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The Economic Assessment of California Field Crop Losses Due To Air Pollution

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The Economic Assessment of California Field Crop Losses Due To Air Pollution

by

Richard E. Howitt
Charles Goodman

ABSTRACT

The benefits of alternative ozone standards on California field crop yields were measured using a regional economic model of production and sales. The total benefits to the state ranged with the ozone standard from a high of $333 million per year to a low of $50 million per year, and were divided approximately equally between producers and consumers.

Comparison of the results with a national crop loss model showed that California had higher overall benefits and a greater proportion of the benefits going to producers. These effects were explained by a higher proportion of more ozone sensitive crops in California and the market impacts of unilateral ozone reduction by California.

The benefits also varied significantly among crops and regions, and different standards by region were shown to yield gains in economic efficiency. Statistical analysis on crop acreage changes over time shows that farmers respond to changed conditions within five years which justified the use of a static model.

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1.0 Introduction

1.1 Background

The detrimental impact of air pollution on crops in California has been noted for over 35 years (Middleton et al., 1953). In the past ten years the precision in yield response data and the severity of the problem have given rise to several economic analyses of air pollution impacts on crops (Adams & Crocker, 1984; Adams & McCarl, 1985; Howitt et al., 1984; Shortle et al.,1986). The economic losses shown by these studies on a national or state basis bring the analysis of crop impacts to the point where the significance of the losses cannot be ignored.

Crop yield losses from ozone results in impacts on agricultural producers and consumers of the crops. This requires that the effects on consumers be analyzed on a statewide or market level, particularly in the case of California whose market share in some crops is sufficient to induce substantial changes in price from changed production. On the other hand, agricultural production varies widely between regions, which are often also differentiated by air sheds. An analysis of ozone impacts should be calculated on a regional air shed basis and should address the following questions:

1. What is the direct cost of lost crop yield to the individual producer?
2. What cropping pattern changes by the producer would mitigate the pollution effect, and what would the mitigation cost?
3. What are the market linked effects on other producers and on the secondary crop impacts?
4. What is the economic effect on the consumers of the product?

The California Agriculture and Resources Model (CARM) has been developed over the past nine years to reproduce the interactions between land allocations, water use and regional crop production in California. The model is calibrated to reproduce the regional cropping patterns in a specified base year and respond to changed economic conditions or resource constraints in a way that maximizes the returns to regional agricultural production given the constraints.

1.0 Study Objectives

CARM was used to investigate the impact of ozone related crop yield changes for selected crops on a statewide basis (Howitt et al., 1984). The current study extended this first approach by crops, regions and impacts to estimate the effect of possible vegetative ozone standards in California. Specifically the objectives of the first phase of this study were as follows:

1. Modify, update and calibrate the CARM to reflect yield losses based on 1984 data for the principal air sheds in agricultural producing regions.

2. Use the county level annual crop acreage and yield data collected in the CARM data base to extend the dose-response relationships estimated by researchers at the Statewide Air Pollution Research Center to measure regional crop impacts.
3. Integrate the updated CARM with the regional response functions estimated by researchers at the Statewide Air Pollution Research Center and ozone levels to estimate the economic impact of particular air quality and crop loss scenarios.

A second phase of the research has two additional objectives:

4. Evaluate the differences between National and State measures of consumer surplus benefits.
5. Evaluate the rate at which crop farmers respond in their cropping patterns to changes in yield or economic parameters.

The completion and results of these objectives is the basis of this report. The updated model and the results of project objectives one to three are described below . The structure and assumptions of the updated 1984 base year version of CARM are presented on pages 2 through 16 . The linkage between CARM and the crop dose-response functions estimated by the Air Pollution Research Center is explained on pages 16 and 17. The ozone scenarios and the assessment of the economic impact of the ozone scenarios are presented on pages 18 to 24. Much of this data has already been presented in an Air Resources Board staff report and in the publication Howitt and Goodman, 1988. The results for objectives four and five are presented with conclusions from the research on pages 24 to 37. Pages 24 to 27 present an analysis of the response lag of farmers to the impact of an ozone policy and gives an argument for the use of a static model to assess the economic impact of the ozone policy. Pages 33 to 37 compare the CARM benefit estimates with published results of a national model.

2.0 The Application of CARM to Ozone Assessment

2.1 Introduction

In the same vein as the majority of the studies of economic effects of ozone in recent years (Adams, Glyer & McCarl, 1988), CARM uses an optimization methodology that is composed of an economic objective function constrained by physical and economic factors. The central assumption of this type of model is that farmers will grow those crops that lead to a maximum value of the objective function, given the constraints. The farmer is assumed to maximize anticipated profits.

The essential difference between the model used in this study and most other optimization approaches is that we use a "positive programming" approach to calibrate a nonlinear cost function for each crop and region from the base year data (Howitt 1989). This method allows each regional cropping pattern to be exactly calibrated to the base year data without additional constraints that would inhibit response to changes in ozone scenarios.

CARM, the basis for the pollution assessment, incorporates 17 state agronomic regions. The regions are aggregated from county level data. To assess the effect of regional standards, the agronomic regions were further aggregated into nine regions that coincide with the major air basins in California (California Air Resources Board, 1987).

The effect of changes in crop quantity produced on crop price is captured using demand functions. The functions are estimated for the 43 crops in the model using observations over the past 20 years. The linear regressions obtained from this data explain a substantial amount of the variability in price for California crops. A key explanatory variable is the quantity of crop marketed. The demand relationship thus captures the effect on crop sales prices of changes in quantities sold due to ozone standards.

The objective function of the regional model reflects profit maximizing producers and consumers whose market preferences are represented by the demand functions. The responsiveness (or flexibility) of California prices to changes in production varies widely. As California production is increased by lower ozone levels, crop prices can be expected to fall. The critical factor for economic measurement is the proportional reduction in price caused by a given increase in production. Those crops that are specialty food items, and which are largely grown in California have prices that are very responsive to changes in California production. However, the feed and fodder crops are quite insensitive in price, California production being only a small proportion of national output.

2.2 The Structure of CARM

The general structure of the model is a constrained quadratic programming model with 17 production areas covering the entire state of California. At present, more than 43 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 the fixed resources land, and water. Energy, labor, and fertilizer costs are currently included in the variable costs of production. The quadratic objective function is maximized according to regional or statewide constraints on the availability of the fixed land and water resources.

CARM is an expectation model that attempts to predict acreage and market conditions under alternative yield scenarios and under 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 1984 under alternative yield scenarios. The current demand equations are estimated with data for 1969-1984. Base yields use a three year average to smooth unusual yields in any one year. Base prices use existing 1984 prices and quantities demanded. The complexity and linkages in the model with the broader agricultural economy are necessary to correctly estimate the economic costs of changing ozone levels on crops.

If the potential adjustments by farmers and food consumers to lower yields and higher costs are not taken into account, the economic impacts will be over-estimated. Economic theory, and more importantly, common sense, tells us that both farmers and consumers will change their production and consumption patterns to make themselves as well off as they can under the new conditions. In its specification of increasing production costs for increased crop output and reduced consumption levels as crop prices rise, CARM adjusts the economic impact of ozone changes for the adjustments that producers and consumers would make. This complex process is contrasted with the relatively simple process of assessing the costs of health effects where the effect directly impacts the individual, and the ability to avoid or substitute the effects is very limited. A quantitative measure of the differences in the economic costs under alternative methods is shown in Table 4 in the empirical section of the report.

A Mathematical Statement of CARM

CARM has the following form:

$$\text{Maximize } Z = c' x_t + 1/2\, x_t' D x_t - (a' x + 1/2 x' G x)$$

subject to $Ax \leq b$,

where:

	z	=	sum of producer and consumer surplus;
	x_t	=	a vector of statewide cropping activities;
	x	=	a vector of regional cropping activities;
	c	=	a vector of intercepts of statewide linear demand functions;
	D	=	a diagonal matrix of slopes of the statewide demand functions;
	a	=	a vector of regional linear cost coefficients;
	G	=	a diagonal matrix of regional quadratic cost coefficients;
	A	=	a matrix of linear input-output coefficients for the regional activities;
	b	=	a vector of physical resource limits.

To what degree does this structure meet the minimum practical requirements for modelling competitive microeconomic systems, and how has it evolved from earlier forms which were not quite up to the task?

The objective function is diagrammed in Figure 1. The objective function is quadratic in revenue and cost because it maximizes the area between linear demand and supply curves. The maximand consists of, a standard measure of net economic welfare, the sum of consumer and producer surplus (these terms are defined in the glossary at the end of the report). The model implicitly assumes a reasonably competitive economic system where individual consumer and producers are price takers. Linear demands and supplies are chosen because they meet a minimum standard of plausibility consistent with a manageable computational burden. The statewide demands correspond to the market demand curves of a competitive system, with the regional implicit supply curves being associated with price-taking firms operating within such a system.

The regional cost function consists of the linear portion $\mathbf{a}'\mathbf{x}$ and the nonlinear quadratic form $\mathbf{1/2x}'\mathbf{Gx}$. The matrix **G** presupposes the existence of decreasing returns or increasing costs with rising production of a given activity, due to declining yields as operations expand onto less suitable lands as well as to the increasing risks of specialization.

The linearity of the **A**-matrix is to some extent a drawback, but an inevitable one in view of the lack of other than county average data for estimating the $\mathbf{a}_{ij}$'s (elements of the A-matrix). Thus, the brunt of representing decreasing returns in the model falls on the objective function matrix **G**, which is not known and must be derived from regional data.

The development of a methodology for determining the elements of **G** and **a** turns out to be the critical prerequisite to the proper calibration and verification of the model. How the CARM structure evolved in response to the need to find a workable solution to this problem of calibration is discussed next.

2.3 The Calibration Problem in Linear Programming Models

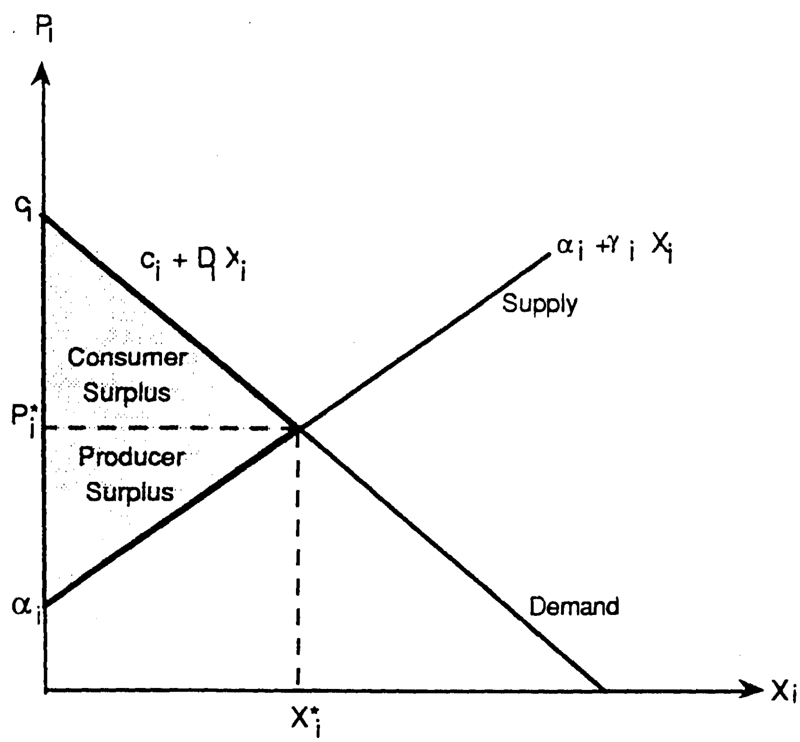
For many years the programming model most frequently employed in agricultural economic studies has been the simple linear programming (LP) formulation:

$$\text{Maximize } Z = c'x \qquad \text{subject to } Ax \leq b,$$

where c is a vector of net revenues. The widespread use of LP stemmed both from the availability of reasonably cheap computer algorithms and a history of successful application of LP to problems of industrial engineering. However, in the case of agricultural economics, the LP formulation is generally inadequate, since it has been difficult to verify a base-period cropping pattern without adding large numbers of *ad hoc* constraints to the regional cropping activities. This problem of calibration results from the inherent linear structure and associated implicit economic assumptions of LP.

