Energy and Resource Consultants, Inc.

Economic Assessment of the Effects of Air Pollution on Agricultural Crops in the San Joaquin Valley

Reviewed and Approved ____

Energy and Resource Consultants, Inc.

ECONOMIC ASSESSMENT OF THE EFFECTS OF AIR POLLUTION ON AGRICULTURAL CROPS IN THE SAN JOAQUIN VALLEY

Robert D. Rowe, Project Manager
Lauraine G. Chestnut
and
Craig Miller
of
Energy and Resource Consultants, Inc.

with

Michael Treshow
University of Utah

Herbert O. Mason
California State University, Fresno

Richard M. Adams
Oregon State University

Richard E. Howitt
University of California, Davis

John Trijonis
Santa Fe Research, Inc.

Energy and Resource Consultants, Inc.
P.O. Drawer O
Boulder, Colorado 80306
(303) 449-5515

ERC Contact:
Robert D. Rowe

March, 1985

California Air Resources Board Contract No: A2-054-32
CARB Project Manager: Sylvia Champomier

ARBCD (67)

ABSTRACT

Economic Assessment of the Effects of Air Pollution on Agricultural Crops
In the San Joaquin Valley

This study quantifies the economic value of ozone and sulfur dioxide induced agricultural losses in the San Joaquin Valley of California. In 1978, the economic impact of air pollution on crops in the San Joaquin Valley was estimated to exceed $117 million (in 1978 dollars). Over 98 percent of these losses are attributed to ozone. The economic losses from exceeding the California hourly ozone standard of 10 pphm were $106 million. These estimates are thought to be lower bounds on the economic damages from air pollution, because conservative assumptions and methods were used throughout this analysis.

Yield losses have been estimated for 33 crops, using regression analysis of field data on yields and air pollution, and with the best available chamber study evidence. The field data regression approach was found to provide acceptable non-zero yield loss estimates for only the most sensitive crops; yet, the estimates sometimes varied substantially depending upon the equation specification and ozone measure used.

The California Agricultural Resources (CAR) model was used to estimate economic welfare measures of changes in producers' and consumers' surplus resulting from changes in yields. The CAR model was used to estimate farm costs and behavior change as yields change, including substitution of acreage among crops. It is also used to model the effects of the change in supply upon market price and quantity sold.

ACKNOWLEDGEMENTS

This effort received substantial assistance and support from Sylvia Champomier, Homero Cabera, John Sanders, Malcolm Dole and Carolyn Stromberg of the California Air Resources Board. At Energy and Resource Consultants, Inc., Cedron Jones, Lisa Nelowet, Michael Yokell, as corporate reviewer, and Ron Norman, contributed to the design and execution of the project; and Document Control and Marianne Austin produced the report.

We would like to acknowledge the specific efforts of the outside contributors. Michael Treshow assisted with the design and writing of Appendix A2. Richard Adams assisted with the design and review of the entire project through periodic critical insight. Bert Mason contributed throughout the effort and, with Dick Howitt, performed the majority of the CAR model analysis. John Trijonis assisted in the air quality analysis, specifically, the sulfur dioxide analysis, and reviewing the entire analysis.

Special thanks go to numerous individuals throughout California in state and local governments, universities, and private concerns, who provided a great deal of data, ideas and comments which increased our ability and enjoyment in undertaking this research.

Regardless of the involvement of the above-mentioned individuals, the responsibility for errors and omissions remain with the project manager.

This report was submitted in fulfillment of Contract Number A2-054-32, titled "Economic Assessment of Air Pollution On Agricultural Crops in the San Joaquin Valley," by Energy and Resource Consultants, Inc. under the sponsorship of the California Air Resources Board. Work was completed as of November, 1984.

RDR, 12/84

DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their sources or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

TABLE OF CONTENTS

TABLE OF CONTENTS

Continued

TABLE OF CONTENTS
Continued

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES
Continued

LIST OF TABLES

Continued

LIST OF TABLES
Continued

1.0 INTRODUCTION AND SUMMARY OF FINDINGS

1.1 OBJECTIVES

The primary objective of this study was to estimate the total economic value of air pollution induced agricultural losses in the San Joaquin Valley of California. The model estimates technically correct economic surplus measures of losses incurred by producers and consumers. This was accomplished, to the extent possible, by accounting for changes in farming practices and market conditions which would result from changes in yields per acre as air pollution changes. The analysis focused upon ozone (O_3) and sulfur dioxide (SO_2), as these are the only pollutants which occur at sufficiently high levels in the San Joaquin Valley to potentially cause detectable yield losses.

Other objectives of the study were to:

- Test the strength of the field data regression approach as a method to estimate the relationship between air pollutants and actual yields.
- Separately estimate the total losses incurred by producers and consumers.
- Separately estimate the losses incurred by subregions within the San Joaquin Valley.
- Separately estimate the magnitude of losses for selected major crops.
- Estimate the relative importance of yield losses due to O_3 versus SO_2 and estimate any synergistic effects when both pollutants are present.

The San Joaquin Valley (SJV) was appropriately selected for the analysis of the economic value of air pollution effects upon agriculture. The SJV, with over $5 billion in annual agricultural receipts, is the largest agricultural production area in California and one of the largest in the United States. Two crops -- cotton and grapes -- each account for over $1 billion in annual receipts. Other major crops include fruit and nut trees and vegetables. The SJV experiences pollution episodes in excess of state and national ambient air quality standards and above levels known to reduce crop yields. For example, chamber study research suggests that yields for cotton and grapes are reduced by at least 10 percent at typical ozone levels in the SJV (Heck et al. 1983, Brewer 1983). Even though these figures suggest the potential importance of air pollution induced crop damage in the SJV, no economic analysis of damages for the entire valley has been conducted. National benefit analyses of ambient ozone standards are currently being assessed and prevention of agricultural damages are an important category of benefits. Hence, this study fills an important need.

The estimation of technically correct measures of economic damage was stressed as part of the primary objective. Some previous analyses have mistakenly estimated economic damages as per-acre yield loss times the existing number of acres and market price. This simplistic approach assigns all economic losses to the farmer and may grossly misstate damage by ignoring potential economic adjustments to the air pollution effects. As crop yields change, farmers may adjust the amount and mix of crop acreage planted, and may adjust the inputs used to mitigate air pollution damage. These adjustments may change the amount of crops brought to market and thereby affect market prices. When yields are reduced by air pollution, this passes some of the economic losses on to the consumer. Potential changes in quantities and prices of crops make the simplistic yield loss times current price approach invalid.

The field data regression approach to estimating yield losses attempts to relate actual yields experienced in the field to ambient air pollution conditions. This approach offers an alternative to the chamber study approach, where a plant's environment is closely monitored in a chamber and controlled amounts of air pollutants are introduced to assess the effects of the pollutants. If the field data approach can be successfully used to estimate air pollution-yield relationships for the selected study crops and situation, it may be used to estimate air pollution damages for other crops in other situations, at potentially large dollar and time savings relative to the chamber study approach. Preliminary evidence from other field data regression studies is mixed regarding the usefulness and accuracy of this method. Therefore, additional careful analysis is warranted. There is also the possibility that air pollution losses observed in the chamber may not be the same as those which occur in the field due to confounding environmental conditions or farmer behavior. Field data regression studies, if successful at estimating air pollution effects, could help determine if chamber studies adequately reflect yield losses in the field. Conversely, controlled chamber study experiments are useful to establish hypotheses about effects, and to validate field based regression estimates.

The study goes beyond previous efforts by considering more crops, (including grapes, for which no previous damage estimates have been reported); and by using policy-relevant air pollution scenarios.

1.2 STUDY APPROACH

The analysis entailed five steps.

Step 1. The principal study crops, time period, and air pollution control scenarios were selected (Chapter 2). There are hundreds of agricultural crops in the SJV, too many to receive detailed attention with the field data regression analysis. Therefore, ten crops were selected for detailed analysis. Thirty-one major crops were considered in the final economic analysis. The ten selected crops account for nearly 80 percent of the dollar value of agriculture in the SJV. Potatoes and lettuce were included in the detailed analysis in order to give attention to crops grown during the seasons when SO_2 levels are highest in the SJV. The study period was 1970-1981. This time period was selected due to data availability and because changes in crop varieties through time cause difficulty in isolating air pollution effects over a longer time period. Economic losses from air pollution are calculated for 1978, the year for which the California Agricultural Resources model, used in the economic analysis, is calibrated.

The economic impacts of air pollution in the SJV were calculated for three alternative scenarios, as compared to the conditions which existed in 1978. Because less than five percent of damages are attributable to SO_2, the scenarios focus upon alternative O_3 levels. The 1978 baseline and alternative scenarios, described in detail in Section 2.3, are:

- BASELINE. Existing 1978 conditions for O_3 and SO_2. There were over 700 growing season hours in 1978 when O_3 levels exceeded the California state standard of 10 pphm (parts per hundred million).

Depending upon location in the SJV, the 1978 ozone levels were roughly consistent with a standard of 13-16 pphm.* This was higher than typical ambient ozone levels in the SJV. During the study period SO_2 hourly concentration in the SJV rarely exceeded the California state one-hour SO_2 standard of 5 pphm, except in the winter in Kern County where hourly values as high as 34 pphm were recorded.

- SCENARIO 1. Fifty percent reduction in the number of hours when O_3 is greater than or equal to 10 pphm and SO_2 levels are not to exceed the 1978 level or an average of 3 pphm, whichever is lower. This ozone level is more representative of a typical year in the San Joaquin Valley and is roughly consistent with a standard of 11-13 pphm (approximately 12 pphm average), depending upon location in the valley.

- SCENARIO 2. Meeting the current state standard of 10 pphm for O_3 and daytime SO_2 average not to exceed 1978 levels or 2 pphm, whichever is lower.

- SCENARIO 3. Meeting an O_3 standard of 8 pphm and SO_2 daytime average not to exceed 1978 levels or 2 pphm, whichever is lower. Limited O_3 damage is expected to occur at levels below 8 pphm. This scenario is therefore used to provide conservative estimates of the maximum economic damage from ozone in the SJV.

Step 2. The appropriate economic methods and concepts literature, and previous economic studies concerning agricultural losses from air pollutants were reviewed (Chapters 3 and Appendix A1). This review provided the foundation for the development of conceptually correct methods employed in this study, and identified strengths and weaknesses in other studies which were either followed or avoided.

Step 3. Chamber study results for the crops in the SJV were reviewed and summarized (Appendix A2). This review provided yield loss estimates used for comparison with and

---

* A standard is an hourly maximum value not to be equalled or exceeded on more than a limited number of times per year; usually one or two hours.

validation of the field data regression results, and provided yield loss estimates where the regression approach did not work or for crops for which the field data regression approach was not used.

Step 4. The field data regression analysis to estimate the relationship between yields in the field and ambient air pollution conditions was designed and executed (Chapters 4 and 6). This included the definition and measurement of the variables and functional form specifications to be examined. Four alternative ozone measures were used, each defined and measured over the daytime hours of the growing season for each crop by county. The location of the crop within the county was also taken into consideration. These ozone measures included the daytime O_3 average (03AVE), the number of hours from 9 a.m. to 5 p.m. when O_3 equaled or exceeded 6 pphm (03GE6), the number of hours when O_3 equaled or exceeded 10 pphm (03GE10), and the total dose for all hours when O_3 equaled or exceeded 10 pphm (03DOS). Weather variables included the daytime temperature, seasonal precipitation, and the number of cold and hot days over the growing season. Other agricultural variables included the trend in productivity per acre, fertilizer use, acreage planted, and labor use. These variables are described in detail in Chapter 6.

Step 5. The California Agricultural Resources (CAR) model was applied to estimate the economic effects of the different yields per acre expected under the alternative scenarios (Chapters 5 and 6 and Appendix A3). The CAR model analyzes how farmers will change the amount and mix of acreage planted by crop as a result of changes in per acre yields, and predicts the resultant effect upon production costs. The model also considers how changes in farmers' output will affect the equilibrium prices and quantities sold in the market. From this information, changes in the economic well being of farmers can be calculated. Changes in the well being of the consumers can also be calculated from the predicted changes in market prices and changes in the quantities purchased. In economics parlance, the changes in well being the model calculates are known as changes in consumers' surplus and producers' surplus. These calculations were made on a crop by crop basis for each subregion in the CAR model (there are four such subregions in the SJV, see Figure 1.1) and aggregated to regional and state totals by crop and for all crops.

Figure 1-1

Regions in the California Agricultural Resources Model

1.3 SUMMARY OF FINDINGS

Yield Function

Field data regression analysis was undertaken for ten primary study crops. The yield data regression results revealed relative ozone sensitivities largely consistent with those expected from the review of chamber study results. Statistically significant effects of 0_3 on yields were found for four crops -- dry beans, cotton, potatoes, and grapes -- although the estimated yield losses for ozone occasionally varied dramatically (100 percent) with changes in the yield function specification.

Overall, the results suggest that ozone is causing yield losses in the SJV, but that the field data regression approach only captured the effects for the most sensitive crops. The errors inherent in the measurement of the variables and yield function specification make it difficult to isolate and measure the ozone effects on intermediate and tolerant crops at the ozone levels experienced in the SJV.

Sulfur dioxide effects were only found for potatoes grown during the winter in Kern County. Sulfur dioxide-ozone interaction variables were never found to be negative and still statistically significant. These SO_2 results are attributed to the low SO_2 levels in the SJV during the primary growing season, and due to multicollinearity problems between $S0_2$ and 0_3, as well as the other variables in the regression specifications.

The results of the analyses suggest that the use of field data to estimate yield function will be effective for identifying sensitive crops, and for roughly measuring crop damages due to air pollution when air pollution levels are high enough to cause significant damage, which will depend upon the crop, and a fairly wide range in air pollution levels over the study area and time period.

As to the selection of an ozone measure, the 03GE10 measure, on average, outperformed the others in terms of expected results and statistical significance of the coefficient; although the implied yield losses often were not substantially different from those estimated with the other 0_3 measures. The results do suggest that an analysis which uses an 03AVE measure should also use a nonlinear yield-to-ozone specification with increasing marginal damages as ozone increases. This result is consistent with the National Crop Loss Assessment Network (NCLAN) findings (Heck et al. 1983).

Estimated Yield Improvements Under the Alternative Scenarios

Yield improvements under the alternative scenarios, as compared to the existing case in 1978, were calculated using the field data regression analysis for dry beans, potatoes, cotton and grapes; using regression analysis of chamber study results where they existed; by assigning the yield loss for a similar crop; or by assuming zero yield losses. Where a zero yield loss assumption was made but was uncertain, the acreage planted in the crop was forced to remain constant across all scenarios. This assured that zero yield change assumptions result in conservative economic estimates of improvements in air quality (see Section 5.5).

The estimated yield per acre improvements by crop under each alternative scenario are presented in Table 1-1.

Economic Estimates of Benefits From Controlling Air Pollution

It is assumed that farmers make production decisions so as to maximize net income. Their decisions therefore depend upon, for each crop, per acre production costs (fixed and variable), per acre yields and market prices for the crop among other factors. As air pollution is reduced in the SJV, maximum attainable yields per acre for affected crops increase. As yields of affected crops increase, it becomes more profitable to produce these crops in the SJV relative to other crops previously less affected, and relative to the same crop in other locations around the state. As yields increase, however, so does the market supply, which causes prices to fall. The size of this price change depends upon the importance of California production in the market and the demand for the crop. These price effects reduce the incentive for the producer to simply produce as much as possible on as many acres as possible, because this depresses prices, and consequently reduces net income below what would have occurred if prices did not change. In most cases, it becomes most profitable to produce more tonnage on somewhat less acreage in the SJV.

The California Agricultural Resources (CAR) model predicts changes consistent with the above discussion. For most crops produced in the SJV, as air pollution is reduced, production increases, but by less than the per-acre increase in yields. The difference is the result of acreage reductions. For crops such as grapes, where the market price is signifi-

Table 1-1

Improvements in Yields Per Acre Under Alternative Air Quality Conditions In the San Joaquin Valley, 1978

Crop	Percent Improvement in Yields* Scenario 1 (12 pphm O_3)	Scenario 2 (10 pphm O_3)	Scenario 3 (8 pphm O_3)
I. Non-Zero Changes**			
Alfalfa	4.0 - 5.3	8.0 - 11.1	8.0 - 11.1
Barley***	3.6 - 4.0	7.4 - 8.4	8.7 - 10.6
Carrots	1.8 - 3.9	4.0 - 4.7	4.9 - 6.7
Corn	1.5 - 2.8	4.3 - 6.0	4.9 - 7.6
Cotton	4.8 - 5.5	17.0 - 0.1	19.3 - 22.9
Dry Beans	7.3 - 8.5	14.8 - 17.0	17.5 - 21.4
Grain Hay	3.6 - 4.0	7.4 - 8.4	8.7 - 10.6
Grain Sorghum	.8 - .9	1.7 - 2.2	2.1 - 2.9
Grapes	4.4 - 6.4	8.4 - 12.5	8.7 - 12.7
Lettuce	4.8 - 5.3	7.2 - 9.7	10.9 - 13.3
Irrigated Pasture	3.6 - 4.0	7.4 - 8.4	8.7 - 10.6
Potatoes	6.0 - 2.2	11.1 - 24.5	11.1 - 32.4
Sunflower	1.8 - 3.9	4.0 - 5.4	4.9 - 6.7
Silage	1.5 - 2.8	4.3 - 6.0	4.9 - 7.6
Tomatoes	1.8 - 3.9	4.0 - 5.4	4.9 - 6.7
Wheat	3.6 - 4.0	7.4 - 8.4	8.7 - 10.6

II. Crops with zero yield improvements under all scenarios

Almonds, Lemons, Nectarines, Peaches, Rice, Sugar Beets

III. Crops with zero yield improvements under all scenarios and with acreage held constant

Apples, Asparagus, Avocados, Cantaloupe, Cauliflower, Dry Onions, Oranges, Pears, Plums, Prunes, Walnuts

* Improvements in yields comparing scenarios to existing 1978 ozone levels. The scenarios are defined as approximate hourly standards.

** Yield losses vary depending upon location in the valley. All damages are from ozone except for potatoes where the highest figure also includes SO_2 damages in Kern County. For more detail see Section 6.4, Table 6.7.

*** The most recent NCLAN results, released while this report was in final draft, suggest barley sensitivity may be much smaller than herein reported.

cantly influenced by increases in California production, yield increases are significantly offset by acreage decreases. In this way more can be produced on fewer acres at lower costs so even with lower prices, profits increase. For crops such as cotton, where California production comprises a smaller portion of the total market, and therefore has much less impact upon market prices, much smaller acreage reductions occur relative to yield increases and production and profits dramatically increase.

In Table 1-2, the benefits of reduced air pollution for the producers and consumers of selected crops are summarized. The first column lists the benefits to producers in the SJV and the second column the benefits to all producers in the state, including those in the SJV. The difference in these columns reflects two influences. Per-acre production increases in the SJV cause production to be shifted from other parts of the state into the SJV, and increased production in the SJV reduces prices received by all producers, including those outstate producers for whom production has not increased to offset price increases. While the figures in column 1 are of more interest to growers in the SJV, the figures in column 2 are more relevant for state policy makers. The figures in column 3 represent the benefits to all consumers of the crop. This figure cannot be broken down into regions as the consumers are often spread throughout the state or nation.

The magnitude and distribution of benefits differ considerably depending upon the crop. For cotton, where yields would increase dramatically, but increased production affects national prices very little, the SJV producers realize substantial benefits from decreased air pollution. Consumers, however, realize much smaller benefits due to the small decreases in prices. For grapes, where yields would increase dramatically but increased yields also lead to substantial reduction in prices, the benefits are more equally split between producers and consumers.

Table 1-3 shows the total of benefits for all crops due to the air pollution reductions described in each Scenario. Section I presents the benefits to producers and consumers when all adjustments throughout the state are considered. Section II presents the benefits to SJV producers by location within the SJV (see Figure 1.1 for definitions of the regions). Again, gains by SJV producers are partially offset (six to eight percent) by losses by producers in other parts of the state. Producers in the southern and western part of the Valley stand to gain the most from air pollution reductions, largely because this is the cotton production region.

Table 1-2

Producers' and Consumers' Benefits of Air Pollution Improvements in the San Joaquin Valley, 1978 / Selected Crops, Scenario 3 ($ millions)

Crop	Producers In the San Joaquin Valley	Producers Statewide (including the SJV)	All Consumers
Cotton	$58.2	$57.8	$4.3
Grapes	9.2	8.5	11.0
Alfalfa	6.3	6.1	4.3
Pasture	4.2	2.3	3.2
Tomatoes	2.1	1.3	1.3
Dry Beans	1.7	.9	1.6
Barley	3.9	3.8	.7
Lettuce	1.0	.1	.9
Potatoes	1.1	.8	.7
Wheat	1.8	1.8	.1
Corn	3.1	2.4	.1

*The most recent NCLAN results, released while this report was in final draft, suggest barley sensitivities to air pollution may be much smaller than used in this report, and therefore the economic impacts may be smaller.

