilities, have been found in plants exposed to SO_2 (12). Some studies have found that reduced photosynthetic rates lead to reduced yield (13). Miller and Sprugel (14) and Sprugel et al. (15) have found that reductions in the yield of soybeans can occur from exposure to various concentrations of SO_2 without visible injury to the soybean plants. Brisley et al. (10) have found that cotton yield in terms of the number of bolls decreased as the result of SO_2 exposure.

It has also been found that plants can be positively affected by SO_2 under certain circumstances. Plants grown in sulfur-deficient soil that are subsequently exposed to SO_2 have been found to use the atmospheric SO_2 for their sulfur requirements. As compared to plants of the same species grown under the same conditions but without SO_2 exposure, the SO_2-exposed plants had greater yields (16,17). Noggle and Jones (18) found that cotton located close to certain coal-fired power plants produced more biomass than cotton grown at a distance from the power plants.

Factors Which Affect the Response of Plants to Air Pollution

The majority of studies which examine the effect of air pollution on plants has been conducted in greenhouses and growth chambers. The plants are generally grown under optimal conditions (i.e., adequate moisture, temperature, and nutrients) which do not tend to replicate actual field conditions. Even open-topped field chambers, a substantial improvement over greenhouses and growth chambers, have been criticized because the air velocity throughout the chambers is less than that in the field (19). In this section we will briefly discuss the factors which tend to affect the response of plants to air pollution. Given the lack of studies on the effects of particulate matter on plants, we will concentrate on studies which examine the factors that affect the response of plants to SO_2.

Length and Concentration of Exposure--

The length and concentration of exposure to air pollution are extremely important in analyzing plant susceptibility. Equal doses of pollution do not result in equal plant response if the concentration and duration of the exposures differ. In general, plants are more susceptible to high doses of pollution over a short period of time than an equal amount of pollution in low doses over a longer period of time (20).

Temperature--

The temperature at which plants are grown and the temperature at which they are exposed to air pollution affects the susceptibility of plants to air pollution. This relationship, however, is dependent upon plant species (21). In general, plant sensitivity to SO_2 increases with increasing temperatures (22).

Humidity--

Increasing relative humidity tends to increase the susceptibility of plants to SO_2 (23). Susceptibility varies, however, depending on the plant species and level of humidity.

Light--

Since SO_2 enters the plant through the stomata, plants with open stomata are more susceptible to SO_2 than plants with closed stomata. Light is an important factor which can influence the opening and closing of the stomata and consequently will affect the susceptibility of plants to SO_2. Plants are more susceptible to SO_2 in the daylight than in the dark (24).

Soil Moisture--

Soil moisture, like light, influences stomatal opening and therefore is an important factor in determining plant sensitivity. Plants grown under water-stress conditions tend to be less susceptible to SO_2 than plants grown with a sufficient water supply (23). A study by the National Academy of Sciences (25) found, however, that sudden changes in soil moisture do not have much influence on plant sensitivity to SO_2.

Soil Fertility--

As mentioned previously, plants exposed to SO_2 that are grown in sulfur-deficient soils have been found to have greater yields than plants grown under similar conditions without SO_2 exposure. Setterstrom and Zimmerman (23) have found that soil nutrient deficiencies increased the susceptibility of alfalfa to SO_2.

Genetic Factors--

Genetic factors play an important role in determining the susceptibility of plants to air pollution. Different plants have been shown to exhibit differing degrees of sensitivity to air pollution. Cultivars of a particular species have also been found to vary in susceptibility to air pollution (26,27).

Stage of Development--

The sensitivity of plants to air pollution is affected by the age of the plant during exposure. Setterstrom and Zimmerman (23) and Webster (28) have found that developing and older leaves tend to be more resistant to SO_2.

Plant Disease--

Susceptibility to disease resulting from air pollution exposure varies, depending on the plant and the disease. Both increased and decreased incidence of disease have been found in plants exposed to air pollution (29).

Interaction With Other Pollutants--

The response of plants to simultaneous exposure to two or more air pollutants varies. Plant response in these instances can be less than additive, additive, or synergistic. Reinert *et al*. (30) have reviewed the literature in this area.

Assessment of Crop Losses

The studies reviewed in the last section have concentrated on the biological and physiological responses of plants to air pollution. These studies have been instrumental in uncovering the physical effects (visible and subtle) of air pollution but cannot provide any information on the economic impact of these effects. Researchers have attempted to quantify these effects in a number of ways. The effects of air pollution on plants have generally been quantified through: (1) field surveys of crops exposed to air pollution; (2) development of dose-response functions from the results of laboratory and field studies; or (3) economic studies. It is these studies that we will now review.*

Field Surveys--

Middleton and Paulus (33) were among the first researchers to undertake a survey designed to identify crops injured from air pollution, the location of the injury, and the pollutant causing the injury. Similar surveys were done by Lacasse et al. (34) in 1969, and Lacasse (35) in 1970 in Pennsylvania. Trained researchers were used to identify and evaluate air pollution damage to commercial and non-commercial plants in order to estimate the total cost of agricultural losses due to air pollution in Pennsylvania. One of the objectives of these studies was to determine the ranking of pollutants in terms of their effect on vegetation. It was also hoped that the surveys would provide a basis for estimating the nationwide impact of air pollution on vegetation.

Direct losses from air pollution were estimated to be in excess of $3.5 million, with indirect losses of $8 million in the 1969 study. Direct losses of $218,306 and indirect losses of $4,000 were estimated

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* The summary of the studies assessing the economic effects of air pollution on plants through the survey methodology relies on information contained in References (31) and (32).

in the 1970 study. Lacasse reported that better air quality in 1970 accounted for the difference in the estimates of the agricultural losses for the two years.

The Lacasse surveys are useful because they provide additional knowledge on the relationship between air pollution and plants and give some idea of the magnitude of the air pollution problem in Pennsylvania in 1969 and 1970. The surveys can be criticized because the damage estimates are based on a non-standardized method of translating physical damage into economic damage. Although the damage estimates were made by trained researchers, it is likely that some subjective judgments were made. Another criticism of the study regards the definition of direct and indirect losses. Direct losses to growers included only production costs. Losses in growers' profits resulting from air pollution were considered to be indirect losses, although it would have been more appropriate to include this in the direct loss category. In addition, the loss estimates for non-commercial vegetation are questionable since the effect of air pollution on these types of plants is not clearly understood and there is some question as to what value should be attached to these plants.

Several other studies have estimated the dollar losses that result from the exposure of vegetation to air pollution using methods similar to Lacasse. Millecan (36) examined the effect of air pollution on agricultural crops in California in 1970 through a survey. Loss estimates were calculated for 15 counties in the state and were estimated to be over $26 million. Except for citrus and grapes, these loss estimates did not include estimates for subtle damages such as reductions in growth or yield. The loss estimates also did not include losses to forests and landscapes. Ozone was the pollutant found to be the most damaging.

Feliciano (37) reported that agricultural losses due to air pollution in New Jersey in 1971 were $1.19 million. An attempt was made to standardize the estimation of loss from crop damage information using Millecan's "Rule of Thumb" valuation method (36) (i.e., 1-5 percent injury of the plant leaves of the crop would be estimated as a 1 percent loss, 6-10 percent injury was estimated as a 2 percent loss, 11-15 percent injury translated into a 4 percent loss, and 16-20 percent injury resulted in an 8 percent loss). Like the Lacasse surveys, no account was made for losses that may have occurred without visible injury to the plant and profit losses were not included in the loss estimates.

Pell (38) did a follow-up study to the Feliciano study in New Jersey in 1972. Direct losses were estimated to be approximately $130,000. The lack of soil moisture in 1972 was cited as the reason for the difference in loss estimates.

Naegele et al. (39) estimated direct losses to be $1.1 million in New England for the 1971-1972 growing season. Losses were based on surveys in 40 counties of the six New England states. This study included profit losses in the direct loss estimates. Oxidant air pollution was found to be the most damaging.

Millecan (40) conducted another survey in California in order to estimate air pollution damages from 1970-1974. Four types of crops were covered: fruits and nuts, field crops, vegetables, and nursery and cut flowers. An improved standardized method for estimating losses was developed in this study. Losses from the exposure of alfalfa to air pollution were calculated from a crop-dose conversion scale. This scale ensured that equal exposure to air pollution would result in equal loss estimates. Losses ranged from $16.1 million in 1970 to $55.1 million in 1974. It was acknowledged that the dollar value of these loss estimates could differ from year to year due to increases in the prices and quantities of the crops under study, and a better understanding and reporting of the effects of air pollution, as well as increases in the level of pollution.

Dose Response Function Studies--

In an attempt to standardize the methods for translating physical damages into economic losses, numerous studies have developed crop loss equations. These equations enable the researcher to predict the economic value of plant damage from the dose of air pollution. Obviously, the accuracy of the economic losses predicted from these equations depends on how well the crop loss equation is specified.

One of the first studies that used a crop loss equation to estimate economic losses was Benedict et al. (41,42). This study was conducted to provide comprehensive estimates of the economic losses to agriculture in the United States. A crop loss equation was developed from information regarding the air pollution concentrations of fuel emissions throughout the country and the sensitivity of specific types of vegetation to air pollution. This equation was developed in order to estimate losses from exposure to emissions of oxidants, sulfur dioxide, and fluorides. Counties where air pollution was considered to be a problem were selected to be studied. The "relative potential severity" of oxidant and sulfur dioxide pollution was estimated based on fuel consumption data, a pollution concentration rate factor, a factor representing the total area in the county, and the number of days likely in an air pollution episode. The relative sensitivity of the commercial crops, forests, and ornamental plantings was extrapolated from information contained in the literature. Crop value was estimated based on the Census of Agriculture and state and county reports. Forest values were based on Federal and state information. Ornamental plants were valued at maintenance and replacement costs. Using the above information, economic losses for plant j in county i were calculated according to the following loss equation:

$$\text{Plant Loss}_{ij} = \text{Plant Value}_{ij} \cdot \text{Plant Sensitivity}_{j} \cdot \text{Pollution Potential}_{i}$$

Aggregate losses were obtained by summing over all plants and counties. For 1964, total losses to crops and ornamentals in 687 of the 3078 counties in the United States from oxidants, sulfur dioxide, and fluorides was $131.8 million. Total losses in 1969 were estimated to be $134.6 million. These loss estimates accounted for 0.99 percent and 1.84 percent of the total crop value in the counties included in the study in 1969 and 1974, respectively. As Table 9-1 shows, losses due to oxidant pollution made up the major portion of the total losses in both years.

As part of the National Crop Loss Assessment Network program (NCLAN), Moskowitz et al. (43) updated the Benedict et al. model to estimate agricultural losses due to oxidants in 1969 and 1974. Basically the same methodology was used with updated information on emissions and crop values. In 1969 dollars, the total annual losses from oxidant pollution were estimated to be $130.0 million and $290.0 million in 1969 and 1974, respectively. These losses account for 1.2

TABLE 9-1. BENEDICT ET AL. LOSS ESTIMATES
(in million $)

1964	Oxidants	Sulfur Dioxide	Fluorides
Crops	78.0	3.3	4.3
Ornamentals	43.0	3.0	0.2
1969	**Oxidants**	**Sulfur Dioxide**	**Fluorides**
Crops	77.3	4.97	5.25
Ornamentals	42.8	2.70	1.70

percent of the vegetation value in the counties studied in 1969 and 2.2 percent in 1974.

As in the studies which use surveys to estimate the economic losses to vegetation, these studies are useful because they provide information on the air pollution-plant relationship and give some idea of the magnitude of the air pollution problem throughout the United States. They can be criticized, however, for the following reasons: (1) loss estimates were not based on actual pollution levels within each county but on a "potential pollution" level that was calculated from fuel consumption and meteorological data, (2) sensitivity of plants to air pollution were extrapolated from studies that measured the response of plants to air pollution in environments that differed significantly from the environments in which the plants are typically grown, and (3) the possibility that reductions in crop output would lead to higher output prices was not considered.

Oshima (44) and Oshima et al. (45) estimated crop loss functions for crops grown under conditions that closely approximated ambient air quality conditions in several areas of Southern California. Crop loss equations, as a function of oxidant pollution, were estimated for alfalfa, cotton, and tomatoes.

Liu and Yu (46) estimated crop loss as a function of an oxidant index, sulfur dioxide level, crop value, and several climatological variables for ten crop categories. Since data on crop loss information were not available, Liu and Yu used the crop loss estimates calculated by Benedict et al. (41,42). As previously discussed, these estimates are subject to criticism.

Armentano (19), in a study of the Ohio River Basin, estimated crop loss functions for oxidants and sulfur dioxide based on a review of the literature. The crops included in the analysis were soybeans, corn, and wheat. Crop loss functions were derived using the results of studies primarily conducted in the field. Air pollution concentrations around coal-fired electrical generating stations in the Ohio River Basin were estimated using a plume dispersion model based on air quality variables. The calculation of losses for each crop were done by Miller and Usher (19) and proceeded in the following manner:

(1) Air quality concentrations around the generating stations impacting the acres on which the crop was grown were estimated from a dispersion model.

(2) Using a crop loss function that was developed from the literature, the percentage loss in crop yield associated with this air pollution concentration was determined.

(3) Because the crop production observed in the Ohio River Basin reflects the effect of air pollution, estimates for the probable clean air production (i.e., the probable production under the assumption that there is no SO_2 in the atmosphere) were made based on the following formula:

$$\text{Probable Clean Air Production} = \frac{\text{Average Production From 1975-1977}}{100 - \text{\% Loss in Production Due to Pollution}} \times 100$$

(4) Crop loss, in terms of bushels, for each impacted area was estimated as the difference between the probable clean air production and the observed level of production.

(5) Total crop losses for each crop for the area around coal-fired electrical generating stations in the Ohio River Basin were estimated as the summation of the individual impacted areas.

Recognizing that the decrease in production due to air pollution will probably impact product prices, Miller and Usher did not attempt to place a dollar value on crop losses. An increase in soybean yield of 681,285 bushels resulting from the abatement of direct SO_2 impact from coal-fired electrical generating stations in 1985 were estimated for the states of Illinois, Indiana, Kentucky, Ohio, Pennsylvania and West Virginia. It is questionable, however, whether the estimated bushel losses can be considered to reflect losses accurately since the loss functions on which the estimates are based do not take into account the actions a farmer may take to mitigate the effects of air pollution. For example, a farmer may have switched to a pollution-resistant cultivar or changed fertilization practices in order to diminish the effect of air pollution on his crop. In this case, the production estimates used reflect the production after the farmer has adjusted to air pollution and consequently may result in underestimates of the effects of air pollution on the crop. In addition, the estimates do not reflect the possible costs of adjustment that are incurred by the farmer in order to mitigate the effects of pollution.

Economic Studies

Recently, more attention has been given to the incorporation of both economic and environmental factors in determining the impact of air pollution on crops. Adams *et al.* (31) were the first researchers to incorporate both of these factors into the development of their model of the assessment of oxidant pollution damages in Southern California. The impact of a change in quantity on product price was specifically examined. Using the equations developed by Larsen and Heck (47) to estimate percentage leaf damage as a function of ozone concentration and Millecan's "Rule of Thumb" method for translating leaf damage into yield reduction estimates, yield reductions for all crops included in the study except cotton were estimated. The yield reductions for cotton were estimated using the yield loss equation for cotton developed by Oshima *et al.* (45). Through the estimation of a price forecasting equation, the change in price resulting from a change in the quantity produced of each crop was obtained. Consumer losses of $14.8 million per year from 1972 to 1976 were estimated to have occurred due to the exposure of certain vegetable and field crops to ozone.

Although the Adams *et al.* study is an improvement over other studies trying to assess the economic damages of air pollution in that it takes account of price changes resulting from air pollution damages, it still does not take into account the actions that the producer may take to offset the effects of pollution. In addition, the estimated yield reductions resulting from exposure to ozone based on Millecan's "Rule of Thumb" method are somewhat arbitrary.

Leung *et al*. (48) also incorporated both environmental and economic factors into the development of a model that assessed the impact of ozone on crop yield in the California South Coast Air Basin. In the interim report, crop production equations were developed for five crops: strawberry, tomato, lemon, navel orange, and Valencia orange. Production was estimated to be a function of ozone, temperature, and rainfall. Significant negative relationships were found to exist between ozone and yield for the five crops.

One of the problems apparent in the implementation of the methodologies which incorporate both economic and environmental factors is the lack of data. Both Adams *et al*. and Leung *et al*. could not incorporate information on the producer's use of inputs (e.g., fertilizer, machinery, and labor) into the estimation of their models.