Figure 1 - The CARM Objective Functior

Diagrammed for a single crop at the statewide lev



(As used here α_i and γ_i are weighted averages of the relevant regional values)

Max Z_i = Consumer + Producer Surplus

$$\therefore Z_i = \int_0^{X_i^*} (c_i + D_i X_i) dX_i - \int_0^{X_i^*} (a_i + g_i X_i) dX_i$$

$$= c_i X_i^* + 1/2 D_i X_i^{*2} - (a_i X_i^* + 1/2\, g_i X_i^{*2})$$

Recall that the simplex method maximizes the objective function by iteratively solving a linear equation system, each time changing the basis in such a way as to increase the value of the objective function. Elementary linear algebra requires that, if the A-matrix has m rows and is of full rank, any basic feasible solution will contain m variables in the basis. That is, the total number of activity and slack variables must equal the number of constraints (m equations, m unknowns in the solution). Since a slack variable leaves the basis for each binding constraint, the number of optimal nonzero activity variables equals the number of binding constraints (in the nondegenerate case).

Suppose one needs to calibrate an agricultural model with 15 nonzero cropping activities observed in the base year for a particular region. Practically speaking, how many potentially binding resource constraints can be identified, assuming a normal base year? Land, surface water, possibly operating capital, possibly processing capacity for a few crops, labor, machinery, and perhaps crop rotations are the likely candidates. However, one would be truly hard-pressed to justify absolute limits on most of these items, except for the first two. In a normal year, additional labor, machine time and operating capital can be obtained at some price and thus would more appropriately be recorded in the farmer's cost function than in some artificially determined physical limit. Generally, rotational constraints reflect arrangements which are deemed to be less costly than alternative cropping plans, and moreover really make sense at the farm, rather than the regional level. Finally, processing capacity tends to follow production rather than vice versa and thus may not be tightly constraining. For example, during the peak of the 1983 processing tomato season, processors operated for weeks at up to 112 percent of "absolute capacity" (California Tomato Grower, 1983).

Often for the purpose of running scenarios, strict calibration constraints are replaced with a set of "flexibility restraints," wherein the lower and upper crop limits become functions of historical acreage levels. This can produce an unintended result, with "future" shifts in the cropping pattern tightly welded to past observations. Models verified and applied in this manner are restricted in evaluating changes in regional comparative advantage resulting from particular ozone level scenarios.

Since the marginal revenue and marginal cost functions cannot intersect under the linear specification, production simply expands until some resource b is exhausted or a constraint is binding. Only by accident will this occur anywhere near the actual base year acreage level. A fundamental assumption is that agricultural production is characterized by increasing costs in a given crop. Therefore, since farmers are price-takers, they must be facing increasing unit costs as production rises in order for their perceived marginal benefit and marginal cost calculations to be equal at the empirically observed levels. The fact that the number of observed activities is so much larger than the number of truly fixed constraints should induce us to construct a nonlinear objective function with the ability to measure decreasing returns. As Baumol has stated:

> In general we may state that with diminishing returns...the number of positive variable values will tend to be greater than the number of constraints... It follows that if we try to approximate a nonlinear problem

> with a linear programming calculation, then if there are diminishing returns we should suspect that the answer will contain too few positive values...(Baumol, 1977)

Of course, in the particular case of agriculture, it can be directly observed, rather than merely suspected, that the LP solution contains too few positive variables.

Were farmers irrational, one might be inclined to accept the normative conclusion of LP that they are producing too many activities. On the other hand, assuming farmers are indeed rational, and have through experience generated an appropriate product mix given the production and market conditions they face, then we should be seeking a more positive objective function which incorporates their observed behavior. Accurate calibration will occur only when what is optimal from the farmers' point of view also is considered optimal from the model's point of view. An explanation of this calibration method is shown in Appendix 1.

2.4 Elaboration of Elements of CARM

Model Optimization

The model allows for the optimization of economic returns to farmer's land and management by changing the percent 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 10 percent since the costs of rapid changes in this type of crop are very high. The current version of the model changes all inputs in direct proportion to the amount of acreage under cultivation by crop type.

Crop List and Regional Specification

The crop selection process is necessarily somewhat subjective, since a ranking of the top California crops by acreage produces a different listing than does a ranking by value. From the standpoint of measuring ozone impacts, acreage would seem to be the more important of the two criteria and, accordingly, was assigned a higher weight in the selection process.

The CARM crop list, which may be found in Table 1, incorporates fruit and nut crops and important short-term perennials (alfalfa hay and irrigated pasture) that were omitted from earlier models. The 43 crops (there are 65 crops if seasonal vegetables are reckoned as separate crops) chosen accounted for roughly 95 percent of the state's acreage and value in 1978.

CARM divides the state into 17 agricultural production regions, as shown in Figure 2. The regional breakdown employed by CARM diverges from its predecessor in a few instances, most notably the division of Fresno County at the Fresno Slough into western and eastern portions.

The development of a suitable regional framework introduces the modeller to a three-way tradeoff among the aggregation level, data availability and computational feasibility. The more disaggregated the regional setup, the more difficult the data-gathering task, and the more costly it becomes to solve the model on the computer. But, on the other hand, the greater the number of regions, the greater the ability to capture local differences in climate, resource availabilities and prices, markets, and airsheds.

To minimize aggregation error, the agricultural production regions need to possess an adequate level of homogeneity with respect to soil and climatic conditions, as well as water costs. A pioneering 1970 study by Shumway et al., identified 95 separate "homogeneous production areas" (HPAs) based upon as set of joint soil-climate categories which themselves were aggregated. These 95 HPAs consisted of irregularly shaped geographic entities paying no heed to the political boundaries upon which most available data are based.

The 17-region formulation thus represents a compromise. The number of activities is held to a manageable level. County boundaries are followed to the extent feasible, with divergences in cases where the advantages of a more homogeneous specification are believed to outweigh the difficulties in securing data.

Demand Relationship

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

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

where P is a (Nx1) vector of prices, c is a (Nx1) vector of constants, D is a negative diagonal matrix of price-quantity slope coefficients, and q is a (Nx1) 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 1

Crops Included in the California Agricultural Resources Model

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

FIGURE 2

CARM REGIONS

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.,
q_{si} = substitute crop production quantity,
Y = U.S. aggregate disposable personal income.

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 CARM are similar to those estimated in the literature, and are equal to or larger than those used by Leung et al. (1981) and Manuel et al. (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.

The variables of income and U.S. production are not included in CARM 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 1984. The final equations used in the model, therefore, are of the following form:

$$P_{ci} = a + b_1 q_{ci} + b_2 q_s$$

These price forecasting equations and 1969-1984 price flexibility coefficients for the study crops are presented in Table 2. 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.).

The demands are calibrated to the base year using the actual prices and quantities for 1984 and a price flexibility estimated from the time series of consumer responses.

Given the linear demand function and an average yield per acre, the two demand parameters c_i and d_{ii} (see Figure 1) can be calculated from the base year price, quantity, and flexibility for the crop.

Table 2 contains the prices, quantities, and flexibilities used for the base year runs. The numerical values after some of the crop acronyms denote the seasonal nature of those crops.

Production Coefficients and 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. Land is divided by region into total and irrigable acreage. Irrigable land is defined as Soil Conservation Services (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.

- 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 CARM 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. Yield and cost data are averaged over three years.

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.

Empirical Calibration of CARM

The base year used to calibrate the regional model was 1984. Using the positive programming procedure, the regional model was calibrated to reproduce the regional cropping patterns and statewide quantities and prices to within less than half a percent error for each region and crop. The calibrated model was only constrained by regional land and water availabilities, thus allowing it to respond to different scenarios. Since it is assumed that the effect of any regulatory changes would occur gradually, the model should not be constrained by those farm level constraints that can be relaxed over a five to ten year time horizon.

TABLE 2

CARM Demand Data

Crop	Price	Flexibility	Quantity
ALF	92.26	–.189	15801.707
ALM	1906.02	–.54	224.962
ALS	1.10	–.0088	51517.988
APL	242.89	–.623	190.173
APR	301.41	–.356	127.459
ASP	72.50	–.401	915.102
AVO	523.78	–1.849	273.598
BAR	3.05	–.103	25191.372
BNS	29.21	–.787	3123.815
BRO1	24.84	–.17966	9313.269
BRO2	24.84	–.36608	2118.903
BRO3	23.54	–.30525	2345.444
BRO4	23.54	–.24578	2595.165
CAN2	16.79	–.62645	40890.061
CAN3	11.82	–.39358	7866.297
CAN4	16.28	–.26839	1703.177
CAR1	11.86	–1.1034	2857.244
CAR2	11.86	–.63149	4042.882
CAR3	10.88	–.52331	1644.475
CAR4	10.88	–.061029	2640.756
CAU1	33.46	–.14335	1268.491
CAU2	33.46	–.49232	1268.491
CAU3	25.26	–.18216	1009.065
CAU4	25.26	–.25	1616.601
CEL1	13.72	–4.2306	2503.013
CEL2	13.73	–4.6208	4170.688
CEL3	9.58	–.79122	1768.881
CEL4	11.17	–3.7537	4170.688
COT	336.00	–.154	3059.584
CRN	3.74	–.078	73038.800
GFT	116.98	–.097	299.532
GPR	166.39	–.357	2541.636
GPT	350.65	–.15	560.7871
GPW	204.73	–1.647	5304.300
GRH	74.00	–.189	570.882
GRS	3.15	–.005	3808.944
LEM	139.55	–1.136	736.351
LET1	11.79	–2.8774	48676.044

Table 2 (continued)

Crop	Price	Flexibility	Quantity
LET2	11.20	–5.1774	15557.375
LET3	10.98	–2.6212	10260.966
NCT	269.58	–2.034	198.188
OAT	2.26	–.094	3555.747
OLV	529.40	–.272	95.397
ONS	7.94	–.457	8100.458
ORN	192.38	–.734	2243.803
PAS	40.00	–.189	5053.861
PCH	188.07	–.65	720.637
PLM	443.87	–1.496	203.904
POT1	9.19	–.3276	20131.304
POT2	11.09	–.41337	5688.769
POT3	10.89	–.14508	1303.003
POT4	8.05	–1.2731	8051.641
PRN	701.83	–.682	149.355
PRS	137.59	–.4039	305.858
PST	2683.18	–.57	23.907
RCE	7.39	–.729	34680.814
SAF	280.47	–1.3	88.988
SIL	23.35	–.189	3631.341
SRB	38.04	–.003	12032.605
TMF2	31.86	–.3628	2232.797
TMF3	20.82	–2.3953	2590.037
TMF4	22.81	–1.3393	2590.037
TOM	55.94	–.277	7429.830
WAL	828.49	–.604	646.475
WHT	3.96	–.237	96578.497

2.5 Linkage Between CARM and the Ozone Scenarios

The critical linkage between the base year regional model and ozone standard scenarios is provided by Olszyk et al., (1988). Fifteen of the most economically significant crops were chosen and their yield response functions from ozone were estimated or compiled from previous studies. The fruit and nut tree crops are notable for their omission from those considered susceptible to ozone damage by the model. This approximation was necessary because of the lack of empirical field data and the difficulty of growth chamber experiments with this group. The model was run both with and without constraints on the acreage change in this important group. Although the most important field crops are incorporated in the model, the omitted crops will cause a conservative bias in the estimated benefits from ozone standards.