Table 1-3

Benefits of Air Pollution Improvements in the San Joaquin Valley 1978 — All Crops ($ millions)

	Scenario 1 (12 pphm O_3)	Scenario 2 (10 pphm O_3)	Scenario 3 (8 pphm O_3)
I. Statewide			
Total Consumers & Producers	$42.6	$105.9	$117.4
To Consumers	13.4	27.7	30.3
To Producers	29.2	78.2	87.1
II. In the San Joaquin Valley			
To All SJV Producers	31.8	82.9	92.5
To Producers in Region 11	18.2	49.9	55.6
To Producers in Region 10	8.9	23.3	26.1
To Producers in Region 8	2.8	6.0	6.8
To Producers in San Joaquin County	1.9	3.7	4.0

The importance of using an economic model which accounts for market and farm reactions is highlighted by comparison to simple damage-function estimates (yield changes times existing prices and acreage in the SJV). Damage-function estimates for cotton and grapes are $96.6 million and $71.2 million respectively, which significantly overstates actual economic damage. Due to conceptual flaws with the damage function approach, such estimates for other crops were not made.

Comparison of the estimated benefits under the alternative scenarios suggests important policy conclusions. The benefits of having met a standard of approximately 12 pphm O_3 in the SJV in 1978 would have been $42.6 million (in 1978 dollars). The benefits from having met the state standard of 10 pphm O_3 would have been $105.9 million, or an increase of $63.3 million over Scenario 1. The benefits of having met a standard of 8 pphm, or near background levels for agricultural damages, would be $117 million, or only $11.5 million in benefits beyond the 10 pphm standard. This suggests that below 10 pphm, benefits will increase very slowly from further reductions in air pollution. As determined by the damage functions, over 98 percent of the economic value of agricultural damages from air pollution in the SJV are attributable to ozone, and less than two percent to sulfur dioxide.

Physical and economic estimates are subject to numerous inaccuracies and biases, many of which cannot be quantified. Consequently, it is impractical to determine statistical confidence intervals around the point estimates. However, conservative procedures and assumptions have been used throughout the analysis so the reported benefit estimates are felt to be understatements of "true" benefits of improving air pollution (see Section 6.6).

This report analyzes the benefits from air pollution control only in the SJV. If air pollution were to have improved throughout California in 1978, the benefits to SJV producers would have been slightly less, but the benefits to the sum of all producers in the state and to consumers would be substantially larger than herein reported.

1.4 CONCLUSIONS AND RECOMMENDATIONS

This analysis suggests that air pollution can, and did cause substantial economic losses to both agricultural producers and consumers in 1978. The use of field data regression approaches to estimate physical damage is likely to be less precise than chamber studies, but may be quicker and easier to determine the relative importance of air pollution yield losses across crops, or to identify crops for which chamber studies should be undertaken. The use of an economic model which considers both farm and market adjustments appears to be critical to accurately estimate economic costs of air pollution.

Additional research can refine the estimates, and most likely lead to increased damage (benefit) estimates from air pollution (control). The research should include more studies to estimate physical damage functions for more crops particularly the economically important fruit and nut crops. For example, if this study had been completed two years ago, a researcher would have significantly understated air pollution benefits by assuming zero damages for grapes due to lack of information. Next, there is a lack of information concerning the level of mitigative behavior of farmers through the use of different levels of factor inputs as air pollution changes. This could affect both the physical damage and economic damage estimates. Future field data regression efforts could be aided by the collection of better subcounty yield data and pest loss estimates, presumably by governmental agencies. Finally, this analysis for the SJV could readily be extended to the whole state through the use of best available damage estimates for both annual and perenial crops, and through the reapplication of the CAR model. This would provide improved estimates of statewide benefits.

2.0 STUDY DESIGN

2.1 STUDY AREA, POLLUTANTS AND TIME PERIOD

Study Area

The study area includes the agricultural regions of the eight counties in the San Joaquin Valley (SJV). These counties and the air quality monitoring stations operated in 1981 are depicted in Figure 2-1. The San Joaquin Valley is the largest agricultural production area in California, and one of the largest in the United States, and it experiences periodic pollution episodes in excess of state and national standards and above thresholds known to influence agricultural crop production. Farming in California is an important industry to both the state and nation.* While California farms comprised only 3.3 percent of the 1980 U.S. farm acres (2.8 percent of U.S. harvested croplands), they accounted for 9.9 percent of the U.S. farm marketing cash receipts. California farms have an average net income per farm 3-1/2 times that of the average U.S. farm, and there are many more corporate farms. California leads the nation in the production of many crops, and is among the top five states in production for nearly every agricultural output produced in the state.

The San Joaquin Valley holds over 45 percent of the state's cropland acreage, and over 63 percent of the Valley is used for farming. The SJV is the highest producing area in California for nearly every major agricultural crop produced in the valley, as illustrated for the study crops below. Due to the size and significance of the agricultural output from the SJV, even small air pollution effects on yields can potentially have dramatic economic consequences.

*Many of the data in this section are taken from a report by the Cooperative Extension, University of California, April 1982, entitled "A Statistical Picture of California Agriculture".

Figure 2-1
San Joaquin Valley Air Basin Monitoring Stations Operating During 1981

LEGEND

- ● Gaseous pollutant or multipollutant mornitoring site
- ○ High volume particulate sampling only
- ✧ ARB operated site
- * Discontinued during year

Study Pollutants

This study will examine crop yield impacts from O_3 and SO_2 individually and in combination. As reviewed in Appendix A2, there is substantial evidence that these pollutants, at the levels experienced in the SJV, may significantly affect crop yields. There is also research evidence to suggest that the levels of other air pollutants experienced in the Valley will not significantly affect crop yields.

The San Joaquin Valley is not always noted for its air pollution problems, as are the South Coast Air Basin and other areas around the country. Nevertheless, in 1981, for example, there were 717 hours spread over 130 days of the peak growing season (April through October) when ozone readings in the Valley exceeded the one-hour California O_3 standard of 10 pphm, and there were 203 hours spread over 69 days when the ozone readings exceeded the national primary and secondary O_3 standard of 12 pphm. No readings in excess of 20 pphm were recorded in the SJV in 1981 although this was not the case in other years, such as 1978, when 20 pphm was reached several days in several counties, and there were over 300 hours at 12 pphm or more. Serious sulfur dioxide pollution concentrations have occurred in Kern County in southern SJV. For example, in 1981 the Oildale-Manor air quality monitoring station was the only one in the state to report SO_2 readings in excess of the 24-hour California Ambient Air Quality Standard. In 1981 the same monitoring station recorded hourly SO_2 readings during the winter as high as 34 pphm, well above the state one-hour SO_2 standard of 5 pphm. Carbon monoxide (CO) incidences occasionally exceed national 8-hour standards in Fresno and Kern Counties. The exceedences for CO and SO_2 generally occur in the winter months. Suspended particulate standards are also regularly exceeded.

Study Period

The time period 1970-1981 was chosen for the yield loss analysis with the economic damage calculated specifically for 1978 due to:

- o The availability of air pollution and agricultural data over this period of time. Before 1970, defensible air quality data are not readily available. Further, changes in the cultivars in use and in agricultural practices over a period of time greater than 10 to 15 years would greatly complicate the effort to sort out these effects on yields from air pollution effects on yields.

- o A regular occurrence of pollution episodes which have exceeded national and California air quality standards over this period of time in the SJV. If, in fact, SJV crop yields are affected by air pollution, this should be reflected in the data for 1970 through 1981.

- o The California Agricultural Resources model, used to evaluate the economic impacts of changes in yields, is calibrated for the year 1978.

2.2 CROP SELECTION

In 1980, there were over 24 crops in the San Joaquin Valley (SJV) which had an annual economic value exceeding $25 million -- more than could be given adequately detailed examination at each stage of the analysis. A subset of crops was therefore selected as "primary study crops" for detailed analysis using the following criteria listed in order of importance.

1. Economic importance of the crop in the SJV, the state and the nation, stated in terms of relative dollar volume of production. The crops with the largest value of production in the SJV naturally draw the most attention. The larger the dollar volume of a crop, the more likely even a small pollution-induced yield loss can result in substantial economic losses. The size of the SJV production relative to state and national totals is also important because the larger the SJV share, the more likely a change in the SJV supply caused by changes in air pollution will have significant price effects in the state and national markets, thus affecting both producers and consumers.

2. Diversity of crop is desired to examine the air pollution impacts on a variety of crop types, including agronomic and vegetable crops, fruit and nut crops, perennials, annuals, and others.

3. Expected susceptibility to ozone and sulfur dioxide, based upon chamber studies or previous yield equation studies. Crops such as potatoes and cotton, for example, have repeatedly been shown to be sensitive to air pollution, and are therefore likely to also experience significant economic damage (see Appendix A2).

4. Crops selected should have been grown with sufficient spatial variation and temporal occurrence to facilitate an accurate statistical analysis. This requires that the

crop be grown under different air pollution conditions, which are also sufficient to potentially decrease yields. If a crop is grown in only one county it is likely to be subjected to very similar rates of pollution year after year and the statistical analysis will be unable to estimate the air pollution-yield relationship. Similarly, crops grown only in winter will probably not be subjected to ozone levels high enough to produce yield reductions high enough to estimate. However, winter lettuce and potatoes, grown primarily in Kern County, were specifically included to test yield reductions from winter episodes of SO_2 in that area.

Tables 2-1 and 2-2 list the selected primary study crops and their relative economic importance in the SJV, state, and nation. Table 2-3 and Figure 2-1 give additional summary information on the crop characteristics and growing locations. California production of these crops is also important in international markets, comprising between 33 and 100 percent of total U.S. exports (see Table 2-3).

Major subclasses were examined for tomatoes (fresh and processing), oranges (navel and valencia), peaches (cling and freestone), and grapes (wine, table and raisin), because the subclasses may have significantly different air pollution-yield relationships, and the markets and prices are different, potentially resulting in substantially different economic impacts for even the same yield reduction. The subclasses were eventually grouped together where the statistical analysis suggested there was no difference or where insufficient information existed to accurately separate subclasses.

Table 2-4 and Figure 2-2 illustrate the growing seasons for the study crops. This analysis considered air pollution and weather impacts only during each crop's growing season (i.e. when crops are most sensitive to these factors.) Consideration of variations in these factors when no crop is in the ground or when a perennial is dormant, can only serve to increase the error in the analysis and limit the ability to detect the relationships of interest.

The primary study crops make up over 75 percent of the economic value of agricultural output in the SJV. However, 23 other crops grown in the San Joaquin Valley are also given attention and are included in the CAR model analysis.

Table 2-1

Summary of Primary Study Crops' Production and Yield Characteristics (1980)

Crop	1980 San Joaquin Total Production ($ million)	SJV Percentage of[1] California Production	SJV Percentage of[2] U.S. Production	San Joaquin Total Harvested Acres
Alfalfa Hay	$317.101	45	3.7[3]	463,660
Almonds	444.144	86	86.0	239,224
Cotton	1,163.885	90	27.0	1,387,395
Dry Beans	62.195	50	9.0	99,613
Grapes	1,182.763	83	76.0	474,245
Lettuce	65.022	17	11.0	20,285
Oranges	286.026	66	11.0[4]	120,130
Peaches	152.535	73	0.6	45,036
Potatoes - Spring	51.557	80[5]	N/A	20,400
Potatoes - All	60.447	38	3.0	23,159
Tomatoes, Fresh	66.196	35	11.0	12,793
Tomatoes, Processing	115.206	42	37.0	77,951
"Primary Study Crops" TOTAL	$3,967.077	-	-	2,983,891

NA - Not Available

1 Based on county agricultural commission reports.

2 Due to differences in county agricultural commission totals for California production and those reported in USDA Agriculture Statistics, this column was calculated:

$$\frac{\text{Ag. Com. San Joaquin total \$}}{\text{Ag. Com. California total \$}} \times \frac{\text{USDA California total \$}}{\text{USDA U.S. total \$}}$$

3 Based on tons rather than dollars.

4 Uses 1979-80 season for U.S. production.

5 Based on USDA estimates of California spring (and total) potato production.

Table 2-2

1980 Economic Value of Primary Study Crops by County
($ Millions)

	San Joaquin	Stanislaus	Merced	Madera	Fresno	Kings	Tulare	Kern	TOTAL
Alfalfa Hay	35.150	18.600	38.025	27.300	59.655	25.076	58.909	58.422	317.101
Almonds	51.678	80.181	73.710	32.275	42.600	7.704	15.570	140.426	444.144
Cotton	-	-	49.661	42.254	385.535	255.921	126.676	303.838	$1164.00
Dry Beans	18.149	23.991	4.723	1.575	4.828	.976 (Inc. Rice)	5.304	3.625	62.00
Grapes, Table & Raisin	37.897	28.848	18.643	38.156	62.516	1.861	22.902	46.208	257.00
Grapes, Table & Raisin	31.317	4.919	5.264	76.406	415.701	6.954	236.739	148.432	926.00
Lettuce	-	-	-	-	32.335	8.422	-	24.265	65.00
Oranges, Valencia	-	-	-	4.236	10.104	-	64.075	11.444	286.00
Oranges, Navel	-	-	-		37.105	-	125.744	33.318	
Peaches, Cling	10.470	30.784	17.731	1.387	5.565	3.381	3.666	7.200	153.00
Peaches, Freestone	2.889	4.200	4.556	2.994	35.210	3.795	18.707		
Potatoes, Spring		-	-	-	-	-	-	51.557	52.00
Potatoes, All	6.916							53.531	60.00
Tomatoes, Fresh	22.578	3.872	6.255	-	10.510	1.716	20.607	.658	66.00
Tomatoes, Processed	32.265	11.066	11.948	1.527	50.753	1.065	.615	5.967	115.00

Source: County Agricultural Commission Reports

Table 2-3

California's Share of U.S. Exports for the Primary Study Crops, 1980

Crop	California's Share of 1980 U.S. Crop Exports (Percent)
Alfalfa	37.7
Almonds	100.0
Cotton	43.3
Dry Beans	51.2
Grapes, fresh and raisin	99.0
Grapes, crushed	72.0
Lettuce	73.9
Oranges	58.2
Peaches, Freestone	71.2
Peaches, Cling	100.0
Potatoes	33.0
Tomatoes, processed	88.0
Tomatoes, fresh	29.5

Source: University of California Cooperative Extension, 1983

Table 2-4

San Joaquin Valley Crop Growing Seasons Used in the Air Pollution Yield Analysis

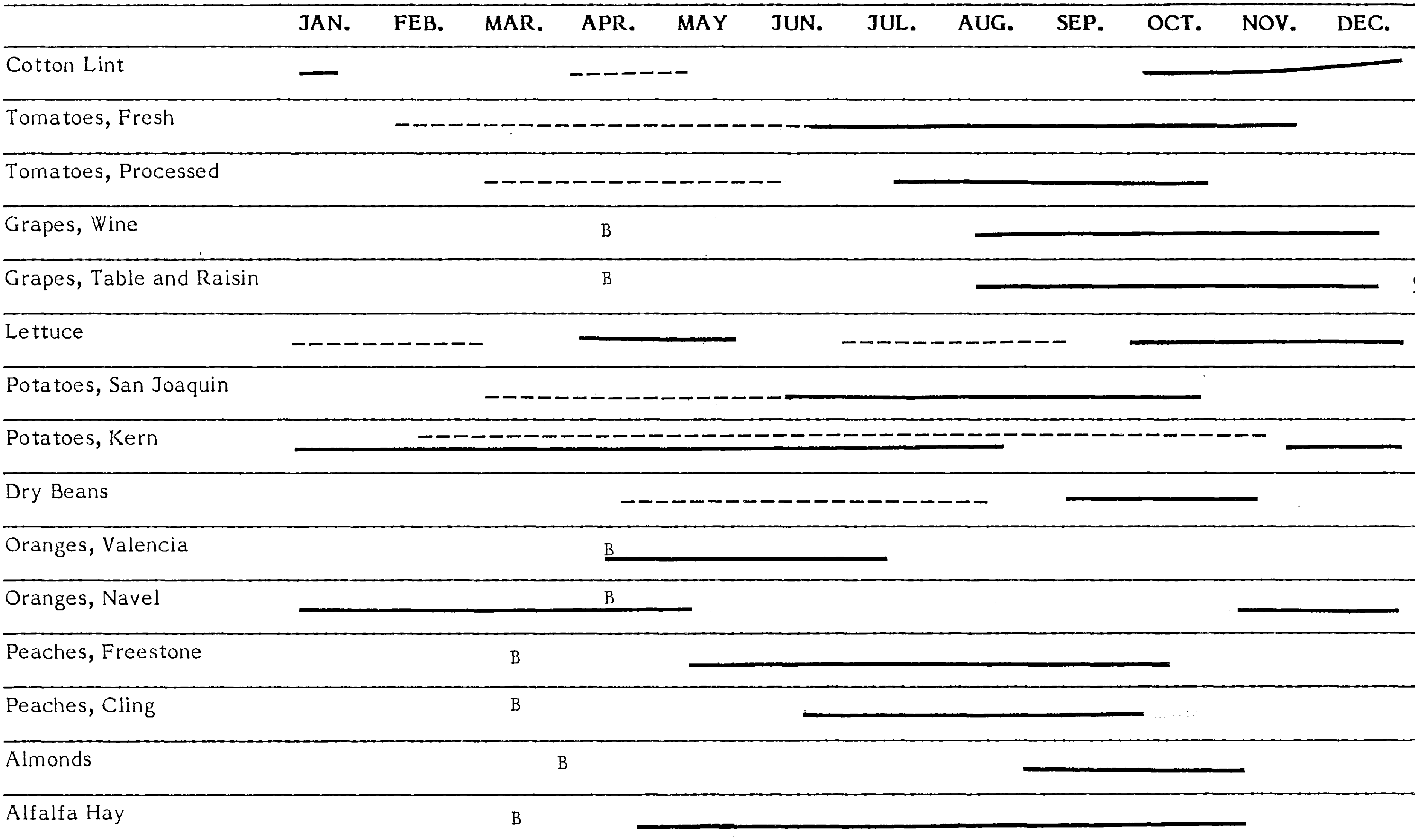
Crop	Duration (months)	Months
Alfalfa	8	March-October
Almonds	7	March-September
Cotton	7	April-October
Dry Beans	7	April-October
Grapes, Wine	8	March-October
Table & Raisin	8	March-October
Lettuce, Spring	4	January-April
Fall	5	July-December
Oranges, Navel	8	April-November
Valencias	12	April-March
Peaches, Freestone	7	March-September
Cling	7	March-September
Potatoes, Summer	7	March-September
Winter	5	November-April
Tomatoes, Processed	7	March-September
Fresh	9	February-October

Source: California Crop and Livestock Reporting Service, Crop Advisory Boards

Notes:

- Almonds are harvested primarily in August-October, however, most nuts are allowed to dry on the tree for about one month, so little growth occurs during the last month. Fruits and nuts are particularly affected by air pollution during their early months after blossom.
- Cotton is harvested primarily in October and November, but growth has largely stopped by late October.
- Grapes foliate in March and flower in April.
- Oranges are particularly affected by air pollution during their first months after blossom. Navel oranges are largely dormant after the first freeze around December 1, and are harvested in November-April of the next year. Valencias blossom in April and are harvested in March-October of the following year. Growth in one crop stops in April when blossoms for the next crop begin.
- Freestone peaches are harvested May-September. Cling peaches have four harvest seasons during June-September. Peaches are particularly affected by air pollution during their early months after blossom.
- Potato tuber growth is affected by leaf growth starting shortly after planting, rather than for late growth just prior to harvesting.

Figure 2-2
Approximate Crop Seasons in the San Joaquin Valley



Source: County Agricultural Commission Reports

B = Approximate Time of Blossom or, for Alfalfa, Start of Growth

----------- Planting

———— Harvesting

*B

2.3 SCENARIOS USED TO CALCULATE THE BENEFITS OF AIR POLLUTION CONTROL

The benefits of three alternative air pollution control scenarios, had they occurred, were calculated for the year 1978 for each crop. The benefits were calculated for the state as a whole, and for county groupings within the San Joaquin Valley. The estimates are what the economic benefits would have been with the levels of air pollution experienced in each alternative scenario as compared to the existing situation in 1978. The changes in air pollution in the scenarios were assumed to reflect possible alternative conditions in the San Joaquin Valley only. Air pollution conditions in the rest of the state were assumed to remain at their 1978 levels. (For additional discussion, see Section 5.5.) The base case and alternative scenarios can be described as:*

BASELINE: EXISTING 1978 OZONE AND SO_2 LEVELS. Ozone levels were relatively high in the San Joaquin Valley in 1978 with 10 pphm reached during over 700 hours across more than 130 days during the primary growing season (April-October); 12 pphm reached during over 300 hours over more than 70 days; and 20 pphm reached on 3 days. The actual 1978 ozone levels were roughly consistent with an implicit standard, not to be equalled or exceeded, of 13-16 pphm**, depending upon location in the valley. This is in excess of the current federal standard of 12 pphm.

Except for Kern County, 1978 hourly concentrations of SO_2 rarely exceeded 5 pphm, and 24-hour averages rarely exceeded 2 pphm. In Kern County, hourly values were reported as large as 34 pphm and 24-hour averages as large as 14.8 pphm. These high observations all occurred in the winter.