Finally, Stanford Research Institute (49) estimated the benefits of meeting SNAAQS in the agricultural sector. Crop damage functions developed primarily from field studies were used to estimate the percentage reduction in yield resulting from crop exposure to air pollution in counties exceeding the secondary standard in 1980. The yield reduction functions did not incorporate any information on environmental conditions and therefore are not likely to represent the reduction in yield resulting from exposure to air pollution if environmental conditions are different from those in the field studies. These functions were developed for economically important agricultural crops and were combined with information on crop production and price to calculate the cost of damage to these crops:

$$\text{Cost of damage} = \text{reduction in yield} \cdot \text{production} \cdot \text{price}$$

The benefits of implementing SNAAQS were estimated to be $1.78 billion in 1980 dollars. The reduction in sulfur dioxide accounted for benefits of $34 million with the remainder of the benefits being attributed to the reduction in oxidants.

METHODOLOGY

The problem, as stated in the introduction to this section, is to try to provide an accurate assessment of the agricultural economic benefits that are associated with the implementation of alternative SNAAQS. In this subsection, we explain the methodological framework that is used to examine the economic effects of SO_2 on the two crops we have chosen to study in this sector: cotton and soybeans.

Yield Functions

The process by which a producer transforms inputs into outputs can be expressed in terms of a production function. The production function is a mathematical expression that relates the quantities of the inputs the producer employs with the quantities of the outputs he produces. For the farmer, inputs can be considered to be land, labor, equipment, fertilizer, insecticide, and seed. In agricultural production, this process is also heavily influenced by factors over which the producer does not have control: temperature, rainfall, ambient air quality, etc.

Typically, most farmers produce more than one output. The production processes of these farms can be represented by the implicit production function,

$$f(Q_1, \ldots, Q_n; X_1, \ldots, X_m) = 0 \qquad (9.11)$$

This implicit function relates all of the output produced (Q's) to all of the inputs used (X's). The production function of any one output, i, by farmer j can be expressed by the explicit function:

$$Q_{ij} = z(X_{1j}, \ldots, X_{mj}) \qquad (9.12)$$

In this study, we estimate this function in terms of a yield response function by using actual crop production data. Air pollution enters into this function as a negative input. (Improvements in air quality, on the other hand, may be viewed as a positive input.) It is assumed that the farmer does not have any control over the quantity and timing of use of this negative input. Because of the unavailability of data on the farm level, the county is used as the unit of observation. Specifically, the yield of crop i for county j is hypothesized to be a function of a set of physical and economic variables:

$$YLD_{ij} = f(L_{ij}, K_{ij}, F_{ij}, I_{ij}, S_{ij}, M_{ij}, T_{ij}, H_{ij}, R_{ij}, SO2_{ij}, E_{ij}) \tag{9.13}$$

where YLD_{ij} = yield of crop i for county j.

L_{ij} = labor.

K_{ij} = capital machinery and equipment.

F_{ij} = fertilizer.

I_{ij} = insecticide.

S_{ij} = seed.

M_{ij} = management.

T_{ij} = temperature.

H_{ij} = humidity.

R_{ij} = rain.

$SO2_{ij}$ = ambient level of sulfur dioxide.

E_{ij} = other environmental variables affecting yield such as light duration and intensity, and other pollutants.

The first-order partial derivatives of yield with respect to the economic inputs and the climatological variables of temperature and rain are expected to be positive (e.g., $\partial YLD_{ij}/\partial L_{ij} > 0$). It is our hypothesis that SO_2 has a deleterious effect on crop yield. Consequently, the first-order partial derivative of crop yield with respect to this variable is expected to be negative (i.e., $\partial YLD_{ij}/\partial SO2_{ij} < 0$). The first derivative of yield with respect to the other environmental variables is uncertain. (See Literature Review.)

Assume for the moment that a significant negative relationship is found to exist between SO_2 and crop yield (i.e., $\partial YLD_{ij}/\partial SO2_{ij} < 0$). The increase in yield resulting from an incremental improvement in the level of SO_2 can then be calculated:

$$\Delta YLD_{ij} = \left(\frac{\partial YLD_{ij}}{\partial SO2_{ij}}\right) \Delta SO2_{ij} \qquad (9.14)$$

In this case, Equation (9.14) could be used to calculate the <u>physical</u> improvement in yield resulting from an improvement in the level of SO_2.

Functional Forms--

A number of different functional forms of these yield functions will be estimated in order to reflect the various relationships that may exist between crop inputs and output. These functions are briefly summarized as follows, using labor (L_{ij}), rain (R_{ij}), and $SO2_{ij}$ as representative inputs:

<u>Linear</u>--

$$YLD_{ij} = \alpha_0 + \alpha_1 L_{ij} + \alpha_2 R_{ij} + \alpha_3 SO2_{ij} \qquad (9.15)$$

This function assumes that the relationship between crop yield and the inputs is linear and implies that the marginal productivity of each input is constant. That is, the partial derivative of yield with respect to any one of the inputs is constant, regardless of the level of the input used. With respect to SO_2, this can be stated as:

$$\frac{\partial YLD_{ij}}{\partial SO2_{ij}} = \alpha_3 \qquad (9.16)$$

The linear function also implies that the elasticity of substitution between factor inputs is infinity. This means that any input can be easily substituted by another input. This may not be possible with respect to the negative input of SO_2 since it may not be possible to offset totally the effects of SO_2 by the additional use of other inputs.

Quadratic--

$$\begin{aligned} YLD_{ij} = {} & \alpha_0 + \alpha_1 L_{ij} + \alpha_2 (L_{ij})^2 + \alpha_3 R_{ij} + \alpha_4 (R_{ij})^2 \\ & + \alpha_5 SO2_{ij} + \alpha_6 (SO2_{ij})^2 \end{aligned} \qquad (9.17)$$

The quadratic function implies that the marginal productivity of each input depends upon the level of each input used. The marginal productivity of SO_2 in the quadratic yield function is equal to:

$$\frac{\partial YLD_{ij}}{SO2_{ij}} = \alpha_5 + 2\alpha_6 (SO2_{ij}) \qquad (9.18)$$

If both α_5 and α_6 are negative, this means that the deleterious effect of SO_2 on crop yield increases as the level of SO_2 increases.

Logarithmic--

$$YLD_{ij} = \alpha_0 L_{ij}^{\alpha_1} R_{ij}^{\alpha_2} SO2_{ij}^{\alpha_3} \tag{9.19}$$

This function can be equivalently written as:

$$\begin{aligned} \log (YLD_{ij}) = \alpha_0 + \alpha_1 \log)L_{ij} + \alpha_2 \log(R_{ij} \\ + \alpha_3 \log(SO2_{ij}) \end{aligned} \tag{9.20}$$

This yield function implies that the marginal productivity of the positive factor inputs increase at a decreasing rate as the amount of input used increases (i.e., $\partial^2 YLD_{ij}/\partial L_{ij}^2 < 0$). This is reasonable since the farmer is faced with a fixed amount of land and increasing the application of inputs to a fixed amount of land will tend to result in smaller and smaller increases in the yield of the crop.

The marginal product of the negative input SO_2 is equal to:

$$\frac{\partial YLD_{ij}}{\partial SO2_{ij}} = \alpha_3 \frac{YLD_{ij}}{SO2_{ij}} \tag{9.21}$$

Assuming that α_3 is negative, this yield function implies that the marginal productivity of SO_2 decreases at a decreasing rate as the level of SO_2 increases (i.e., $\partial^2 YLD_{ij}/\partial SO2_{ij}^2 > 0$). In other words, the marginal crop damage due to SO_2 decreases as the level of SO_2 increases. This may not be realistic since since crop damage tends to be more serious for higher levels of pollution.

Linear Interaction--

$$YLD_{ij} = \alpha_0 + \alpha_1 L_{ij} + \alpha_2 R_{ij} + \alpha_3 SO2_{ij} + \alpha_4 (R_{ij} \cdot SO2_{ij}) \quad (9.22)$$

Since evidence exists that the susceptibility of plants to air pollution may be influenced by the environmental conditions under which the plant is grown, this equation will be estimated in order to test for "interaction" effects between SO_2 and climatological variables. This effect can be clearly seen by taking the first partial derivative of yield with respect to SO_2:

$$\frac{\partial YLD_{ij}}{\partial SO2_{ij}} = \alpha_3 + \alpha_4 R_{ij} \quad (9.23)$$

In this interaction equation, the change in yield due to a change in the level of SO_2 is also dependent upon the level of rain.

This function can also be used to test the possibility that farmers may take mitigative actions, such as the application of more fertilizer, to offset the effects of SO_2 on their crop. For example, a variable expressing the interaction between SO_2 and fertilizer

$(SO2_{ij} \cdot F_{ij})$ in the yield equation would be able to indicate that the change in yield due to a change in the level of SO_2 is dependent on the amount of fertilizer used.

Separate yield functions for soybeans and cotton will be estimated using regression analysis and cross-sectional and time series data on a county basis from 1975 to 1977. These functions provide the means of estimating the physical impact of SO_2 on crop yield.

Supply and Demand Relationships

The yield function is designed to estimate the physical relationship between inputs and outputs. This function is only one element in the process that determines how much of a crop is supplied in a particular year. It does not provide any information on how the price of a crop will be affected by a change in yield. In order to estimate the economic effects of a change in SO_2 in the agricultural sector, the physical effects of a change in crop yield must be integrated with information on how crop price responds to such changes. For the purposes of this study, the estimation of the economic effects of the implementation of alternative SNAAQS is done through the estimation of a system of crop supply and demand equations.

Supply Equations--

As mentioned in the introduction, the supply of a crop can be considered to consist of two parts: stocks in year t-1, and production in year t*. For agricultural commodities, "crop production" in any year is generally expressed in terms of an acreage response function.** It is assumed that the aggregate number of acres planted of a particular crop i in year t is a function of the price at which the crop is expected to be sold when harvested (P^e_{it}), the expected price of substitute crops in production (P^e_{st}), and a variable representing government support programs for crop i (G_{it}). The general form of the acreage response equation we use to estimate the effect of SO_2 on crop supply will therefore be:

$$ACPL_{it} = g\left(P^e_{it}, P^e_{st}, G_{it}\right) \qquad (9.24)$$

where $ACPL_{it}$ = the aggregate number of acres planted of crop i in year t.

A priori, it is expected that the following relationships hold:

$$\frac{\partial ACPL_{it}}{\partial P^e_{it}} > 0 \quad ;$$

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* The equation used to estimate stocks is discussed in the demand equation subsection.

** See Houck, Ryan, and Subotnik (50), Adams (51), and Maumes and Meyers (52).

and

$$\frac{\partial ACPL_{it}}{\partial P^e_{st}} < 0 \quad .$$

The relationship between $ACPL_{it}$ and G_{it} is undetermined a priori. An increase in the government's price support could be interpreted as a reduction in the price risk associated with the crop and consequently would cause an increase in acres planted. It is also possible that farmers may interpret the increase in the support price as an indication of a poor market for their crop and therefore would cause a decrease in acres planted.

For this analysis, expected prices in year t are assumed to be equal to the prices received in year t-1, P_{t-1}. In other words, producers base their planting decisions in year t on the price received for the crop in year t-1. Since producers react to past prices, this equation can be called a supply recursive equation.

The parameters of this equation will be estimated by ordinary least squares. The data used to estimate this equation will consist of annual time series data on the national level from 1955 to 1977.

The number of acres harvested of crop i in year t ($ACHR_{it}$) is assumed to be a constant percentage of the number of acres planted:

$$ACHR_{it} = b \cdot ACPL_{it} \quad (9.25)$$

where b = the percentage of acres planted that are harvested estimated from historical data.

The general form of the acreage response curve is shown in Figure 9-3.

Obviously, the acreage response curve shown in Figure 9-3 does not reflect the true supply of the crop in a particular year because crop yield and stocks left over from the previous year are not taken into account. The total production of crop i can be obtained by multiplying the number of acres harvested of crop i by the average yield of crop i estimated from Equation (9.13):

$$Q^S_{it} = ACHR_{it} \cdot \overline{YLD}_{it} \quad (9.26)$$

where Q^S_{it} = the quantity of crop i produced in year t.

$\overline{YLD}_{it}$ = the average yield per harvested acre of crop i in year t.

Total supply of crop i in year t (S(q)) is equal to the sum of the total production of crop i in year t (Q^S_{it}), the commercial stocks of crop i in year t-1 ($Q^K_{it}(-1)$), and the stocks held by the Commodity Credit Corporation:

$$S(q) = Q^S_{it} + Q^K_{it}(-1) + Q^{CCC}_{it}(-1) \quad (9.27)$$

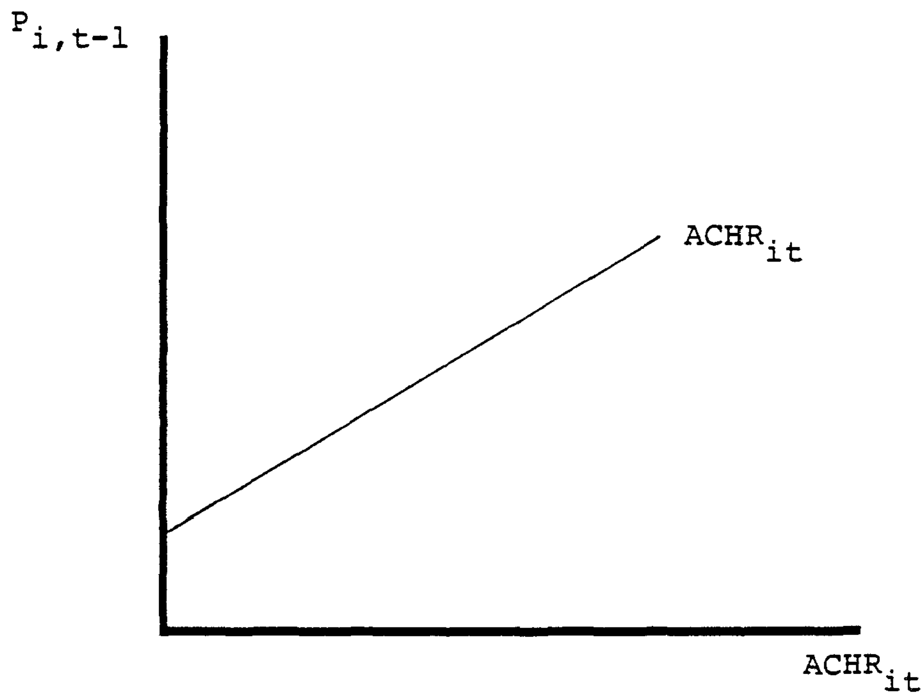

Figure 9-3. Acreage supply curve for crop i.

The supply curve for crop i is shown in Figure 9-4.

Demand Equations--

In this analysis, crop demand will be estimated by a system of demand equations.* This system consists of three equations: domestic demand, export demand, and stock demand. Domestic demand for crop i in year t (Q^M_{it}) is assumed to be a function of crop price (P_{it}), a vector of the prices of goods that are substitutes in consumption for crop i (P_{jt}), and a vector of other variables -- such as population -- that affect the domestic demand for i (Z_{it}). The general form of the domestic demand equation is:

$$Q^M_{it} = m(P_{it}, P_{jt}, Z_{it}) \qquad (9.28)$$

where $\partial Q^M_{it}/\partial P_{it} < 0$;

$\partial Q^M_{it}/\partial P_{jt} > 0$;

and $\partial Q^M_{it}/\partial Z_{it} > 0$ for variables such as population.

Export demand for crop i in year t (Q^X_{it}) is assumed to be a function of crop i's price in the United States (P_{it}), a vector of the prices of goods that are substitutes in consumption for the crop (P_{qt}), the quantity of the crop produced outside of the United States

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* See the studies by Houck, Ryan and Subotnik (50), Baumes and Meyers (52), and Womack (53) for further information on the estimation of demand systems for agricultural commodities.