The basis yield response functions from Olszyk *et al.* (1988) were calibrated to the 1984 CARM model regions using regional yield data and local county level ozone air monitoring sites (California Air Resources Board, 1987). Thus, for any given ozone standard, the response function provides a percentage crop yield change from the actual regional yield and ozone level for 1984, against which the economic model is calibrated. 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:

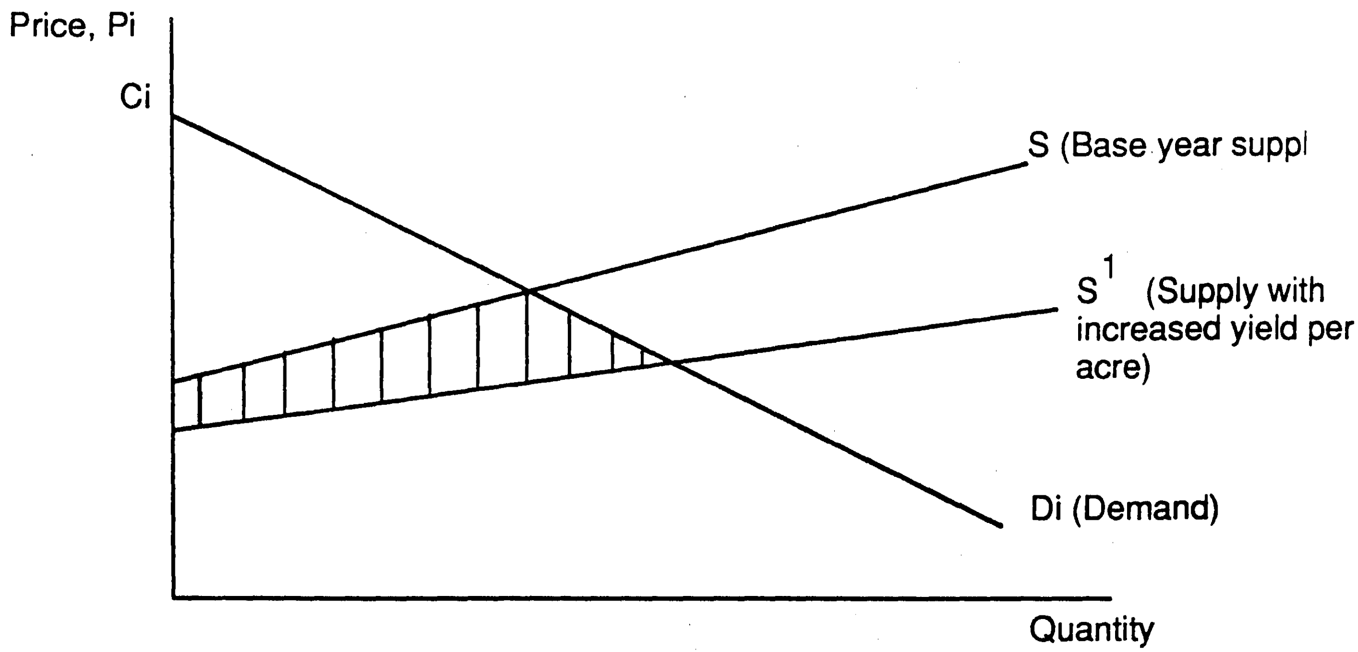
$\frac{1}{(1+p_{ij})}$, and changes the slope by

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

The change in the marginal cost curve from S to S^1 is illustrated in Figure 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 3

Shift in the Supply Curve with Increasing Yields per Acre



Changes in crop yields per acre will change the marginal physical product (MPP) 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 marginal value product (MVP) or marginal physical product (MPP) 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 1.65 as for wine grapes (Table 2), the positive price effect will eliminate the negative productivity effect and in the absence of crop acreage expansion, the relative MVP of wine 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. The regional yield effects of standards are now used in the model to calculate the economic impact of the standards on consumers of Californian crops and regional crop producers. The benefits are predicated on there being no change in ozone levels in other areas of the country that produce crops that compete with Californian products.

3.0 The Ozone Impact Assessment

3.1 Ozone Assessment Scenarios

Seven ozone scenarios were suggested by the California Air Resources Board research staff for analysis.

Five ambient seasonal ozone standards from .06 parts per million seasonal 12-hour mean to the largest reduction of .025 ppm seasonal 12-hour mean were specified. These seasonal standards will be termed .025, .04, .045, .05, and .06. The current hourly threshold standard of .10 ppm ozone was also evaluated. Of particular interest is a regional standard scenario in which the main agricultural producing area--the San Joaquin Valley (SJV)--was held to a .045 ppm seasonal mean standard, but in other areas of the state the seasonal standard is relaxed to .05 ppm. This latter scenario is designated .05-.045.

3.2 Results from the Scenarios

Table 3 shows the statewide benefits in total, and divided between producers and consumers. The benefits are shown for four of the seven scenarios. The .05 seasonal standard and regional standards will be addressed later in the paper.

The strict seasonal mean standard of .025 shows substantial annual benefits of $333 million. The benefits are split between consumers and producers in a 48/52 percent ratio. This ratio holds for a relaxation of the standard to .04, but a further relaxation to .06 ppm or the hourly .10 ppm criteria reverse the benefit ratio slightly to 52/48 percent in favor of the consumer. As well as the ratio between consumers and producers changing, the total benefits/unit reduction change substantially over the .025-.06 seasonal mean range. From .06 to .04 ppm the total annual benefit per .01 ppm is $41.55 million, however, over the .04-.025 range the benefit per .01 ppm more than doubles to $84.93 million. The benefit function in this range is shown to have a strong upward curvature, predominantly due to the nonlinear dose response functions. This does not imply that an agency should maximize benefits by setting lower ozone level standards, since the costs of implementing these standards are doubtless also sharply increasing.

Comparing the .10 ppm hourly standard with the .06 ppm seasonal mean standard shows that the .10 hourly standard yields more benefits than the .06 seasonal mean but substantially fewer than the .04 seasonal mean. These results show that both the level and way of setting the standard greatly affect the net benefits.

A justification of a complex economic analysis of ozone benefits is that the twin effects of price changes and crop substitution will cause benefits from profit maximizing farmers to differ considerably from the earlier simple benefit calculations for different scenarios. Table 4 compares the benefits resulting from CARM with the traditional method of multiplying the total yield loss by the current price. The economic model projects consistently lower benefits than the price/yield method. The difference is not just a simple ratio, over the .025-.06 ppm range the economic benefits vary from 51 percent to 61 percent of the price/yield benefits. An accurate translation of yield losses to economic losses requires a model that reflects changing rates of substitution and price flexibility.

Table 5 shows the statewide benefit changes by crop for different scenarios. Of note is the wide range of benefit change between crops for a given standard, and also the different way crop benefits change with changed standards. Among the selected crops in Table 4 we can focus on cotton and corn for the .025 scenario. This strict standard only yields a benefit change of 2.4 percent above base for corn but a 48.0 percent improvement in cotton benefits. Alfalfa shows a low 5.8 percent. Under the most lenient seasonal mean standard, .06 ppm, cotton benefits drop by three quarters to 12.4 percent, alfalfa benefits are negligible while corn benefits drop by 80 percent to a low 0.5 percent benefit change. Evidently, the combination of yield

TABLE 3

CARM Model Projections of Annual Consumer and Producer Benefits in 1984 for All Crops by Ozone Scenario

	STATEWIDE BENEFITS ($ MILLIONS)			AVERAGE BENEFITS PER FARM ($ THOUSANDS)	AVERAGE BENEFITS PER ACRE ($ DOLLARS)
OZONE SCENARIO	CONSUMER	PRODUCER	TOTAL	PRODUCER	PRODUCER
Seasonal Ozone .025	160.0	172.9	332.9	2.2	24.0
Seasonal Ozone .04	98.1	107.4	205.5	1.4	14.0
Seasonal Ozone .06	26.0	23.9	49.9	0.3	2.0
Hourly Ozone .10	53.2	48.2	101.3	0.6	5.0

TABLE 4

Annual Statewide Agricultural Benefits in 1984 A comparison of CARM and of Traditional Valuation Estimates by Ozone Scenario

Ozone Scenario:		CARM Model Results Dollar Benefit ($ Million)	Traditional Valuation Results Dollar Benefit ($ Million)
Ozone .025	Seasonal	332.9	647.3
Ozone .04	Seasonal	205.5	372.6
Ozone .045	Seasonal	158.6	286.2
Ozone .05-.045	Seasonal	151.1	263.5
Ozone .05	Seasonal	118.9	197.0
Ozone .06	Seasonal	49.9	82.2
Ozone .10	Hourly	114.4	199.7

TABLE 5

CARM Model Projections of Statewide Agricultural Benefits in 1984 by Ozone Scenario and Crop

Crops:	1984 Benefits ($ Millions)	Increased Benefits As a Percentage of Base Year: Seasonal Ozone .025	Seasonal Ozone .04	Seasonal Ozone .06	Hourly Ozone .10
Alfalfa	320.1	5.8	2.5	0.0	1.9
Corn (field)	84.8	2.4	1.9	0.5	1.1
Cotton	284.9	48.0	33.3	12.4	15.9
Grapes (table)	78.7	20.5	11.5	1.3	7.0
Rice	165.0	10.4	4.8	1.0	1.6

response, price effect and crop substitution are not amenable to simple exptrapolation over ozone levels.

Table 6 shows the change over the base run for the .05 ppm seasonal mean standard for selected crops. The changes are shown for statewide tonnage acreage and price of the crops, they illustrate the two effects of price change and acreage substitution in the economic model. As would be expected for normal consumption goods, the price/quantity relationship between tonnage and price is inverse. For the crops shown, under the .05 ppm standard, tonnage is up and price is down, by substantially different percentages. The relationship between acreage and price is complicated by the substitution effect that changes the crop mix in different regions. While all crops have a decrease in price per ton, some experience an acreage increase and some an acreage decrease. The effect of ozone on yield is the only factor that has changed between this run and the base run. The effect of constraining the acreage of fruit and nut crops to ±5 percent of their base acreage was tested. The results did not differ substantially from the unconstrained results presented in this paper.