---

* Ozone scenarios are given detailed attention compared to the SO_2 scenarios. This is because preliminary research indicates that at current air pollution levels in the San Joaquin Valley, over 98 percent of all crop damage is due to ozone.

** A lognormal distribution was used to calculate the implicit standard here and for each alternative scenario. Due to the instability of the actual number of observations in the tail of the distribution, the implied standard is calculated allowing it to be equalled or exceeded on up to .3 percent of the hourly observations, or for 1 or 2 days of exceedances.

SCENARIO 1: OZONE - 50 PERCENT REDUCTION IN THE 1978 NUMBER OF HOURS AT OR ABOVE 10 PPHM. SO_2 - DAYTIME AVERAGE NOT TO EXCEED CURRENT LEVELS OR 3 PPHM, WHICHEVER IS LOWER. This scenario is more representative of the typical year in the San Joaquin Valley during the period 1970-1981. It is approximately equal to a 13 percent reduction in the seven-hour daytime ozone average during the 1978 crop growing season. It is also roughly consistent with an implicit standard not to be equalled or exceeded of 11-13 pphm, depending upon location in the Valley; or on average, it reflects what would happen if the national standard of 12 pphm were approximately met in the Valley.

SCENARIO 2: OZONE - 100 PERCENT REDUCTION IN THE 1978 NUMBER OF HOURS AT OR ABOVE 10 PPHM. SO_2 - DAYTIME AVERAGE NOT TO EXCEED CURRENT LEVELS OR 2 PPHM, WHICHEVER IS LOWER. This scenario would have all locations in the Valley meet the state ozone standard. Depending upon location and crop growing season, this would roughly have required a 35 to 50 percent reduction in the seven-hour daytime average during 1978 growing season.

SCENARIO 3 OZONE - ZERO HOURS TO EQUAL OR EXCEED 8 PPHM. SO_2 DAYTIME AVERAGES NOT TO EXCEED CURRENT LEVELS OR 2 PPHM, WHICHEVER IS LOWER. This is a more stringent ozone standard than the current state or federal standard. In addition, few crops show yield losses at continued exposures to less than 8 pphm. Consequently, this standard is used as a conservative estimate of the maximum ozone damage experienced in the San Joaquin Valley. It would roughly require a 45 to 60 percent reduction in the seven-hour daytime ozone average during the 1978 crop growing season, depending upon crop and location. At the SO_2 levels in this scenario, few crops have been shown to exhibit yield losses.

COMPARISONS

Comparisons of the base case and the alternative scenarios for ozone have several policy implications. Comparing the base case to Scenario 1 estimates the approximate benefits of experiencing a typical year in the Valley rather than a year with high concentrations of ozone, such as 1978. Comparing the base case to Scenario 1 also reveals what the approximate benefits of meeting the national standard of 12 pphm would have been in 1978. Comparing the base case to Scenario 2 estimates the benefits to be derived from meeting the California standard. Comparing the base case to Scenario 3 estimates the benefits from controlling ozone to near background levels in terms of crops sensitivities. Comparing Scenarios 1, 2 and 3 allows the calculation of economic benefits to be derived from the implementation of alternative standards of 12, 10 and 8 pphm.

Comparisons across the alternative standards can also be used in a sensitivity analysis. For example, if one were to assert that the per-acre crop loss estimates were understated by between 0 and 50 percent, then the actual benefits from having had Scenario 1 rather than the Base Case would be between the benefits calculated for Scenario 1 and Scenario 2. Comparing Scenario 1 to Scenario 2 and 3 provides estimates of benefits from meeting the 10 and 8 pphm standards in a "typical" year in the SJV.

3.0 ECONOMIC APPROACHES TO MEASURING AIR POLLUTION DAMAGE IN THE AGRICULTURAL SECTOR

3.1 INTRODUCTION

The economic approach to measuring agriculture damage from air pollution relates air pollution induced changes in yields to the economic well-being of agricultural producers and consumers. For an increase in air pollution, producers may experience losses in terms of reduced crop production which may reduce revenues and returns on investments. Consumers may be affected if the reduction in agricultural output increases market prices. The correct economic approach to measuring damage is based upon net damage, given that economic agents will adjust their behavior to mitigate the adverse impacts.* Therefore a complete analysis will consider yield reductions, market effects and adjustments to input mixes, cropping patterns, and consumption patterns, to obtain the appropriate measure of the change in producers' and consumers' well-being induced by a change in air pollution.

This chapter first describes the most simplistic damage function approach to measuring economic damage from air pollution and highlights its accuracy limitations. Next, the generally accepted economic welfare approach (consumers' and producers' surpluses) to measuring economic damage, which accounts for and overcomes the limitations in the simple damage function approach, is presented in detail. The measures presented in Section 3.3 are those estimated in this report for air pollution impacts in the San Joaquin Valley (SJV). Finally, secondary and other related impacts, which can be important to consider but are not addressed in this research, are introduced.

---

* Damage of allowing air pollution, and benefits of controlling air pollution will often be used interchangeably in concept; however, damage and benefit measures, for the same rate of change in air pollution, need not be the same. This may occur because of non-linearities in air pollution dose response functions, or supply-and-demand functions, and because economic agents may undertake different behavior adjustments to mitigate damage and enhance benefits.

3.2 SIMPLE-DAMAGE FUNCTION APPROACH

This approach is often used because it is the easiest to estimate damage from air pollution; nevertheless, its limitations may result in substantial inaccuracies. The approach simply translates air pollution induced agricultural yield losses, obtained through surveys, chamber studies, or estimated yield loss equations, into dollar values by multiplying estimated losses per acre by the acreage and crop prices currently existing in the market. The total dollar value of the loss is then assigned to the agricultural producers. Examples of this procedure include the earlier Stanford Research Institute (SRI) assessments and the more recent estimates of Moskowitz et al. (1982) and Shriner et al. (1983) discussed in Appendix A1.

This approach can produce serious estimation errors because it focuses upon producer damage, assuming no producer, consumer or market adjustments occur (Crocker 1982). Specifically, these limitations include:

- **Price effects.** If air pollution were removed, agricultural output would increase. If the output market is in equilibrium and is unregulated so it is free to adjust to new supply-and-demand conditions, and demand is price sensitive, the new supply conditions will result in increased quantities consumed at lower prices. Consumers realize benefits by paying lower prices for the previous level of consumption and through increased consumption. Producers may also benefit from increased revenues and, therefore, returns on investments. However, because of price decreases, the producers' benefits of reduced air pollution will not be as great as estimated in the damage function approach. In fact, if demand is unresponsive to changes in price or there are relatively constant marginal costs of production, price may decrease enough that even with increased output, total revenues to the producers may decrease.

- **Changes in Agricultural Practices.** The simple damage function approach assumes that the same level and combination of factor inputs will be utilized to produce the same combination of outputs before and after a pollution change. Experience in the South Coast Air Basin and elsewhere suggests that farmers do substitute crops, and they may restructure the use of production inputs to mitigate air pollution inputs or to produce a lower level of output less expensively. Crops that are not sensitive to air pollution are substituted for sensitive crops when and if this is less detrimental to revenues than producing the sensitive crop in adverse conditions. This is similar to farmers who switch crops as prices and other conditions change within and throughout seasons.

- **Secondary Effects.** Secondary effects in related input and output markets, such as the demand for fertilizer, equipment, and demand for processing services and consumer goods can also be affected by changes in agricultural practices.

The net effect of ignoring these effects is that the simple damage function approach will overstate total air pollution damage by ignoring mitigating behavior and market adjustments, and will misallocate the damage between producers and consumers. On the other hand, the simple damage function approach will understate pollution control benefits by overlooking enhancing behaviors or the reduction in mitigating behavior that have previously been undertaken.

A demonstration of the importance of these effects is found in Adams et al. (1982) where, for an improvement in air quality, an economic model found total consumer benefits to be about 25 percent of producer benefits, and found that consideration of economic behavior changes resulted in total benefit estimates to producers alone of roughly 60 percent the amount that would be calculated with a simple damage function approach. An updated version of the same model is used in the analysis for the San Joaquin Valley reported herein.

3.3 WELFARE MEASURE APPROACHES

The economic impacts of air pollution upon agricultural markets can best be analyzed by considering the objectives of economic agents and how economic benefits are defined. This section defines the objectives of consumers and producers and relevant measures of their well-being before illustrating how changes in air pollution affect these measures of consumers' and producers' well-being.

The Consumers' Surplus Measure

Consumer demand theory provides a framework for defining the objectives of the individual and for analyzing changes in an individual's well-being due to changes in market conditions. The theory asserts that individuals derive well-being, or "utility," from the consumption of goods and services. Thus any change in the level of consumption affects utility. This change in utility may be either a benefit or damage, depending whether the individual's well-being is enhanced or diminished. The objective of the individual consumer is simply to maximize his utility from the consumption of goods and services, subject to his budget constraints and market prices.

Economists rely on demand curves, which show the amount of a good demanded as a function of price, to determine effects of a change in market conditions. Three related monetary measures of value can be derived from demand curves: willingness to pay (WTP), expenditures, and consumers' surplus. These are illustrated in Figure 3-1. The WTP is the maximum amount an individual will pay to obtain an additional amount of a good and is represented by the corresponding points along the demand curve--P_1 for quantity Q_1 and P_2 for quantity Q_2. The WTP represents the maximum monetary expenditures an individual will expend for a good and be no worse off than if he or she had spent the money elsewhere. Expenditures represent the actual amount a consumer spends, and is represented by the price of each unit times the quantity of units--the area P_1DQ_1O for quantity Q_1 and a constant price P_1. In the illustrated case, the consumer is paying less than his maximum WTP for all but the last unit. This surplus value, or the difference between maximum WTP and expenditures is called (ordinary) consumers' surplus and is the area AP_1D at equilibrium price P_1 and quantity Q_1. For changes in prices or quantities of a good, expenditures and consumers' surplus change. For example, if price falls from P_1 to P_2, consumers' surplus increases by P_1DEP_2 as the desired level of consumption increases to Q_2. The consumer benefits by paying less for the amount of units previously consumed (P_1DHP_2) and paying less than his WTP (DEH) for the additional units consumed.

The change in consumers' surplus is used as the welfare measure of a price change because it represents the change in income which would have the same effect on utility as the price change.

Figure 3-1

Demand for a Market Good

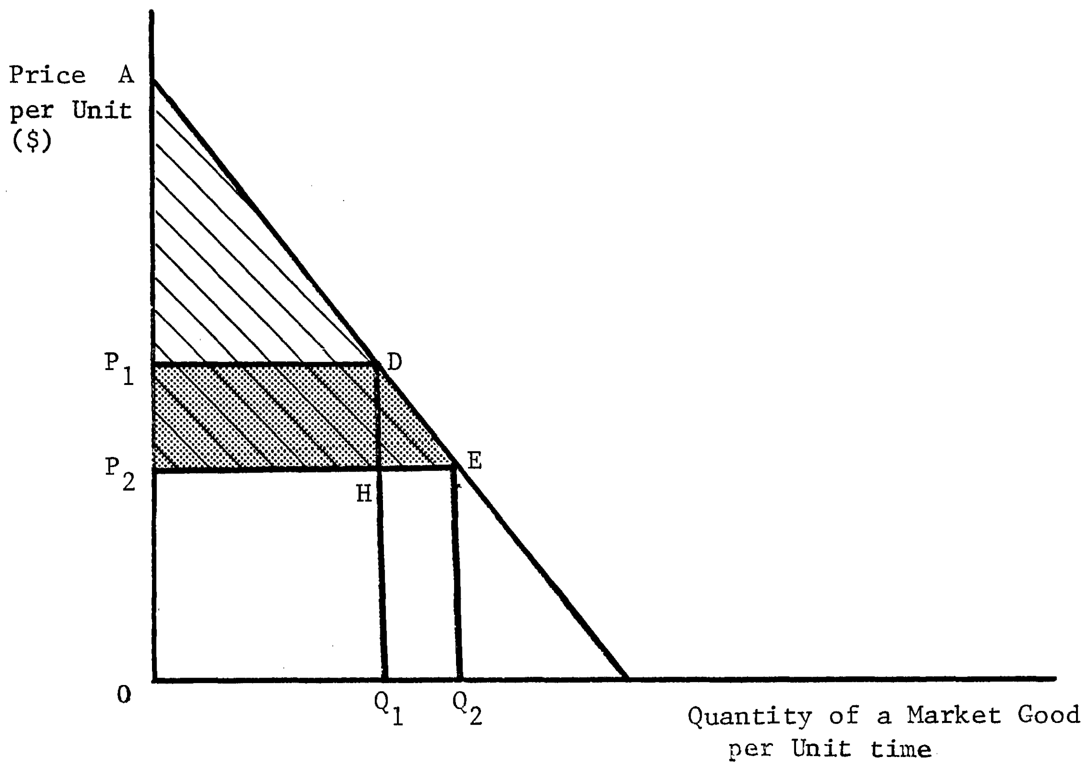
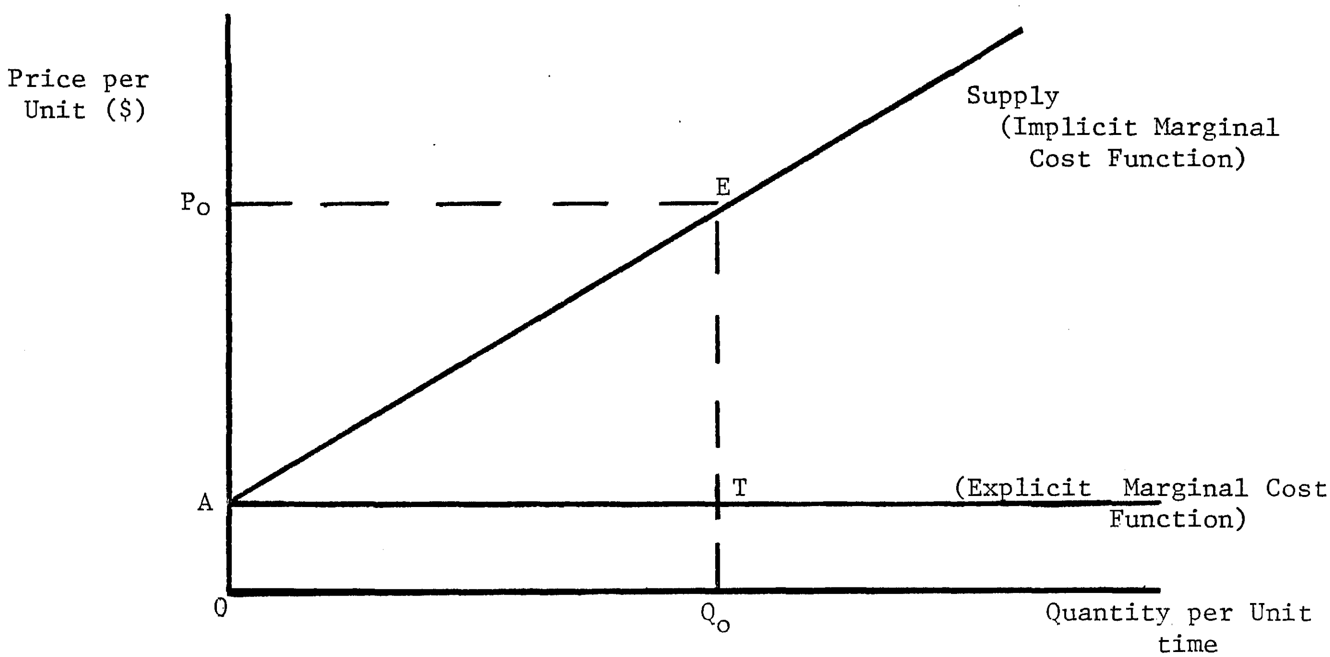


Figure 3-2

Supply of a Market Good



There are four refined measures of consumers' surplus (equivalent variation, compensating variation, equivalent surplus, and compensating surplus), defined by Hicks (1944) and refined by many authors (see Rowe and Chestnut, 1983 or any traditional microeconomics text for a thorough review). Each of these measures has slightly different interpretations and all are theoretically more accurate measures of an individual's change in well-being from changes in market conditions relative to the ordinary consumers' surplus (OCS) measure defined above. Willig (1976) and Randall and Stoll (1980) have defined conditions under which the OCS measure can be expected to be an accurate estimate of the theoretically correct welfare measure. The OCS measure will be an accurate welfare measure for the case of air pollution-induced changes in agricultural markets when the price change is not large, the expenditures on the individual good are not a large component of income, and the income effect on consumption is not likely to be large.

The Producers' Surplus Measure

The agricultural producer's objective is generally considered to be the efficient and cost effective transformation of inputs into outputs for the purpose of generating maximum profits. The inputs that enter into the production process include land, labor, fertilizer, climate and soil conditions, capital equipment and air quality. Producers are willing to supply increased quantities of a crop if the price meets or exceeds their increased costs of production. The paradigm used to illustrate this is the supply function, which relates quantity supplied to price received, and reflects that producers will only be willing to increase quantity supplied at higher prices to cover higher per-unit costs as less efficient land and more expensive inputs are brought into play.

Within the agricultural framework, supply can be considered in three classes: very short-run, in which the supply is fixed regardless of price; the short-run, where some factors are fixed and others may vary resulting in a positively sloped supply curve; and the long-run supply curve where all factors are variable. A special case of this is the long-run competitive-market supply curve, where the quantity supplied is infinite (perfect price elasticity of supply) at a fixed price; however, this case is not addressed here. A typical short-run or long-run supply curve, as depicted in Figure 3-2, represents the marginal cost of production and equals the minimum monetary compensation a producer will accept and still supply the commodity. At price P_o, Q_o units are supplied and total revenues are OP_0EQ_0. The total marginal cost of producing Q_0 is $OAEQ_0$. This leaves an excess of AP_0E as producers' surplus to be used as a return to fixed factors of production. It represents the surplus between what the producer receives and the minimum he must receive to be willing to supply the additional amounts of the good.

Producer rent is the technical term that refers to the return on capital. In the short run, producers may ignore these (and other) implicit opportunity costs of capital and land and hope to cover explicit marginal costs, such as labor, water, fertilizer, etc. which may be relatively constant per unit of production. In Figure 3-2, these explicit costs may, for example where short-run input prices are fixed, be represented by the line AT. In the short run covering only explicit marginal costs, the producer may perceive the area AP_0ET as returns above costs, which are called quasi-rents.

The sum of consumers' surplus (CS) and producers rent (PR) is often referred to as economic surplus. Illustrated as the shaded area in Figure 3-3, it is the difference between the maximum willingness to pay and minimum willingness to accept, and as such, represents the net benefits to society from the transactions between the producers and consumers.

The Welfare Effects of Changes in Air Pollution

Air pollution can be considered a negative input (i.e., it has an adverse effect on crop production) in the agricultural production function. As air pollution increases, it becomes more expensive to produce the same level of output, because with the same input expenditures, less output can be produced. This is illustrated in Figure 3-4 where some input adjustments are possible and where S_0 and D_0 are the initial supply and demand schedules for a specified crop. The market equilibrium is reached at point C with price quantity combination (P_0 Q_0) and with economic surplus of ACD (producers' rent = P_0CD, consumers' surplus = ACP_0). With an increase in air pollution, the supply curve shifts back to S_1, as it now costs more to produce the same level of output. Eventually a new equilibrium is reached at point B with price quantity combination (P_1, Q_1).