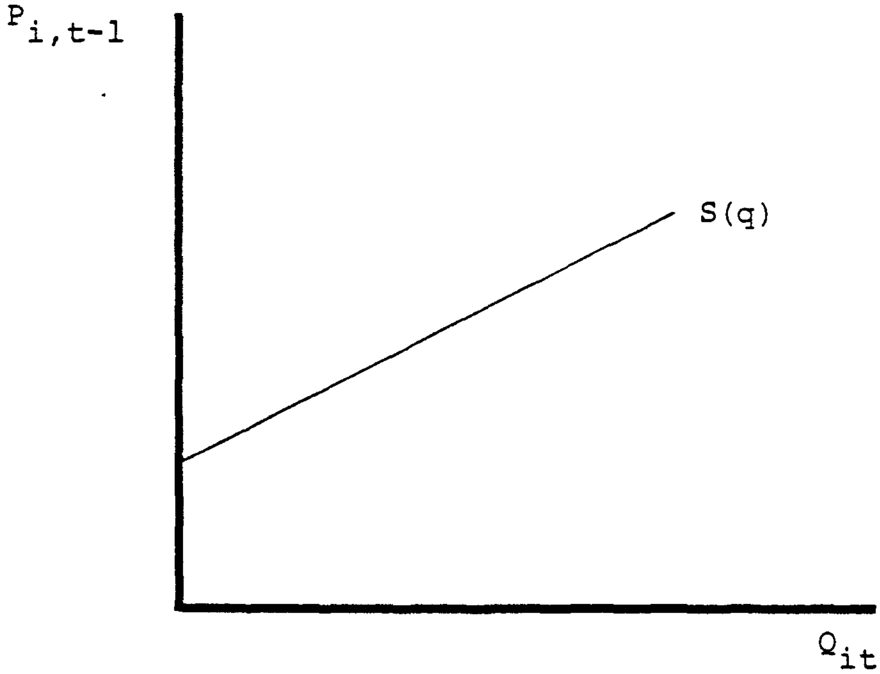

Figure 9-4. Supply curve of crop i.

(Q^E_{it}), the costs of transporting the crop from the United States to the importing country (T_{it}), the exchange rate between the United States and the importing country (XR_t) (i.e., the amount of foreign currency obtainable per U.S. dollar), and a vector of other variables -- such as population in the importing country -- which affect the export demand for i (V_{it}). The general form of the export demand equation is:

$$Q^X_{it} = x(P_{it}, P_{qt}, Q^E_{it}, T_{it}, XR_t, V_{it}) \quad (9.29)$$

where $\partial Q^X_{it}/\partial P_{it} < 0$;

$\partial Q^X_{it}/\partial P_{qt} > 0$;

$\partial Q^X_{it}/\partial Q^E_{it} < 0$;

$\partial Q^X_{it}/\partial T_{it} < 0$;

$\partial Q^X_{it}/\partial XR_t < 0$;

and $\partial Q^X_{it}/\partial V_{it} > 0$ for variables such as population.

Since the two crops we examine in this analysis can be stored for an extended period of time without perishing, it is necessary to estimate a stock demand equation. The general form of the stock demand equation is:

$$Q^K_{it} = k(P_{it}, P^e_{i,t+1}, C_{it}, Q^S_{it}, Q^K_{i,t-1}, G_{it}) \quad (9.30)$$

where Q^K_{it} = the commercial stocks of crop i held in year t [i.e., the total quantity of stocks held excluding those stocks owned by the Commodity Credit Corporation (CCC)].

P_{it} = price of crop i in year t.

$P^e_{i,t+1}$ = the expected price of crop i in year t+1.

C_{it} = the opportunity cost of holding stocks of the crop (e.g., the interest rate).

Q^S_{it} = the quantity produced of crop i.

$Q^K_{i,t-1}$ = the commercial stocks held in year t-1.

G_{it} = the capacity constraints of processing the crop into a final good.

This stock equation reflects three motives for holding stocks: speculation, transaction, and precaution (60). Speculative holdings of a crop take place if there is an expectation that future prices of the crop will exceed the current price of the crop plus the costs of holding the crop as a stock. The variables P_{it} and $P^e_{i,t+1}$ are included to reflect the speculative motive for holding stocks. C_{it} is included to reflect the fact that the opportunity cost of holding the stock influences the amount of the stock that is held. It is expected that:

$$\partial Q^K_{it}/\partial P_{it} < 0 \;;$$

$$\partial Q^K_{it}/\partial P^e_{i,t+1} > 0 \;;$$

and

$$\partial Q^K_{it}/\partial C_{it} < 0 \;.$$

Stocks are held for transaction purposes because of the nature of the agricultural production process. Crop harvesting is cyclical, occurring only in the fall, while consumption remains relatively constant throughout the year. It is therefore necessary to hold some level of stocks throughout the year. It is assumed that stocks held for transaction purposes are a percentage of the amount of the crop produced (Q^S_{it}). In addition, it is assumed that the level of stocks in year t are related to the level of stocks in year t-1 ($Q^K_{i,t-1}$). The following relationships are expected to hold:

$$\partial Q^K_{it}/\partial Q^S_{it} > 0$$

and

$$\partial Q^K_{it}/\partial Q^K_{i,t-1} > 0 \quad .$$

Stocks of the crop may also be held due to capacity constraints. Due to the cyclical nature of crop production, backlogs in the processing of the crop may result in more of the crop being held in stock. The variable used to reflect the capacity is G_{it}. A priori, it is expected that:

$$\frac{\partial Q^K_{it}}{\partial G_{it}} > 0 \quad .$$

The probability of the occurrence of unforeseen circumstances may cause some level of stocks to be held as a precaution against these occurrences. For example, a certain level of stocks may be held because of the impact that changes in the weather may have on crop production. For this study, it is assumed that the precautionary demand for stocks is a relatively small component of total stock demand and is therefore assumed to be reflected in the constant term of the stock demand equation.

Because crop price and quantity demanded are determined simultaneously, the parameters of this system of demand equations will be estimated using two-stage least squares. Like the supply equations, these demand equations will be estimated using aggregate annual time series data from 1955 to 1977.

The general form of the crop demand curve depicting the relationship between crop price and quantity demanded is shown in Figure 9-5. D(q) is equal to the horizontal summation of the domestic, export, and stock demand curves.

$$D(q) = Q_{it}^{M} + Q_{it}^{X} + Q_{it}^{K} + Q_{it}^{CCC} \qquad (9.31)$$

where Q_{it}^{CCC} = stocks of crop i owned by the Commodity Credit Corporation in year t.

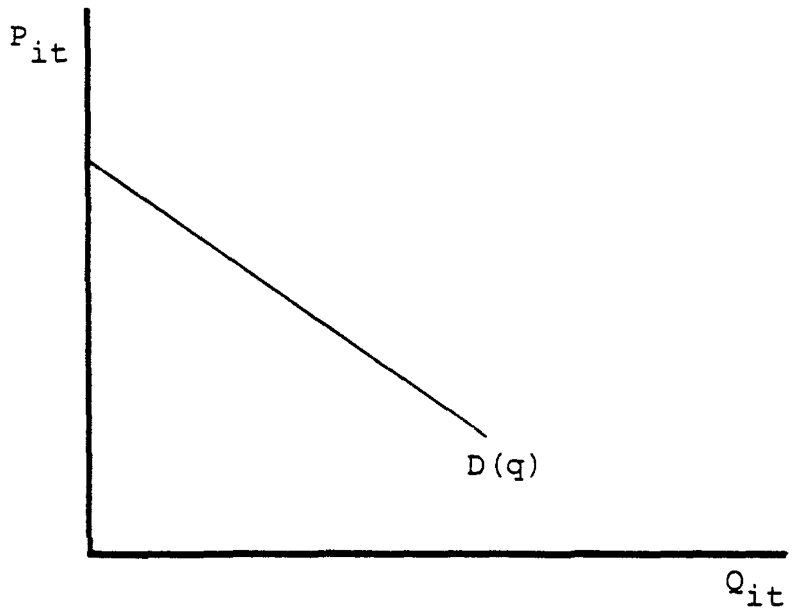

Figure 9-5. Demand curve for crop i.

Market Clearing Identity--

Once the parameters of the supply and demand equations have been estimated, the system can be solved for market quantity and price. Since the supply of the crop is assumed to be a function of crop price in year t-1, crop supply in year t enters the demand system as predetermined. The components of demand and crop price in year t can be solved for simultaneously, based on the market clearing identity:

$$Q^{S}_{it} + Q^{K}_{i,t-1} + Q^{CCC}_{i,t-1} = Q^{M}_{it} + Q^{X}_{it} + Q^{K}_{it} + Q^{CCC}_{it} \qquad (9.32)$$

Estimation of the Economic Impact of a Change in SO_2

The mechanism by which a change in the level of SO_2 influences the market for a particular crop can be shown graphically by considering the following scenario. Assume that in the presence of a certain level of SO_2, long-run market equilibrium for crop i is established in year t at price P and quantity Q.* This is shown in Figure 9-6.

Assume that the concentration of SO_2 permanently decreases and that this improvement in air quality has a positive impact on the

* In order to facilitate the graphical presentation, we have assumed that long-run equilibrium in the market for crop i has been established prior to the change in air quality. In the actual calculation of benefits, however, we have made no assumptions regarding the existence of long-run equilibrium in the market for crop i.

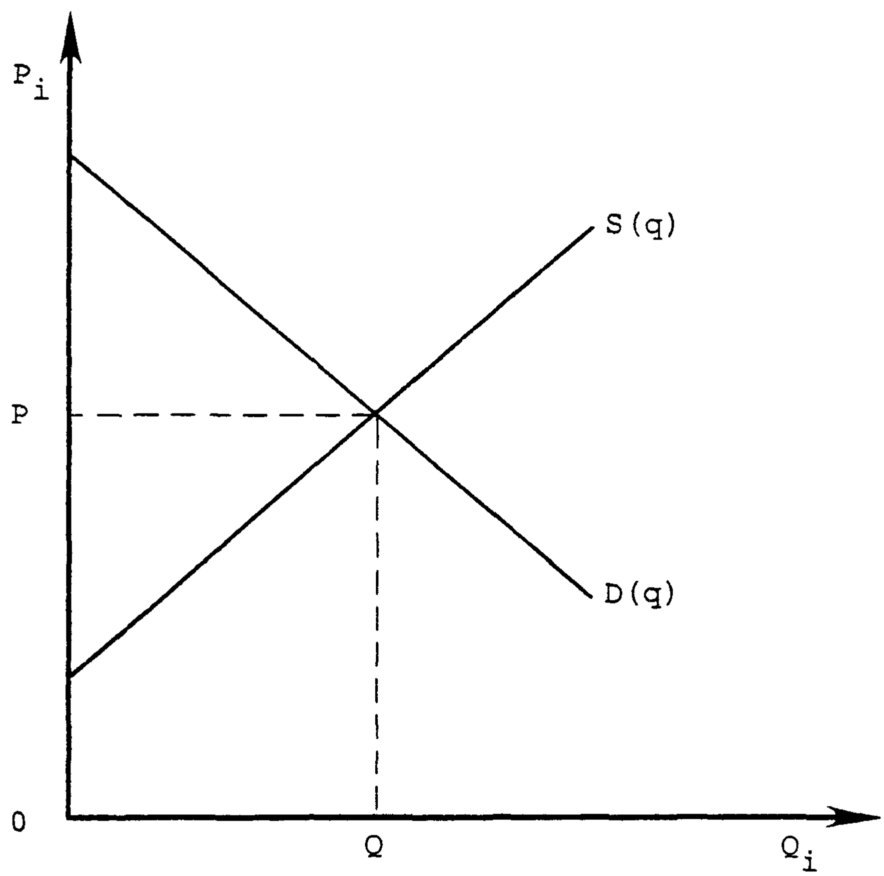

Figure 9-6. Long-run equilibrium for crop i.

crop's yield in the counties growing the crop in year t+1. This impact can be estimated from our yield equation. Equation (9.14) can be used to calculate the change in yield in each county j that will result from a reduction in SO_2 in year t+1 from SO_2 to SO_2':

$$(YLD'_{ij} - YLD_{ij}) = \partial YLD_{ij}/\partial SO2_{ij}(SO2'_{ij} - SO2_{ij}) \qquad (9.33)$$

The increase in yield in each county will result in an increase in the average yield of the crop and, consequently, an increase in crop supply. This increase is shown by the parallel shift of the supply curve from S(q) to S(q)' in Figure 9-7. Since it is assumed that crop supply in any year is a function of the price received for the crop in the previous year, the decrease in the level of SO_2 will result in Q_1 of the crop being supplied in year t+1. In order to sell the quantity Q_1, price in year t+1 must drop to P_1. This lower price in year t+1 will induce a lower quantity of the crop to be supplied in year t+2 (i.e., Q_2). This smaller supply induces a price increase from P_1 to P_2 in year t+2. Assuming that the demand curve is more elastic than the supply curve and assuming that no other changes occur, this dynamic process will continue in the typical cobweb fashion until a new long-run equilibrium is reached at P^* and Q^*. Note that equilibrium price decreases and equilibrium quantity increases because of the improvement in the level of SO_2.

The economic impact of this change in the level of SO_2 can be estimated by comparing the economic surpluses that exist in the market

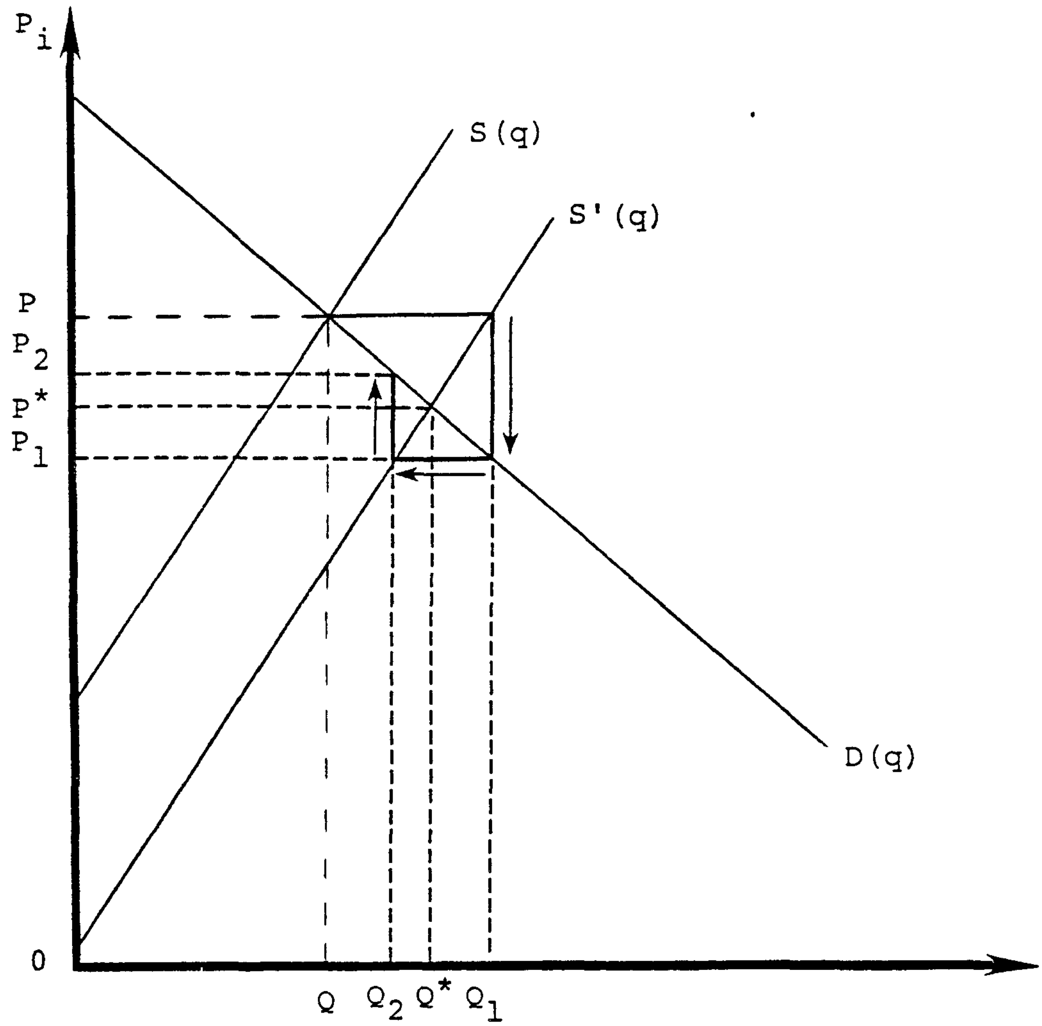

Figure 9-7. Effect of a change in SO_2 in the market for crop i.