Table 7 shows the notable differences in regional benefits for different ozone standard scenarios. The regional producer benefits differ in magnitude, and more importantly, sign. This result from the interaction of price and substitution effects has been noted by several authors in previous studies (Adams and McCarl, 1987; Brown and Smith, 1984; Knopp et al.,1985; and Howitt et al., 1984). Table 7 shows that of the five main agricultural air basins, three show producer benefits while two show producer losses from ambient standards. Statewide ambient standards will

TABLE 6

Statewide Projections of Acreage and Production of Selected Crops for Ozone Scenario: Seasonal Ozone .05

Crop	Base Acres (1000)	Percent Change	Base Tons (1000)	Percent Change	Base Price ($/Ton)	Percent Change
Alfalfa	972	-0.4	6,961	0.8	92.3	-0.1
Dry Beans	172	-6.7	156	7.1	584.2	-5.6
Corn (field)	352	0.4	1,334	1.2	133.6	-0.1
Cotton	1,379	2.4	735	13.5	1400.0	-2.1
Grapes (wine)	322	-3.0	2,585	0.7	204.7	-1.2
Lemons	49	-6.5	736	2.6	139.6	-3.0
Rice	489	1.2	1,734	3.9	147.8	-2.8
Statewide Totals	9,608	-0.1				

TABLE 7

Interregional Differences in Producer Surplus ($ Millions)

	Ozone Scenario		
Region:	Seasonal .025 ppm	Seasonal .05 ppm	Hourly .10/ppm
S.J. Valley	158.88	60.39	49.75
Sac. Valley	-2.37	-6.37	-5.31
S. Coast	9.27	4.64	6.69
S.E. Desert	12.24	4.27	6.76
N. Central Coast	-3.91	-1.32	-1.83

change the comparative advantage of different crops in different regions. The San Joaquin Valley dominates the producer's benefits by nature of its greater production value and higher base ozone pollution level.

The regional discrepancy among producer benefits suggests that regional standards would be a more efficient and equitable approach. Table 8compares two runs, one with a statewide .045 ppm seasonal mean standard, and one (.045-.050) with a strict standard of .045 for the San Joaquin Valley, but a looser .05 ppm standard for the rest of the state. The results show that the regional standard captures 81 percent of the total benefits of the stricter statewide standard. No doubt there would be considerably lower implementation costs for the regional standard. The results suggest that where regional differences are pronounced, regional standards can capture the majority of the benefits in a more efficient and equitable manner.

3.3 Sensitivity Analysis on CARM

CARM with its many parameters and assumptions could introduce significant errors in the economic estimates. Measurement errors in the economic data, statistical errors in the the parameter estimates, and algorithmic errors in the model solution may all introduce biases in the economic estimates. A method

TABLE 8

Effect of Regional Standards
($ Millions)

	.045 Statewide	.05 Statewide	S.J.V Regional Standard .045
Consumer Surplus	88.18	66.22	84.01
Producer Surplus	70.42	52.68	67.09
Total benefit	158.60	118.90	151.10
Difference from .05 Statewide	39.70		32.20

termed sensitivity analysis is used to detect if the model results are particularly sensitive to parameters that are uncertain. An extensive sensitivity analysis on all parameters that would require hundreds of costly model solutions was not undertaken. However, the following limited examination of the impact of possible errors in the crop demand functions indicates fairly stable model predictions of the objective function values.

CARM incorporates statistically estimated linear demand functions for fifty different crops. The slopes of each of the demand functions are incorporated into the CARM objective function. The magnitude of the demand slopes influences the solution value of the consumer and total surplus. Errors in the slope of the demand curves would accordingly alter the objective function parameters in the model. The CARM model was run with the altered slope parameters, and the resulting consumer, producer, and total surplus values were examined and compared with previous estimates.

The starting point for this exercise is the .05 ppm ozone scenario. This is called the 'original' CARM run. It has the crop yield increases estimated for the .05 ppm ozone standard and also has the originally estimated demand functions. Four comparison runs of CARM were made with the following changes to the demand parameters:

run 1 - the demand slopes increased by 10%
run 2 - the demand slopes decreased by 10%
run 3 - the demand slopes increased by 50%
run 4 - the demand slopes decreased by 50%.

Effectively, these four model runs provide upper and lower bounds on the demand curves at the 10 percent and 50 percent levels.

The consumer, producer, and total surplus for the original and four comparison runs are given in Table 9. For the plus 10 percent and for the minus 10 percent runs, the consumer surplus varies from the original run by approximately 10 percent. The producer surplus changes by less than one tenth of a percent. The total surplus changes by 5 percent. The implication of the above is that CARM behaves predictably; a ten percent error in the demand slopes results in a less than ten percent change in the estimated value of the total surplus. As also indicated in Table 9, a 50 percent error in the demand slopes results in comparable changes in the consumer, producer and total surplus.

4.0 Farmer Adjustments to Ozone Scenarios

Research objective five addresses an implicit assumption in the use of static models to measure policy impacts. Since it is calibrated to a single base year at a time, CARM is static and assumes that the changes to altered crop profitability and resource availability happen immediately. Clearly, the validity of this implicit assumption depends on how rapidly the farmers actually have

TABLE 9

Impact of Demand Function Errors

	Model Valuations ($ millions)			Percent Change From Original Run		
Demand Function Assumptions:	Consumer Surplus	Producer Surplus	Total Surplus	Consumer Surplus	Producer Surplus	Total Surplus
1. Original Run (.05 ppm scenario)	$3,541.5	$2,818.2	$6,359.7	–	–	–
2. Demand Slopes Increased 10%	3,889.7	2,814.3	6,704.1	+10%	a	+5%
3. Demand Slopes Decreased 10%	3,193.1	2,822.5	6,015.6	-10%	a	-5%
4. Demand Slopes Increased 50%	5,281.7	2,801.3	8,083.0	+49%	-1%	+27%
5. Demand Slopes Decreased 50%	1,794.0	2,848.3	4,642.4	-49%	+1%	-27%

Note: a = less than 1 percent change

responded to economic shifts by changes in crop acreages. If the response lag of farmers is shown to be of the same magnitude as the lag in the impact of an ozone policy, the static model is a sufficiently accurate analysis for that policy.

That is, if the farmers adjust to changes at the same rate that the changes are happening biologically, then modelling both phenomena as if they occurred immediately does not distort the long-run benefit or cost measures. However, if it is shown that farmers take a long time to respond to changed profitability, then the adjustment path of a given policy will influence the benefit measures and a dynamic model should be used. A physical analogy can be made using a strobe light and spinning wheel, if the light flashes and wheel revolutions are synchronized, as in a car timing light, then the lit part of the wheel appears stationary. This is a representative static model of the phenomenon.

The question is, therefore, do farmers adjust their acreages quickly or slowly in response to changed revenues from that crop or associated crops? To determine this, we need to fit a dynamic model of acreage adjustment against a series of data on crop acreages and revenues in California over time. The best lag in farmer response in the model that fits the data is most likely to be the one that farmers actually are responding to. Given this simple criterion, the best statistical model to use is from the class of "time series" models. The particular specification used is termed an autoregressive (AR) specification. This daunting name simply means that the current year's change, in say citrus acreage, is systematically related to past changes. If a farmer observes a change in yield, but for reasons of caution or capital constraints decided only to change his acreage by 10% a year, the current rate of change will be determined by past changes back as far as the original stimulus. If statistical methods can only find a significant relationship going back for seven years, then the linkage is described as an autoregressive process of order seven. That is, the effect of the lagged variables on the current variable goes back seven years. By finding the time series model with the lowest error in predicting acreage, the lag length which is most likely to be used by farmers to adjust to new conditions can be estimated. A good introduction to times series analysis can be found in Granger (1980). Since it is widely acknowledged that crops tend to be grown in rotations with each other, the effects of one crop revenue (for cotton AGTRC) on another crop acreage (COTACR) must be allowed for. This means that we have to include several associated series of acreages and profitabilities together. This type of time series analysis is termed Vector Autoregression.

A frequent criticism of unrestricted Vector Autoregressions (VAR) is that they are prone to "overfitting" with the large number of lags and parameters available. That is, the large numbers of parameters compared with the data points cause the parameters to be fit to the random variations in the time series as well as the systematic components. Very good fits to the data series and very poor forecasts result, (Litterman , 1986), Fair 1979). To overcome this tendency in VAR, Litterman imposes priors on the autoregressive structure in the form of a random walk with priors on the means and variances of the lag coefficients. From the view of a farmer, yields and often prices can be characterized as a random walk with a drift. In forming rational expectations, the decision maker has to filter the systematic drift of technical change or systematic price response to exogenous variables from the random noise in the series. The Baysesian Vector Autorgression (BVAR) method uses priors to restrict the effect of lagged coefficients in the sense that the longer the lag the higher the probability that the coefficient will be close to zero. From a Bayesian viewpoint, conventional structural exclusion constraints are forced to choose between certainty of the effect of the lag (included) or certain knowledge that the lag has no effect (excluded). By adding Bayesian constraints to the VAR specification, Litterman has captured the flexibility of VAR while providing a method to reduce the effects of "overfitting."

A time series estimation was performed on a twenty four year series on crop acreage, price and yield by county. The results shown here are for the three southern San Joaquin counties of Kern, Kings and Fresno from 1963 to 1986. Since crops substitute for one another and are also in a rotation, cotton the key ozone sensitive crop for the region was estimated jointly with two rotating field crops, alfalfa and wheat. Barley and corn were also analyzed. The estimation method used was BVAR. (Litterman 1986).

Lagged explanatory variables up to eight years back were tested in fitting the series, however, lags longer than five years were not found to significantly change the precision of prediction of acreage changes. A lag structure of one, three and five years was found to yield a high degree of explanation in the equation. Figures 4 and 5 show the "in sample" forecasts over time, while Tables 9 and 10 show the statistical results for the equations.

Tables 10 and 11 can be interpreted in the same way as other statistical regression results. The explanatory variable with their associated lags, coefficients, and standard errors are listed. The t statistic can be used to determine the significance of any one coefficient estimate. The explanatory power of the equation as a whole can be assessed from the usual R^2 and F test statistics, which are based on the Regression Sum of Squares (RSS) and Error Sum of Squares (SEE) values shown. The Durbin-Watson statistic is not valid with the current specification including lagged dependent variables. Since we are estimating four equations together as a system, the time series coefficients are more difficult to interpret than single equation values. The grain (both wheat and barley acreages were estimated), cotton, alfalfa rotation specified requires that the lagged acreages of each crop of years one, three, and five are explanatory variables in each equation. Because of the systems approach, individual variables cannot be dropped from single equations. The significance on the previous acreage and revenue variables is concentrated on the variables directly associated with the dependent variable. This indicates that for marginal acreage changes, rotational linkages do not seem to have much effect. The variable acronyms defined in the glossary. Ozone levels were not included as explanatory variables on yield for two reasons, data was not available for this time series, the aim is to estimate farmer response to revenue change and not the reasons for revenue change. A more intuitive estimate of the fit of the equation can be drawn from figures 4 and 5 which plot the predicted and actual acreage values over time. The plots show that the equations accurately capture the dynamic changes over this long time series, and thus have the "best" lag length.

The implication of the maximum lag of five years is that if ozone levels adjust to policy changes over five year or longer intervals, the rate at which farmers adjust their cropping patterns will match the policy effect, and a static analysis model will accurately represent the benefits from policy changes.