In the example, economic surplus decreases by the amount DCBE, and represents the economic losses attributable to the increased air pollution. This represents a real economic loss in the sense that consumers must spend more for each of the Q_1 units still

Figure 3-3
Economic Surplus

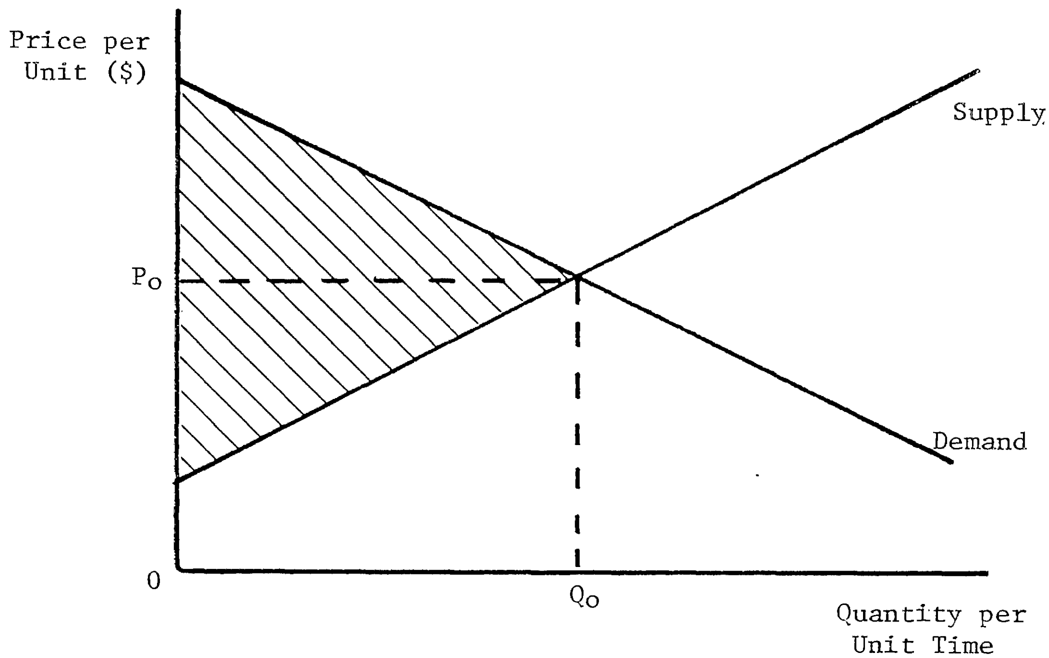
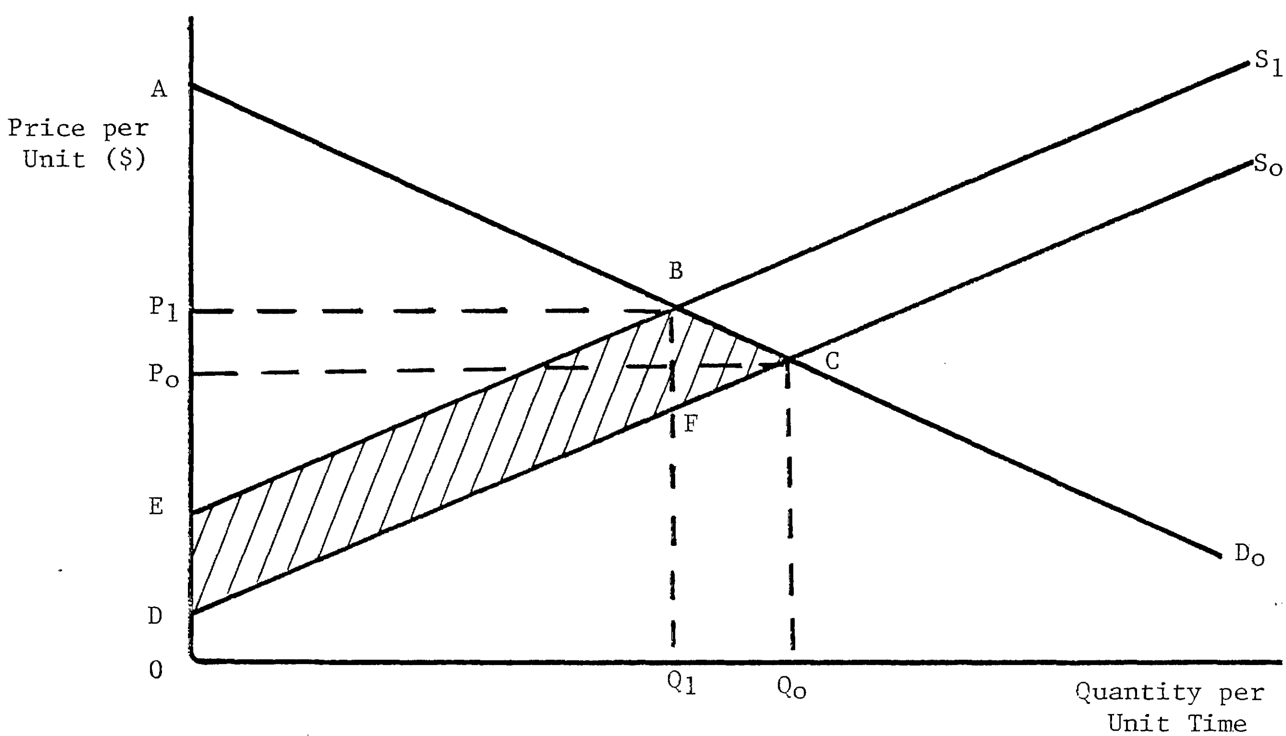


Figure 3-4
Effects of Increases in Air Pollution Economic Surplus
(Short Run With Some Supply and Demand Adjustments)



consumed, leaving less for expenditures on other goods. Producers also lose because each unit of output sold costs more to produce and yields lower producer rents, leaving less to produce other goods and services and resulting in a lower rate of return on investments. In this case, the reduction in expenditures to produce and consume Q_o-Q_1 less crop, represented by the area FCQ_oQ_1, is not an economic loss because these expenditures become available for production and consumption of other goods and services. Although not immediately apparent graphically, the change in economic surplus equals the sum of the changes in consumers' surplus P_1BCP_o and the change in producers' surplus (P_oCD - P_1BE). In general, the split between producers' and consumers' surplus losses depends upon the elasticities of supply and demand for the good under consideration.

Occasionally, consideration of economic losses within the context of a very short-run analysis may be appropriate. For example, when the amount to be brought to market is fixed by contract, and is less than the amount farmers would otherwise desire to supply, vertical supply curves, as depicted in Figure 3-5A, may be appropriate. In this figure, original supply may have been fixed at Q_o, but bad weather, for example, may then reduce available supply to Q_1. The simple damage function approach, as used in many early studies discussed in Section 2, erroneously used this fixed supply at all prices approach, and further assumed that price would remain fixed at P_o when supply changed. Economic damages were then calculated as the area ABQ_oQ_1 and all losses were assigned to producers. When demand for a crop is price sensitive, as depicted, equilibrium price increases to P_1 as supply is reduced to S_1. Producers' revenues change by ABQ_oQ_1-P_1CAP_o, which may be positive or negative depending upon the elasticity of demand. Society loses consumers' surplus of CBA, while the consumers' surplus of P_1CAP_o is transferred to producers. In such a very short-run situation, where supply adjustments are not possible, the net loss to society is CBQ_oQ_1. This is larger than the simple damage function approach would predict for reduced supply (perhaps by increased air pollution), even in the very short-run case. For reduced air pollution and increased supply, the simple damage function will similarly overstate benefits even for the very short run case. This very short-run case, however, is not appropriate for the analysis of air pollution impacts, as these effects occur continuously and change slowly, allowing farmers to observe yields and adjust their behavior accordingly.

Figure 3-5A

Short Run Versus Long Run Supply Adjustments

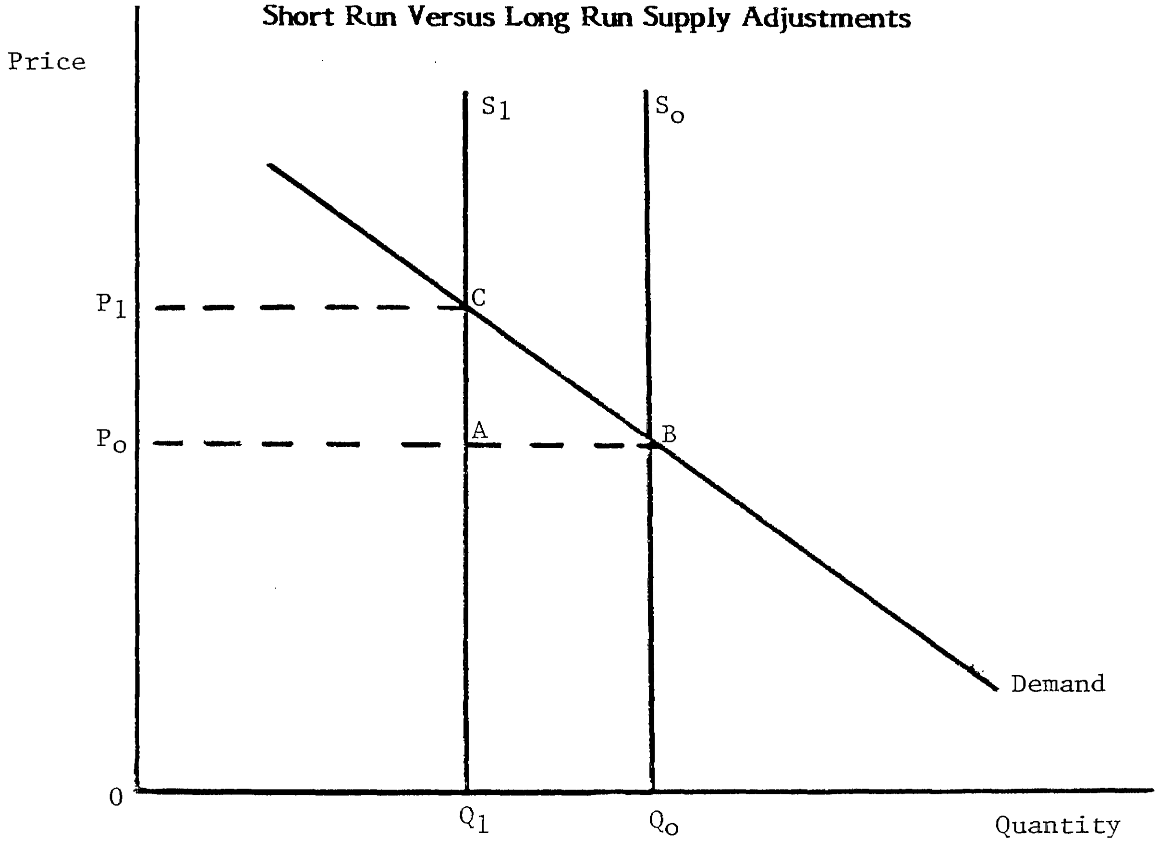
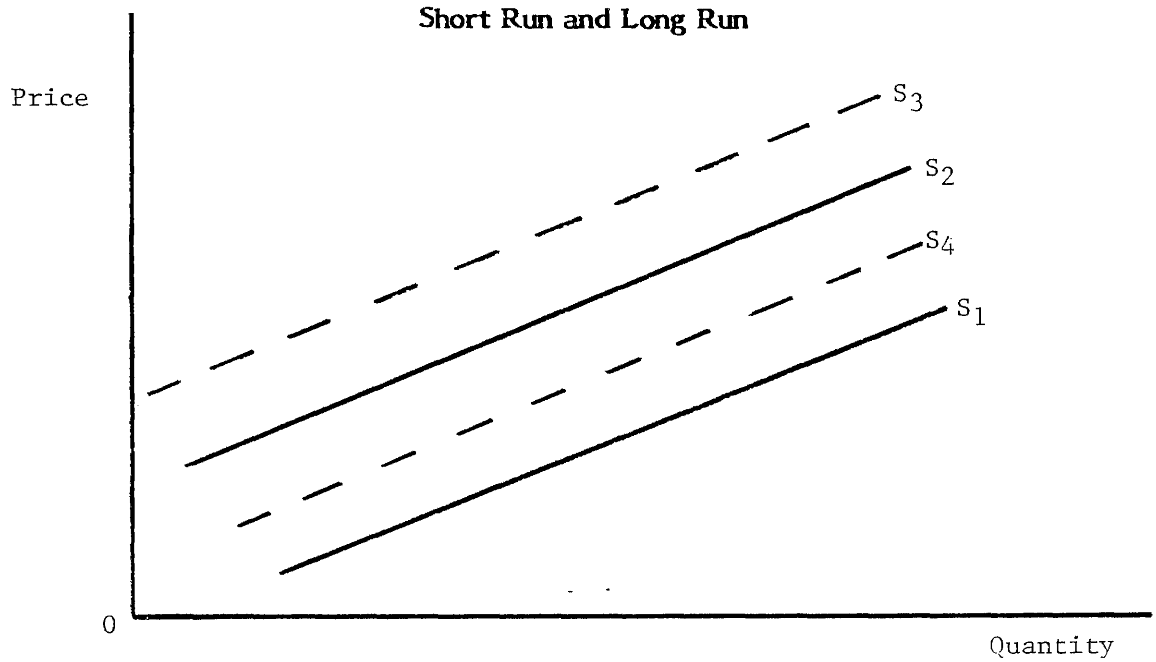


Figure 3-5B

Short Run and Long Run



The analysis undertaken in this report will consider a case of short run with partial adjustments. The analysis allows farmers to adjust marketable levels of a crop through changes in agriculture and marketing practices, and to make limited substitutions of acreage from one crop to another. Acreage changes in tree crops are limited, while acreage changes among row crops are generally unlimited. Further, the level of inputs varies with output, but the mix of inputs is held fixed. As depicted in Figure 3-5B, if air pollution levels were to increase, short-run supply would decrease from S_1 to S_2. If this condition persists, and the crop of concern is relatively pollution sensitive, farmers may substitute acreage to less sensitive crops if it is more profitable to do so. Consequently, through time, the short-run supply of the crop will further shift to S_3. On the other hand, if the crop is relatively insensitive to pollution, while other crops are more appreciably affected, farmers may substitute acreage into this crop, increasing supply to S_4. The time to adjust from one short-run supply curve to another depends upon conditions such as whether the crop is a perennial or annual. For more discussion, see Chapter 5.

3.4 SECONDARY IMPACTS

The term secondary impacts in cost-benefit analyses usually refers to increases or decreases in employment incomes, or the utility of consumers which result indirectly from a project as a consequence of the primary impacts. For example, as agricultural production changes due to changes in air pollution, the primary impacts are to the producers and consumers. Secondary impacts may also be felt, through "backward linkages," by the producers of agricultural inputs; through "forward linkages" by the producers of intermediate processes such as canning and shipping of agricultural goods; and felt by producers of other goods and services, if the change in the consumers' equilibrium quantity demanded also affects the demand for their products. For the economic analysis of air pollution on agriculture in the San Joaquin Valley reported herein, secondary impacts are considered only by way of suggesting their existence and possible importance to the California economy.

The classic economic argument with regard to secondary benefits and costs is that under most circumstances they should not be counted in addition to the primary benefits or costs in the determination of the net present value of a project.* From a national perspective, secondary impacts usually represent a transfer of resources from one location or person to another, rather than a net increase in incomes and utility. For example, increased yields will increase the demand for downline services, such as canning and hauling. In times of full employment, these increased services can only be provided by decreasing the provision of other services in society. Thus, there is simply a transfer of these secondary resources to more socially desirable uses reflected in the change in primary benefits and costs.

There are two cases where secondary benefits are considered in a national benefits analysis:

- o when there are changes in unemployed resources; and
- o when there are gains in economic efficiency from external economics.

In the first case, if a project results in employment of previously unemployed resources, the opportunity cost of alternatives foregone is small, and there is clearly a net benefit (Haveman and Krutilla, 1968). The use of this argument has, however, been extensively debated (see Sassone and Schaffer for a review). The second case refers to situations where the primary change results in technological advances also useful to increase production in other industries without the use of additional resources. For example, the space program has produced numerous technological advances used by many unrelated industries.

Consideration of secondary effects is useful when considering the equity question of who receives the costs and benefits of secondary resource transfers. (As an example, see U.S. Water Resources Council, 1979 for accepted procedures for water resource projects.) In this study, consideration of secondary impacts could be useful in quantifyng the benefits and costs to agricultural related industries in California. Such an analysis would, however, overstate total secondary impacts in California, as many secondary benefits or costs will simply result in transfers in resources from (or offsetting impacts in) other California industries.

---

* This issue is discussed in depth in most benefit-cost textbooks. For example, see Sassone and Schaffer (1978, Chapter 3), Mishan (1973, Parts II and III). For more detail see Mishan (1976, Parts II and II) and Sugden and Williams (1978, Part III).

3.5 MEASURING BENEFITS IN INTERMEDIATE MARKETS

The discussion up to now has represented the demand for agricultural products as that by consumers. Actually, the ultimate consumer obtains the commodity after it has passed through several intermediate markets. The demand for the intermediate good (the crop from the farmer) is a derived demand based upon its value in producing final goods for consumption (cereals, breads, etc.). Conceptually, consumers' surplus only occurs for the consumer of the final goods, but the analysis in this report examines the quantity and price of agricultural outputs that the farmer sells in an intermediate market. A question then is: Do changes in the consumers' surplus measure, which are estimated in the intermediate market, accurately reflect the change in consumers' surplus experienced by the ultimate consumer? This question has been addressed by Schmalensee (1976), Anderson (1975), and Just and Hueth (1979). In summary, these authors have found that under varying market conditions, the change in benefits measured in the intermediate markets is less than or equal to changes in consumer's surplus experienced by consumers in the final markets. Therefore, using intermediate markets provides a conservative estimate of benefits in the ultimate consumer market.

4.0 DAMAGE FUNCTION ESTIMATION

This study attempts to use field data to estimate a relationship between crop yields and air pollution. This chapter details the concepts, methods, and variables used to estimate this relationship. The review of past economic studies (See Appendix A1) suggests the estimation of crop-yield changes from air pollution changes must be carefully performed when using field data. Evidence from Adams et al. (1982), Manuel et al. (1981), and Leung et al. (1982) suggests the regression approach can give results broadly consistent with chamber study findings, although the effectiveness of the field data regression approach used in these studies is limited. Further, the regression results may not be robust due to uncertainty in the correct specifications and the lack of quality data, leading to multicollinearity problems and sometimes unstable regression coefficients. Section 4.1 discusses the general yield function concepts. Sections 4.2 and 4.3 define the variables used, which are summarized in Table 4-6, page 4-24. Sections 4.4 and 4.5 discuss the procedures to estimate economic measures of damage and other issues of concern.

4.1 YIELD FUNCTION CONCEPTS

Production or yield functions are used to relate inputs in the agricultural production process to outputs of the crop. The term "damage function" may also be used when one is considering the effects of an input which adversely affects the production of the crop, such as air pollution or pest infestations. A crop yield function can be generally represented as:

$$Y = f(AP, W, AI, T, O, E) \tag{4.1}$$

where:

Y = yield per acre
AP = air pollution conditions
W = weather variables
AI = agricultural inputs and practices
T = technological changes
O = other influences
E = random error

The first partial derivative of the function with regard to any input represents the marginal physical product of the input in the production of Y, or in the case of air pollution, $\partial Y/\partial AP$ represents the marginal damage (or reduction in yield) from increases in the input. The important considerations in specifying a production function are that the variables included, their definitions, and the specification of the functional form, accurately represent underlying technological and economic assumptions and knowledge. Discussions of the variables and function specifications to be examined in this analysis are addressed in Sections 4.2 through 4.5. The objective here will be to accurately estimate the partial relationship between yields and air pollution. This requires incorporating many other influences (or variables) which explain the production process.

Equation 4.1 identifies broad categories of variables which require further elaboration. Yield per acre is the appropriate dependent variable to eliminate the obvious effect of changes in harvested acres upon total outputs. Harvested acres could be incorporated as an agricultural input variable to reflect potential economies or diseconomies of scale with respect to farm size. Other agricultural input variables include the amount of labor, machinery, irrigation, fertilizers, and pesticides used per acre. Technology measures are included to reflect the fact that the same level of inputs may produce increased output due to changes in the cultivars being used and due to changes in the productive capabilities of inputs. Weather variables such as temperature, precipitation, and humidity are included for their obvious potential impacts on plant growth. Other influences, which may or may not be within the control of the individual farmer, include soil conditions, pest infestations, and others. The variables to be included are described in Sections 4.2 and 4.3 and summarized in Table 4.6.

Yield functions theoretically represent technical biological relationships between inputs and the growth of plants. Factors such as the market price of the crop should not be considered. There may, however, be important reasons for examining price effects in an empirically estimated production function.

Yields in the field and yield estimates based upon marketed quantities of the crop may be different, with the difference being a function of current and past crop prices. In practice, one may not be estimating a "biologic production function," but rather a "marketed production function." With low actual or expected prices, there may be reduced incentive to expend resources to harvest and bring all of the crop to market. The nature of the available yield data is such that it does not represent an in-field yield measure, Y, but rather, a marketed yield, Y*, which may be related as follows:

$$
\begin{aligned}
Y^* &= g(Y, P, \mu) \\
&= g((\cdot), P, \mu) \\
&= g(AP, W, AI, T, O, P, E, \mu)
\end{aligned}
$$

where P is the expected current period price and may be the actual price or a function of past prices and other influences, and μ is a random error.

A second reason for incorporating prices is that it is difficult to quantify all input variables, some of which may be highly correlated with or proxied by price, even when using an exact in-field-per-acre measure. As expected prices increase or decrease, perhaps based upon past period prices, there is more economic incentive to incur the costs of increasing the use of productive inputs in order to produce increased yields. To the extent that these inputs are measured and incorporated into the production function, this effect is captured. Changes in other inputs, however, such as ensuring that all acres are completely cultivated and harvested, and continuing to replace trees and vines before their productivity decreases, are not captured in the measured production functions.

4.2 AIR QUALITY AND METEOROLOGICAL VARIABLES

Several measures of ambient concentrations of ozone, oxidants, and sulfur dioxide were developed, as well as meteorological data. Estimates of each weather and air-quality parameter were prepared for each month from January 1970 through December 1981. An average value was derived for each county. The procedure used to derive the county average values from site-specific data was the same for every data set. Different techniques were used to derive the basic data used to calculate the county average values.

4.2.1 Aggregation of Data to the County Level

The data used in this study were available at different levels of geographical aggregation. For analysis it was necessary to put all of the data on a common basis, so a single observation could include comparable data on crop yield, air quality, weather, and other factors affecting yield. The basis selected was the county level, since many of the data were not available in more detail.