for crop i with and without the change in yield. As mentioned in the introduction, economic surplus consists of two parts: consumer and producer surpluses. Consumer surplus is equal to the area under the demand curve that is above the equilibrium price of the crop. The consumer surplus prior to the air quality change is equal to the area ABP in Figure 9-8. Producer surplus, on the other hand, represents the net return to factor owners or the amount they receive for producing a certain quantity over and above the cost of producing that quantity. For the original level of SO_2, this is represented by the area PBC. The sum of the consumer and producer surpluses is equal to the area ABC. Due to the change in SO_2, quantity Q_1 will be supplied at price P_1 in year t+1. As shown in Figure 9-8, consumer surplus increases to the area AHP_1 at this price and quantity. Similarly, a producer surplus equal to the area P_1FD exists in year t+1. However, producers also incur a loss in year t+1 due to the change in air quality. This loss is equal to the area beneath the supply curve and above the price received for the crop. In Figure 9-8, this is equal to the area GHF. Part of the loss, the area IHF, is simply a transfer from producers to consumers. Consequently, the societal loss is equal to the area GHI. Net economic surplus in this case is equal to the area AID minus the area GHI. The net benefits to society in year t+1 of the improvement in the level of SO_2 is equal to the difference in economic surplus with and without the air quality change. In Figure 9-8, this is equal to the slashed area BIDC minus the dotted area GHI. This area can be found by evaluating the integral:

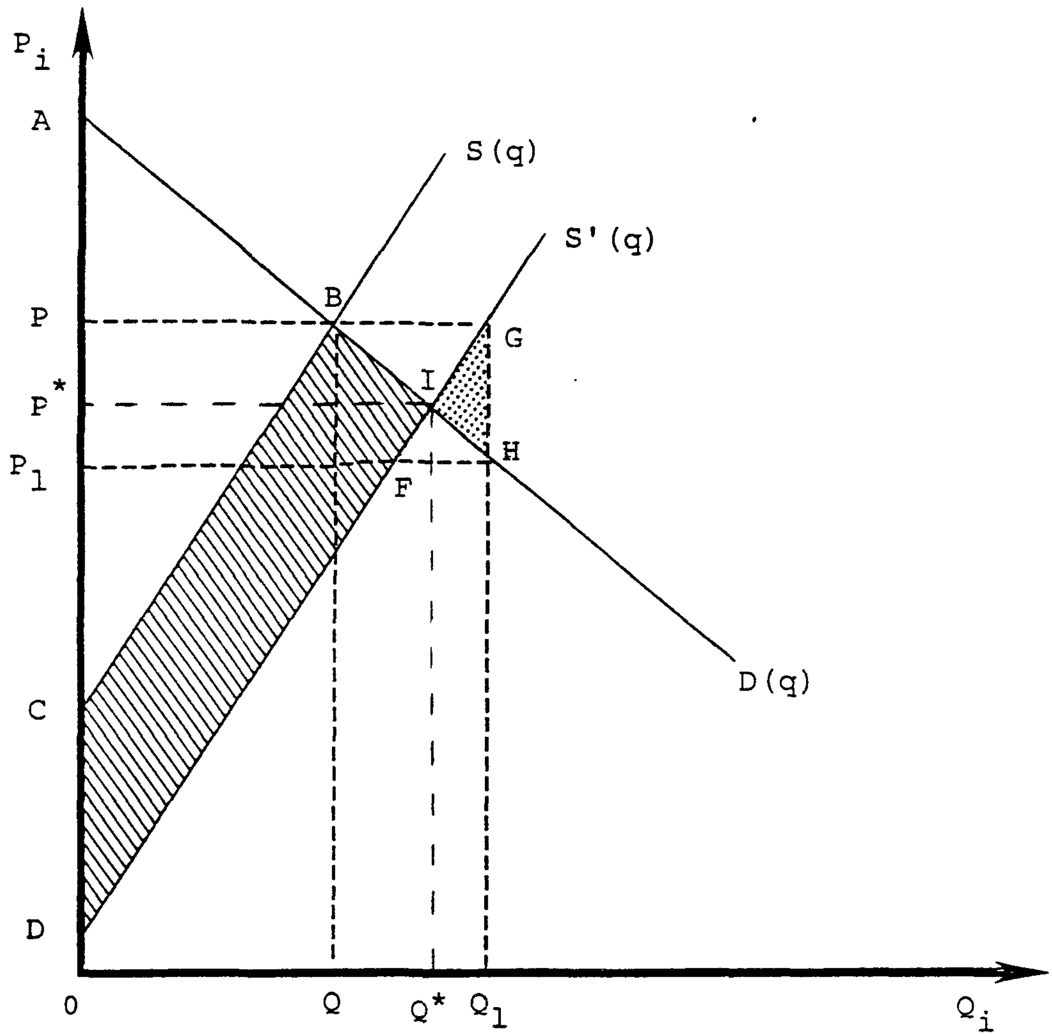

Figure 9-8. Change in economic surplus in year t+1.

$$BIDC - GHI = \int_0^{Q^*} [D(q) - S'(q)]dq - \int_{Q^*}^{Q_1} [S'(q) - D(q)]dq$$

$$- \int_0^{Q} [D(q) - S(q)]dq \qquad (9.34)$$

Since it is assumed that the lower level of SO_2 will be maintained in the future, benefits will continue to accrue in future crop years. Due to the dynamic nature of the model, benefits in successive years will not be equal to the benefits in year t+1. Figure 9-9 will be used to show the benefits in year t+2 of the reduction in SO_2. Since it is assumed that producers base their planting decisions on the price they received for their crop in the previous year, the lower price that prevailed in year t+1 will result in Q_2 being supplied in year t+2. Demanders are willing to pay P_2 for the quantity Q_2 and consequently price rises to P_2. Economic surplus in year t+2 is equal to the sum of consumer surplus -- the area AHP_2 -- and producer surplus -- the area $HFDP_2$. This sum is equivalent to the area AHFD. Like the previous year, the net benefit in year t+2 of the reduction in SO_2 is equal to the difference in consumer surplus with and without the air quality change (the shaded area BHFDC in Figure 9-9). By integrating over this area, this is equal to:

$$BHFDC = \int_0^{Q_2} [D(q) - S'(q)]dq - \int_0^{Q} [D(q) - S(q)]dq \qquad (9.35)$$

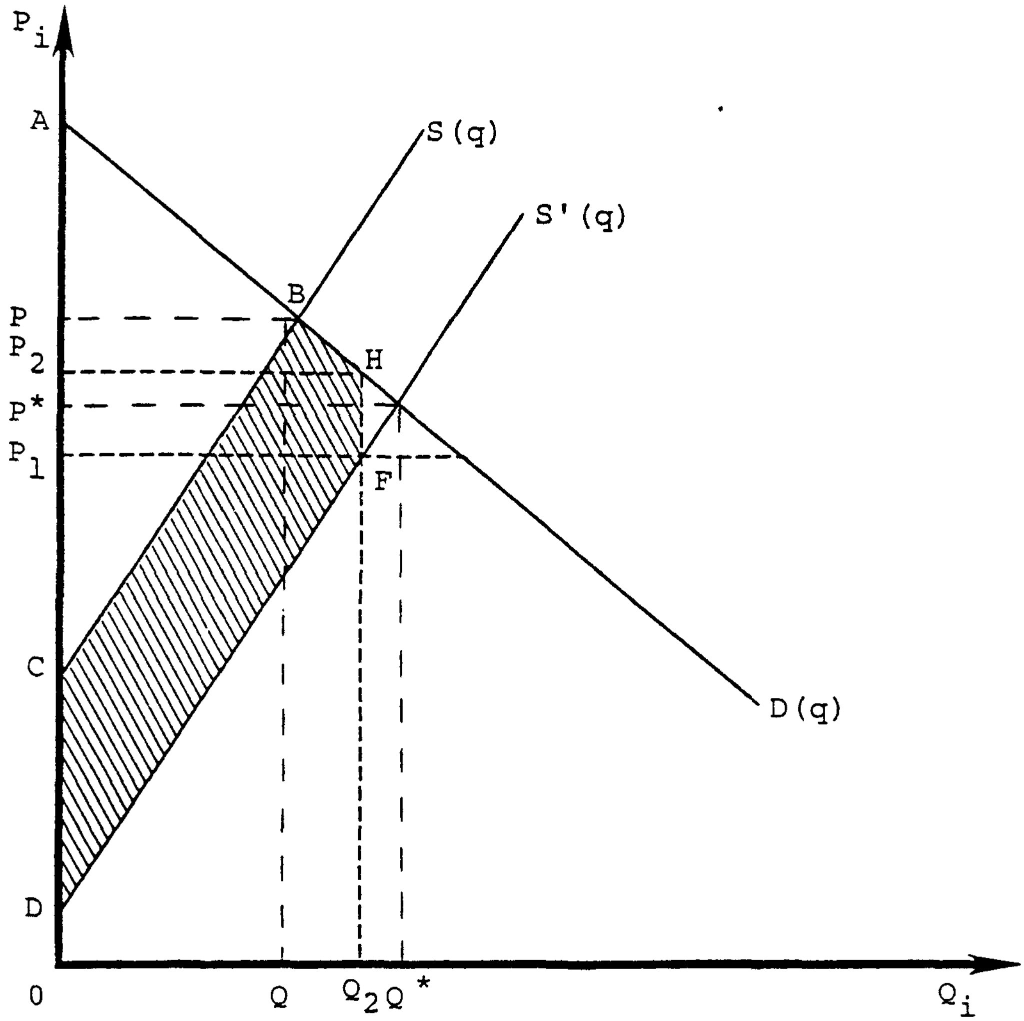

Figure 9-9. Change in economic surplus in year t+2.

Benefits will be calculated according to Equations (9.34) and (9.35) for ensuing years until long-run equilibrium is reached. Once this equilibrium is reached, the net benefits will remain the same in future years. This can be seen in Figure 9-10. At long-run equilibrium P^* and Q^*, net benefits are equal to the the shaded area BIDC:

$$BIDC = \int_0^{Q^*} [D(q) - S'(q)]dq - \int_0^{Q} [D(q) - S(q)]dq \qquad (9.36)$$

The total benefits of the reduction in SO_2 can be found by taking the sum of the discounted present value of these calculated benefits in each year.

DATA

The yield functions discussed in the last subsection will be estimated for both cotton and soybeans using cross-sectional and time series data from 1975 to 1977. As mentioned previously, the cotton data set includes six cotton-producing states. These states accounted for approximately 80 percent of U.S. cotton production in 1977. The soybean data set includes twelve soybean-producing states; these states accounted for approximately 69 percent of U.S. soybean production in 1977. A list of the states included in each of these data sets is found in Table 9-2.

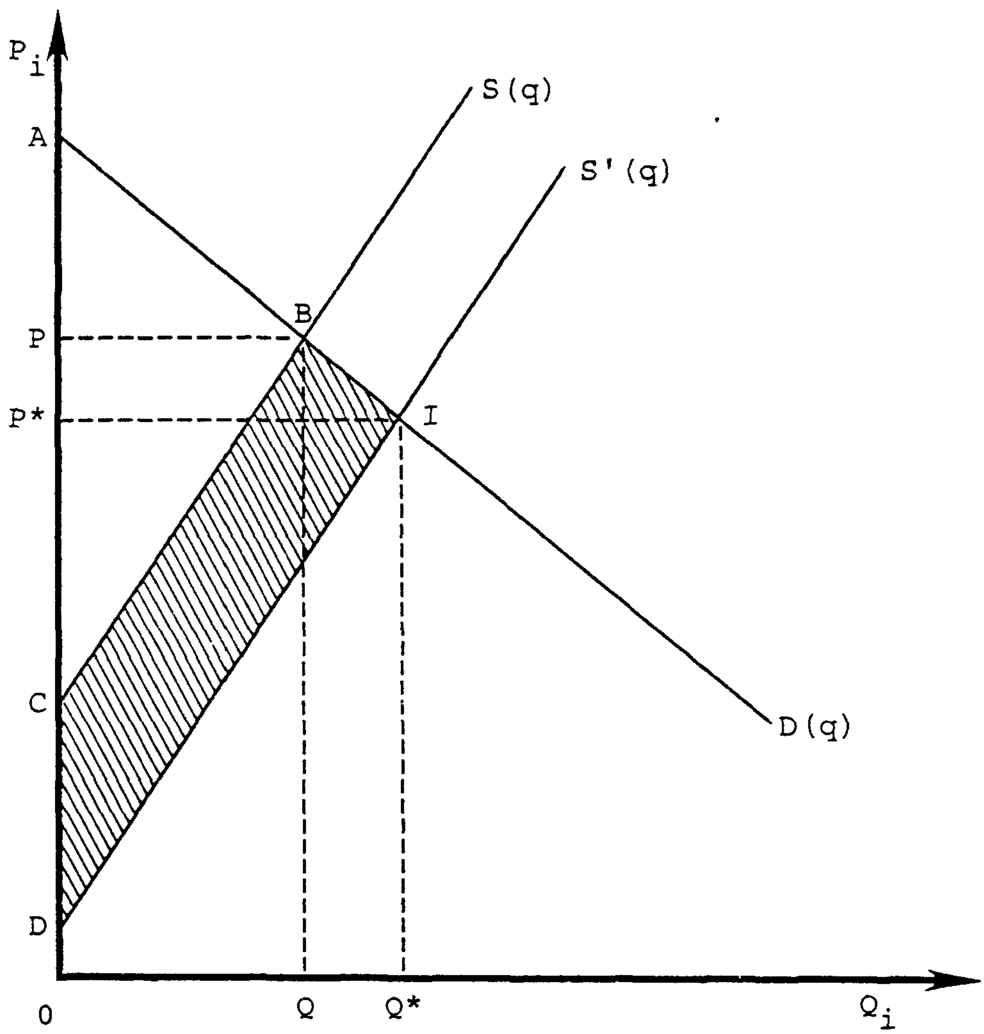

Figure 9-10. Change in economic surplus in the presence of long-run equilibrium.

Ideally, we would have liked to have estimated our yield functions using the farm as the unit of observation. Unfortunately, farm level production data could not be obtained for this analysis. Data on farm production was found disaggregated to the county level; hence, the county is the unit of observation. The use of county level data may tend to obscure the relationship we are trying to uncover if significant variations in SO_2 and yield exist within the county.

The number of observations available for the estimation of the yield equation for each crop was constrained by whether there were reliable economic and environmental data for the counties producing the crop. By far, the most constraining factor was the availability of reliable data for SO_2. Some counties had more than one monitoring station with readings for SO_2, some had only one, and some had none.

TABLE 9-2. STATES INCLUDED IN AGRICULTURAL DATA SETS

Cotton	Soybeans
Alabama	Alabama
Arizona	Georgia
California	Illinois
Mississippi	Indiana
New Mexico	Iowa
Texas	Kentucky
	Michigan
	Minnesota
	Mississippi
	Ohio
	Texas
	Wisconsin

Consequently, our sample is not random since counties that produced the crop but did not have a reliable SO_2 reading had to be excluded from the analysis. This reduced the size of the data set significantly. The soybean data set includes 494 observations (about 164 counties), while the cotton data set includes 84 observations (about 28 counties). Over the three-year period of this analysis, these counties accounted for approximately 14 percent of the United States production of soybeans and approximately 15 percent of the United States production of cotton.

Air Pollution Variables

Sulfur Dioxide--

Table 9-3 lists the sulfur dioxide (SO_2) variables included in this part of the study. Note that these variables are measured at the county level and are available for the second quarters of 1975, 1976, and 1977. Variables on both average and maximum readings are used in this study in order to measure the effect of long-term (average) and acute (maximum) levels of SO_2 on crop yield. Second quarter data were used to control for the seasonal nature of agricultural crop production.*

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* There is evidence that plants are more susceptible to air pollution directly before flowering and pod growth (54). If this is the case for soybeans and cotton, third quarter averages would be a better measure to use in order to determine the sensitivity of plants to air pollution exposure. Hence, the use of second quarter data may understate the effect of pollution on yield.

TABLE 9-3. AIR POLLUTION VARIABLES

Variable	Definition
$AMEAN_j$	The average of the second quarter* arithmetic 24-hour means of SO_2 for the monitoring stations within county j (in $\mu g/m^3$).
$XMEAN_j$	The maximum of the second quarter arithmetic 24-hour means of SO_2 for the monitoring stations within county j (in $\mu g/m^3$).
$A2HI_j$	The average of the second highest 24-hour SO_2 reading for the monitoring stations within county j for the second quarter (in $\mu g/m^3$).
$X2HI_j$	The maximum of the second highest 24-hour SO_2 reading for the monitoring stations within county j for the second quarter (in $\mu g/m^3$).
$RATIOX_j$	The ratio of the average of the second highest 24-hour reading to the average of the second quarter arithmetic means of SO_2 for the monitoring stations within county j (in $\mu g/m^3$); i.e., $A2HI_i/AMEAN_i$.
$RATIOA_j$	The ratio of the maximum of the second quarter second highest 24-hour SO_2 reading to the maximum of the second quarter arithmetic 24-hour mean of SO_2 for the monitoring stations within county j (in $\mu g/m^3$); i.e., $X2HI_i/AMEAN_i$.