5.0 Analysis of Measures of Economic Benefits

As previously explained, CARM uses the economic measures termed consumer's and producer's surplus to measure the benefits from alternative ozone scenarios. While these surplus measures are used by economic models of this type, some important questions have to be resolved. First, are these measures an accurate indicator of public well-being given the level of farm support subsidies for many crops?. Second, the results for the California model show substantially

TABLE 10

EQUATION 1
DEPENDENT VARIABLE 30 ALFACR
FROM 1968- 1 UNTIL 1986- 1
OBSERVATIONS 19 DEGREES OF FREEDOM 14
R**2 .96189776 RBAR**2 .96181140
SSR .24603753E+10 SEE 13256.738
DURBIN-WATSON 2.77532083

NO.	LABEL	VAR	LAG	COEFFICIENT	STAND. ERROR	T-STATISTIC
1	ALFACR	30	1	.6451965	.2304037	2.799315
2	ALFACR	30	3	.1792703	.2393029	.7491355
3	ALFACR	30	5	.8063563E-01	.3040017	.2260060
4	COTACR	31	1	-.1632992E-02	.5840603E-02	-.2796078
5	COTACR	31	3	.3111951E-01	.3515503E-01	.8851879
6	COTACR	31	5	.1569755E-01	.7790077E-01	.2013519
7	WHTACR	32	1	.1934652E-02	.2628510E-01	.7362729E-01
8	WHTACR	32	3	-.1125925	.7417592E-01	-1.517912
9	WHTACR	32	5	.1160910	.9829013E-01	1.181106
10	CONSTANT	0	0	29638.51	193621.2	.1530747
11	COTEXP	1	1	-.1958466E-01	.1479490E-01	-1.323737
12	AGTRA	42	1	40.64071	42.32077	.9601657
13	AGTRC	43	1	-12.24215	28.12385	-.4351394
14	AGTRW	44	1	-89.43437	55.90248	-1.597542

F-TESTS, DEPENDENT VARIABLE ALFACR

VARIABLE	F-STATISTIC	SIGNIF. LEVEL
ALFACR	2.78891	.7987690E-01
COTACR	.30551	.8209825
WHTACR	2.24227	.1284068

EQUATION 2
DEPENDENT VARIABLE 31 COTACR
FROM 1968- 1 UNTIL 1986- 1
OBSERVATIONS 19 DEGREES OF FREEDOM 14
R**2 .90702102 RBAR**2 .88045586
SSR .90052372E+11 SEE 83088.356
DURBIN-WATSON 2.83508165

NO.	LABEL	VAR	LAG	COEFFICIENT	STAND. ERROR	T-STATISTIC
1	ALFACR	30	1	.2811697E-01	.2330538	.1206458
2	ALFACR	30	3	.4688161	1.163391	.4029739
3	ALFACR	30	5	3.195708	2.603400	1.227513
4	COTACR	31	1	.3187400	.1887598	1.688602
5	COTACR	31	3	.2963937	.3954872	.7494393
6	COTACR	31	5	.4605247	.6037146	.7628186
7	WHTACR	32	1	.2343780E-01	.1657029	.1414404
8	WHTACR	32	3	.8012971	.5510017	1.454255
9	WHTACR	32	5	1.069788	.7117407	1.503058
10	CONSTANT	0	0	-1388948.	1243664.	-1.116819
11	COTEXP	1	1	.2100932	.1162267	1.807615
12	AGTRA	42	1	-190.1671	257.9442	-.7372414
13	AGTRC	43	1	111.4537	166.2788	.6702822
14	AGTRW	44	1	-55.43423	341.4702	-.1623399

F-TESTS, DEPENDENT VARIABLE COTACR

VARIABLE	F-STATISTIC	SIGNIF. LEVEL
ALFACR	.54811	.6575490
COTACR	1.93197	.1706463
WHTACR	.94402	.4458220

TABLE 11

EQUATION 3
DEPENDENT VARIABLE 39 BARACR
FROM 1968- 1 UNTIL 1986- 1
OBSERVATIONS 19 DEGREES OF FREEDOM 14
R**2 .96566357 RBAR**2 .93636174
SSR .16313857E+11 SEE 34136.132
DURBIN-WATSON 2.00003030

NO.	LABEL	VAR	LAG	COEFFICIENT	STAND. ERROR	T-STATISTIC
1	ALFACR	37	1	.1003200E-01	.8764004E-01	.1144657
2	ALFACR	37	3	.5957925	.4396446	1.355178
3	ALFACR	37	5	-.1737245	.7872200	-.2204300
4	COTACR	38	1	-.3149640E-02	.1384780E-01	-.2274300
5	COTACR	38	3	.6255299E-01	.8013630E-01	.7806816
6	COTACR	38	5	-.7461229E-01	.1667874	-.4473497
7	BARACR	39	1	.6369691	.1765062	3.606788
8	BARACR	39	3	.1987688	.1063969	1.806374
9	BARACR	39	5	-.1560373	.1970032	-.7917232
10	CONSTANT	0	0	35412.41	419781.0	.8437521E-01
11	COTEXP	1	1	-.7563539E-01	.3340267E-01	-2.240289
12	AGTRA	46	1	-92.27993	113.3254	-.8142916
13	AGTRC	47	1	-20.96043	84.27830	-.2487049
14	AGTRBAR	48	1	230.9008	141.9248	1.626924

F-TESTS, DEPENDENT VARIABLE BARACR

VARIABLE	F-STATISTIC	SIGNIF. LEVEL
ALFACR	.61671	.6155187
COTACR	.25999	.8530000
BARACR	8.01400	.1405087E-02

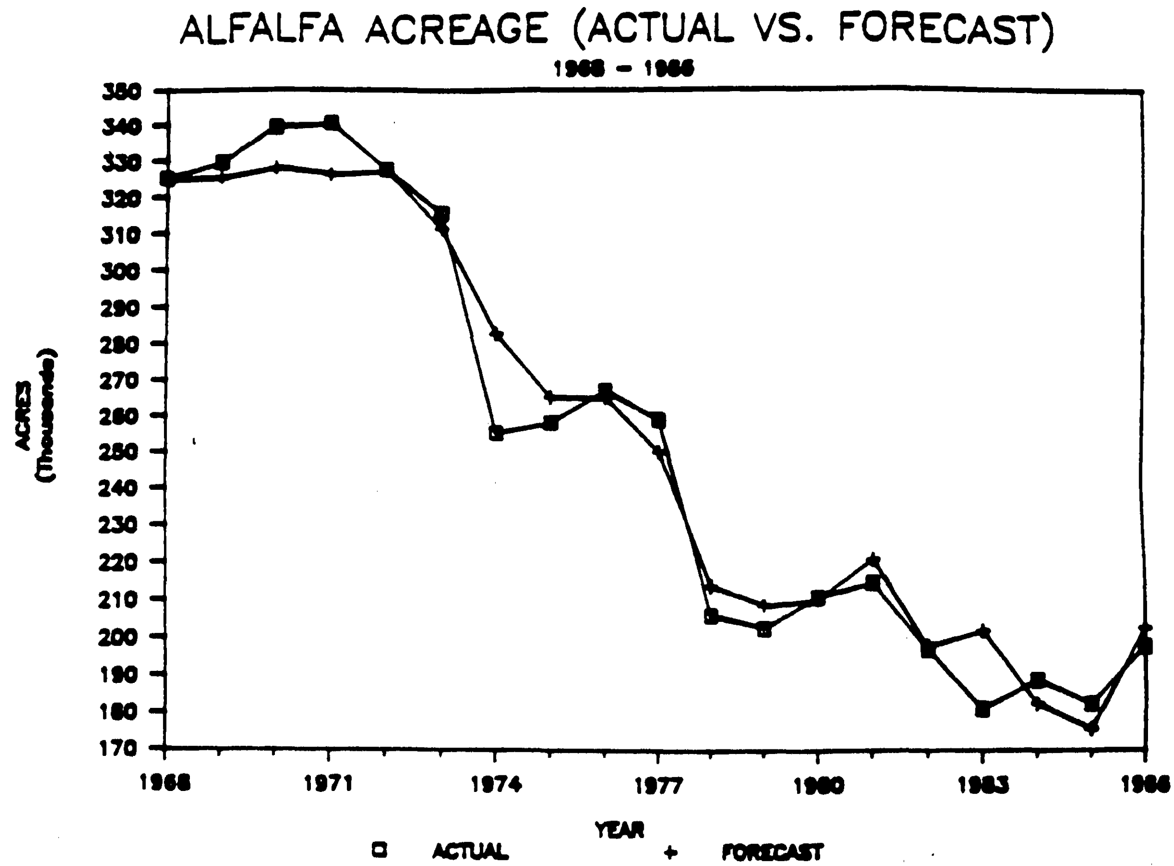
EQUATION 3
DEPENDENT VARIABLE 32 WHTACR
FROM 1968- 1 UNTIL 1986- 1
OBSERVATIONS 19 DEGREES OF FREEDOM 14
R**2 .93132128 RBAR**2 .91169878
SSR .60117458E+10 SEE 20722.229
DURBIN-WATSON 2.73316900

NO.	LABEL	VAR	LAG	COEFFICIENT	STAND. ERROR	T-STATISTIC
1	ALFACR	30	1	-.6084878E-02	.5757675E-01	-.1056829
2	ALFACR	30	3	-.1485856	.2693300	-.5516838
3	ALFACR	30	5	.1237129	.5101228	.2425142
4	COTACR	31	1	.1170064E-02	.9100211E-02	.1295645
5	COTACR	31	3	.4837785E-02	.5308507E-01	.9113115E-01
6	COTACR	31	5	.6247156E-01	.1077333	.5798722
7	WHTACR	32	1	.4892650E-01	.1460068	.3332713
8	WHTACR	32	3	-.8036183	.1320150	-6.087327
9	WHTACR	32	5	-.4390038	.1671940	-2.625701
10	CONSTANT	0	0	79434.13	236465.8	.3359223
11	COTEXP	1	1	.8399595E-02	.2267101E-01	.3704864
12	AGTRA	42	1	61.17657	58.85520	1.039442
13	AGTRC	43	1	-137.1142	38.73046	-3.539486
14	AGTRW	44	1	429.8063	76.06682	5.650946

F-TESTS, DEPENDENT VARIABLE WHTACR

VARIABLE	F-STATISTIC	SIGNIF. LEVEL
ALFACR	.11081	.9492393
COTACR	.12999	.9400033
WHTACR	15.03420	.1170403E-03

FIGURE 4


ALFALFA ACREAGE (ACTUAL VS. FORECAST)
1968 – 1986
ACRES (Thousands)
380
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
1968
1971
1974
1977
1980
1983
1986
YEAR
ACTUAL
FORECAST