County average values for ozone, oxidant, sulfur dioxide, and weather variables were not available in that form and further such data would not necessarily be meaningful for many crops. There is a substantial variation in air quality within counties. This variation required that a technique be developed which could accurately reflect the different conditions experienced by different crops grown in different areas of a county.

The California Department of Water Resources (DWR) collects data on land use by United States Geological Survey (USGS) 7.5 minute quadrangles throughout the state. The data are collected through a combination of aerial and ground surveys. The data set lists the number of acres in each quadrangle devoted to various land uses, including agriculture. The agricultural land is broken down by crop type. Using this data it was possible to determine where each of the study crops was grown within each county in 1983. The DWR study did not distinguish between cling and freestone peaches or between table and wine grapes. It was assumed that the geographic distribution of the two types of peaches and the two types of grapes were the same within a county. Because only the most recent DWR data were available in usable form, it was necessary to assume that the geographic distribution of each crop within a county was roughly the same in the earlier years.

The San Joaquin Valley includes all or part of over 500 7.5-minute quadrangles. These quadrangles were aggregated into groups of four, spanning 15 minutes of longitude and latitude. In project jargon, each group of four quads was called a "superquad."

Estimates of ambient ozone, oxidant, and SO_2 concentrations and all of the weather parameters were developed for each superquad using the methods described below. County values for each parameter were obtained by calculating a weighted average for the values in the superquads spanning the county. The weight assigned to each superquad varied for each crop, with the weight equal to the fraction of the total acreage in the county which was grown in each of the superquads. (See Equation 4.2.)

$$\bar{V}_{ci} = \frac{\sum_{j=1}^{N_{jc}} V_j A_{ji}}{\sum_{j=1}^{N_{jc}} A_{ji}} \qquad (4.2)$$

$\bar{V}c_i$ = the average value of a measure (O_3, oxidant, SO_2, or weather) in County C, for crop i

V_j = the value of the measure in superquad j (V_j is the same for all crops)

A_{ji} = acreage of crop i in superquad j

N_{jc} = number of superquads in County C

j = index indicating superquad number

4.2.2 Ozone and Oxidant Data

This portion of the analysis estimates ozone concentrations for each superquad in the San Joaquin Valley. Four measures were estimated for each month:

(1) average one-hour concentration (O3AVE)

(2) number of hours in which the concentration equalled or exceeded 6 pphm (O3GE6)

(3) number of hours in which the concentration equalled or exceeded 10 pphm (03GE10)

(4) dose for all hours where O_3 equalled or exceeded 10 pphm (03DOS)

A dose measure, defined in Equation 4.3, was used to represent plant exposure to high concentrations of ozone. It approximates the integral of the curve of concentrations over time.

$$D = \sum_{c=10}^{\infty} c*(h(c)-h(c+1)) \qquad (4.3)$$

Where:

h(c) = hours that concentration is greater than or equal to c

D = dose in pphm-hours

c = concentration in pphm

Note that integer values of pphm were used in this calculation.

Since physiological data indicate plants are only affected by pollution while they are growing, only the time between 9 a.m. and 5 p.m. was considered. Observations outside this time period did not contribute to the calculation of the average and were not counted in the tally of high concentrations.

Data on one-hour concentrations of ozone for the period from January 1970 through December 1981 were prepared by the California Air Resources Board (CARB). This data set provided observed concentrations at all available monitoring points. Data for a site was used only if there were observations for 50 percent or more of the growing hours during a month. Other sites were ignored to reduce the risk of biasing the data in the event that, if a site was monitored for only a limited period, operators might have concentrated on a period when unusual ozone levels were likely. When observations for every growing hour were not available, the estimated number of hours over 6 pphm and 10 pphm were scaled linearly to account for the missing observations, and the dose was adjusted accordingly.

There were far more data available in later years than in early years. This affected the technique used for extrapolation from the observed concentrations (at specific points) to the values for the superquads. When there were observations at a sufficient number of points, the values in the superquads were calculated by an inverse-distance-squared interpolation from the monitoring points to the centroid of the superquad. Sufficiency was judged informally. Basically, inverse-distance-squared interpolation was deemed appropriate if the centroid of the superquad was located within 50 miles of a monitor (over 90 percent of the centroids met this rule). This rule was relaxed if the superquads outside the range of monitors did not contain major acreage of the study crops. The centroid of a superquad was assumed to be the point at which the four 7.5 minute quads met. The fact that the quadrangles are trapezoids rather than rectangles, and hence smaller at the north end of the valley, was considered in the calculation of the distance from the monitoring points to the centroids, as was the curvature of the earth, though the latter was a very minor correction.

Monitoring points more than 50 miles from a centroid were not included in the weighting. If more than five monitors were within 50 miles of a centroid, only the five closest were used. For the few superquads for which there were no monitors within 50 miles, the value for any variable was taken to be the arithmetic average of the values at the centroids of the adjacent superquads for which there were values.

In the early years, 1970-1974, there were no ozone monitoring points which had observations during 50 percent or more of the growing hours. Data at a limited number of oxidant monitors were available, but the number of points was too small to use an inverse-distance-squared interpolation as was done for the years after 1974, as most centroids were too distant from the monitors.

To compensate for the lack of monitoring data from 1970-1974, data on typical spatial variances of the four ozone parameters were used. Typical patterns were derived from the post 1974 data. To derive the typical patterns, the four ozone measures were estimated separately for each month from 1975 through 1981. Forty-eight tables were prepared for each monitor, one for each measure for each month. There were some differences between the monthly tables, but only minor differences between the tables for the different measures within a month. The differences between months were relatively small; hence, to conserve project resources, the number of tables was reduced to four, one for each quarter, by averaging the monthly tables. Finally, each table was normalized so the upper left superquad had a value of 1.0.

Data for the years 1970 through 1974 exclusively used oxidant data as opposed to ozone data, but the two were judged equivalent in the San Joaquin Valley. Oxidant data were obtained in aggregate form from two CARB documents: "Ten Year Summary of California Air Quality Data, 1963-1972" and "Three Year Summary of California Air Quality Data, 1973-1975." These documents listed:

- o annual arithmetic mean one-hour concentration
- o annual one-hour standard deviation
- o annual geometric mean one-hour concentration
- o annual one-hour geometric deviation
- o one-hour arithmetic means in each quarter
- o highest one-hour concentration in each quarter.

Data on the quarterly arithmetic mean could be used in the regressions without additional processing. It was assumed that each of the months within a quarter had the same mean concentration.

Data on the number of hours equal to or greater than 6 and 10 pphm in each quarter were not available in published form. The parameters were estimated by assuming that throughout the growing season, the daytime hourly ozone readings have a lognormal distribution. The two parameters of the lognormal distribution are the geometric mean and geometric deviation. These were derived for each site for each quarter from the published data. Since each quarter has approximately the same number of days, the annual average arithmetic mean is the average of the four quarterly means. Similarly, the annual geometric mean is the fourth root of the product of the four quarterly geometric means, which were not given. Since a distinctly linear relationship existed between the annual geometric and arithmetic means, it was assumed that the quarterly geometric means would have the same proportional relationship to each other as the arithmetic means exhibited. With this assumption it was possible to derive an estimate of the geometric mean in the first quarter and, subsequently, the remaining three quarters. The geometric deviation was similarly estimated. Data from sites with less than 6000 hourly observations in a year were not used.

The geometric mean and geometric deviation were first used to calculate the peak hour in each quarter. This was compared to the observed peak hour. The correspondence was not perfect, but the largest deviation was 3 pphm, except for the Bakersfield Chester Street site which was dropped from the analysis. Once the lognormal fit had been validated in this fashion, the number of hours equal to and over 6 and 10 pphm were calculated in each quarter. These estimates were for a 24-hour period. Estimates for the daytime growing period were prepared using scale factors from the years for which data were available. Different scale factors were used for each month and for each measure of concentration. The quarterly dose and number of hours equal to and over 6 and 10 pphm dose were allocated to each month in proportion to the month's length.

By the procedures described above, estimates of each dose and hours equal to and over 6 and 10 pphm were prepared for each available monitoring site. Even using the oxidant data, the available monitoring sites were too sparse for inverse-distance-squared interpolation. The typical spatial distribution derived from the post 1974 ozone data was used to estimate values for the superquad. The procedure was as follows: First, the superquad centroid nearest each site was located and the value at the site was assumed to prevail at the centroid. Then, for each monitoring point available in each quarter, the value of each measure was calculated in each superquad using the normalized spatial distribution tables developed from the 1975-1981 ozone data. Several values were prepared for each superquad for each month — one for each available monitoring point. The value used in the regressions was the average of the values calculated using data from the different monitors. Recall that this procedure was used only for the years 1970-1974. Beginning in 1975, the hourly ozone concentration data were sufficient.

There was substantial variation in the estimates derived from the different monitoring points indicating that the technique used for the spatial extrapolation might have introduced substantial error. To judge the validity of the calculation, the 1970-1974 and 1975-1981 data sets were compared for consistency. In addition, the 1970-1974 data were compared to the CARB published report values to determine if the estimated diurnal variation in concentrations was consistent with the observed values. No obvious discrepancies emerged, but it was not possible to perform a more formal validation of the calculation with the available data. Estimated values for selected ozone measures, crops and years are reported in Tables 4.1 and 4.2.

4.2.3 Sulfur Dioxide Variables

Sulfurous emissions in the San Joaquin Valley are largely concentrated in central Kern County, in the vicinity of Bakersfield and Oildale. Monitoring data are sparse, but indicate that high concentrations of (SO_2) occur primarily in this area. Concentrations in other counties were low enough that effects on crops were highly unlikely. For this reason, the analysis was restricted to the study of effects in Kern County. Three parameters were estimated: monthly average concentration during growing hours (SO2AVE); number of hours in which concentrations were greater than or equal to 6 pphm, (SO2GE6); and dose, as calculated for ozone (SO2DOS).

The sparse amount of monitoring data made it necessary to estimate emissions and to use dispersion modeling to estimate ambient concentrations. Several factors complicated this process:

- The emissions inventories for the years 1973, 1976, and 1979 are not consistent. Over time, the techniques used to develop the inventory have improved. The 1979 inventory is much better than earlier efforts, but the fact that procedures and quality have changed makes it difficult to compare the inventories or accurately assess trends.

- Only the 1979 inventory was available in machine readable form. Since the earlier inventories were not available in machine readable form, it was not possible to use them directly. Manual coding of the earlier inventories would have been prohibitively expensive.

Table 4-1

Estimated Ozone Measures for Cotton in Fresno and Kern Counties, 1970-1981

		County	
O_3 Measure	Year	Fresno	Kern
O_3 Ave	1970	5.73	5.61
	1971	5.32	5.53
	1972	4.98	5.34
	1973	5.16	5.27
	1974	5.30	5.36
	1975	4.87	4.87
	1976	5.58	5.94
	1977	5.44	5.88
	1978	5.65	6.36
	1979	5.79	6.59
	1980	5.29	6.00
	1981	5.19	5.83
03GT10	1970	33	33
	1971	30	33
	1972	12	28
	1973	83	89
	1974	79	92
	1975	63	73
	1976	37	59
	1977	61	88
	1978	143	193
	1979	92	163
	1980	53	120
	1981	37	69

Table 4-2

Estimated Ozone Measures for Selected Crops in 1978

Crop and O_3 Measure	County							
	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stan.	Tulare
Grapes (8 mos)								
O_3 Ave	5.54	6.00	5.43	5.39	5.36	5.35	5.50	6.27
O_3 GE6	652	772	621	617	610	63	643	850
O_3 GE10	159	193	154	138	129	155	151	214
O_3 DO5	17.52	21.23	17.04	15.10	14.24	17.62	17.11	23.50
Cotton (7 mos)								
O_3 Ave	5.65	6.36	5.80	5.69	5.63			6.65
O_3 GE6	597	768	627	607	597			846
O_3 GE10	143	193	156	137	128			214
O_3 DO5	15.79	21.22	17.28	15.03	14.04			23.47
Potatoes								
O_3 Ave		3.75				5.444		
O_3 GE6		73				475		
O_3 GE10		1				108		
O_3 DO5		.13				12.17		
Dry Beans (7 mos)								
O_3 Ave	5.70	6.35		5.66	5.73	5.65	5.90	6.86
O_3 GE6	608	765		606	617	597	653	905
O_3 GE10	145	192		137	139	156	160	231
O_3 DO5	15.99	21.17		15.00	15.61	17.78	18.23	25.20
Processing Tomatoes (7 mos)								
O_3 Ave	5.03	5.70	5.05	5.12	5.14	5.18	5.43	6.00
O_3 GE6	460	611	464	476	481	494	548	684
O_3 GE10	89	136	98	86	82	110	115	156
O_3 DO5	9.78	14.8	10.73	9.30	8.93	12.43	13.11	16.93
Lettuce (9 mos)								
O_3 Ave	4.64	5.17	4.71					
O_3 GE6	508	630	524					
O_3 GE10	139	182	146					
O_3 DO5	15.49	20.12	16.29					

- o Dramatic changes have taken place in the most important emissions category -- steam generation from thermally-enhanced oil recovery -- and these have not been captured accurately in the inventory for the reasons noted in the first item. The changes in estimated emissions from oil production, as reflected in the inventory, are related not only to changes in production, but to fuel types and air pollution controls.

- o The area to be modeled is large. It can be very costly to model an area the size of Kern County. A simple approach is necessary if the calculation is to be done at a reasonable cost.

- o Kern County is not flat. It is very difficult to model dispersion over rough terrain. Fortunately, few crops are grown in the mountainous portions of Kern County, so errors stemming from the assumption of flat terrain in the modeling are assumed not to be critical.

The basic consequence of these complications and the limited availability of quarterly data suggested the modeling effort remain as simple as possible. The steps were as follows:

Step 1: Spatial Distribution of Sources

It was assumed that the spatial distribution of sources in all years was the same as in the 1979 inventory. The inventory for that year was processed to develop estimates of emissions for each quadrangle in a grid system of 10-km square. Estimates were developed for two general source categories: oil recovery emission, and other sources.

Step 2: Estimation of Emission

Oil-Recovery Emissions

Accurate emission trends in the San Joaquin Valley cannot be derived simply by comparing the 1973 and 1979 CARB emission inventories because the CARB inventories for the two years are not consistent. This, in fact, was verified by detailed calculations for oil-recovery emissions. Specifically, our estimate of oil-recovery SO_2 emissions in Kern

County during 1979 agrees with the 1979 CARB value (basically because our calculations are calibrated to that value), but our estimate for 1973 is almost a factor of two lower than the 1973 CARB value.

We estimated historical emission trends using a consistent data base for three basic factors: uncontrolled emission rates, source activity levels, and control schedules. Information for the analysis was assembled by contacting several state and county agencies: the California ARB (Bob Effa, Kevin Cleary, and Russ Tate), California Energy Commission (Dale Rodman and Dennis Smith), California Division of Oil and Gas (Bill Guerard), Kern County APCD (Joe Obannon, Henry Mayrsohn, Mark Chichester, and Citron Toy), Fresno County APCD (Charles Masco), and San Joaquin County APCD (Seyed Savrevin). The ARB contacts were able to provide the most critical and useful information regarding oil recovery emissions. This information led to a rather complete analysis of oil recovery emissions, but data for a complete analysis of other source categories was not available.

Thermally Enhanced Oil Recovery. Table 4.3 presents the estimated historical SO_2 emission trends from oil-recovery operations in Kern County as well as the data on which these estimates are based. Essentially, the trend analysis was calibrated to the 1979 CARB inventory by choosing an uncontrolled SO_2 emission factor for fuel oil consumption of 1.23 lb/10^6 BTU. Emissions for other years were then calculated by proportioning according to annual fuel oil consumption and annual SO_2 control levels.

Table 4.4 presents historical SO_2 emission trends from oil recovery in Fresno County. The data base underlying the emission trend analysis is less complete for Fresno County than for Kern County. This limitation, however, is not important because oil recovery SO_2 emissions are an order of magnitude smaller in Fresno County, as well as throughout the rest of the San Joaquin Valley.

Other SO_2 Sources. An effort was also made to determine SO_2 emission trends for other source categories; most notably petroleum refineries and chemical plants. This effort, however, was thwarted by the lack of data on historical source activity levels, such data being either nonexistent or proprietary. Thus, for other categories, the analysis is forced to use the 1973 and 1979 CARB inventories, even though they do not necessarily reflect true trends.

Table 4.3

Historical SO_2 Emission Trends from Oil Recovery Operations in Kern County

Year	Annual Steam Generation (10^6 bbls H_2O)	Annual Total Fuel Consumption (10^{12} BTU)	Annual Natural Gas Consumption (10^{12} BTU)	Annual Fuel Oil Consumption (10^{12} BTU)	Degree of SO_2 Control by Scrubbers (%)	SO_2 Emissions (tons/day)
1970	122.8	53.2[b]	10.4[c]	42.8	0	72
1971	149.3	64.7[b]	12.1[c]	52.6	0	88
1972	184.1	79.7[b]	13.8[c]	65.9	0	111
1973	190.7	82.5[b]	15.5[c]	67.0	0	113
1974	188.9	81.8[b]	17.2[c]	64.6	0	109
1975	230.2	96.3[b]	21.0[c]	75.3	0	127
1976	252.3	110.1[b]	20.6[c]	89.5	0	150
1977	NA	125.1	18.6[c]	106.5	0	180
1978	319.9	142.2	42.0	118.2	7	185
1979	301.5	140.2	26.0	114.2	22	151
1980	414.8	170.9	28.5	142.4	36	154
	A	B	C	D	E	F

A: Data from California Division of Oil and Gas.

B: Data from ARB. Values labeled "b" are estimated by ratio relationship between Columns A and B.

C: Data from ARB. Values labeled "c" are estimated by linear time-series regression.

D: Column B minus Column C.

E: Data from CARB and Kern County APCD.

F: Computed from Columns D and E with uncontrolled SO_2 emission factor for fuel oil of 1.23 lb/10^6 BTU.

Table 4.4

Historical SO_2 Emission Trends from Oil Recovery Operations in Fresno County

Year	Annual Steam Generation (10^6 bbls H_2O)	Annual Fuel Oil Consumption (10^{12} BTU)	SO_2 Emissions (tons/day)
1970	5.2	2.2	3.7
1971	5.6	2.3	3.9
1972	5.0	2.1	3.5
1973	4.7	1.9	3.2
1974	4.7	1.9	3.2
1975	3.4	1.4	2.4
1976	3.1	1.3	2.1
1977	NA	2.0*	3.4
1978	6.6	2.7	4.7
1979	10.0	4.1	6.9
1980	23.0	9.5	16.1
	A	B	C

A: Data from California Division of Oil and Gas.

B: Based on Column A and the ratio of fuel consumption to steam generation as derived previously for Kern County. Also, for each year, the fuel consumption is assumed to be 95 percent fuel oil and 5 percent natural gas (based on discussion with the ARB and Fresno County APCD).

C: Based on Column B and an uncontrolled emission factor for fuel oil of 1.23 lb/10^6 BTU. Based on discussions with the ARB and Fresno County APCD, it is assumed that there are no scrubber controls in effect during the period.

*: Interpolated

It should be noted that the search for data regarding other source categories suggested a degree of uncertainty in the existing inventories. For example, San Joaquin County APCD apparently reports 4.2 tons per day SO_2 from chemical plants in 1979, as compared to 10.7 tons per day by the CARB in 1979. Also, Kern County APCD apparently reports 30.1 tons SO_2 per day from refineries in 1979 as compared to 25.8 tons per day reported by the CARB in 1979. Fortunately, all other source categories are not very significant compared to steam generation from oil recovery.

Estimates for each cell in the 10-km grid were developed by scaling the total county emissions in proportion to the distribution observed in 1979 across the grid as reported by the CARB.

Step 3: Dispersion from Model Source

Because of the large number of sources involved, and the lack of locations for sources in any year other than 1979, it was necessary to use a "model source" approach. The model source is an area, 10-km on a side, corresponding to the grid used for summarizing emissions. Emissions from the model source were assumed to be 1000 kg per hour. The U.S. EPA's Climatological Dispersion Model (CDM) was used to estimate concentrations at the centroids of the surrounding 10-km grid cells.

Step 4: Estimation of Ambient Concentrations

Ambient concentrations resulting from emissions in each cell of the 10-km grid were estimated by scaling the impact of the model source to the emissions rate estimated in Step 2. For example, if the emissions in a cell were 1500 kg/hour, the ambient concentrations resulting from these emissions would be 1.5 times the values estimated for the model source.

Concentrations at the center of each of the 10-km grid cells were estimated from superimposing the impact of the emissions from all other cells. The 10 km grid was then mapped to the superquad level and average county values estimated as other variables in the analysis.

4.2.4 Meteorological Variables

Monthly values for five weather variables were estimated for use in the analysis. These were: average temperature during the month (TEMP); number of hours in which the temperature dropped below 32°F (COLD); number of days in which the temperature exceeded 95°F (HOT); average humidity during the month (HUMID); and precipitation, during the month (RAIN).