* The second quarter refers to the months April through June.

Source: SAROAD Data Base, 1975-1977.

Use of these air pollution variables is likely to be only an approximation of the ambient air quality within each county since no attempt was made to reflect the dispersion of air pollution from the monitoring stations to the surrounding areas. Since there is evidence that plants are more susceptible to air pollution during daylight hours (24), daytime SO_2 readings would have been more appropriate to use instead of the 24-hour readings. These data were not available at the time the study was undertaken, however.

As discussed in Section 3, the SO_2 data available to us came from two types of monitoring methods: non-continuous and continuous. It has been found that the non-continuous method can lead to biased estimates of the level of SO_2 because it does not control for temperature. A correction factor was developed in order to remove this bias from the SO_2 data measured by non-continuous methods (see Section 3 for the details regarding this conversion).

Other Pollutants--

As mentioned in the Literature Review subsection, the susceptibility of plants to SO_2 may vary depending on the presence of other pollutants in the atmosphere. For example, it has been found that soybeans exposed to both SO_2 and ozone have exhibited greater than additive growth effects (55), but less than additive foliar injury effects (56). Tingey et al. (57) found that although soybeans showed no evidence of injury when exposed to levels of either SO_2 or nitrogen dioxide (NO_2), injury occurred when soybeans were exposed to both of these pollutants.

Although it would have been desirable to include measures of other pollutants such as ozone and nitrogen dioxide as variables in our yield equations, these pollutants could not be incorporated into the present analysis. Data on nitrogen dioxide were not available when the analysis was undertaken. Although data on ozone were available at the county level, the number of counties that had valid observations on both SO_2 and ozone led to a significant reduction in the size of our sample. It was therefore decided not to include ozone in the estimation of our yield equations.

It should be mentioned that if SO_2 is correlated with the pollutants that are excluded from the yield equations, the estimated relationship between SO_2 and crop yield may be biased. If the presence of both SO_2 and another pollutant tend to have a less than additive effect on the yield of cotton and/or soybeans, estimating a yield equation without including both pollutants may result in an underestimate of the isolated effect of SO_2 on the crop. On the other hand, estimation of the yield equation with only SO_2 may result in an overestimate of the isolated effect of SO_2 on crop yield if the exposure of the crop to both SO_2 and another pollutant has a greater than additive effect on yield.

Climatological Variables

As explained in the Literature Review subsection, the susceptibility of plants to SO_2 is influenced by a number of climatological factors. Humidity, temperature, rain, wind, and light intensity are examples of the climatological varibles influencing the susceptibility of plants to SO_2. Data on both rain and temperature were available at the county level. Data on the other climatological factors that influence plant susceptibility were not available on the county level when the analysis was undertaken. Consequently, temperature and rain are the only climatological variables included in the model at this time. The definitions of these two variables are given in Table 9-4.

Like the exclusion of other pollutants from the estimation of the yield equations, the exclusion of relevant climatological variables may also tend to result in biased estimates of the relationship between SO_2 and crop yield. It is possible, however, that rain and temperature may be good surrogates for some of the excluded climatological variables such as humidity and light intensity.

TABLE 9-4. CLIMATOLOGICAL VARIABLES

Variable	Definition
$TEMP_j$	Average temperature in degrees Celsius during April, May and June as reported by one monitoring station within county j.*
$RAIN_j$	Average rainfall in centimeters during April, May and June as reported by one monitoring station within county j.

* The monitoring stations for temperature and rain are not necessarily located in the same place as the monitoring stations for SO_2.

Source: U.S. National Oceanic and Atmospheric Administration, Annual Summary, various states, 1975-1977.

Crop Production Variables

The crop production variables used in the specification of our yield equation are listed in Table 9-5. Information on the use of inputs (labor, fertilizer) by farmers producing soybeans could not be obtained on a county level; consequently, state and regional data had to be used as proxies for the county level use of inputs (see Table 9-6 for the states included in the agricultural regions of the U.S.). The total number of hours used for farmwork in the production of oil crops (soybeans and flaxseed) was used as a proxy for the labor input. This variable was available at the regional level, hence only regional variations in the use of this input were measured. Data on the use of fertilizer (nitrogen, phosphorous, and potash) were available at the state level from the 1976 to 1978 issues of Fertilizer Situation of the Economic Research Service (61).

It should be mentioned that the fertilizer data are, at best, gross approximations of the county-level use of fertilizer. The information obtained from Fertilizer Situation are based on a survey of selected cotton- and soybean-producing fields in certain states. Only information on the amount of fertilizer applied per acre receiving fertilizer in the survey is available. It is not clear that a random sample of farms is included in the survey, and consequently this amount may not be indicative of fertilizer application by the remainder of the cotton- and soybean-producing farms in the state. In addition, since there is a large variation in the fertility of the

TABLE 9-5. CROP PRODUCTION VARIABLES

Variable	Definition	Level
YLD_j	Yield of soybeans in county j; yield is expressed in terms of bushels produced per acre. Source: Reference (58).	County
$YLDC_j$	Yield of cotton in county j; yield is expressed in terms of pounds produced per acre. Source: Reference (58).	County
$ACHR_j$	Number of acres of soybeans harvested. Source: Reference (58).	County
$ACHRC_j$	Number of acres of cotton harvested. Source: Reference (58).	County
$PROD_j$	Number of bushels of soybeans produced. Source: Reference (58).	County
$PRODC_j$	Number of bales of cotton produced. Source: Reference (58).	County
LABOR*	Total number of farmwork hours used in the production of oil crops (soybeans flaxseed). Source: Reference (59).	Agricultural region
LABORC	Total number of farmwork hours used in the production of cotton. Source: Reference (59).	Agricultural region
LIME	Tons of agriculture limestone used. Source: Reference (60).	State
NITROGEN	Number of pounds of nitrogen applied per soybean acre receiving any fertilizer. Reference (61)	State
P_2O_5	Number of pounds of phosphorous applied per soybean acre receiving any fertilizer. Source: Reference (61).	State

* Information on this variable is not available for the state of Mississippi.

(continued)

TABLE 9-5 (continued)

Variable	Definition	Level
K_2O	Number of pounds of potash applied per soybean acre receiving any fertilizer. Source: Reference (61).	State
NITROGENC	Number of pounds of nitrogen applied per cotton acre receiving any fertilizer. Source: Reference (61).	State
P_2O_5C	Number of pounds of phosphorous applied per cotton acre receiving any fertilizer. Source: Reference (61).	State
K_2OC	Number of pounds of potash applied per cotton acre receiving any fertilizer. Source: Reference (61).	State
PRICE	Average price per bushel of soybeans received by farmers. Source: Reference (62).	State
$IRRIG_j$	A 0-1 dummy variable reflecting the presence of irrigation in county j. If the county irrigates the crop, $IRRIG_j$ is equal to 1; otherwise it is equal to 0.	County

TABLE 9-6. STATES INCLUDED IN AGRICULTURAL REGIONS OF THE UNITED STATES

Northeast

Maine
New Hampshire
Vermont
Massachusetts
New York
Connecticut
Rhode Island
New Jersey
Pennsylvania

Southeast

Alabama
Georgia
South Carolina
Florida

Lake States

Michigan
Minnesota
Wisconsin

Corn Belt

Illinois
Indiana
Iowa
Missouri
Ohio

Northern Plains

Kansas
Nebraska
North Dakota
South Dakota

Mountain

Arizona
Colorado
Idaho
Montana
Nevada
New Mexico
Utah
Wyoming

Delta States

Arkansas
Louisiana
Mississippi

Southern Plains

Oklahoma
Texas

Mountain

Arizona
Colorado
Idaho
Montana
Nevada
New Mexico
Utah
Wyoming

Pacific

California
Oregon
Washington

soil within each state, the use of state-level data is likely to be a poor approximation of the use of fertilizer by the counties within the state.

Data on the agricultural consumption of lime by state was used as a proxy for the county-level use of lime by farmers producing cotton and soybeans. Like the fertilizer data, this is a gross approximation of the county-level use of lime. However, since lime is used to control the pH levels of the soil and since there are distinct regional differences in the pH levels of the soil throughout the country, this variable may be useful in controlling for the interregional differences in the use of lime. In addition, it is important to include this variable in the estimation of our yield functions because of its possible relationship to SO_2. For example, soils in the midwestern states tend to be relatively acidic (pH range is approximately 4 to 6) and farmers in these states apply lime to reduce the acidity of these soils. Since the existence of certain levels of SO_2 in the atmosphere can result in increased acidity of the soil, farmers may increase their application of lime in order to mitigate the effects of SO_2. Consequently, it is important to control for the mitigative actions of the farmer when estimating the yield function. Leaving this variable out of the equation may result in an underestimate of the effect of SO_2 on crop yield.

As Table 9-5 shows, only information on the use of labor and fertilizer by farms producing soybeans and cotton could be obtained for our analysis. Information on the use of other inputs such as herbicides, pesticides, and seed was not available. If the use of these inputs changes as a result of the exposure of the crop to SO_2, omission of these variables may result in biased estimates of the relationship between SO_2 and crop yield. This bias can be shown (63) to be equal to:

$$E(\hat{\alpha}_{SO2}) = \alpha_{SO2} + \alpha_X \cdot Cov(SO2,X) \qquad (9.37)$$

where $E(\hat{\alpha}_{SO2})$ = the expected value of the predicted coefficient of SO_2.

α_{SO2} = the "true" coefficient of SO_2.

α_X = the "true" coefficient of the excluded variable.

$Cov(SO2,X)$ = the correlation between SO_2 and the excluded variable.

In other words, the direction of the bias of the coefficient of SO_2 resulting from the exclusion of a relevant explanatory variable in the yield equation depends upon the sign of the coefficient of the excluded variable and the correlation between SO_2 and the excluded variable. For example, if the use of pesticides has a positive effect on yield and the use of this input increases as a result of crop exposure to SO_2, the estimated coefficient of SO_2 will be biased toward zero, thus underestimating the true impact of SO_2 on crop yield. Alternatively, if the use of pesticides decreases as a result of crop exposure to SO_2, the estimated coefficient of SO_2 will be biased away from zero. Since evidence exists that plants can either be more or less susceptible to disease and insects as a result of exposure to SO_2, the direction of the bias of the SO_2 coefficient resulting from the omission of variables such as herbicide and pesticide application is unclear.

It should be mentioned that the use of different cultivars by farmers could not be incorporated into the model. Although information on the use of the three leading soybean cultivars in each state was available from Crop Production of the Crop Reporting Board, USDA (64), these varieties were generally not used for more than 50 percent of the total number of acres harvested. No one cultivar clearly dominated the production in any one state, and the county-level use of these cultivars could not be identified from the available data.

Aggregate Time Series Data

Time series data on the variables used to estimate the acreage response and demand equations were obtained from various issues of Agricultural Statistics (65), Fats and Oil Situation (66), Monthly Bulletin of Agricultural Economics and Statistics (67), International Financial Statistics Yearbook (68), and The Wharton EFA Annual Model (69). These data are listed in Table 9-7 and were collected for the 1955 to 1977 time period. For reasons that will be explained when we

TABLE 9-7. AGGREGATE TIME SERIES DATA

Variable	Definition
ACREP	Soybean acres planted in crop year t (million acres). Source: Reference (65).
ACREH	Soybean acres harvested in crop year t (million acres). Source: Reference (65).
YLDYR	Average yield of soybeans in crop year t (bushels per harvested acre). Source: Reference (65).
BUSHELU	Bushels of soybeans produced in the U.S. in crop year t (million bushels). Source: Reference (65).
BUSHELW	Bushels of soybeans produced in the rest of the world (i.e., outside of the U.S.) in crop year t (million bushels). Source: Reference (65).
QDOM	Domestic disappearance of soybeans in crop year t (million bushels). Source: Reference (65).
QEXP	Net exports of soybeans in crop year t (million bushels). Source: Reference (65).
STOCK	Commercial stocks of soybeans held at beginning of crop year t (million bushels). Source: Reference (66).
STOCK(-1)	Commercial stocks of soybeans held at beginning of crop year t-1 (million bushels). Source: Reference (66).
STOCKC	Stocks of soybeans held by the CCC at the beginning of crop year t (million bushels). Source: Reference (66).
STOCKC(-1)	Stocks of soybeans held by the CCC at the beginning of crop year t-1 (million bushels). Source: Reference (66).
STOCKM	Stocks of soybean cake and meal (1,000 tons).
PSOY	Average U.S. price per bushel of soybeans received by farmers in crop year t (dollars). Source: Reference (66).
TRANS	PSOYUK minus PSOYUSA.

(continued)

TABLE 9-7 (continued)

Variable	Definition
PSOY(-1)	Average U.S. price per bushel of soybeans received by farmers in crop year t-1 (dollars). Source: Reference (65).
PCTN(-1)	Average U.S. price per pound of cotton received by farmers in crop year t-1 (cents). Source: Reference (65).
PWHT(-1)	Average U.S. price per bushel of wheat received by farmers in crop year t-1 (dollars). Source: Reference (65).
PCRN	Average U.S. price per bushel of corn received by farmers in crop year t (dollars). Source: Reference (65).
PFISH	Wholesale price per ton of fish meal in year t; Menhaden 60% protein 100 lb. bags F.O.B. East Coast Plants (dollars). Source: Reference (67).
PGNUT	Import price per kilogram of Senegal groundnuts in France (cents) in year t. Source: Reference (67).
PSOYUK	Import price of a bushel of U.S. soybeans in the United Kingdom in crop year t (dollars). Source: Reference (67).
EXC	Exchange rate between the United States and Germany in year t (deutche marks per U.S. dollar). Source: Reference (68).
INT	User cost of capital in the agricultural sector in year t. Source: Reference (69).
POP	People eating from civilian food supplies in year t (millions). Source: Reference (65).
GOV(-1)	0-1 dummy variable indicating the presence of government support in crop year t-1. Equal to 1 if 5 percent of the total number of bushels were acquired by the CCC in crop year t-1; 0 otherwise.
TREND	Linear time trend variable where 1955 = 1, 1956 = 2, 1957 = 3, etc.
DUM74	Dummy variable equal to 1 in 1974; 0 elsewhere.

present the results of our yield equations, these data were collected only for soybeans.

Data on commodities in the agricultural sector are reported on a crop-year basis. A crop-year is from September 1 to August 31 of the following calendar year.

All prices used in the estimation of the supply and demand equations have been deflated by the Consumer Price Index (70) and are expressed in terms of 1967 dollars.

YIELD EQUATION RESULTS

The estimation results of the yield functions for cotton and soybeans will be presented in this subsection. A detailed explanation of the equations for each of these crops will be followed by a brief summary of the conclusions that can be drawn from this subsection regarding the effect of ambient SO_2 on cotton and soybeans. In the next subsection, these results will be used to estimate the economic benefits of attaining SNAAQS.

The statistics that are reported for each equation are:

1) The estimated coefficient and standard error of each variable included in the equation.

2) The number of observations (NOB) used to estimate the equation.

3) The corrected coefficient of determination ($\bar{R}^2$) which is a measure of the percentage of the variation in the dependent variable that is explained by the variation in the independent variables adjusted for the degrees of freedom.

4) The F-statistic which is used to test the hypothesis that none of the explanatory variables is significantly different from zero.

5) The elasticity of yield with respect to the air pollution variable (εSO_2).

The Durbin-Watson statistic is not reported since serial correlation is not likely to be a problem in the pooled time series cross-sectional data set we are using. Durbin-Watson statistics indicating the presence of serial correlation would be a function of the manner in which the data are entered (i.e., alphabetically by state). Since the Durbin-Watson statistic could be changed simply by rearranging the way in which the data are entered, we have not reported this statistic in order to avoid confusion.

Cotton

The yield functions estimated for the cotton-producing states included in the study are shown in Equations (1) and (2) of Table 9-8. As can be seen in this equation, all of the variables except IRRIG are in logarithmic form. This is because IRRIG is a dummy variable indicating the presence of irrigation in the county. If any of the acres growing cotton within the county are irrigated, the dummy variable is equal to one. Otherwise, it is equal to zero.

TABLE 9-8. YIELD FUNCTIONS FOR COTTON SAMPLE
(standard error in parentheses)

Variable	Equation 1	Equation 2
Constant	-2.250 (1.946)	-2.452 (1.984)
log(AMEAN)	-0.050 (0.080)	---
log(X2HI)	---	0.016 (0.069)
log(TEMP)	0.730* (0.398)	0.794* (0.389)
IRRIG	0.538** (0.110)	0.507** (0.110)
log(NITROGENC)	0.995** (0.132)	1.006** (0.146)
log(LIME)	0.089 (0.071)	0.066 (0.075)
log(LABORC)	0.202* (0.095)	0.209* (0.100)
No. of observations	84	83
F	16.491	15.492
$\bar{R}^2$	0.528	0.515
ε_{SO_2}	-0.050	0.016

* Significant at the 5 percent level.