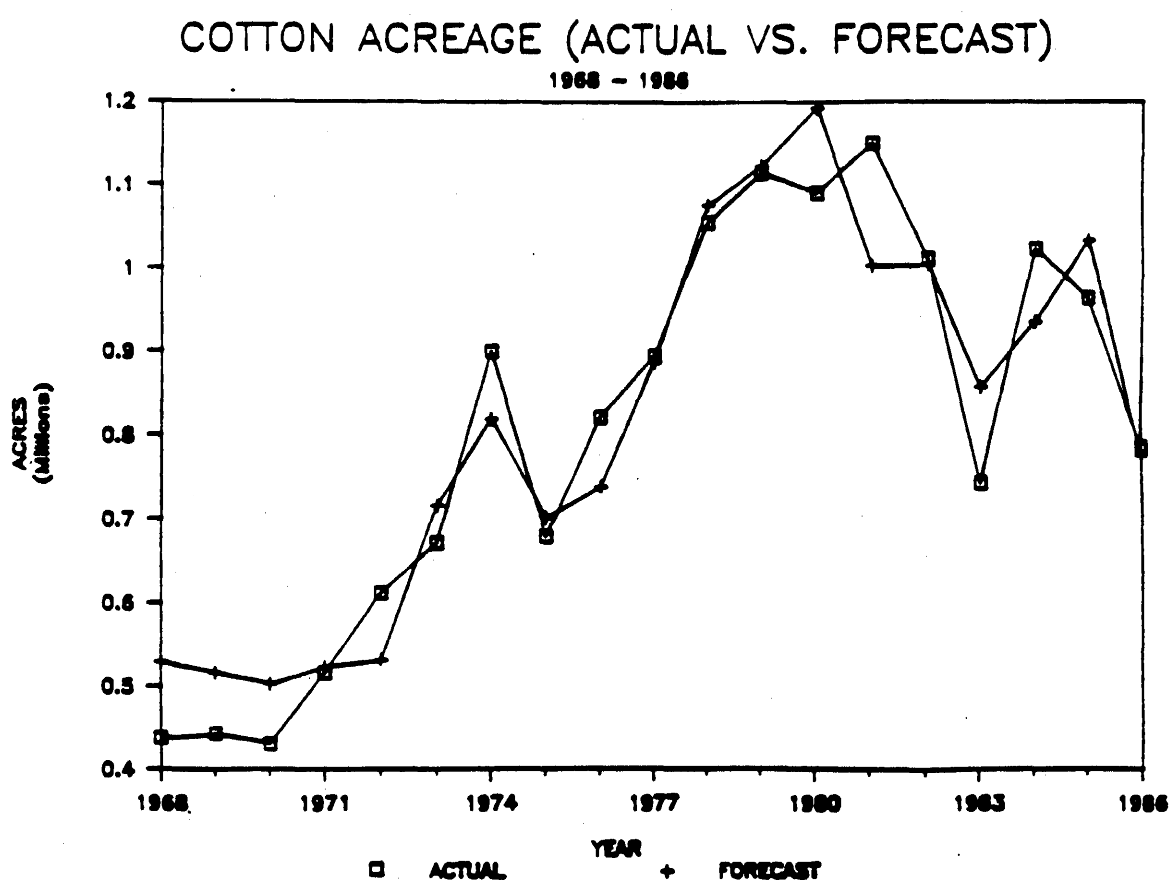
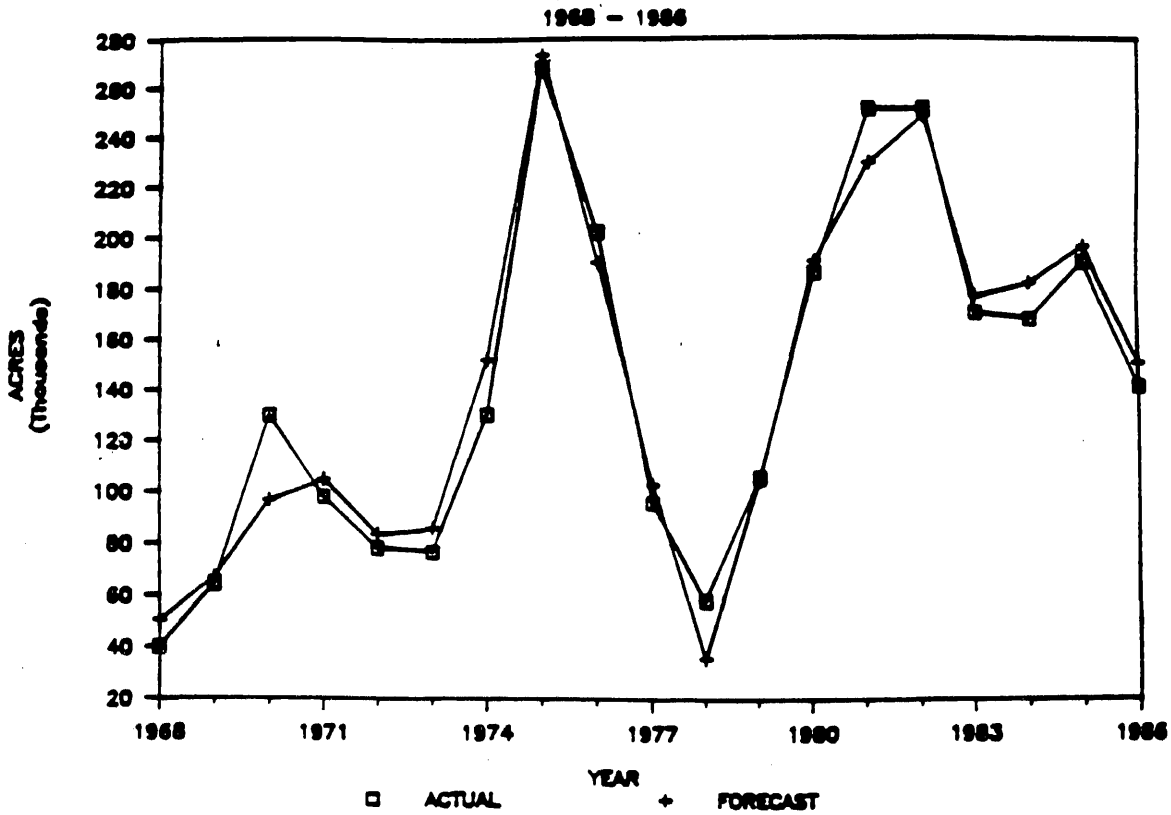
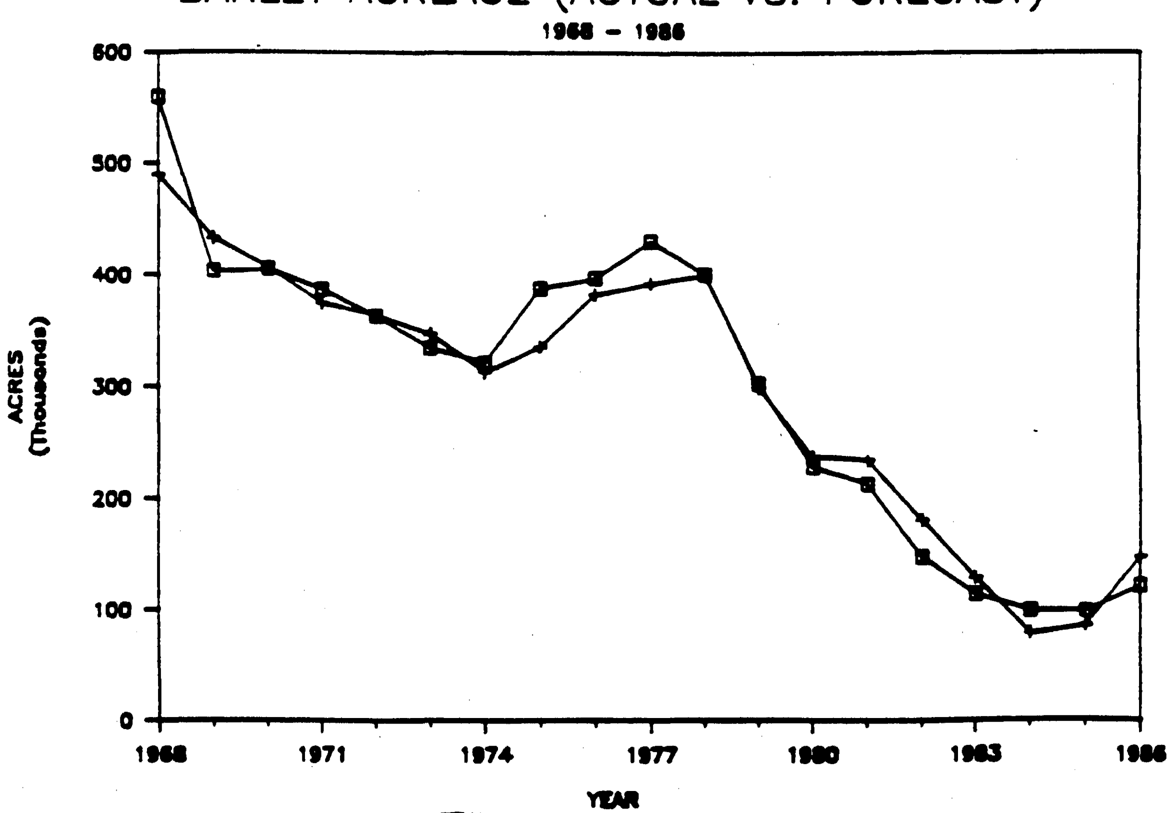

COTTON ACREAGE (ACTUAL VS. FORECAST)
1968 – 1986
ACRES (Millions)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
1968
1971
1974
1977
1980
1983
1986
YEAR
ACTUAL
FORECAST

FIGURE 5

WHEAT ACREAGE (ACTUAL VS. FORECAST)



BARLEY ACREAGE (ACTUAL VS. FORECAST)



higher percentage changes in benefits than results from a national model (Adams *et al.* 1984) for the same percentage change in ozone level. Third, t he distribution of benefits differs noticeably between the California and National model. The California model shows a fairly even split of benefits between producers and consumers. The national model however, shows that benefits are strongly slanted towards consumers.

Questions about the suitability of the economic surplus measures in the presence of subsidies have been raised by Kopp et al.,1985 , McGartland, 1987 and more recently, Madariaga in an unpublished note. McGartland criticized the approach used by Kopp et al., Adams et al., and this study which attributes the changes in surplus from shifts in the supply function as benefits from ozone reduction. The basis of the criticism is that for crops with government subsidies, the producer is paid a higher price than the consumer's marginal price. The difference is the crop subsidy. McGartland successfully argues that the surplus measures should be adjusted downward to remove the effect of subsidies financed by the taxpayer. Madariaga introduces the additional complication of acreage constraints, and concludes that government target prices could be lowered to offset some of the increase in subsidy from the supply shifts.

The concern over the correct measure of national welfare does not greatly alter the criterion for measuring optimal economic benefits to the state of California. From the unilateral view of the state, an increased share of the agricultural subsidy payments to its growers is a real benefit. In addition, the proportion of agricultural subsidies in California has, until recently, been lower than most states due to the unique crop mix in the state. For these reasons, the objective function used for this study remained as the simple sum of producer and consumer surpluses.