The data originated with the National Climatic Center (NCC), which is part of the National Oceanic and Atmospheric Administration. Humidity and the number of days with extreme temperatures were obtained from NCC data which includes hourly and/or three-hour observations of temperature, humidity, and cloud conditions. All data available for the San Joaquin Valley were used. The NCC data are raw, rather than statistically processed, and there are missing and bad values. As a result, the number of stations with good data varies sometimes on an hourly basis. In order to ensure the best available data were used, spatial interpolation from the weather stations to the superquads was done for each hour, rather than simply interpolating monthly summary statistics.

Data on rainfall are not available for short time periods. "Cleaned up" data on daily and monthly rainfall and monthly average temperatures were also obtained from published NCC reports because the cleaned up data were felt to be more accurate than the raw values, and data are available for more stations. The cleaned up data showed a much higher correlation with known temperature gradients in the SJV than did the raw data.

4.3 FARM VARIABLES

This section discusses the remaining farm variables used in the analysis. Many farm practice variables which have been shown to affect crop yields were collected. The focus was to maintain a consistent approach for all crops. Generally if a variable could only be collected for a few crops in a few counties in a few years (such as pest losses, see below), it was not used unless in a specific year a specific crop was known to have experienced a particularly abnormal yield impact (see dummy variables).

Yields/Acre/Price

County-wide estimates were used for crop yields per harvested acre (YIELD), total harvested acres (HACRE) and price per ton (PRICE), as provided in the annual reports of the county agricultural commissioners. It should be noted that these yield-per-acre estimates are based on local surveys which are at times unscientific in nature and may have substantial measurement error. This is reflected in the cotton data where there also exist county-specific yield-per-acre estimates for each year from the U.S. Department of Agriculture (USDA) Bureau of Economic Analysis. The USDA estimates use a different approach by estimating state-wide control totals and disaggregating to county estimates. It is interesting to note that the county agricultural commissioner (CAC) and USDA estimates vary dramatically for any one county and year. The average absolute value of the differences between the USDA and CAC estimated per-acre cotton yields (by county, by year) is 8.3 percent. This uncertainty, or measurement error, in the yield estimates need not bias the estimated air pollution yield relationship (unless the measurement error is actually or spuriously correlated with the air pollution measures) but will make it all the more difficult to accurately detect and measure already small or imprecise relationships between air pollution and crop yields.

It would have been desirable to have subcounty yield data to more accurately correlate yields with air pollution readings, but this was not possible. There were several potential sources of such data, including the county farm advisors and agricultural commissioners who estimate this information to make county-wide projections, however they do not retain the subcounty information. A second source was the Bureau of Reclamation (BOR), which surveys acres per crop, yield, and price for districts within their service area. There are two BOR service areas -- the North Valley (served by the Tracy office) and the Eastern Valley (served by the Fresno Valley office). The State of California Department of Water Resources conducts a similar survey for the western portions of the Valley served by the California Water Project.

The BOR indicated the primary use of the survey was to establish water demand estimates based upon crop-acres and acre-feet irrigation requirements. Consequently, the yield and price information is provided or collected for only a few districts. Data were analyzed for over 30 districts served by the Friant Kern Canal, which stretches from northern Madera County to southern Kern County. The results were discouraging. For nearly every crop the same yield value was reported for nearly every district. Consequently, the data exhibit less variation than the county-wide aggregate yield estimates for the same water-supply area. The question of data accuracy was compounded because the yield values reported in the districts with different yield values were often suspect for reasons that varied from crop to crop.

Fertilizers

Crop yields are influenced by nutrients occurring naturally in the soil and applied through fertilizers. The amount and balance of nutrients in the soil may also influence the yield impacts of air pollution (U.S. EPA, 1978; Setterstrom and Zimmerman, 1939). For example, a plant grown in an alkaline soil may actually benefit from SO_2 deposition. Estimates of fertilizer use in California are available for all fertilizers in each county and for selected crops statewide for a few years, but are not separately reported for individual crops within counties. Therefore, county-wide fertilizer application rates in each year for all crops have been used. This information was obtained from the California Department of Food and Agriculture, Fertilizing Materials reports.

There are limitations in the use of these county-wide measures. Differences in acreage by crop type across the counties or through time in any one county would change total fertilizer use rates without any reason to expect yield changes for any of the crops. Further, if farmers of each crop follow the recommendations of the crop advisory board or the county extension agents, one might expect little difference in fertilizer use rates across the counties in any one year, thereby limiting the ability of the statistical analysis to detect such effects. There is also a problem with multicollinearity across fertilizer measures. County-wide measures for the three most heavily used fertilizers -- nitrogen (N), phosphorus (P) and potassium (K) -- were obtained for each county for each year. Crop-specific values employ the county-wide totals divided by the acreage of each crop, to adjust for acreage changes. Table 4.5 presents common rates of application for N, P, and K for the study crops. The large difference in rates of application and the unknown sensitivity of each crop to changes in any one fertilizer suggests the use of county measures may be quite limited in accurately explaining individual crop yields. It is worth noting that the rate of application for these three fertilizers has been decreasing for all counties over the study period, even though yields have been increasing.

Table 4-5

San Joaquin Valley Fertilizer Use By Crop

Crop	Pounds/Acre - Common Rate of Application N	P_2O_5	K_2O
Alfalfa	20	84	25
Almonds	148	40	100
Cotton	98	44	167
Dry Beans	32	31	1
Grapes (wine)	66	18	215
Grapes (table and raisin)	57	17	35
Lettuce	153	98	70
Peaches	133	21	88
Potatoes	175	53	69
Oranges	110	23	23
Tomatoes	136	76	65
Statewide All-Crop Average	106	47	34

Source: "Survey of Fertilizer Use in California, 1973" Bulletin 1887, Division of Agricultural Science, University of California, Berkeley.

Productivity/Technology

With advancements in cultivar development, irrigation and planting practices, equipment efficiencies, etc. yields per acre can be expected to have increased over time. Quantifying each of these changes in the yield equation would be difficult, if not impossible. The U.S. Department of Agriculture has attempted to quantify indexes of technological productivity advances through time, relating output indexes to input indexes for all farm outputs. Unfortunately, technological advance has occurred at a very different pace for different farm outputs and the use of such an aggregate measure could not be expected to perform well in a crop-by-crop analysis, as found by Thanavibulchai (1979) who attempted this approach.

We have devised two alternative crop-specific measures. The first (PROD) is the U.S. crop output index by crop type (reported in USDA, 1981, Table 631) divided by total U.S. acreage for each crop type. Crop type categories included fruits and nuts, vegetables, hay and forage, and cotton. The coefficient for this variable should reflect general productivity trends so the regression constant and the coefficients for the remaining weather, air pollution and fertilizer variables reflect productivity growth differences among the SJV counties, and between the SJV and the nation. The second measure (PREMP) uses the USDA measure of U.S. crop output per labor-hour index (LAPROD) (reported in USDA 1981, Table 635) multiplied by county level man-weeks of preharvest labor per crop-acre in the SJV using California Employment Development Department reports on farm employment by crop. Due to the voluminous amount of these employment data and the aggregate categories used in the definitions, for consistency (there were three different reporting procedures in the 11-year study period), we sampled employment for the second week of each month for each year and county for cotton and vineyards. Preharvest employment only was used since harvest employment was expected to be a function of yields, not visa versa. Only vineyards and cotton had enough preharvest employment to be reported.

Capital and Labor

Sufficient data do not exist to measure crop- or county-specific capital input usage for each study year. Labor inputs per acre (EMP) were obtained from the California Employment Development Department for cotton and vineyards for each county and year. It should be noted that using a labor variable in the absence of a capital measure may give misleading results for the labor variable's coefficient because capital and labor and other factor input levels are, in equilibrium, jointly determined by their marginal physical productivity and factor prices such that the ratio of marginal physical product of an input to the price of the input is equal across all inputs. However, if the labor variable is uncorrelated with the air pollution variable, and its inclusion reduces the imprecision of the equation, its inclusion also increases the precision of the air pollution coefficient.

Machinery input measures are not readily available for California agriculture. Therefore, the USDA Pacific Region machinery and labor inputs for all crops were divided by all crop acreage in the region to define regional average labor (LABOR) and machinery (MACH) inputs per acre (USDA, 1983). These showed significant time trends, positive and negative, respectively, and were highly correlated with PROD.

Pest and Insect Losses

A substantial percentage of many crops are lost in any one year to pest and insect infestations. For example, pest infestations reduced alfalfa yields in 1978 by an estimated 33 percent (Calif. DFA, 1979). Unfortunately, estimates of these losses on a crop-by-crop, year-by-year, or county-by-county, basis are not available. The California Department of Food and Agriculture published reports on statewide crop losses from pests based upon casual surveys. In only one year were the estimates presented as percent loss by crop. In the other years estimated losses were reported by pest or insect. Because any one insect may attack a number of crops, there is no way to use the data in this analysis. There are also reports on the statewide use of pesticides, but they are equally difficult to use because of the sheer number of pesticides in use, their uncertain spacial distribution in use, and overlapping effects of any one pesticide on many pests and, therefore, many crops.

Soils

Soil type was frequently noted by county farm advisors and personnel within the California Department of Food and Agriculture or the USDA as an important determinant of crop yields (Storie and Weir, 1980). Unfortunately, soil data are too complex to use. Under certain assumptions, however, their omission may have a minimal effect on the analysis.

The primary soils index available in California is the "Storie Index," which provides a numerical measure of the relative degree or suitability of a soil for general agriculture. The rating is based on soil characteristics only, and is obtained by evaluating such factors as depth, texture of the surface soil, drainage, salts and alkali. Relief climate, availability of irrigation and the like are not considered. Soils are grouped by type and rated within that type. As shown in the USDA Soil Conservation Service Soil Survey Reports (1971), soil differences can result in up to a 100 percent difference in yield rates for the study crops.

The appropriate soil measure would be, for each crop and within each county, an average of the soil value weighted by the amount of each crop planted in each soil type. For example, in the Soil Survey: Eastern Fresno Area (USDA, 1971), which covers roughly the eastern third of the county, there are about 350 mapping units with individual soil classification segments ranging from 1/16 to over five square miles. To obtain the soil values for this area would have required coding 104 maps with an average of 150 soil segments and correlating this to the crop location data. When extended to the whole Valley the task is clearly formidable and, for this reason, was not undertaken.

The elimination of the soil variable increases the imprecision in the production/damage function estimation, but may not be a severe problem. If the differences in soil type by crop across counties are uncorrelated with air pollution readings, as one might expect, the air pollution yield relationship will not be biased by the omission of this variable. Further, soil classifications can be expected to be relatively constant across time and any one crop is likely to be primarily planted in the same soil types in each county, thus minimizing the influence of soil variations in the analysis.

Dummy Variables

Dummy variables are introduced into the analysis when there is a specific reason to expect that important variations in yields may have occurred, but are not being captured by the other variables in the production/damage function. For example, a year with early damaging spring rains but a drier summer causing the seasonal precipitation value used in the analysis to appear normal, could be captured through the use of a dummy variable. Another example is that differences in crop varieties or growing conditions across counties could result in different per-acre yields and could be accounted for with county dummies. The danger here is that the use of county dummy variables may capture, and therefore obscure, the measurement of air pollution effects, as well as reduce the degrees of freedom in the analysis.

The definitions of dummy variables tested in the analysis are included in Table 4-6. These were determined through background research on the study crops, counties and years and through examination of the yield data. The reasons for their use are described for each specified crop analysis in Chapter 6.

Table 4-6

Regression Variables

Variable Name	Source	Explanation
COUNTY		1 = Fresno, 2 = Kern, 3 = Kings, 4 = Madera, 5 = Merced, 6 = San Joaquin 7 = Stanislaus, 8 = Tulare
YEAR		1970 - 1981: Code as 70-81
YIELD	1,2	Yield per harvested acre in tons
HACRE	1,2	Harvested acres
CHACRE		Change in harvested acres from the prior year
PRICE	1	Crop price per unit weight (generally tons)
APRICE	1,4	Real crop prices: PRICE divided by an index of prices paid by farmers for all production commodities
N	3	Nitrogen, 10^3 tons. Amount used in the county and year.
P	3	Phosphorous, 10^3 tons. Amount used in the county and year.
K	3	Potassium, 10^3 tons. Amount used in the county and year.
PROD	4	U.S. output index divided by crop harvested acres (10^6).
03AVE	5	Sum of the monthly mean 0_3 level during the growing season.
03GE10	5	Sum of the hours over the growing season with $0_3 \geq 10$ pphm.
03DOS	5	Total dose over the growing season for hours with $0_3 \geq 10$ pphm.
036E6	5	Sum of the hours over the growing season with $0_3 \geq 6$ pphm.
SO2AVE	5	Sum of the monthly mean SO_2 level over the growing season.
SO2GE10	5	Sum of the hours over the growing season with $SO_2 \geq 10$ pphm.
SO2DOS	5	Total dose over the growing season for hours with $SO_2 \geq 10$ pphm.
TEMP	6	Sum of the monthly average temperatures over the growing season months.
COLD	6	Number of hours with TEMP 32^oF. over the growing season.
HOT	6	Number of days in which temperature exceeded 95^oF during each month.
HUMID	6	Average monthly relative humidity.
RAIN	6	Monthly average daily precipitation summed over the growing season months.
LABOR	4	Farm labor index per acre - Pacific Region.
MACH	4	Mechanical power and machinery index - Pacific Region.
EMP	7	Man-weeks per acre of non-harvest labor for cotton and vineyards.
PREMP		Labor productivity per acre = EMP x LAPROD.
LAPROD	4	Index of production per labor hour for U.S. fruits, nuts, and cotton.
Y70-Y81	8	Yearly dummy variables. For example, Y78 = 1 if year = 1978; Y78=0 otherwise.
C1-C8	8	County dummy variable. For example, C1 = 1 if Fresno County; C1 = 0 otherwise.

SOURCES:

1. County Agricultural Commissioner Annual Reports.
2. U.S. Department of Agriculture, Bureau of Economic Analysis.
3. California Department of Food and Agriculture.
4. U.S. Department of Agriculture.
5. California Air Resources Board, as refined. See Chapter 4.2.
6. National Oceanic and Atmospheric Administration.
7. California Employment Development Department.
8. ERC telephone surveys of farmers, county extension agents, and crop specialists in state government and university systems.

4.4 ECONOMETRIC PROCEDURES

With ten crops, several ozone and SO_2 measures, and the large number of potential functional form specifications, it was not possible to test every possible variation with every crop. Therefore, initially a basic specification using each of the ozone measures and two different functional forms were estimated for each crop. In addition to the pollution variables, the independent variables used in the basic specification were HACRE, APRICE, N, P, K, PROD, TEMP, COLD, and RAIN. Refinements of the basic specifications depended on these first estimation results and on the characteristics of the specific crop. Important considerations in this first step of the yield function estimations included:

- Differences in the results with the use of different air pollution measures.
- Implications of the appropriate functional form for the yield equation.
- Indications concerning the potential usefulness of dummy variables.

Ozone Measure

Each of the four ozone measures (O3AVE, O3GE6, O3GE10 and O3DOS) is a different characterization of the O3DOSE ambient ozone conditions to which plants respond. It is not clear that one measure need be any better than the others (see Appendix A.2). O3AVE will reflect changes in the mean ozone values over the entire range of pollution levels but may not capture differences in the variance or distribution of ozone levels. For example, a month with some very high and some very low ozone levels could have the same average as a month with all intermediate levels, but if the crop is particularly suspect to high ozone levels, this will not be accurately captured with O3AVE. The number of hours above a threshold measure might better capture ozone levels that are the most damaging to crops, but this ignores the distribution of the hours above the threshold and all variations in ozone below the threshold. Appropriate threshold levels are also not well established. The dose measure attempts to incorporate both the threshold and by how much the threshold was exceeded, but these measures are again subject to the selection of the appropriate threshold and to variations in the response to different ozone levels lost in the summarization process.

The use of different ozone measures, even if highly correlated, will affect the estimated regression coefficients or elasticities for comparison. The elasticity is the percentage change in yields for a given percentage change in ozone. For the same change in air pollution conditions and the same change in yields, the estimated elasticity using O3AVE will exceed the elasticity using a threshold measure. The threshold measures reflect changes in the tail of the ozone distributions. A small percentage increase in the mean of the distribution of ozone exposure could be associated with a large percentage increase in the number of hours in excess of a threshold.

Another point often overlooked in previous air pollution crop damage studies is that because the distribution of the hourly ozone observations is either lognormal (or normal), the functional form relating yields to one ozone measure infers specific characteristics of the yield relationship using other ozone measures. For example, a linear relationship between yield and O3AVE implies the relationship between yield and O3GE10 is curvilinear with decreasing marginal damages as pollution increases (Panel 6 - 1a). This does not seem consistent with results reported in the chamber study literature. On the other hand, a linear relationship between yield and O3GE10 implies a curvilinear relationship between yields and O3AVE, and visa versa (Panel 4-1b), which seems closer to in keeping the chamber study literature.

Yield Equation Functional Forms

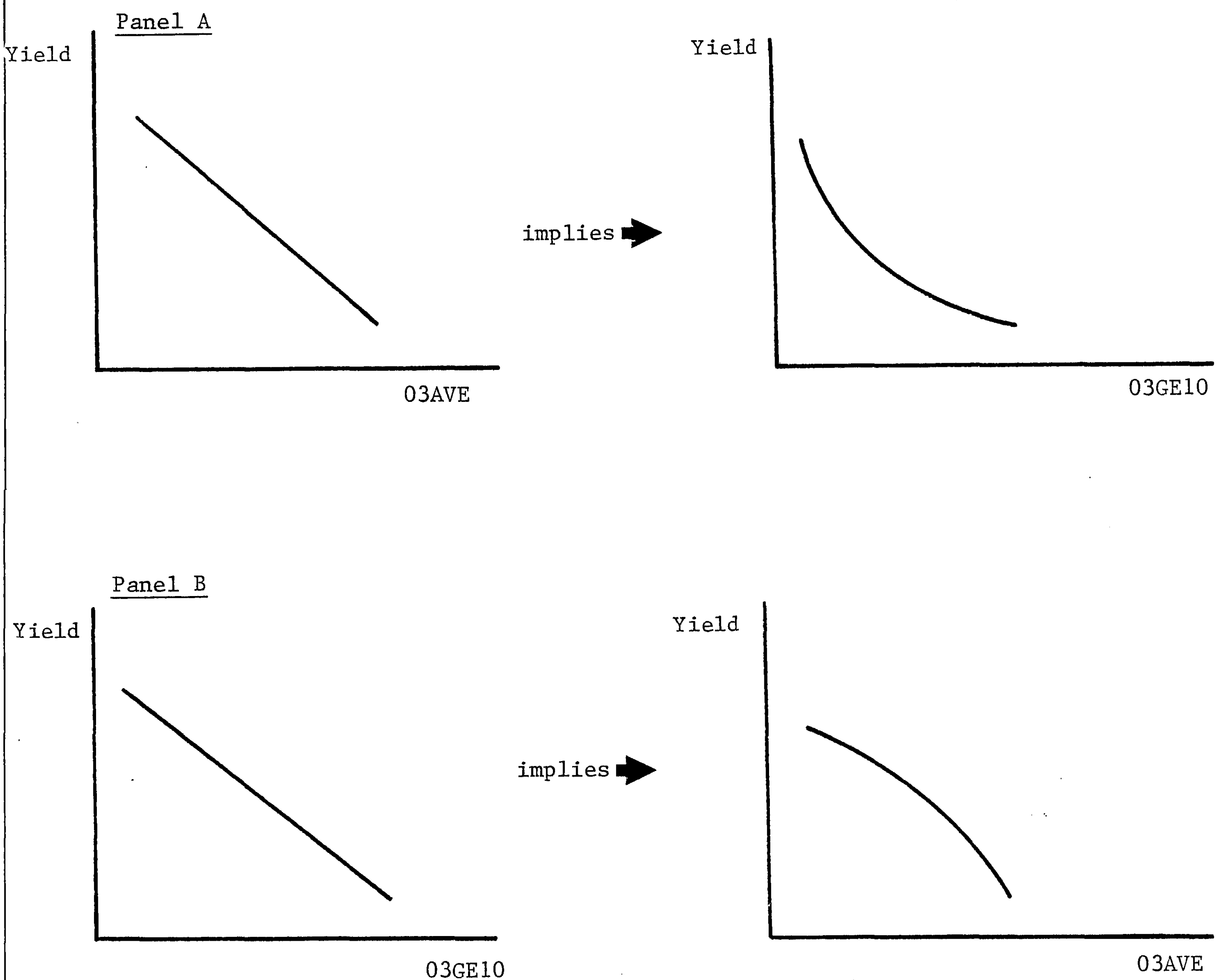
There are important economic implications of alternative functional forms for estimating the yield equation. Assume the yield equation for Crop 1 to be of the form:

$$Y1_{it} = Y1(AP_{it}, X_{it})$$

where $Y1_{it}$ and AP_{it} are the yield and air pollution variables for Crop 1 at location i in time period t; X_{it} represents other variables in the yield equation. By hypothesis, the marginal impact of air pollution upon crop yields, $\partial Y1_{it}/\partial AP_{it}$, is negative. There are two additional concerns about the properties of this function; whether the marginal impact of air pollution is independent of other yield function variables, and how the marginal impact of air pollution changes as air pollution increases, which is measured by the second derivative, $\partial^2 Y1_{it}/\partial AP^2_{it}$. It is hypothesized that the second derivative may not be zero, implying that marginal damages change (become more or less severe) as air pol-

Figure 4-1

Implicit Relationships Between Yields and Ozone Measures



lution increases. To test this hypothesis, initial function forms tested must be flexible enough to allow the second derivative to be positive, negative, or zero as the data may reveal.