** Significant at the 1 percent level.

The $\bar{R}^2$ of Equation (1) is 0.528. All of the coefficients of the economic variables included in the equation are of the expected signs. As the t-statistic indicates, LIME is not significantly different from zero.*

The coefficient of NITROGENC, significantly different from zero at the 1 percent level, is extremely high, indicating that a 10 percent increase in the use of nitrogen will result in approximately a 10 percent increase in cotton yield. The magnitude of this sign may be the result of the fact that NITROGENC may be correlated with variables that are not included in the equation. Inclusion of other fertilizer variables, however, did not affect the magnitude of the sign. IRRIG, the dummy variable indicating the presence of irrigation, is positive and significant at the 1 percent level. TEMP also has a significant, positive effect on cotton yield.

The variable representing the exposure of cotton to SO_2, AMEAN, is negative but not significant.** Alternative specifications did not affect the sign or significance of this variable.

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* Unless otherwise stated, significance levels are reported at the 5 percent and 1 percent levels. In general, when an independent variable is said to be significantly different from zero, it means that the variable can be considered to have a potential effect on the dependent variable.

** Since evidence exists that SO_2 can either enhance or diminish crop yield, we will use a two-tailed test when evaluating the significance of the coefficient of SO_2. One-tailed tests will be used to evaluate the significance of the other input variables since it is hypothesized that the partial derivatives of yields with respect to these inputs are positive.

In Equation (2), an alternative measure of SO_2 is used in the yield equation. The coefficient of X2HI has a positive sign but is not significant. The significance of the coefficients of all of the other variables are relatively unchanged.

Other specifications of the yield functions for the cotton-producing counties that were tried generally did not change the reported results for SO_2.

Because there may be significant differences in the production process throughout the country that cannot be controlled for in our yield functions (i.e., soil conditions, cultural practices), we have also estimated yield equations for regional subsets of the cotton-producing states. Estimating yield equations may enable us to uncover more reliable estimates of the true relationship between crop yield and SO_2, since these excluded factors may not vary within a particular agricultural region.

Equations (1) through (3) of Table 9-9 present the results of the regional cotton yield equations for: (1) Arizona, New Mexico and California, (2) Alabama and Mississippi, and (3) Texas. Except for California, the states included in each region are based on the breakdown of agricultural regions listed in Table 9-6. California was included in the Mountain Region since there were not enough observations to estimate a yield equation for this state independently.

TABLE 9-9. REGIONAL YIELD FUNCTIONS FOR COTTON SAMPLE
(standard error in parentheses)

Variable	Equation 1 AZ, NM and CA	Equation 2 AL and MS
Constant	418.405 (385.846)	-569.429* (257.680)
X2HI	-0.177 (0.180)	--
A2HI	--	-0.138 (0.127)
TEMP	-6.066 (17.630)	20.471* (9.981)
RAIN	-3.079 (3.703)	-0.393 (0.750)
NITROGENC	5.760** (1.515)	7.681** (2.282)
LABORC	-9.128 (20.424)	--
No. of observations	33	33
F	7.109	6.772
$\bar{R}^2$	0.488	0.419
ε_{SO_2}	0.074	0.052

* Significant at the 5 percent level.

** Significant at the 1 percent level.

(continued)

TABLE 9-9 (continued)

Variable	Equation 3 TX
Constant	-5.992 (4.142)
log(A2HI)	0.349** (0.090)
log(TEMP)	1.267 (0.756)
IRRIG	0.567** (0.109)
log(NITROGENC)	1.108* (0.509)
log(LIMEC)	0.166 (0.321)
No. of observations	33
F(5/27)	8.634
$\bar{R}^2$	0.476
ε_{SO_2}	0.349

* Significant at the 5 percent level.

** Significant at the 1 percent level.

Equation (1) shows a linear cotton yield specification for Arizona, New Mexico, and California. The $\bar{R}^2$ of this equation is approximately 0.488. The only variable in this equation significantly different from zero is NITROGENC. RAIN, TEMP, and LABORC are negative although insignificant. The coefficient of X2HI, although negative, is insignificant.

Alternative specifications of this regional yield equation were tried (i.e., log-linear, quadratic), but did not significantly alter the results for SO_2. The coefficients of the SO_2 variables were generally positive and insignificant in the log-linear specifications. When the SO_2 variables were entered with an interaction term (e.g., X2HI · RAIN and X2HI · TEMP), the coefficients of these terms were insignificant.

A regional production function for Arizona and New Mexico was also estimated to see if the production function would be better specified using a more homogeneous region. The results for SO_2 were not significant in these specifications.

The linear yield equation generally behaved better than the log-linear functions for the agricultural region including Alabama and Mississippi. As Equation (2) shows, $\bar{R}^2$ is equal to 0.419 with TEMP and NITROGENC being of the expected signs and significantly different from zero. Surprisingly, the coefficient of RAIN is negative, although insignificant (cotton is not irrigated in Alabama and Mississippi). The coefficient of the A2HI term is not significant.

Alternative measures of SO_2 were used in place of A2HI but were not significant. Interaction terms between SO_2 and the climate variables did not improve the specifications and were not significant. When the other fertilizer variables were entered into the equation, they generally were not significant and had inconsistent signs.

The third regional equation specified for the cotton data set is for Texas. Texas is the leading producer of cotton in the United States (Agricultural Statistics, 1979). A complete set of observations, however, were only available for approximately 14 of the 152 cotton-producing counties in the state. As Equation (3) shows, A2HI, IRRIG, and NITROGENC are significantly different from zero at the 1 percent level. A2HI is positive and, surprisingly, significant at the 1 percent level. The elasticity of yield with respect to A2HI is 0.349, which is extremely high relative to the other elasticities that have been reported for the cotton yield equations.*

The coefficients of TEMP and NITROGENC seem to be extremely high in this equation. It is interesting to note that LIMEC, although positive, is not significantly different from zero. This may be due

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* The elasticity is a measure of the percent change in one variable that can be expected from the percent change in another variable; i.e., $[(\partial Y/Y)/(\partial X/X)]$.

to the fact that the data used as proxies for these inputs are state-specific. Consequently, only year-to-year variations in the use of lime are measured by the variables in the Texas yield equation.

The sign and significance of X2HI were relatively constant over all of the alternative specifications that were tried. When X2HI was entered into the yield equations instead of A2HI, it was positive but insignificant. XMEAN and AMEAN were negative but not significant. The strong positive relationship exhibited between A2HI and crop yield may be due to the soil composition in Texas. The soil in the southwestern part of the country tends to be alkaline with pH levels in the 7 to 8.5 range (as per conversation with state soil scientists). In alkaline areas such as these, plants may have to rely on the SO_2 in the atmosphere for their sulfur needs. Consequently, it is possible that SO_2 may have a positive impact on crop yield. As explained in the literature review, plants grown in sulfur-deficient soils have been shown to metabolize SO_2 from the atmosphere for their sulfur requirements (18). However, injury will occur if the amount of the sulfur ions present in the plant cell exceed that which can be oxidized and assimilated. In order to test for this possibility, a quadratic SO_2 term was included in the specification of the yield function. The linear term remained positive and significant in this specification, while the square term, although negative, was insignificant.

Soybeans

The results of the yield equations estimated for the soybean-producing counties are presented in Table 9-10. The results of a log-linear yield equation are reported in Equation (1). Because of the lack of data on the use of fertilizer and labor for all of the states included in this analysis, this equation is based on 271 observations. The coefficients of all of the economic variables except LIME and TEMP are significantly different from zero. The signs of the coefficients of NITROGEN and K_2O do not conform with *a priori* expectations, however. Besides the fact that the data used to reflect the use of these fertilizers are gross approximations of county level use, the perverse signs exhibited in Equation (1) may be due to the relationship between fertilizer application and the inherent quality of soybeans and the soil. Soybeans are known to be a nitrogen-fixing plant, meaning that instead of taking nitrogen out of the soil for their nutritional requirements, soybeans *provide* the soil with nitrogen. Consequently, it is not surprising that nitrogen application has a negative impact on soybean yield in Equation (1). In addition, soils that are rich in nutrients will not need to be fertilized as intensively as those soils that are lacking nutrients. Thus, the relationship exhibited in Equation (1) does not necessarily reflect a cause-and-effect relationship and does not mean that the application of more K_2O will result in lower soybean yields. It is more likely that the application of larger amounts of this fertilizer in certain regions indicates that the soil is inherently lacking the

TABLE 9-10. YIELD FUNCTIONS FOR SOYBEAN SAMPLE
(standard error in parentheses)

Variable	Equation 1	Equation 2
Constant	2.075** (0.427)	2.509** (0.336)
log(X2HI)	---	-0.015 (0.018)
log(AMEAN)	-0.015 (0.020)	---
log(TEMP)	0.077 (0.094)	0.090 (0.066)
log(RAIN)	0.110** (0.036)	0.022 (0.036)
log(NITROGEN)	-0.146** (0.057)	---
P_2O_5	0.212* (0.116)	---
K_2O	-0.150* (0.078)	---
log(LIME)	0.008 (0.028)	-0.007 (0.020)
log(LABOR)	0.184** (0.050)	0.183** (0.019)
No. of observations	271	459
F	32.896	45.497
$\bar{R}^2$	0.486	.0.327
ε_{SO_2}	-0.015	-0.015

* Significant at the 5 percent level.

** Significant at the 1 percent level.

nutrients necessary to grow soybeans and the yields in these areas will tend to be less than areas where the soil is inherently rich in nutrients. Thus, K_2O may be acting as a proxy for the presence of poorer quality soils in certain states.

The coefficient of AMEAN is negative but not significant. When the other SO_2 variables were used in Equation (1) in place of AMEAN, they also were not significant.

Alternative specifications of the yield function were tried but did not result in an improvement of the reported results.

Since the use of different amounts of fertilizer will tend to diminish the variation in the fertility levels of the soils growing soybeans, we have dropped these variables from Equation (1) under the assumption that the fertility of the soils in which soybeans are grown are basically the same due to fertilization. LIME was not dropped from this equation because of the suspected relationship between atmospheric SO_2 and the application of LIME (i.e., the pH level of soil may be increased through the application of lime). This enables us to include the states excluded from Equation (1) due to the lack of fertilizer data. These results are shown in Equation (2). Compared to Equation (1), the $\bar{R}^2$ is reduced significantly in this equation. The coefficient of LABOR is positive and significant, and relatively unchanged from Equation (1). The coefficient of X2HI is negative but insignificant. It is interesting to note that the magnitude of the coefficient of X2HI is the same as the coefficient of AMEAN. The remainder of the variables included in the equation were not significant.

The equation was re-estimated using the different measures of SO_2 in place of X2HI. Although the coefficients of these variables were negative, none of them were significant.

In order to determine whether regional differences were obscuring the posited relationship between SO_2 and soybean yield, yield equations were also estimated for specific agricultural regions. Based on the regions listed in Table 9-10, regional yield functions were estimated for: (1) Mississippi; (2) Illinois, Indiana, Iowa, and Ohio; (3) Texas; (4) Alabama, Georgia, and Kentucky; and (5) Michigan, Minnesota, and Wisconsin. The results of these estimations are reported in Equations (1) through (5) of Table 9-11.

Equation (1) presents the results of the estimated yield function for Mississippi. Although the coefficient of A2HI is negative, it is insignificant. The F-test for this and alternative specifications of the Mississippi yield equation indicated that none of the coefficients in the equation were significantly different from zero.

Equation (2) presents the results of the equation estimated for the Corn Belt Region (Illinois, Indiana, Iowa, and Ohio). The $\bar{R}^2$ of this equation is relatively low (0.151) compared to the other regional

TABLE 9-11. REGIONAL YIELD FUNCTIONS FOR SOYBEANS
(standard error in parentheses)

Variable	Equation 1 MS	Equation 2 IL, IN, IA, OH	Equation 3 TX
Constant	13.882* (8.439)	7.130 (5.292)	-101.562** (41.183)
X2HI	---	-0.006** (0.002)	0.882** (0.249)
A2HI	-0.007 (0.004)	---	---
(X2HI · TEMP)	---	---	-0.038** (0.011)
TEMP	-0.213 (0.249)	0.479** (0.162)	5.266** (1.944)
RAIN	0.024* (0.012)	-0.001 (0.011)	0.070** (0.023)
LIME	1.495E-05** (5.831E-06)	4.483E-07* (2.133E-07)	1.243E-04 (8.153E-05)
LABOR	---	0.215** (0.062)	-4.650 (3.555)
No. of observations	35	234	19
F	2.541	9.312	3.539
$\bar{R}^2$	0.154	0.151	0.458
ε_{SO_2}	-0.040	-0.049	-0.124

* Significant at the 5 percent level.

** Significant at the 1 percent level.

(continued)

TABLE 9-11 (continued)

Variable	Equation 4 AL, GA and KY	Equation 5 MI, MN and WI
Constant	-12.749** (3.498)	-4.252** (1.610
log(X2HI)	1.525* (0.612)	---
log(RATIOX)	---	-0.041 (0.084)
log(X2HI) · log(RAIN)	-0.317* (0.130)	---
log(TEMP)	0.256 (0.225)	0.936** (0.340)
log(RAIN)	1.841** (0.690)	-0.060 (0.113)
log(LIME)	0.399** (0.080)	0.084 (0.054)
log(LABOR)	0.202 (0.217)	1.576** (0.332)
No. of observations	108	98
F	12.740	6.957
$\bar{R}^2$	0.397	0.235
ε_{SO_2}	0.064	-0.041

* Significant at the 5 percent level.

** Significant at the 1 percent level.

equations. Alternative specifications did not significantly improve the $\bar{R}^2$, and the coefficient of RAIN is negative but not significant in this equation. The coefficients of the other variables in the equation have their expected signs and are significantly different from zero. In addition, a significant negative relationship between SO_2 and soybean yield in the Corn Belt Region is observed from the results of this equation.

Alternative specifications and SO_2 measures that were tried consistently revealed a significant negative relationship between SO_2 and YLD. The addition of the fertilizer variables into the equation did not affect the size or significance of the coefficient of X2HI.

The results of the yield function estimated for Texas are shown in Equation (3). A linear yield function gave the best results for this state. Neither LIME nor LABOR are significantly different from zero in this equation. The coefficients of the climatological variables are positive and significant, however. Both X2HI and the variable expressing the interaction between SO_2 and temperature (X2HI · TEMP) are significantly different from zero. Their signs indicate that SO_2 may have a positive impact on soybean yield for a range of temperatures that are relatively low. As temperature increases, however, this positive impact on yield diminishes and at some point becomes negative. When evaluated at the mean of TEMP, the partial derivative of YLD with respect to X2HI is -0.0185.

Equation (4) of Table 9-11 presents the regression results for the regional yield functions including the states of Alabama, Georgia and Kentucky. Mississippi was not included in this set due to its lack of data on LABOR. Due to an insufficient number of observations on NITROGEN, P_2O_5, and K_2O, these variables could not be included in the equation. Since these variables do not tend to be correlated with the SO_2 variables, their omission is not a serious concern.

As can be seen in Equation (4), all of the estimated coefficients are significantly different from zero except for TEMP and LABOR. The lack of significance of LABOR may be due in part to the lack of variation in the variable across the regions included in this data set. LIME has a positive sign and is strongly significant.

In addition to including X2HI and RAIN as separate variables, the log-linear yield function reported in Equation (4) includes a term that reflects the interaction between X2HI and RAIN. This variable is included to test for the possibility that the effect of SO_2 on soybeans may differ depending on the level of rain. As evidenced by Equation (4), both of the terms, including X2HI, are significant. Evaluated at the mean of RAIN, the elasticity of soybean yield with respect to X2HI is 0.064 and significantly different from zero.

The results of the yield equation estimated for the Lake States (Michigan, Minnesota and Wisconsin) are listed in Equation (5) of Table 9-11. The $\bar{R}^2$ of this equation is 0.235. The only variables significantly different from zero in this equation are TEMP and LABOR. Both of these variables are of their expected signs. The coefficient of LABOR is extremely high, suggesting that it might be acting as a proxy for another variable. Surprisingly, neither the coefficient of LIME nor RAIN is significant. RATIOX is negative but insignificant. The coefficients of the other SO_2 variables that were tried were generally positive but were not significant. The alternative forms of the yield function and alternative measures of SO_2 that were tried also did not improve the results.