With the onset of the 1985 Farm Bill, enrollments of California growers in farm programs increased. Some runs were made to test a method of incorporating the higher prices and additional constraints of the programs in the model. The updated base year chosen was 1986. Data on the crop enrollment proportions by county, the support prices, and acreage "set asides" required were collected. The crops that showed significant enrollment, principally rice, cotton, wheat and barley, were specified in the model under two activities for each crop and region. The activities were specified as enrolled and non-enrolled crop acreage The PQP calibration method (appendix1) was then applied to each acreage in turn so that the resulting nonlinear cost function reflected both the increasing costs of production and the cost of being in the government program to the farmers. The resulting model calibrated accurately to the 1986 base year and showed less tendency to respond to supply shifts than the model without the government program constraints. Two sets of data updating for CARM were performed during the time period of the contract. The first set of updates was from 1978 to 1984. The data on cropping acreages by area was assembled from the annual County Agricultural Commissioner's reports. The report aggregation involved extensive hand tabulation and data reconciliation between the counties. Data on water availability and costs of groundwater pumping and surface supply costs was obtained from the California Department of Water Resources. In addition to the data update, the model regions were expanded from 14 to 17 for better regional precision.

Subsequent to the analysis performed under the contract, the data base and model specification were updated to 1986. The same data base was used. In both cases, new updated cost data was not available, thus the 1978 base costs were updated by the USDA price index of prices paid by farmers. Currently, a jointly funded survey by the University and State agencies is being processed, and will be used to update the costs in the future. The updated model has now been converted to a more accessible program called GAMS/MINOS. Aggregated versions of the model can now be run on the large models of personal computers. This development will make the CAR model much more accessible in the future. There is no practical barrier to prevent a version of the model aggregated to the major airsheds, from being run on ARB desk computers in the near future. A full GAMS/MINOS listing of the model is available if required. This updated version of the model will be used for future work in estimating the economic impact of future increases in air pollution in the San Joaquin and Sacramento valleys.

6.0 Benefit Comparisons with National Models

Adams et al, 1986 published the results of a national model of the benefits from changed ozone levels in agricultural production. In many respects the Adams model is similar to CARM Both models use a price determining system with linear demands based on previous time series. The models also have the same objectives of maximizing surplus, assuming profit maximizing behavior from farmers. The models differ in the way that agricultural supply response is specified. The Adams model does not use the PQP approach and continuous functions, but uses a series of past supply levels to define a step function. This different supply specification can account for some differences in the producer surplus measures, but it is unlikely that all the differences in the model results are due to the specification change.

The benefit results from the two models are difficult to compare directly since they are on different scales, regions, crops and specifications. For instance, the Adams model includes the livestock sector of agriculture which is omitted from the CARM model. The model results can be compared proportionally by reducing the ozone scenarios and the consumer and producer surplus results to percentage changes. Table 12 which is calculated on this basis, shows two distinct differences in the model results. The percentage increase in total benefits per ten percent decrease in ozone level is over twice as high at 3.2% for CARM as for the Adams model. Division of the total change in benefits into the consumer and producer proportions shows that while the CARM results have a fairly even division, the Adams results strongly favor the consumer over the producer.

TABLE 12

Benefit Comparison Between Models
% Change in Benefits per 10% Decrease in Ozone

	ADAMS (National)	CARM (California)
Consumer surplus	0.9%	1.54%
Producer surplus	0.37%	1.66%
Total Benefit	1.27%	3.2%

The difference between the total response is puzzling until the breakdown by crop in tables 5 and 6 are examined. The dominant effects in both yield response and proportion of the California cropping mix are seen to be in cotton and table grapes. Nationally, grapes are insignificant and the importance of cotton pales beside corn, soybeans, and wheat. The higher California benefit response is due to having crops that are more ozone susceptible such as cotton and grapes comprise a dominant part of the agricultural field crop revenue. This point can be crudely illustrated by Table 13 in which Table 12 is recalculated from table 5, omitting cotton from the major crop list.

TABLE 13

Benefit Comparison Between Models Cotton omitted from CARM
% Change in Benefits per 10% Decrease in Ozone

	ADAMS (National)	CARM (California)
Consumer surplus	0.9%	0.91%
Producer surplus	0.37%	0.988%
Total Benefit	1.27%	1.9%

When adjusted for the strong impact of ozone changes on the cotton crop, the changes in consumer's surplus are of the same magnitude, the greater the proportional gain in producer's surplus is explained by the unilateral action of California in the CARM model.

Figures 6 and 7 are simple diagrams of the effect of changes in supplies of a single commodity from two producing regions on a single market. The two regions are California and the rest of the United States. In Figure 6, both regions (the nation) show downward shifts (increases) in their supplies which could be caused by higher yields from reduction in ozone. The effect on the producer's surplus for the regions depends on the elasticity of demand for the product. In Figure 6, the change in producer surplus from P_0, QC_0 and QR_0 to P_+, QC_+ and QR_+ is questionable.With the increase in quantity and fall in price we are comparing the areas in the top rectangle lost to producers, to the bottom triangle gained by producers. The producers may have small gains. The gains in consumers surplus in the market is large and unequivocal, the addition to the consumer surplus by the market price drop from $P_0 \rightarrow P_+$ and quantity increase from $Q_0 \rightarrow Q_+$ is clear. The situation in Figure 6 corresponds to the national model by Adams *et al.*

Figure 7 shows the effect of a unilateral reduction in ozone , and a consequent supply shift by California. Yields for the rest of the U.S. are assumed to remain constant. The effects are very different, the market price reduction is less and thus the gain in consumer surplus between P_0 and P_+ is reduced. The producers in the rest of the U.S. lose both market share and price, the producers surplus in the rest of the U.S. is clearly reduced. Californian producers gain an increase in both market share and producers surplus. The Californian market share increases from QC_0 to QC_+, while the rest of the U.S. decreased from QR_0 to QR_+.

The policy conclusion from the diagrams is that, for crops with substantial competition in other regions, unilateral ozone reduction will result in greater benefits to California producers. Since a large proportion of California's agricultural production is exported, the producer benefits should weigh strongly with California's policy makers. Where Californian crops are not strongly competing with other regions, and the market demand is unresponsive (inelastic), yield increases can lead to reductions in producer surplus.

An analytic check of the conclusions drawn from Figures 6 and 7 was made by modifying a simple model of national and regional crop production. The computer model was simplified to include cotton wheat and rice production in California and the rest of the United States (RUS). The model was calibrated from 1984 U.S.D.A. crop data. Cotton has a demand elasticity of –.22 while wheat and rice were set at - 15.

The scenarios run were a 20% increase in cotton yields for California and RUS against a 20% yield increase for California alone. The surplus measures and percent change are shown in Table 14.

FIGURE 6

NATIONAL REDUCTION EFFECT

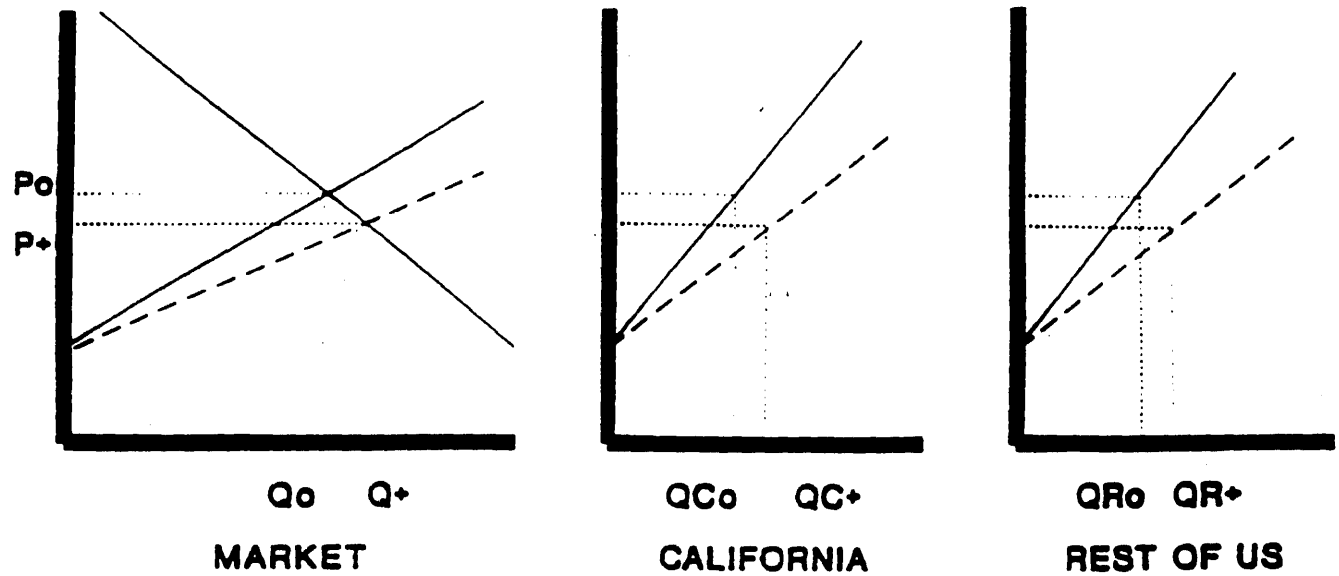


FIGURE 7

UNILATERAL ACTION BY CALIFORNIA

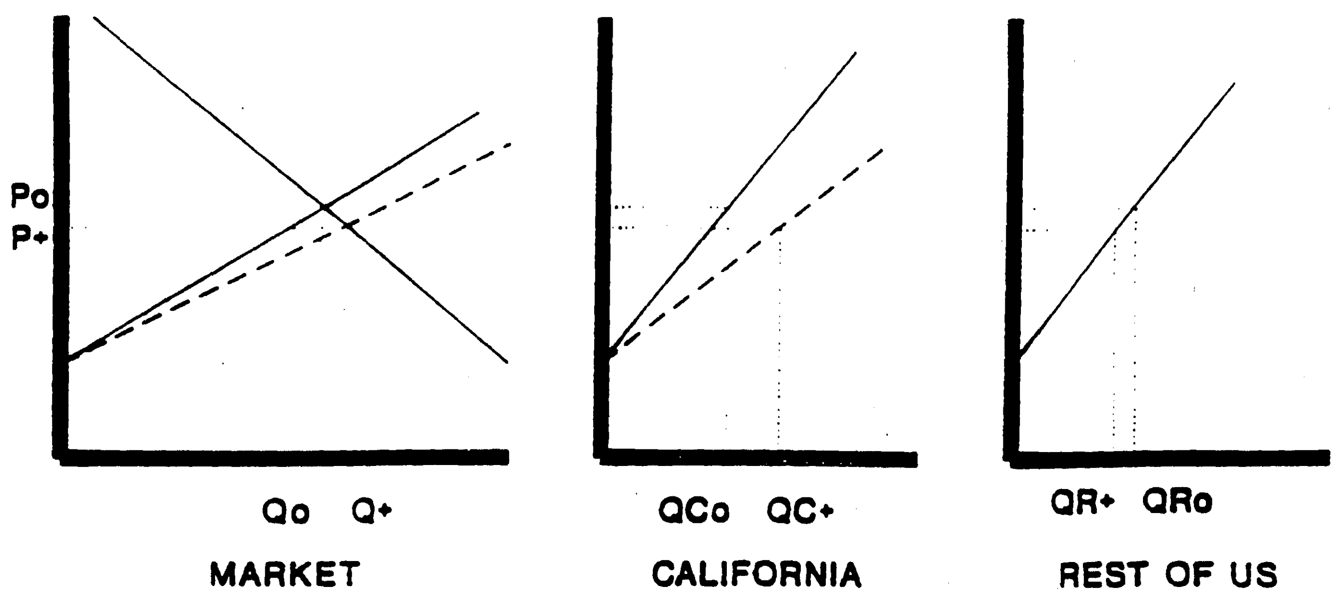


TABLE 14

Effects of Unilateral vs. National Yield Changes in Cotton

Scenario	Consumer Surplus	Producer Surplus California	Producer Surplus R.U.S.
Base year	48,513	572	10,257
Cal Cotton +20% yield	49,645 (+2.3%)	772 (+34.9%)	9,696 (–6.5%)
Cotton + 20% yield: Both Regions	52,184 (+7.6%)	606 (+5.9%)	10,786 (+5.2%)

Table 14 shows the same impact and qualitative results as Figures 6 and 7. The percentages are naturally different due to the effect of other crops, but the message is consistent. There is a rational explanation of the different proportions and benefit levels between the national and Californian results. The reason leads to the policy conclusion that unilateral action to improve California's yields by ozone reduction can be more beneficial to growers where they face strong competition from other regions.