The functional forms considered in this analysis are given in Table 4-7. Forms (2) and (5) were used in all initial evaluations described above and in testing the second derivative hypothesis. Forms (1) and (4), which are special cases of Forms (2) and (5), and Form (3) all restrict the second derivative and were evaluated if the initial analysis suggested they might be appropriate. Estimation with more detailed and flexible functional forms such as Box Cox Transformations, exponential, semi-log exponentials, and Weibull, did not appear to be warranted (see results in Chapter 6).

The choice of functional forms used for the final yield change estimates was based upon the statistical power of the equation, reflected by the R^2, t-tests for the coefficients, etc., and whether the estimated coefficients and relationships reflected those expected from the review of plant physiology and previous economic studies (see Appendices A1 and A2.)

Other Specifications and Tests

To test for a cumulative effect of several years' air pollution upon a specific year's yield for the perennial crops (grapes, oranges, peaches, almonds), distributed lag models relating current yields to current and prior year pollution levels were tested. It was hypothesized that pollution in each preceding year would have a declining effect on yields. This would allow the use of a simple Koyak model.

Tests were made concerning potential interaction of O_3 and SO_2 by adding an O_3 x SO_2 variable. This test was constrained by the relatively few non-zero observations for SO_2, as is discussed in Chapter 6.

Other adjustments were also considered as seemed appropriate when the initial estimations did not show significant results. These included weighted least squares, weighting high-acreage counties more heavily than low-acreage counties on the hypothesis that the residuals of counties with low acreage in a crop would show higher year-to-year variations (heteroskedasticity). This could occur in low-acreage counties where the addition of one farm in the planting of the crop could greatly change average county wide yields.

Table 4-7

Alternative Functional Forms

	Yield Function[1]	Interaction of Air Pollution and Other Variables	Sign of Second[4] Derivative for Air Pollution Variables
1.	Linear $Y = Bo + B_1\ AP + B_2Z + E$	Yes[2]	Zero
2.	Quadratic $Y = Bo + B_1\ AP + B_2Z + B_3AP^2 + B_4Z^2 + E$	Yes[3]	Positive for $B_3 > 0$ Zero if $B_3 = 0$ Negative for $B_3 < 0$
3.	Log $Y = BoAP^{B_1}Z^{B_2}e^E$	Yes[3]	Positive
4.	Semi-Log $Log\ Y - Bo + B_1\ AP + B_2Z + E$	Yes[3]	Positive
5.	Quadratic Semi-Log $Log\ Y = Bo + B_1AP + B_2Z + B_3AP^2 + B_5Z^2 + E$	Yes[3]	Positive for $(2B_3AP + B_1)^2 + 2B_3 > 0$ Zero for (.) = 0 Negative for (.) < 0

NOTES:

1. For selected crops: Y = yield; AP = air pollution measure, measures for both SO_2 and O_3; Z = other variables; E = error terms. All equations estimated for years 1970-1980 and for up to eight San Joaquin Valley Counties.
2. Add terms B_3AP*Z, where Z is the other air pollution measure or other explanatory variable.
3. Same as Note 2; quadratic interaction terms are possible, but to limit the analysis are not considered.
4. Assuming $B_1 < 0$, as is hypothesized.

This would be less likely in counties with higher crop acreage. Additionally higher ozone thresholds for some crops were also explored on the hypothesis that the lower ozone levels had no effect on crop yields and might be obscuring a statistically significant relationship in the higher ozone levels. These additional thresholds were examined by limiting the analyses to those observations above a certain level, such as where the seasonal O3AVE is equal to or greater than 5.5 or where O3GE10 is equal to or greater than 50 hours over the course of the season, etc.

The ozone measures were also separated into measures for the early, middle and late parts of the growing season to see if any of these might better explain the measures covering the entire growing season. This makes it possible to test whether ozone is more detrimental in the early, middle or late growing season.

It is possible that in using pooled time series and cross-sectional data, some special statistical problems may arise. One is that there may be serial correlation in the error terms within counties. The effects of this are that the coefficients estimated with ordinary least squares are still unbiased but inefficient, while the estimated variances and, therefore, t-tests and confidence intervals are biased. It may also be the case that the coefficients or the variances of the errors are not constant across counties. These types of problems were examined for the final specifications.

Any observations with missing values for the yield or air pollution variables were dropped. The 1981 value of PROD was the only other missing value. It was replaced with a first-order replacement technique using a time series of the previous observations to predict this value.

Measurement error between the actual value and calculated values exists to some degree in each of the variables used in the analysis due to imprecision in scientific measuring devices, survey techniques, and interpolation schemes used to obtain the calculated values. Except where specifically noted otherwise, measurement error is assumed to be random with a zero mean and an unknown, but constant variance, because there is no evidence to make other more exact assumptions. The two yield-data sets (County Agricultural Commissioners and USDA) available for cotton give one test of the potential effect of one type of measurement error on the robustness of the estimated air pollution yield relationships.

A summary of the hypotheses tested is presented in Table 4-8.

4.5 THE EFFECTS OF MITIGATING FARM BEHAVIOR ON YIELD EQUATION ESTIMATES

For each of the selected crops, the yield equations attempt to estimate the partial relationship between the change in air pollution, AP, and the change in crop yield per acre, Y_i (for all i = 1, 2, ..., 10 crops): $\partial Yi/\partial AP$. However, the observed yield values, Yi*, may also reflect the influence of changes in farm practices to mitigate the effects of air pollution. For example, different combinations or levels of inputs may have been utilized to offset the air pollution induced yield reduction when these practices were cost effective. For example, more fertilizer may have been used to increase yield. If inputs were adjusted, this effect should ideally be captured by a regression analysis which included input variables; otherwise, the yield damages of air pollution are understated.

Air pollution induced changes in input usage are generally not captured in yield equations, as few inputs were incorporated in the equations due to the limited availability and accuracy of input data on a county-wide basis. Because farmers will likely only want, or be able to partially mitigate air pollution through changes in inputs, this effect upon input usage should be small and difficult to separate from other agricultural practice changes also embodied in the data. We have come across no verified analyses concerning the mitigation of air pollution impacts through input usage, other than through the development of resistant cultivars. Therefore the magnitude of this effect on the analysis is unknown; although the direction of the effect on the economic estimates is to understate the benefits of improved air quality.

Table 4-8

Summary of Hypotheses Tested

Hypotheses Description	H_o (Null Hypothesis)	H_a (Alternative Hypothesis)
1. Increasing air pollution decreases crop yield (Y = yield; AP = O_3 and/or SO_2)	$\partial Y / \partial AP = 0$	$\partial Y / \partial AP > 0$
2. Marginal damages change as air pollution increases	$\partial^2 Y / \partial AP^2 = 0$	$\frac{\partial^2 Y}{\partial AP} \neq 0$
3. Other factors (Z) influence yield.	$\frac{\partial Y}{\partial Z} = 0; \frac{\partial^2 Y}{\partial^2 Z} = 0$	$\frac{\partial Y}{\partial Z} = 0; \frac{\partial^2 Y}{\partial^2 Z} \neq 0$
4. SO_2 and O_3 have a synergistic effect on yields.	$\partial^2 Y / \partial O_3 \, \partial SO_2 = 0$	$\partial^2 Y / \partial O_3 \, \partial SO_2 \neq 0$
5. Air pollution in previous years influences current yields for perennial crops.	$\partial^2 Y_t / \partial AP^2_{t-a} = 0$	$\partial^2 Y_t / \partial AP^2_{t-a} \neq 0; a = 1, 2, \ldots$
6. Errors in the equation are distributed with classical linear regression model assumptions (t = 1-12 years, i = 1-8 counties).	$E(E^2_{it}) = \sigma^2 \; \forall i, t$	$E(E^2_{it}) = \rho\sigma^2_{i,t-1\,j}\; i=1,12$ and/or $E(E^2_{it}) = \sigma^2_i;\; i=1,\ldots 12$

5.0 CROP SUBSTITUTION AND WELFARE LOSS ESTIMATION

5.1 INTRODUCTION

The California Agricultural Resources (CAR) model is used in this analysis to estimate the economic surplus measures associated with the effects of changes in air pollution on agriculture. This model has been developed and maintained by the Giannini Foundation and is run at the University of California at Davis. This mathematical programming model allows assessment of crop price and quantity effects from air pollution impacts within a supply and demand framework such as used by Adams et al. (1982), Leung et al. (1981, 1982), MathTech (Manual et al. 1981), and Smith and Brown (1981) . (See Appendix A1 for a review of these studies and the importance of using theoretically correct economic models.) This approach has the added benefit of allowing the determination and inclusion of mitigating behavior by farmers in terms of crop substitution effects using estimated production and cost functions for over 40 crops in 14 California study regions.

5.2 SELECTION OF THE CAR MODEL

An optimization model that represents crop production costs and alternatives is needed to account for potential mitigating behavior by farmers, and to determine the aggregate economic welfare effects from air pollution-induced changes in crop yields. The criteria used in selecting such a model is its calibration to the specific costs and practices of central California agriculture and the supply and demand conditions of the California crops under analysis, and that it can be easily available and adaptable to the present study. Two such candidate models were available -- the CAR model and the linear programming model of California developed and maintained by the U.S. Department of Agriculture and the California Department of Water Resources. One could, of course, develop an entirely new model, however it is unlikely such a model of supply and demand conditions, farm costs and agricultural practices could be developed in a short period of time and such that it would match the professional defensibility of those models continuously developed by the University of California and government researchers over a ten-year period. Development of such a new model seemed unwarranted and is beyond the scope of this project.

Additional selection criteria focused on the theoretical and methodological strengths and weaknesses of the two approaches considered. The quadratic programming (QP) approach employed by the CAR model appeared superior to the linear programming (LP) approach for modeling farmer behavior for this analysis for the following reasons.

- Risk can be incorporated into the analyses, allowing relaxation of the typical LP model assumption of risk indifference for all producers.

- Use of a quadratic rather than linear programming approach allows endogenous solution of both market prices and quantities for each crop. The approach often used in previous air pollution analyses was to estimate the yield reduction caused by air pollution and multiply that quantity by an invariant price (e.g. Benedict et al., 1971; Shriner et al., 1982). The CAR model approach explicitly incorporates the impact of yield reductions induced on supply, such as those arising from air pollution-induced yield changes, and the resulting effects upon equilibrium market prices and quantities.

- The objective function in the QP, as will be discussed in the following section, is equivalent to maximizing consumers' surplus and producers' surplus. This objective function lends itself to analyzing the economic welfare effects of air pollution on crops.

All crops included in this study were incorporated into the CAR model, so no expansions were required, and the model was already defined for study regions well suited to our analysis. Consequently, the CAR model was a cost-effective approach to analyzing farmers' responses and market supply and demand conditions to accurately estimate economic welfare measures for our study crops and regions. In addition, the CAR or analytically similar models have been used effectively for related air pollution-yield economic analyses (Adams et al. 1982). The CAR model is also being used in a similar EPA/NCLAN-sponsored study for selected annual crops in California (Howitt et al., in progress).

5.3 STRUCTURE OF THE CAR MODEL

The CAR model was originally developed by Adams (1975) to study the effects of energy price increases on California agriculture. This section summarizes the assumptions, structure, and data sources that underpin this model.

The general structure of the model is a constrained quadratic programming model with 14 production areas covering the entire state of California, each with two irrigable soil types.* At present, more than 40 annual and perennial crop activities are included, with some crops having multiple activities (e.g. dryland vs. irrigated). For each crop, there is a linear demand function relating the price received by California producers to the quantity of production in California. The constant term in the demand function is adjusted to allow for production in the rest of the U.S. and for demand-shift factors, such as income growth and changes in exports. For each producing activity, there is a variable cost coefficient which is generated from a set of input coefficients and input prices. For each activity, there is also an explicit cost coefficient for several scarce or fixed resources -- land, water, energy, labor and fertilizer. The quadratic objective function is maximized according to regional or statewide constraints on the availability of the fixed land resources.

The CAR model is an expectation model that attempts to predict acreage and market conditions under alternative yield scenarios and the assumption that the objective function is attempted to be maximized (producers and consumers attempt to maximize their surpluses) subject to constraints. The model is currently calibrated to predict expected conditions in 1978 under alternative yield scenarios. The current demand equations are estimated with data for 1969-1978. Base yields use a 1977-1979 average to smooth unusual yields in any one year. Base prices use existing 1978 prices and quantity demanded.

* This discussion of the CAR model is taken from personal communication and an unpublished memo, "California Agricultural Resources Model," provided by Richard Howitt, University of California Davis, dated 1982.

Mathematical Statement of the Model

The structure of the CAR model assumes the crop markets operate in a manner which can be stated in the following mathematical form. Equation (5-1) is the objective function to be maximized subject to the constraints in Equation (5-2).

$$\text{Max } \pi = q'(c + \tfrac{1}{2} Dq) - q^{*\prime}(k^* + \tfrac{1}{2} I^* q^*) \qquad (5\text{-}1)$$

$$q_j = \sum_{j=1}^{14} a_{ij} q^*_{ij}, \qquad j = 1\ldots N \text{ crops}, \quad i = 1\ldots 14 \text{ regions}$$

Subject to:

$$Aq^* \leq b \qquad (5\text{-}2)$$
$$q \geq 0, \; q^* \geq 0$$
$$q^* \leq q^0$$

Where:

- o q is a (N x 1) vector of statewide crop quantities (NCROPS)
- o q^* is a (14N x 1) vector of regional cropping acreage.
- o q^0 is a (N x 1) vector of actual base year regional crop acreages.
- o a_{ij} is the regional per-acre yield coefficients for region j and crop i.
- o c and D are elements of the linear demand structure of the form $P = c + Dq$ where P is a (N x 1) vector of prices, c is a (N x 1) vector of intercepts and D is a (N x N) negative diagonal matrix of price-quantity slope coefficients (implying zero cross-price elasticities at the farm level).
- o k^* is a (14N x 1) vector of constant total variable costs per acre for each crop and region.
- o I^* is a diagonal matrix of quadratic regional variable cost coefficients.

- $Aq^* \leq b$ is the convex constraint set that bounds the objective function, where A is a (M x 14N) matrix of technical coefficients (A_{ij}) and b is a (M x 1) vector of regional resource availability levels.

- π is the sum of ordinary consumers' surpluses and producers' surpluses (Takayama and Judge 1971, p. 108). Differences between ordinary and compensated consumers' surpluses are assumed to be insignificant, since income elasticities and consumers' surpluses or expenditures as a percentage of income for the study crops are not likely to be large (Willig, 1976).

A common shortcoming of linearly constrained models is that a complex and rigid constraint structure is needed to approximate the regional crop production equilibrium observed in practice. The CAR model incorporates a regional crop supply function which is based on the assumption of a quadratic production function in land for each regional cropping activity, with Leontief fixed proportions for the other inputs. Given the varying yield across soil types and regions in California, this specification is justified. The quadratic cost function that results from the quadratic production function can be estimated, subject to the other resource constraints, from the necessary conditions and the regional crop production acreages observed over several years. Specific details of the empirical and theoretical basis of this approach, termed "positive quadratic programming" may be found in Howitt and Meau (1983).

An advantage of the positive quadratic approach is that the model closely reproduces the observed crop acreages in the base year, without the addition of spurious constraints. The absence of empirically unjustified constraints enables the model to react on the basis of changed comparative advantage to ozone induced yield changes. Thus, as the comparative advantage of regions, crops and inputs change due to changes in ozone levels the cropping patterns respond. This approach allows regional and intra-regional changes in cropping patterns to occur.

The positive quadratic programming approach estimates a cost function for each regional crop that is implied by the first-order conditions required to ensure a maximum of the objective function at the observed crop acreage levels. The marginal implicit cost function then becomes the regional crop acreage supply function.

Crops and Production Regions. The current version of the CAR model includes more than 40 crops grown in California. These crops are listed in Table 5-1. The 1978 prices and quantities produced for the primary study crops are listed in Table 5-2. The CAR model separates California into fourteen homogeneous production regions. These regions are defined on the basis of similarities among production characteristics--climate, soil, and water availability and costs. The fourteen production regions are illustrated in Figure 5-1.

Model Optimization

The model allows for the optimization of by changing the percent of available acreage that is cultivated in each region, by adjusting the mix of crops, and by accounting for cost and market effects of these acreage and production changes. However, the rate of change in perennial crop acreage is usually constrained not to exceed a certain percent (see Section 5-4 below). The current version of the model changes all inputs in direct proportion to the amount of acreage under cultivation by crop type.

Demand Relationships

Linear price forecasting equations, which are inverse demand functions, are estimated for each of the crops in CAR model. These functions are of the following general form:

$$P = c + Dq \tag{5-3}$$

where P is a (N x 1) vector of prices, c is a (N x 1) vector of constants, D is a negative diagonal matrix of price-quantity slope coefficients, and q is a (N x 1) vector of quantities. The diagonal D matrix implies zero cross-price elasticities for competing commodities at the farm level. Estimates of cross-price elasticities were attempted, but never found to be statistically significant in the specifications of demand for California crops.

Table 5-1

Crops Included in the California Agricultural Resources Model

1.	Alfalfa hay	23.	Lemons
2.	Alfalfa seed	24.	Lettuce
3.	Almonds	25.	Nectarines
4.	Apples	26.	Onions - dry
5.	Apricots	27.	Oranges
6.	Asparagus	28.	Pasture - irrigated
7.	Avocados	29.	Peaches
8.	Barley - dry land	30.	Pears
9.	Barley - irrigated	31.	Plums
10.	Beans - dry	32.	Potatoes
11.	Broccoli	33.	Prunes
12.	Cantaloupes	34.	Rice
13.	Carrots	35.	Safflower
14.	Cauliflower	36.	Silage - corn
15.	Celery	37.	Strawberries
16.	Corn - field	38.	Sugar beets
17.	Grain hay	39.	Tomatoes - fresh
18.	Grain sorghum	40.	Tomatoes - processed
19.	Grapefruit	41.	Walnuts
20.	Grapes - raisin	42.	Wheat - dry land
21.	Grapes - table	43.	Wheat - irrigated
22.	Grapes - wine		

Table 5-2

Primary Study Crop 1978 Statewide Production and Prices Used in the CAR Model

Crop	Units	Quantity	Price ($)/Unit
Almonds	Tons	1,75,059	1955.50
Table Grapes	Tons	505,842	233.56
Raisin Grapes	Tons	1,992,389	153.04
Wine Grapes	Tons	1,739,513	206.61
Oranges	Tons	1,584,646	130.98
Peaches	Tons	810,617	144.75
Lettuce			
Winter	Cwt	9,477,275	8.75
Spring	Cwt	14,009,240	8.75
Summer	Cwt	14,967,890	8.75
Fall	Cwt	9,821,239	8.75
Potatoes			
Winter	Cwt	1,027.670	6.97
Spring	Cwt	9,273,640	6.97
Summer	Cwt	2,011,368	6.97
Fall	Cwt	5,581,832	6.97
Tomatoes, Fresh			
Spring	Cwt	1,662,641	24.95
Summer	Cwt	5,297,688	24.95
Fall	Cwt	3,069,617	24.95
Tomatoes, Processed	Tons	5,708,293	61.75
Alfalfa Hay	Tons	6,654,574	77.44
Dry Beans	Cwt	3,888,561	32.61
Cottons	Lbs	1,486,819,000	0.70

Figure 5-1

CARM Regions in the California Agricultural Resources Model

Farm level price equations (or inverse demand equations) are used to forecast prices for each commodity. For each crop, the general specification of the price-forecasting model is as follows:

$$P_{c_i} = f\,(q_{ci}, q_{oi}, q_{si}, Y) \qquad (5\text{-}4)$$

where:

P_{c_i} = seasonal average price received by farmers in California for commodity i,
q_{ci} = seasonal production, California,
q_{oi} = seasonal production, rest of U.S.,
Y = U.S. aggregate disposable personal income,
q_{si} = substitute crop production quantity.

For most crops (particularly vegetables), it is assumed that the current year's production is not affected by current values of the other variables in the same equation. Quantity is then used as an independent variable to forecast price. For some crops, such as processing tomatoes and citrus, institutional arrangements suggest simultaneity between current price and quantity. Thus, single-equation estimates are possibly biased. For these crops, price forecasting equations are derived from detailed demand studies for each crop.

Additional possible limitations in the demand analyses include the use of linear rather than non-linear functional forms, and the omission of lagged prices and current period cross-price effects. The evidence, however, suggests that cross-price effects are weak and that lagged prices more typically affect current period supply rather than demand. The use of linear demand specifications will likely introduce little measurement error due to the small changes in output in this analysis relative to the national totals.