Summary of Results

Based on the results reported in Tables 9-8 and 9-9, we are unable to assert that ambient SO_2 concentrations have a significant negative impact on cotton yield in the counties in our study. Although the results suggest that in some cases SO_2 may be negatively related to cotton yield, these results were not significant. In fact, the only significant relationship exhibited between SO_2 and YLDC was found in the Texas yield function and indicated that SO_2 had a positive effect on cotton yield. The results of the yield functions estimated for the cotton-producing counties are not too surprising for a number of reasons.

One reason for the lack of significance between SO_2 and cotton yield may result from the possibility that the SO_2 levels in the counties included in this study are not high enough to have a deleterious effect on cotton yield. For example, the average of the maximum of the annual average SO_2 readings (XMEAN) for the 84 counties included in this study is 29.08 $\mu g/m^3$. Given that the soils in some of the cotton-producing areas tend to be rather alkaline, it is possible that the cotton plants are drawing on the SO_2 in the atmosphere for their sulfur requirements and consequently would not be negatively impacted by exposure to SO_2. In fact, as the results of the Texas yield function show, it is possible that crop yield may actually be enhanced due to the exposure to SO_2. This result is consistent with studies which have found that plants grown in soils deficient in sulfur can be positively affected by exposure to SO_2 (16,17). Since none of the sample cotton-producing counties in Texas in 1977 had an SO_2 reading for A2HI that excluded 215 $\mu g/m^3$, the relationship exhibited between SO_2 and cotton yield in Texas is certainly reasonable.

Although the yield functions estimated for the entire soybean data set did not find a significant negative relationship between SO_2 and soybean yield, certain regional yield functions that were estimated indicated that such a relationship did exist on the regional level. The significant differences in the relationship between SO_2 and soybean yield exhibited in the regional yield equations suggest that various climatological and soil factors within each region may play an important part in determining the susceptibility of soybeans to air pollution.

The yield functions estimated for Mississippi and the Lake States Region (Michigan, Minnesota and Wisconsin) did not indicate that the soybean yield and SO_2 were negatively related. The results of the yield equation for the Lake States Region are particularly surprising since approximately 36 percent of the counties included in our sample exceeded 260 $\mu g/m^3$ for the average of the second highest SO_2 readings within a county ($\overline{X2HI}$).

A significant relationship was found to exist between soybean yield and SO_2 in the states of Alabama, Georgia and Kentucky. The relationship exhibited in these states indicates that in the presence of relatively large amounts of rain (123.08 centimeters), SO_2 can have a deleterious effect on soybean yield. This result is somewhat similar to the results of laboratory studies that have found that plants are more susceptible to SO_2 in the presence of adequate amounts of soil moisture.

Significant negative relationships between soybean yield and various measures of SO_2 were also found to exist for the Corn Belt Region (Illinois, Indiana, Iowa and Ohio) and Texas, and this relationship remained consistent in the alternative specifications that were tried. Interestingly, the relationship between SO_2 and soybean yield in Texas was dependent on temperature.

The results of our estimation of regional yield functions for both cotton and soybeans are certainly plausible given the data with which we were working. Since this analysis examines the effect of SO_2 on yields during 1975 to 1977, it is possible that farmers have had time to adjust to past levels of SO_2 and that the yields in 1975 to 1977 reflect this adjustment. Changes in the amount of the crop planted in a particular area and changes in the type of seed (cultivar) used are examples of the adjustment that farmers may have made to avoid the effects of SO_2 on their crops. Consequently, the true effect on yield will be understated if these types of adjustment to ambient SO_2 have already taken place. In addition, it is possible that the air quality during the 1975 to 1977 time period has improved so that the deleterious effects of SO_2 on cotton and soybean yields are not discernible.

As mentioned in the Data subsection, the relationship between SO_2 and crop yield may be obscured because our data sets are comprised of information on farm production and SO_2 aggregated to the county level. The different effects of SO_2 on yield within each county cannot be identified in this analysis. This may be particularly relevant in counties where the air quality varies significantly throughout the county. For example, if certain farmers within a county experience depressed yields because their farms are located downwind of a power plant and farmers upwind of the plant are not affected by the plant's emissions, the aggregation of yields to the county level will tend to obscure the relationship between SO_2 and yield.

It is also possible that the relationship between SO_2 and crop yield may be obscured due to the air quality data used in this analysis. Evidence exists that certain plants are more susceptible to air pollution during their flowering stages, which tend to occur during the third quarter of the year (54). Use of the means and second highest values of SO_2 during the second quarter of the year may consequently underestimate the impact of SO_2 on crop yield.

Even with these data limitations, a significant negative relationship between SO_2 and soybean yield has been found to exist in certain regions of the country. In the next subsection, we will use the yield functions of these regions to estimate the change in yield that can be expected from attainment of alternative SNAAQS. It is important to note that based on these data limitations, these estimates will be considered to be lower-bound estimates of the benefits of attaining alternative SNAAQS.

BENEFIT ESTIMATION

In this subsection, we will estimate the benefits of attaining alternative SNAAQS for those regions where our estimated yield functions indicate that a significant negative relationship between SO_2 and crop yield exists. Since such a relationship was not found for any of the states included in the cotton sample, and in only some of the states included in the soybean sample, agricultural benefits will be calculated only for the soybean-producing counties of Alabama, Georgia, Kentucky, Illinois, Indiana, Iowa, Ohio and Texas.*

The scenario for reaching the secondary standard is identical to the one used in the other sections of the report; i.e., the level of SO_2 will improve by half of the amount necessary to reach the secondary standard by the end of 1986 and by the remaining amount by the end of 1987. It is also assumed that these improvements will be instantaneous, occurring on the last day of 1986 and 1987. In the agricultural sector this means that half of the improvement will occur during the crop year of 1986 and the remaining half will occur during the crop year of 1987. Once the secondary standard is attained at the end of 1987, it is assumed that it will be maintained indefinitely into the future. It is assumed for our analysis that any soybean-producing county that was in excess of the primary standard in 1977 will be assumed to be meeting the primary standard in 1985, and benefits will be estimated for the change in pollution from the primary to the secondary standard. Benefit calculations for any soybean-producing county that had a level of pollution in 1977 that was less than the primary but more than the secondary standard will be based on the change in pollution from the 1977 level to the secondary standard. Any soybean-producing county that was meeting the secondary

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* Although the significant positive relationship found to exist between SO_2 and cotton yield for the sample counties in Texas indicates that reductions in the level of SO_2 will result in reductions in crop yield, the "negative" benefits (i.e., costs) in these counties need not be calculated since none of these counties exceeded the alternative SNAAQS in 1977.

standard in 1977 is assumed to be meeting it in 1985.* Consequently, under our assumptions there would be no economic benefits in these counties resulting from the implementation of SNAAQS.

Benefits estimates will be based on compliance with these alternative standards:

SO_2	Alternative secondary air quality standard ($\mu g/m^3$)**
Annual arithmetic mean	60
24-hour maximum+	260
3-hour maximum+	1,300

Given this scenario and the requirement that a significant negative relationship exists between SO_2 and soybean yield, our benefit calculations will be limited to the soybean-producing counties in Illinois, Indiana, Iowa and Ohio (hereafter referred to as the Corn Belt Region).++ The counties in the other regions where a significant relationship between SO_2 and soybean yield has been found to exist

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* The other sections of this study base the estimated reduction in pollution necessary to meet the secondary standard on 1978 pollution levels.

** The standards listed above are not, in all cases, part of the current Federal regulations. The source of the standards shown here is Stern *et al.* (71), p. 159; and Air Quality Data, Annual Statistics, 1977 (72).

\+ This value is not to be exceeded more than once a year.

++ The Corn Belt Region, as defined by the U.S. Department of Agriculture, also includes the state of Missouri.

would not experience an increase in soybean yield as a result of the improvement in air quality.*

In order to calculate the economic benefits of increased soybean yields, we have also assumed that the soybean market in 1977 can be used to represent the soybean market over the period for which we will calculate benefits. In other words, except for the level of SO_2, all the factors influencing soybean yield, production, and price in 1977 are assumed to hold over the period of our analysis.**

Based on the above scenario, the physical increases in yield (in terms of bushels) that can be expected from the implementation of SNAAQS can be calculated using the relationship between yield and SO_2 estimated in the soybean yield function for the Corn Belt Region (see Equation (2) in Table 9-11). The improvement in yield for each county exceeding the secondary standard in the Corn Belt Region can be calculated from:

$$\Delta YLD = 0.006 \ (\Delta SO_2)$$

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* See the Results subsection for explanation of the interaction between climate and SO_2 in the production functions for Alabama, Georgia, Kentucky and Texas.

** This may tend to underestimate the benefits of achieving SNAAQS since the amount of acreage planted into soybeans has been increasing over the past and is expected to continue to increase in the future (73).

where $0.006 = \partial YLD/\partial SO_2$; the change in yield due to a change in SO_2 that is estimated from the Corn Belt Region yield function.

Table 9-12 lists the estimated increases in the average yield of soybeans that can be expected from moving from the primary to the alternative secondary standard.

Supply and Demand Equations

As mentioned in the Methodology subsection, it is necessary to examine the estimated relationship between SO_2 and crop yield within the framework of the soybean market. The estimated supply and demand equations that will be used to calculate the benefits of implementing alternative SNAAQS are reported in this subsection.

The statistics reported for these equations are the same as the ones reported for the yield equations. Two additional statistics, however, are reported for these equations. They are:

(1) The Durbin-Watson statistic (DW) which is used to test for the existence of serial correlation among the error terms.

(2) The correlation coefficient (λ) between the error terms in period t and period t-1 is reported when serial correlation is suspected to be a problem.

TABLE 9-12. AVERAGE YIELD OF SOYBEANS IN THE UNITED STATES UNDER ALTERNATIVE SO_2 LEVELS

	Bushels
Average yield in the presence of the primary standard	30.587
Average yield after moving halfway to the alternative secondary standard	30.591
Average yield after attaining the alternative secondary standard	30.596

Supply--

Acreage Response Equation--The soybean acreage response equation is reported in Table 9-13. The specification used in Table 9-13 is similar to the acreage response equations developed for soybeans by Houck et al. (50), Adams et al. (51), and Baumes and Meyers (52).

The variables used to reflect the price expectations of farmers in year t are the prices of soybeans and substitute crops in production in year t-1.

All of the price variables included in this equation have their expected signs and are significantly different from zero. The price of soybeans in year t-1 has a significant impact on the number of soybean acres planted in year t, indicating that producers base their planting decisions on the prices received for soybeans in the previous year. Alternative lagged soybean price variables were tried, such as PSOY(-2) and [PSOY(-1) - PSOY(-2], but were not significantly

TABLE 9-13. SOYBEAN ACREAGE RESPONSE EQUATION
(standard error in parentheses)

Variable	ACREP
Constant	16.681** (2.441)
PSOY(-1)	6.794** (1.051)
PCTN(-1)	-0.189* (0.075)
PWHT(-1)	-3.860** (1.045)
TREND	1.192** (0.096)
GOV(-1)	0.655 (0.729)
No. of observations	23
F(5/17)	330.051
$\bar{R}^2$	0.987
DW	1.95
$\varepsilon_{PSOY(-1)}$	0.512

* Significant at the 5 percent level.

** Significant at the 1 percent level.

different from zero. The elasticity of soybean acres planted (ACREP) with respect to PSOY(-1) is 0.512. This elasticity is larger than the elasticity of 0.39 reported by Houck et al. (74) and smaller than the elasticity of 0.84 reported by Houck and Subotnik (75). It is reasonably close to the elasticity of 0.56 reported by Gardner (76) and within the range of elasticities of 0.21 to 0.97 reported by Adams et al. (51).

The lagged price of cotton and wheat were included in the soybean acreage response equation in order to control for the impact that the prices of other crops that compete with soybeans for acreage have on the quantity of soybean acreage planted. The coefficients of these variables -- both negative and significantly different from zero -- imply that farmers are responsive to the lagged prices of crops that can be planted in place of soybeans. Wheat is a substitute crop for soybeans in the Lake States agricultural region, while cotton is a substitute crop in the agricultural regions comprising the Atlantic and Delta States. Given the significant increase in the production of soybeans relative to the production of cotton in the Delta States over the period of this analysis, it is not surprising that the lagged price of cotton has a significant impact on the number of acres of soybeans planted. When the lagged price of corn, a major substitute for soybeans in the Corn Belt Region, was included in Equation (9.13), it was plausibly signed but insignificant. Equation (9.13) was also estimated with the lagged price of wheat being replaced by the lagged price of corn. Although the coefficient of the lagged price of corn was negative and significantly different from zero, the F-statistic decreased to 269.007 and the Durbin-Watson statistic suggested that serial correlation was a problem. Consequently, it was decided not to use this specification.

The linear time trend variable (TREND) that is included to reflect the secular trend in the number of soybean acres planted is positive and significantly different from zero. GOV(-1), the dummy variable indicating the presence of government support operations in the year prior to the planting of soybeans, is positive but not statistically different from zero.

The $\bar{R}^2$ of the equation is 0.987, indicating that the estimated equation fits the historical data quite well. The Durbin-Watson statistic (DW) does not indicate that serial correlation is a problem in this equation.

Acres Harvested--Over the period of this analysis (1955 to 1977), approximately 98.6 percent of the soybean acreage planted has been harvested. Therefore, we will use this percentage to estimate the number of soybean acres harvested in each period.

Demand Equations

The components of the demand for soybeans are reported in Tables 9-14 to 9-16. Due to the simultaneous determination of the price of soybeans (PSOY) and the components of demand, these equations are estimated using two-stage least squares.

Domestic Demand--

Table 9-14 reports the results of the domestic demand equation for soybeans. Preliminary estimation of this equation suggested that there was serial correlation of the error terms in successive years. Consequently, the equation was re-estimated with the variables transformed into generalized differences.*

All of the variables included in the equation exhibit their expected signs and are statistically different from zero. The elasticity of the domestic demand for soybeans with respect to its own price, PSOY, is equal to -0.350. The price of corn (PCRN), a feed grain consumed by livestock, is positive and significantly different from zero. Although not a perfect substitute for soybeans in terms of

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* The form of the generalized difference domestic demand equation is: $QDOM - \lambda \cdot QDOM(-1) = \beta_1(1-\lambda) + \beta_2 (PSOY - \lambda \cdot PSOY(-1)) + \beta_3 (PCRN - \lambda \cdot PCRN(-1)) + \beta_4 (PFISH - \lambda \cdot PFISH(-1)) + \beta_5 POP - \lambda \cdot (POP(-1)) + \beta_6(DUM74 - \lambda \cdot DUM74)$, where λ is the estimated correlation coefficient between the error terms in year t and t-1, and β_n is the estimated coefficient of the variable. See Pindyck and Rubinfeld (77) and Cochrane and Orcutt (78) for an explanation of this process.

TABLE 9-14. SOYBEAN DOMESTIC DEMAND EQUATION
(standard error in parentheses)

Variable	QDOM
Constant	-2184.860** (290.023)
PSOY	-78.071** (18.481)
PCRN	96.545* (46.286)
PFISH	0.447* (0.185)
POP	14.853** (1.512)
DUM74	-109.139** (29.448)
No. of observations	23
F(5/17)	29.629
$\bar{R}^2$	0.867
DW	1.99
ε_{PSOY}	-0.350
λ	0.8005

* Significant at the 5 percent level.

** Significant at the 1 percent level.

TABLE 9-15. SOYBEAN EXPORT DEMAND EQUATION
(standard error in parentheses)

Variable	QEXP
Constant	-869.865** (203.928)
PSOY	-125.288** (23.273)
PGNUT	5.596* (2.606)
PFISH	0.608** (0.215)
BUSHELW	-0.177** (0.064)
TRANS	-44.965* (24.470)
EXC	-164.224** (37.803)
TREND	21.614** (2.841)
No. of observations	23
F(7/15)	199.891
$\bar{R}^2$	0.984
DW	2.23
ε_{PSOY}	-1.175

* Significant at the 5 percent level.

** Significant at the 1 percent level.

TABLE 9-16. SOYBEAN STOCK DEMAND EQUATION
(standard error in parentheses)

Variable	STOCK
Constant	73.616** (119.191)
PSOY	-39.886** (11.527)
PSOY(-1)	42.771* (13.618)
STOCKM	0.239* (0.099)
BUSHELU	0.054 (0.037)
INT	-6.407 (7.315)
STOCK(-1)	0.410** (0.145)
No. of observations	21
F(6/14)	13.227
$\bar{R}^2$	0.786
DW	1.66
ε_{PSOY}	-1.216

* Significant at the 5 percent level.