7.0 Summary and Conclusions

This research has shown that it is possible to measure the economic impacts of ozone regulation on agricultural production on a regional scale that can be used to assess the value of ozone standards. Previous studies had shown aggregate impacts, but were not able to specify the effects for specific airsheds and agricultural regions. The integration of CARM with the dose response functions from Okszyk et al., allows the economic impacts to be projected over regions and time as the ozone levels and cropping pattern changes.

The benefits of ozone reduction to food consumers and agricultural producers in the state are substantial. The producers benefits of ozone reduction of $24 to $14 per acre may seem low in terms of gross output. However, when viewed as a proportion of net returns of $60 - $200 per acre for field crops, these levels of ozone reduction would noticeably affect farm profits from field crops. The total annual statewide benefit represents an equivalent return from a capital investment of $2-3 billion. Against these benefits, must be weighed the substantial costs of ozone reduction, which would be imposed on agriculture and residents of urban areas in agricultural regions.

Projections of increasing air pollution levels in the San Joaquin Valley indicate that the benefits of ozone control in the San Joaquin Valley may be substantially higher in the future than shown here. These trends will be assessed in ongoing work with the model.

The ability to analyze regional impacts shows that benefits vary substantially by region for reasons of ozone and cropping variability. The costs of setting regional standards should be investigated. Gradual introduction of standards over a five or ten year period would be consistent with the rate of crop acreage change shown by statistical analysis of past cropping patterns.

At the end of the first stage of the study, the discrepancies between measures of benefits from the national and statewide model were thought to be due to differences in the crop demand functions used. A crop specific breakdown shows that California's higher benefits per unit of ozone reduction are due to the higher proportion of ozone sensitive crops grown in California. An analysis of benefit shares between producers and consumers showed that there are advantages to California producers to taking action on reducing agricultural ozone before other competing regions do so.

A clear recommendation of the study is that the costs of regional ozone standards in the San Joaquin valley should be investigated. The benefits to San Joaquin producers of a seasonal standard of .05 - .045 ppm currently range between $60 - 70 million per year. The benefits will increase as the background pollution levels increase. The returns to this investment are substantial and likely to grow, but the costs of control must also be weighed in the decision since the criteria used in this study are purely economic.

lk 8/14/89 PRO.3

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Appendix 1

The theory and analytical details of the positive programming method used is detailed in Howitt (1989). An intuitive grasp of the calibration approach can be obtained using figure 2. Figure 2 is for a very simplified case modelling two crop allocations in wheat and oats with a single land constraint of five units. The acreage allocations x_w and x_o are plotted in a "back-to-back" manner against costs and returns on the vertical axis. The prices times yields are assumed constant at P_w and P_o respectively. The average costs are likewise at $\bar{c}_w$ and $\bar{c}_o$ under the linear constant returns assumption.

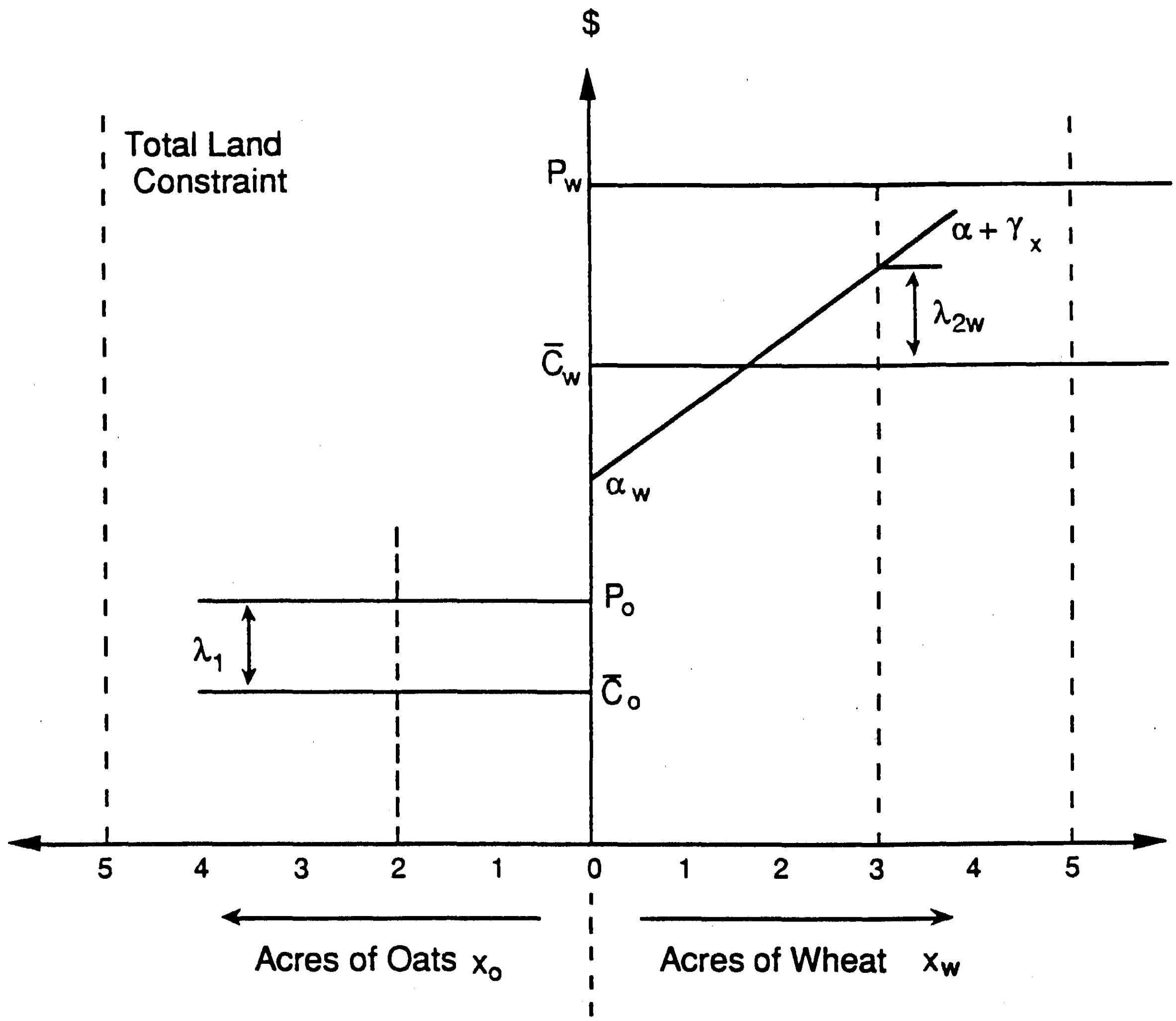
In Figure 2, the observed acreages of each crop are shown by the vertical broken lines at 3 for x_w and 2 for x_o. If the most profitable crop, wheat, was constrained to the observed level of 3, the dual, or shadow value of the constraint would equal l_{2w}. l_1, the net return from oats would be the opportunity cost of the land constraint.

Using the formulas derived in Howitt (1989) the nonlinear cost function parameters a_w and g_w can be derived from l_{2w} and $\bar{c}_w$. The linear cost $\bar{c}_w$ is now replaced by the nonlinear cost $a_w x_w + g_x x_w^2$. Figure 2 shows that this cost function drives the net return from wheat production to equal the marginal marginal return on oats at the observed acreages of 3 and 2 for x_w and x_o respectively. It is worth noting that the average net return for wheat is still higher than oats, but the marginal net returns are equal at the observed acreages. This is, of course, consistent with the equimarginal principle of input allocation in neoclassical micro theory. CARM uses the approach to calibrate the regional crop acreages observed in the base year without resorting to restrictive constraints.

FIGURE 8

PQP Diagram

Two activity/one constraint



Note : (1) The opportunity cost of land is always l1, the gross margin from oats.

(2) Given the PQP cost function, a + lx, at three acres of wheat the Marginal net revenue of what = l1 = opportunity cost of land.

Glossary

Consumers' Surplus — the net benefit to consumers is the area under the demand curve minus the area under the price line. The surplus comes for the fact that the good can be purchased for a price lower than some consumers would have been willing to pay for the good, i.e., those points on the demand curve above the price line represent points where consumers would have paid more, but bought less.

Cross Price Effects — cross price effects arise when the price of one good influences the demand for another.

Cross Price Elasticity — this represents the extent to which a change in the price of one good effects the quantity demanded of another good. A zero value means there is no effect.

Demand Function — the typical demand function is downward sloping with quantity demanded dependent on price and other relevant variables.

Elasticity of Demand — the effect of a change in price on quantity demanded. High absolute values of elasticity signify a large change in quantity demanded from a change in price.

F Statistic — the F statistic is being used to test the significance of each variable in the equation. Generally, values of 2 or larger can be regarded as significant.

Linear regression — this is used to statistically estimate the demand functions from the data on price and quantity observed in past years to come up with intercept and slope coefficients.

Marginal Physical Product — for an input it is the increase in output that results from a one unit increase in the use of the input, holding the amount of all other inputs fixed.

Marginal Value Product -- the change in total revenue resulting from an additional unit of an input, holding the amount of all other inputs fixed.

Nonlinear Cost Functions — are used because of the decreasing fixed marginal productivity of inputs, and the increasing risk of specialization.

Positive Programming Approach — see the Appendix.

PQP -- Positive Quadractic Programing -see the Appendix.

Producers' Surplus — the area under the price line minus the area under the marginal cost curve which in the short-run is the same as the supply curve. The surplus is the difference between what the producer receives and what he would have been willing to accept as a price for selling certain quantities.

Random Noise — the random noise in a regression equation is the stochastic error term usually interpreted as accounting for a number of individually insignificant and independent factors whose presence means that the dependent variable can never be exactly forecasted.

R-squared — the value of R-squared represents the percentage of the change in the dependent variable which can be explained by changes in the explanatory variables as opposed to "random noise," hence the closer the value to 1 the better.

T-statistic — this tests the significance of each of the regression coefficients. Generally, absolute values greater than 1 mean the coefficient is significantly different from zero.

Acronyms used in the regression results are:

Alfacr	Alfalfa acreage
Cotacr	Cotton acreage
Whtacr	Wheat acreage
Baracr	Barley acreage
Agtra	Total revenue/acre for alfalfa
Agtrc	Total revenue/acre for cotton
Agtrw	Total revenue/acre for wheat
Agtrbar	Total revenue/acre for barley
Constant	Constant term in the regression
Cotexp	A variable for a cotton export payment that was available in some of the years