It is important to note that the price flexibility estimates in the CAR model are similar to those estimated in the literature, and are equal to or larger than those used by Leung et al. (1981) and Mathtech (1981) in similar analyses. The effect of larger price flexibilities is to reduce the estimated benefits from reductions in air pollution; therefore, the estimates in this analysis will be conservative relative to the work of Leung et al.

Additional discussion and presentation of the most current demand relationships used in the CAR model for all crops is found in Auslam and Associates (1981).

The variables of income and U.S. production are not included in the CAR model and are constant for all scenarios examined with the model. The final versions of the price equations used in the model incorporate these national variables into the intercept using values for 1978. The final equations used in the model therefore are of the following form:

$$P_{ci} = a + b_1 q_{ci} + b_2 q_s \tag{5-5}$$

These price forecasting equations and 1969-78 price flexibility coefficients for the study crops are presented in Table 5-3. Price flexibility is the percentage change in price resulting from a one percent change in the quantity of the crop produced, and allows a faster comparison of relative price effects than comparing slope coefficients based upon different units of production (tons, bales, etc.).

Production Coefficients and Constraints

Constraints

Data specifying production activities by region and crop include: the regional constraints on land, water, and processing capabilities; yields and costs for regional cropping activities; and the input-output (technical) coefficients for each cropping activity.

The availability and use of land is the driving input or constraint. Land is divided by region into total and irrigable acreage. Irrigable land is defined as Soil Conservation Service (SCS), Type I and Type II soils not used or zoned for other purposes. Data sources include the USDA/SCS. The remaining inputs are changed in fixed proportions to the changes in acreage by the crop type. These inputs are used as follows:

- Water is divided into surface and ground water sources. Costs and availability of water by region are estimated primarily on the basis of information provided by the California Department of Water Resources and data from water districts in each region.

Table 5.3

Summary of Price Forecasting Equations for Primary Study Crops

Crop	Intercept: From Regression	Intercept: Adjusted[1]	California[2] Slope Production Coefficient	California[2] 1969-1978 Units	Price Flexibility	R^2
Almonds	845.89	1841.50	-3.1685	1,000 tons	-0.42	.33
Table Grapes	520.56	520.56	-0.6842	1,000 tons	1.42	.73
Raisin Grapes	129.28	280.18	-0.5322	10,000 tons	-0.67	.62
Wine Grapes	35.15	253.45	-0.5799	10,000 tons	-0.31	.85
Oranges						
Fresh	419.18	450.15	-0.2459	1,000 tons	-1.70	.92
Processed	131.45	114.78	-0.1315	1,000 tons	-2.33	.92
Peaches	121.53	215.59	-0.6846	10,000 tons	-0.41	.55
Lettuce	157.05	272.13	-0.4778	10,000 tons	-0.50	.46
Potatoes						
Winter	4.53	--	-0.6950	million cwts	-0.14	.24
Spring	5.50	--	-0.1480	million cwts	-0.31	.19
Tomatoes						
Fresh	293.31	659.35	-0.6052	1,000 tons	-0.47	.75
Processed[3]	68.00	68.00	-2.4800	million tons	-0.24	--
Alfalfa Hay	50,173.00	97.66	-5.3576	million tons	-0.56	.54
Dry Beans	37.82	36.73	-3.3878	million cwts	-0.36	.63
Cotton[4]	264.81	264.81	-4.3100	million bales	0.04	--

Source: Auslam and Associates (1981).

[1] The adjusted intercept is obtained by incorporating 1978 values for national income and production variables into the intercept.

[2] Coefficients and flexibilities are with respect to California production.

[3] Results from King et al. (1978). Actual regressions were not utilized as processed tomato prices and acreage are typically set by contract before planting.

[4] Price forecasting equations cannot be directly estimated due to a price-support allotment program in 1954-1972. Results derived following King et al. (1978).

- Energy use and farm cost (for each crop and region) are estimated for gasoline, diesel fuels, and electricity. These estimates are based on several sources, including current cost and rate data by crop and region.

- Nitrogen fertilizer applied to each crop and region is estimated using data from the California Department of Food and Agriculture.

- Labor requirements are obtained from the University of California Extension County Farm Advisors.

An additional implied constraint is that farmers are only allowed (modeled) to take short-run economic mitigating behavior in terms of selection of the amount and mix of crop acreage. Technological changes, such as different input combinations or the use of new crop varieties, are not incorporated. The effect of these constraints is to produce conservative benefit estimates from air pollution control, and overestimates of damages from increased air pollution.

Crop Yields and Cost Data

The final data required for the CAR model are information by crop and region on per-acre yields and production costs. Yields and costs vary across regions and between soil types.

The technical coefficient matrix (a_{ij}) provides estimates of physical input-output relationships for each crop by region. The primary sources of data for estimating these technical production coefficients are the annual county Agricultural Commissioners' Reports, which contain information on production yields by crop for each county. These data are checked with farm budget information generated by the University of California Agricultural Extension Service. Previous year yield and cost data are averaged between 1975 and 1977.

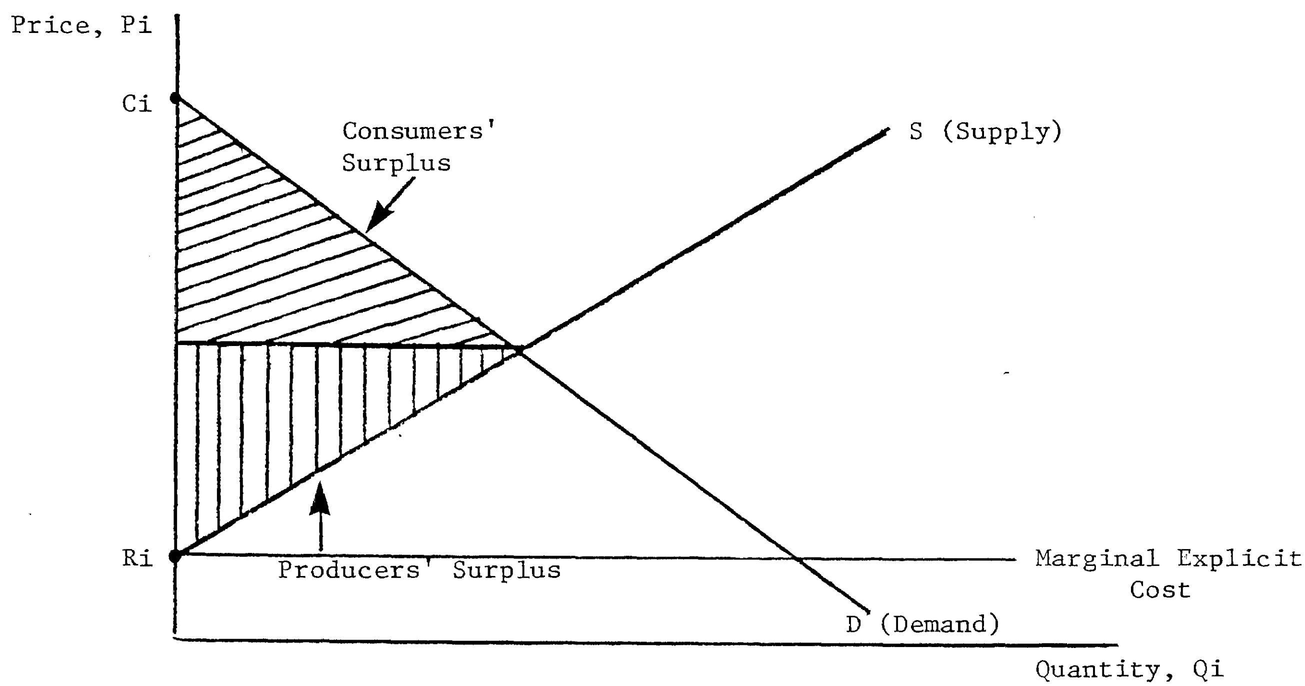
Production costs for each crop are based on University of California Agricultural Extension Service budgets. These budgets are available for geographical areas and, therefore, include regional differences in production costs.

Mathematical and Graphic Model Presentation

The graphical and mathematical representation consumers' surplus and producers' surplus specific to the CAR model is as illustrated in Figure 5-2 and Equations 5-6 - 5-12 (Howitt, 1982):

Figure 5-2

Consumers' Surplus and Producers' Surplus in the CAR Model



Where:

D (demand) is: $P_i = C_i + D_i q_i$ (5-6)

S (supply) is: $S_i = k_i + I_i q_i$ (the estimated marginal implicit cost functions aggregated over all regions)

Where:

$$k_i = \sum_{J=1}^{14} \frac{k^*_{ij}}{d_{ij}} \text{ and the } i^{th} \text{ diagonal element } j$$

I is defined as $l_{ii} = \sum_{i=1}^{14} e^*_{iij} \, a^2_{ij}$

It should be noted that the supply for crop i and base year quantity are both aggregated over all regions which grow crop i to simplify the graphical exposition. The actual computer model optimizes the regional supplies and acreages separately, subject to the aggregate statewide crop demand.

In addition, the demand function is modified by multiplyng the slope coefficient D by 1/2 to ensure that the equilibrium first order conditions are consistent with perfect competition.

The PQP objective function illustrated in Figure 5-2 is Equation 5-1, augmented by a weighted aggregation of the regional supply functions obtained from the estimated implicit cost functions.

$$\max \ \pi = q^1(C + 1/2Dq) - q^1(k + 1/2Iq) \tag{5-7}$$

The first order conditions for the unconstrained optimization of π satisfy the perfectly competitive equilibrium conditions:

$$\frac{\partial \pi}{\partial q} = 0, \text{ implies } c + Dq = k + Iq \tag{5-8}$$

or equivalently, price equals marginal cost.

Equation (5-7) can be rewritten for a particular crop i as:

$$\pi_i = q_i(c_i + 1/2\ D_iq_i) - q_i(k_i + 1/2\ I_iq_i)$$

$$= q_i(c_i + D_iq_i) - q_i(k_i + 1/2\ I_iq_i) - 1/2\ D_iq_i^2 \qquad (5\text{-}9)$$

The first right hand term at the optimum q_i is:

$$q_i(c_i + D_iq_i) = q_iP_i \qquad (5\text{-}10)$$

The second right hand term is:

$$k_iq_i + 1/2\ I_iq_i^2 = \Sigma_0^{q_i}\ k_i + I_iq_idq_i = \text{total cost of } q_i \qquad (5\text{-}11)$$

Therefore, the first two terms on the right side of (5-9) are Total Revenue at q_i - Total Cost at q_i = Producers' surplus at q_i.

The third term on the right side of (5-9) is:

$$-1/2D_iq_i^2 = 1/2q_i\ (-Dq_i) \qquad (5\text{-}12)$$

$$= 1/2q_i\ (c - c - Dq_i)$$
$$= 1/2q_i\ (c - P_i)$$
= Consumers' Surplus at q_i.

Thus the objective function maximizes the sum of consumers' and producers' surplus over all crops i = 1...N.

As the supply curve is shifted as a result of varying levels of air pollution, the objective function measures the changes in net welfare from the effect, and its distribution among producers and consumers.

5.4 APPLICATION OF THE CAR MODEL TO AIR POLLUTION ANALYSES

In order to assess the impacts of various levels of air pollution on equilibrium prices and quantities of the study crops, yield adjustment coefficients, as estimated in Chapter 6, are applied to each crop and region. The coefficients represent the percent change in the yield per acre of each crop in each region. The yield per acre value a_{ij} is therefore multiplied by $(1+p_{ij})$ where p_{ij} is the percent yield adjustment (such as 10 percent or - 10 percent). Because the model uses a quadratic cost function in crop acreage, this shifts the intercept of the marginal cost curve by:

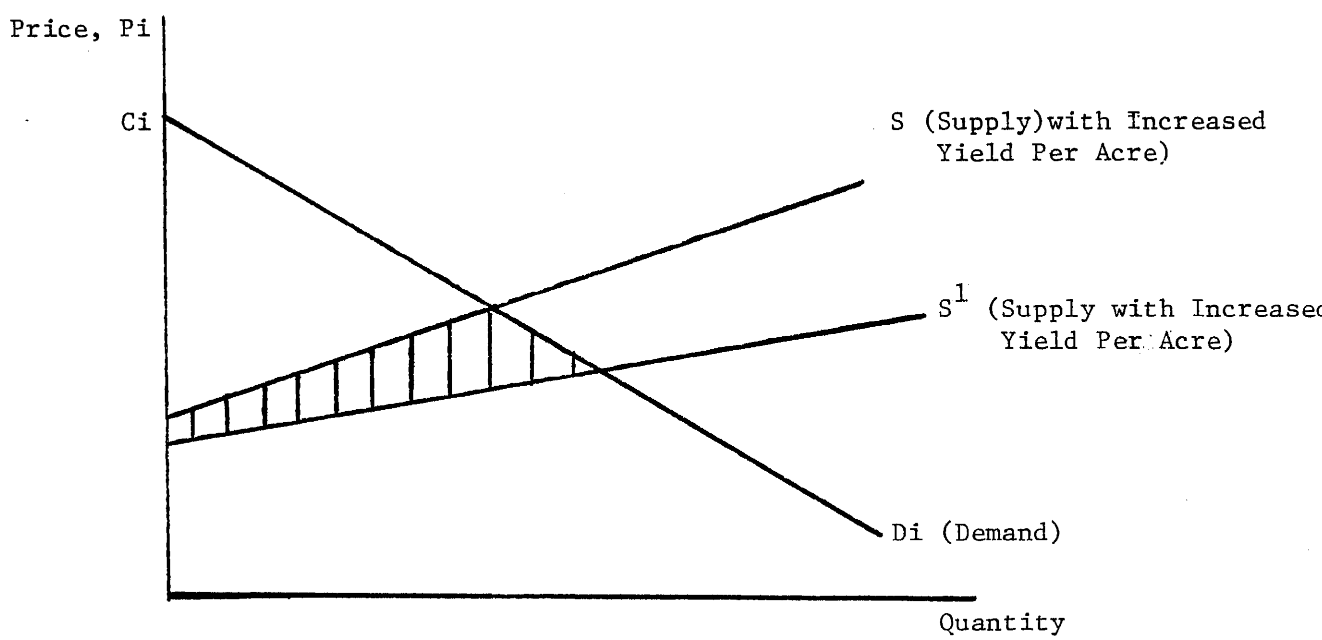
$\frac{1}{(1 + p_{ij})}$, and changes the slope by

$$\frac{1}{(1 + p_{ij})^2}.$$

The change in the marginal cost curve from S to S^1 is illustrated in Figure 5-3 for an increase in yield per acre (p_{ij} greater than zero), with the shaded area equal to the change in producers' and consumers' surplus.

Figure 5.3

Shift in the Supply Curve with Increasing Yields per Acre



These effects can be demonstrated in the mathematical model. Specifically, Equation 5-1 shows the total regional crop cost on a per acre basis, as:

$$q^* (k^* + 1/2\ I^* q^*)$$

If the approximate yield per acre coefficient for region j and crop i is a_{ij}, then the quantity produced from q^*_{ij} acres equals $a_{ij} q^*_{ij} = q_{ij}$. Thus, in terms of q_{ij} the quantity of regional supply, the regional supply function is:

$$q_{ij}(k_{ij} + 1/2\ l_{iij} q_{ij})$$

Where:

$$k_{ij} = \frac{k_{ij}}{a_{ij}} \text{ and } l_{iij} = \frac{l_{iij}}{a_{ij}^2}$$

As a_{ij} is adjusted by $(1 + p_{ij})$, k_{ij} and l_{iij}, the supply intercept and slope, are adjusted by $(1 + p_{ij})^2$.

Since the model has the statewide crop demand functions built into the objective function, shifts in the supply function will have both price and quantity effects statewide. The supply curve for most crops usually results from the production of five or more districts, some of which may be outside the San Joaquin Valley. Thus, the shift up in the state aggregate supply function will be proportionately less than the reduction in average San Joaquin Valley yield.

The analysis of each crop's price and quantity changes expected to result from yield reductions is complicated by the multiproduct nature of farm production, subject to a binding land input constraint. First order conditions for the optimal allocation of constrained land inputs among alternative outputs require that the marginal value product (MVP) of land is equal to its opportunity cost for all cropping activities. That is:

$$MVP_{land\ (i)} = MVP_{land\ (j)} = \text{opportunity cost/acre}$$

and prices for other affected crops would also fall. Consequently, the benefits experienced from improvements in air pollution only in the SJV, as estimated in this study, will overstate the benefits from air pollution improvements in the Valley if the whole state improves.

The difference in benefits from improvements in air pollution in the SJV need not be large under the two alternative air pollution cases (controls in the SJV only, versus the entire state). This is because air pollution levels are generally considerably lower in other agricultural regions, and the ability to substitute production from one region to another is as much limited by climate, soil and other conditions as it is by yield improvements from reduced air pollution. The South Coast Air Basin is the only area which grows similar crops and has higher air pollution levels. Yields could increase even more dramatically from air pollution improvements there than in the SJV. This would cause additional price decreases, however, due to the relative sizes of the markets, the additional price effect would not be as large as from improvements in the SJV. Also, because of acreage limitations in the South Coast Air Basin, acreage increases in this area would be limited. Therefore, the additional effects in the SJV from air pollution improvements throughout the state would be relatively small.

Benefits from air pollution improvements in the SJV alone will underestimate total benefits from air pollution improvements throughout the entire state. In particular, the potential magnitude of benefits that could be experienced from air pollution improvements in the South Coast Air Basin could dramatically add to the benefits estimated for the San Joaquin Valley.

Changes in crop yields per acre will change the marginal physical product for each crop due to both productivity and price effects. An exogenous increase in ozone will reduce both the average and marginal product of a crop given the quadratic production function which underlies the quadratic cost function. The productivity effect of an ozone increase reduces the MVP or marginal physical product is reduced, but the reduction in total product increases the price which tends to increase MVP. If the crop has a relatively high price flexibility, say 1.42 as for table grapes (Table 5-3), the positive price effect will eliminate the negative productivity effect and in the absence of crop acreage expansion, the relative MVP of table grapes will increase. In this situation, a yield depression over all the major producing regions could theoretically increase producers' surplus and decrease consumers' surplus. In this way the grower can mitigate the effects of ozone increases through economic shifts and effects.

In addition to price effects, growers will substitute increased acreage of the more profitable crops to offset ozone induced yield increases in all crops. This input substitution response may lead to reductions in acreage and total production of lower valued crops that exceed the total production increase in more profitable crops, even though the more profitable crops may have a much greater reduction in per acre yield from ozone.

5.5 APPLICATION OF THE CAR MODEL TO THE SAN JOAQUIN VALLEY

There are several issues that must be addressed, and assumptions that will be made when applying the CAR model to crop damages from air pollution in the San Joaquin Valley. These include additional constraints to be made in the analysis, how the study area will be defined, and the effects of analyzing air pollution changes in this one area versus the whole state.

For each alternative yield scenario in the SJV, the production coefficients are changed but the inputs on a per-acre basis are held constant, because to date there is no evidence of an interaction effect between ozone and fertilizer, pesticide, or water input levels. Thus, despite lowered yields and consequent increased costs per unit output, a profit maximizing farmer would not alter the previously optimal per acre application of other inputs. For the other ten CAR model regions outside the SJV, the ambient 1978 ozone level is assumed to remain unchanged.

For this analysis, additional constraints have been imposed on the programming model. First it was assumed the rate of change in acreage for any fruit and nut crop in any region will not be more than 10 percent. This is a short-run assumption because changes in growing conditions in one year are not likely to result in large-scale plantings or removals of these trees; however, a persistent long-run change in growing conditions, such as lower pollution, may result in a long-run change in fruit and nut acreage of more than 10 percent. The net effect of this assumption is that benefits of improved air pollution will be understated.

A second constraint was that for crops for which there was no evidence as to whether or not current air pollution levels in the SJV cause yield losses (e.g. asparagus), acreage was held constant across the base case and all alternatives. The effect of assuming zero yield losses and no acreage changes is conservative benefit estimates from reduction in air pollution and overstatements of damages from increases in pollution.

For this analysis, the SJV encompasses the agricultural areas of CAR Regions 8, 10, 11, and part of Region 3. For the purpose of the analysis, the air pollution changes and crop yield changes have been calculated for all of Area 3, which includes San Joaquin, Sacramento, Solano and Contra Costa counties. Fortunately, the majority of crops in this area are produced in San Joaquin County, and the air pollution levels in the agricultural areas of the other counties are similar to those in San Joaquin County, so little error is introduced by applying the yield loss coefficients in San Joaquin County to all of Region 3. For the calculation of economic losses experienced in the SJV, the losses in Region 3 are separated into those in San Joaquin County and those in the rest of the area according to the percentage of each crop grown in each county. The regions are relatively homogenous with respect to climate, cropping, soils, and water availability, thus a given seasonal crop can be represented by a single regional production relationship. County level production functions are not available.

The application of the CAR model to this analysis assumes that air pollution reductions only occur in the SJV. This has an important implication for the interpretation of results. If air pollution were also reduced throughout the state, the benefits in the SJV would be different. This is because yields for the same and additional crops would increase in other agricultural regions; there would be less shifting of planted acreage selected crops from other regions into the SJV; prices for the crops in the SJV would fall further than if only yield increases from reduced air pollution occurred only in the SJV;