** Significant at the 1 percent level.

protein content, the sign and significance of this variable indicate that higher corn prices will lead to the more intensive use of soybeans as an animal feed. The price of fish meal (PFISH), a high-protein livestock feed, is also positive and significantly different from zero, indicating that fish meal is used as a substitute for soybeans in consumption. A variable for livestock, representing one of the primary demanders of soybeans, was also included in the domestic demand equation. It did not conform to a priori expectations, and consequently was excluded from the final equation.

Since soybeans are also consumed by humans (e.g., soybean oil, processed foods), various variables, such as the consumption of fats and oils by humans, were included to reflect this component of demand. These variables were generally not significantly related to domestic soybean demand. As seen in Table 9-14, POP, a variable measuring the number of people eating from civilian food supplies, is positive and significantly related to domestic demand.

The coefficient of DUM74, representing the unusual conditions of the soybean market in 1974 (i.e., smaller acreage and sharply reduced yields) is negative and statistically significant.

Export Demand--

The export demand equation for soybeans is reported in Table 9-15. Like the acreage response equation, the percent of variation in export demand (QEXP) explained by the variables included in this equation is extremely high ($\bar{R}^2 = 0.984$). The Durbin-Watson test for serial correlation was in the indeterminate range for this equation. Consequently, no corrective measures were taken.

The relationship between QEXP and PSOY is negative and significant. The elasticity of QEXP with respect to PSOY is -1.175. This is much higher than the "own-price" elasticity reported for the domestic demand equation. This is to be expected since importing countries are more likely to substitute soybeans from other countries (e.g., Brazil, Nigeria) for U.S. soybeans than U.S. demanders. The elasticity reported in Table 9-15 is higher than the -0.54 export elasticity of demand reported by Houck et al. (50). It is lower, however, than the export demand elasticity of -1.99 reported by Baumes and Meyers (52).

The coefficients of the variables measuring the effect of the prices of substitute goods in consumption, PGNUT and PFISH, are both positive and statistically significant.

BUSHELW, the number of bushels of soybeans produced by the rest of the world, has a significant negative impact on the export demand for soybeans. TREND, the variable representing the upward trend in soybean exports over time, is positive and significantly different from zero.

Since the export demand for soybeans also depends on the cost of transporting soybeans from the United States to the importing countries, a variable reflecting this cost is also included in the export demand equation. A variable reflecting the actual cost of soybean shipment was not available when the export demand equation was estimated; therefore, the difference between the price of soybeans in the United Kingdom and the United States (TRANS) was used as a proxy for transport cost. Since Western Europe imports a significant amount of soybeans, it was felt that TRANS would be an appropriate proxy. As Equation (9.15) shows, TRANS is negative and significant.

The export demand for soybeans will also be influenced by the exchange rate between the U.S. and foreign currencies. Since West Germany is a primary demander of soybeans, and since the currencies of Western European counties, with the exception of the English pound, move somewhat in tandem with the West German deutsche mark, the exchange rate between the deutsche mark and U.S. dollar (EXC) was used as a proxy for the exchange rates between the United States and importing counties. Time did not permit development of a broader measure of exchange rates.

The coefficient of EXC, positive and significant, indicates that soybean export demand is quite sensitive to changes in the exchange rate. The elasticity of export demand with respect to the deutsche mark-U.S. dollar exchange rate is -1.98. This is higher than -1.39 elasticity of the exchange rate variable in the study of the soybean market by Baumes and Meyers (52). Although it seems likely that the export demand for soybeans would be responsive to changes in the exchange rate since importing countries can buy soybeans from a number of different exporting countries, the price elasticity of this equation is somewhat unrealistic.

Stock Demand--

Table 9-16 reports the results for the soybean stock demand equation. Because ordinary least squares will result in biased and inconsistent coefficient estimates when some of the variables included in the equation are lagged endogenous variables, it could not be used to estimate the stock demand equation since both PSOY(-1) and STOCK(-1) are lagged endogenous variables. Using a technique developed by Fair (79), an instrumental variable for the endogenous variable in the equation (PSOY) was created and the equation was estimated using generalized least squares.

The coefficient of PSOY conforms to *a priori* expectations, indicating the people will hold fewer stocks of soybeans as the market price for soybeans rises. The elasticity of stock demand with respect to PSOY is quite high, -1.216. This is much larger than the stock demand elasticity of approximately -0.06 reported by Houck *et al.* (50), but lower than the elasticity of -2.29 reported by Baumes and Meyers (52).

PSOY(-1) is included in the equation in order to reflect the speculative demand for soybeans. It is positive and significant, indicating that higher prices for soybeans in year t-1 will result in more soybean stocks being held in year t. The price of soybeans in year t+1 [PSOY(+1)] was also included in order to reflect the possibility that stockholders base their expectations on future prices. The coefficient of this variable was implausibly signed and not significantly different from zero.

The coefficient of stocks in year t-1 is positive and significantly related to soybean stock holdings in year t. BUSHELU, the variable reflecting the transaction demand for soybean stocks, although positive, is not significantly different from zero. Similarly, the coefficient of the variable reflecting the opportunity cost of holding stocks (INT), although conforming to *a priori* expectations, is not significant.

Since soybeans are processed into soybean oil and meal, STOCKM is included as a proxy for the capacity constraints of processing soybeans into final products. STOCKM represents the stocks of soybean cake and meal that are held in year t. The coefficient of this variable conforms to the expectation that higher amounts of soybean meal stocks that are held will result in higher levels of soybean stocks.

Calculation of Benefits

In order to calculate the economic benefits of the attainment of alternative secondary national ambient air quality standards, the soybean model is simulated over the period in which benefits are expected to occur using the supply and demand equations reported in Tables 9-13 through 9-16 of this subsection. The model is simulated under two scenarios -- one assuming that the SO_2 levels existing in 1977 will prevail indefinitely into the future, and one assuming that the alternative secondary standards listed in Table 9-12 will be met by 1987. Benefits are then calculated according to the procedure discussed in the Methodology subsection (see specifically Equations 9.34 through 9.36.)

Using a 10 percent discount rate, the economic benefits in the soybean market of reducing the maximum of the second highest 24-hour SO_2 reading within a county to 260 $\mu g/m^3$ are estimated to be $21.6 million in 1980 dollars. The economic benefits of meeting the secondary standard in terms of the 24-hour equivalent of the maximum of the second highest 3-hour SO_2 reading are estimated to be $0.18 million. These benefits are much lower than the benefits estimated using the 24-hour SO_2 readings since only one county in our sample exceeded the 24-hour equivalent of the 3-hour secondary standard in 1977. Both estimates are discounted present values in 1980 and assume an infinite time horizon.

It should be mentioned that these benefit estimates are based on a sample of counties that accounted for approximately 17.6 percent of the soybean production within the Corn Belt Region in 1977. Consequently, these benefits are not indicative of the benefits that would be realized for the entire Corn Belt Region if there are any soybean-producing counties in this region that exceed the alternative secondary standard but are not included in our sample.

Our estimates indicate that the implementation of the 24-hour secondary standard for SO_2 would result in an annual increase in production of 500,000 bushels of soybeans.

Comparison With Other Studies

To date, we have found only two studies that have specifically analyzed the economic impact of SO_2 on soybean production. As mentioned in the Literature Review, Armentano and Miller and Usher (19) estimated the impact of emitted SO_2 from coal-fired electrical generating stations in the Ohio River Basin Area Energy Study (ORBES). Specific estimates of the impact of these emissions on soybeans were made for the states of Illinois, Indiana, Kentucky and Ohio. They calculated that there would be a probable gain of 651,690 bushels of soybeans due to the total abatement of SO_2 emissions from 31 generating stations in 1976.

Stanford Research Institute (49) estimated that the implementation of SNAAQS would result in annual benefits of $1.78 billion (1980 dollars) in the agricultural sector. Although the benefits of the increased production of soybeans resulting from the reduction of SO_2 to the secondary standard were not specifically reported in the study, annual benefits of the increased production of soybeans of approximately $4.8 million are implied based on information in the report. If one assumes that this level of annual benefits continued into the indefinite future, then the equivalent discounted present value at a 10 percent discount rate would be $48 million. Thus, our estimate is about one-half as large.

Although our estimates are quite reasonable with respect to these studies, they are not strictly comparable with these studies for the following reasons:

- Different methodologies - Both Miller and Usher and SRI use crop loss functions in order to calculate benefits. Consequently, their estimates do not reflect the effects of changes in crop yield on price.
- Different time periods - The SRI study is based on air quality data from 1974 to 1978, while the ORBES study includes 1976 air quality data. The benefits in this study are based on 1977 data.
- Different sample - SRI included all counties that exceeded the secondary standard for SO_2 in 1980. The ORBES sample included all counties impacted by 31 coal-fired generating sations within Illinois, Indiana, Kentucky and Ohio. Our benefits estimates are based on 17 percent of the soybean-producing counties within the Corn Belt Region.

- Different scenarios - ORBES uses a clean air scenario to measure the impact of SO_2 on soybeans. SRI assumes that the secondary standard is met in 1980. Our scenario calls for equal reductions in the level of SO_2 in 1986 and 1987.

CONCLUSIONS

In this section we have analyzed the economic impact of achieving secondary national ambient air quality standards for two economically important crops in the agricultural sector: cotton and soybeans. Economic benefits were measured within the framework of the crop production process. Individual crop yield functions were developed which relate the quantity of output produced to the amount of inputs used. Inputs into the crop production process included both economic and climatological factors with the ambient level of SO_2 being considered a negative input. These yield functions were estimated in order to test the hypothesis that ambient SO_2 levels have a deleterious effect on the yield of cotton and soybeans. The results of these estimations were integrated with market supply and demand relationships in order to measure the impact of SO_2 on crop price.

This model has several conceptual advantages over previous studies that have estimated the effect of SO_2 on crops. First, subtle injury from SO_2 that results in reduced yield is capable of being measured. Many past studies have based their crop loss estimates on only the visible damage that occurs as a result of exposure to SO_2.

This approach tends to underestimate economic losses since crop yield may be adversely affected as a result of subtle injury.

Second, since the yield functions estimated in this section measure the effects of SO_2 on each crop using actual crop production data, the problems inherent in the extrapolation of the results of controlled experiments to field conditions are avoided. This is particularly important in the measurement of the impact of SO_2 on crop production because the susceptibility of plants to ambient levels of SO_2 can vary significantly due to climatological factors. Rain and temperature are the two climatological factors specifically controlled for in our analysis.

In addition, actions taken by the farmer that involve the use of different amounts of inputs in order to mitigate the effects of SO_2 are capable of being taken into account in this model. Past studies have not been able to incorporate the effects of these countermeasures on crop damage and consequently may result in overestimates of actual crop damages. Conversely, some studies tend to underestimate losses since their estimates are based on crop production after adjustments to existing pollution levels have taken place.

Although the model is able to take into account the countermeasures undertaken by the farmer in order to avoid the effect of SO_2 once the crop is planted, it is unable to reflect the farmer's decision process regarding "how much" and "what" crops to produce.

Consequently, the possibility that a farmer chooses not to produce a particular crop because of the effects of SO_2 on the crop cannot be reflected. This may tend to underestimate the actual economic damage if a portion of the acreage planted of a crop is taken out of production due to SO_2. Obviously, this is one of the limitations of the model as it is currently structured.

A third advantage of the model presented in this section is that the crop yield functions are brought into a more general framework which specifies the crop's supply and demand relationships. This implies that the effects of SO_2 on crop price can be measured. These effects must be measured in order to accurately estimate the economic impact of SO_2 on crop production. This is a major conceptual advantage of this model over models that estimate the impact of SO_2 on crop production in dollar terms without taking these price effects into account.

Using pooled cross-sectional county level data from 1975 to 1977, the hypothesis that SO_2 has a deleterious effect on crop yield was tested through the estimation of the crop yield functions. The existence of a significant negative relationship between ambient SO_2 and cotton yield could not be supported based on our sample data. Given the location of the cotton-producing counties included in our sample, this result is not surprising. These counties are located in areas where the soil tends to be alkaline, and it is conceivable that the cotton plants are utilizing atmospheric SO_2 for their sulfur requirements. Although there was not any evidence that ambient SO_2 has a deleterious effect on soybeans on the national level, our results indicated that such a relationship does exist for certain regions of the country. A negative relationship between ambient SO_2 and soybean yield was found for the states of Illinois, Indiana, Iowa, Ohio and Texas.

These results are plausible considering the time period of our analysis. Since our data set included crop production and air quality data from 1975 to 1977 and air pollution problems have existed prior to 1975, it is quite possible that farmers have adjusted their cropping patterns to mitigate the effects of SO_2 on their crops. Consequently, this study reflects the relationship between ambient SO_2 and cotton and soybean yield with respect to cropping patterns that most likely have been changed due to past ambient air quality. In addition, since air quality has been improving over the past decade, the deleterious effects of ambient SO_2 on crop yield from 1975 to 1977 may not have been as severe as they were in the late 1960's.

It must be kept in mind, however, that the relationship between SO_2 and crop yield exhibited in this analysis may tend to underestimate actual damage occurring in some locations because our data sets are comprised of farm production and air quality data aggregated to the county level. Intra-county variations in yield due to variations in SO_2 levels cannot be measured in this analysis.

Consequently, the impact of SO_2 on cotton and soybean yields may tend to be underestimated.

Although evidence exists that greater reductions in plant yield occur from exposure to SO_2 during the early stages of growth than during later stages (80), there is also evidence that plants are susceptible immediately before flowering and during pod growth (54). If cotton and soybeans tend to be more susceptible to SO_2 during the later stages of growth, the use of SO_2 data from March, April and June may underestimate the true relationship between SO_2 and crop yield.

The use of 24-hour means and second highest values may also tend to obscure the relationship between SO_2 and soybean and cotton yield since evidence exists that plants are more susceptible to SO_2 during daylight hours (24). Information on SO_2 levels during the daylight hours were not available for this analysis, however.

Incorporating the results of our yield functions within the framework of the demand and supply for the crop, the economic benefits of the implementation of alternative SNAAQS were calculated based on SO_2 levels and farm production existing in 1977. Since none of the counties in our Texas sample exceeded the secondary standard of 260 $\mu g/m^3$ for the 24-hour maximum of SO_2 in 1977, our estimates are based on the economic benefits for the soybean-producing counties in the states of Illinois, Indiana, Iowa and Ohio that are included in our sample. Approximately 40 percent of these sample counties exceeded the alternative secondary standard in 1977. The discounted present value of the economic benefits of the reduction in SO_2 levels in these counties to the proposed secondary standard of 260 $\mu g/m^3$ are estimated to be $21.6 million in 1980 dollars at a 10 percent discount rate. Only one county in our sample exceeded the secondary standard for the 24-hour equivalent of the maximum of the second highest 3-hour SO_2 reading. Benefits are estimated to be $0.18 million for this county.

Refinements

It is clear from this study that the economic impacts of air pollution on agricultural crops must be analyzed within the framework of the production process. Various data limitations, however, prevented this production process from being completely modeled for the crops included in this study. This limits the conclusions that can be drawn regarding the impact of SO_2 on cotton and soybeans. If these data limitations exist for other crops, the conclusions that can be drawn using this model to estimate the economic impact of air pollution control on other crops will also be limited.

A possible way of circumventing the data problems associated with the estimation of the yield function would be to analyze the economic impact of pollution on agricultural production through the estimation of a cost function. In this approach, the costs of crop production are assumed to be a function of ambient air quality. This approach would be similar to the one used in Section 7 of this study.

During our analysis, we found that data exists on the prices of the factor inputs used by farmers. If data on the costs of production are also available, this approach would be a viable alternative to the crop yield function approach in the estimation of the economic benefits of air pollution control.

Concluding Remarks

Given the data limitations encountered in this study, the estimated economic benefits of increased soybean production from the implementation of alternative SNAAQS, while conditional, seem reasonable. They indicate that soybean production in certain regions of the country are negatively impacted by SO_2. The areas where these negative impacts were found correspond to the areas that are known to have air quality problems.

The methodology developed in this subsection can be a useful tool in measuring the economic impacts of air pollution control in the agricultural sector. It can be used to investigate the impact of these controls on all agricultural commodities. Although the methodology is sound, its use at the present time is somewhat limited due to the sparse data. As this analysis shows, both better air quality and farm production data are needed before any definitive statements can be made regarding the true economic impact of SO_2 on agricultural crop production.

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