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Volume VI

THE VALUE OF AIR POLLUTION DAMAGES TO AGRICULTURAL ACTIVITIES IN SOUTHERN CALIFORNIA

by

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This volume summarizes the methodological and empirical findings of the series. The concensus of the empirical reports is the benefits of air pollution control appear to be sufficient to warrant current ambient air quality standards. The report indicates the greatest proportion of benefits fran control resides, not in health benefits, but in aesthetic improvements, maintenance of the ecosystem for recreation, and the reduction of damages to artifacts and materials.

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ABSTRACT

In spite of an enormous amount of literature on the phytotoxic effects of air pollution, few research efforts have been directed at the implications of these effects for agricultural markets. Of those few studies that do exist, nearly all do no more than multiply the results of a field survey or experimental study of yield reductions by an invariant price in order to estimate the economic losses attributable to air pollution. The adjustments in output and input prices and cropping and location patterns that agricultural markets and growers make in response to altered levels of air pollution have been neglected. The three essays in this volume weigh some of the economic implications of these air pollution-induced adjustments for southern California agriculture.

The initial essay employs a mathematical programming technique to assess 1976 air pollution-induced losses to fourteen of southern California's most highly valued annual vegetable and field crops. A measure of the distributional consequences of these losses is also provided. Results indicate that 1976 benefits of air pollution control for the fourteen included crops would have been about 3.7 percent of their gross farm value, or $46 million. About three- quarters of these benefits would have accrued to the crop producers, with the rest being acquired by consumers.

A second essay provides estimates of the losses in earnings that workers in citrus groves bear from the oxidant air pollution to which they are exposed in their work environments. Fourteen of the seventeen workers studied suffered losses. Of these fourteen, there were order-of-magnitude differences in losses among them. The average daily earnings of all seventeen workers were reduced by two percent.

A final essay provides empirical evidence of a moderately strong positive association between a frequently employed measure of the risks faced by agriculturists and increases across space and time in southern California air pollution. No pecuniary measure of the burdens this association might imply for agriculturists is provided.

On the basis of the above three sets of results, our informed yet conservative judgment is that the levels of ambient oxidants prevailing in southern California in the mid-1970's were responsible for at least a four percent reduction in the total economic surpluses generated by the area's agricultural activities.

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Even in the wealthiest countries, agricultural production is strongly influenced by factors beyond the control of producers. Despite a tremendous increase in agricultural yields during the past three decades due, in part, to successful breeding of high yield and disease resistant varieties of plants, favorable weather conditions, and heavy usages of fertilizers, insecticides, and modern farm machinery, aggregate world food production has often not kept pace with world population growth. Further, in the more wealthy countries, yield plateaus appear to have been reached for some crops. For specific sites, this leveling of yields may be partially attributable to human-induced changes in environmental factors, such as the shifting of production to soils of lower inherent productivity and the general degradation of environmental quality, including worsened ambient air quality caused by encroachment of urban and industrial growth upon agricultural lands. Perhaps the most vivid example of the conflict between urban and industrial activities and agriculture through the intermediary of air pollution is to be found in southern California.

The fact that air pollution poses problems for southern California agriculture is well documented.[1/] Injury to vegetation from photochemcial oxidants in the immediate vicinity of Los Angeles was first characterized in 1944 [Middleton, et al. (1950)], but was soon recognized to exist over a large part of southern California [Middleton, et al. (1958)]. Potentially phytotoxic levels of photochemical oxidants are now generally acknowledged to extend from the Los Angeles Basin eastward into the Mojave Desert and the Imperial Valley and northward into the Ventura-Oxnard Plain. In addition, areas of previously low pollution concentrations, such as the San Joaquin Valley and the Central Coast Valley, have recently been experiencing locally generated ambient oxidant concentrations that are potentially damaging.

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In spite of an enormous literature on the phytotoxic effects of air pollution, few research efforts have been directed at the implications of these effects for agricultural markets. Of those few studies that do exist, nearly all do no more than multiply the results of field surveys or experimental studies of yield reduction by an invariant current price in order to estimate the value of air pollution-induced losses, e.g., Thompson and Taylor (1969), Benedict, et al. (1973), Millecan (1976). The adjustments in output and input prices and cropping and location patterns that agricultural markets and growers make in response to altered levels of air pollution have been neglected. The three essays in this volume weigh some of the economic implications of these air pollution-induced adjustments for southern California agriculture.

The initial essay uses a mathematical programming technique to assess air pollution-induced losses to fourteen of southern California's most highly valued annual vegetable and field crops. This technique allows us to estimate the losses in consumer surpluses and grower rents occurring after growers have been permitted to alter cropping patterns and locations in response to changes in ambient concentrations of photochemical oxidants. As we have used it, however, the technique falls somewhat short of capturing all economically relevant features of the impacts of air pollution upon agricultural markets. Among other things, such as the impact of air pollution on intertemporal agricultural investment patterns, it forces us to disregard losses that inputs employed but not owned by the grower may suffer. In addition, as we have used it, the technique embodies an assumption that air pollution has no influence upon the uncertainties that growers and the inputs they employ face.

The second essay provides estimates of the losses in earnings that workers in citrus groves bear from the oxidant air pollution to which they are exposed in their work environments. Although citrus is not among the fourteen crops to which the mathematical programming technique is applied, the greater than two percent earnings losses that air pollution imposes upon citrus grove workers gives cause to wonder whether labor for other agricultural crops might suffer similarly. If so, these losses would be in addition to those weighing upon consumers and growers.

The final essay is the only one of the three which does not present pecuniary equivalents of some facet of the losses that the air pollution originating from southern California urban and industrial activities forces upon the areas' agriculture. Instead, after a brief discussion of why uncertainty is costly to the agricultural sector, we provide empirical evidence of a moderately strong positive association between a frequently employed measure of the risks faced by agriculturists and increases across space and time in southern California oxidant air pollution.

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The research efforts displayed in these three essays neither embrace all oxidant air pollution impacted crops grown in southern California nor do they capture all plausible facets of the impacts of oxidants upon the input and output markets for these crops. For example, losses in consumer surpluses and producer rents from reductions in citrus yields are not included and economic losses generated by any yield uncertainties that oxidants cause are absent. Despite these blanks, and assuming that the crops and inputs we have studied have a reasonably representative distribution of air pollution sensitivities, our informed yet conservative judgment is that the levels of ambient oxidants prevailing in southern California in the mid 1970’s were responsible for at least a four percent reduction in the total economic surpluses generated by the area’s agricultural activities.

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[1] For details, see the bibliography at the end of Chapter II in Committee on Medical and Biologic Effects of Environmental Pollutants (1977).

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CHAPTER II

AN ECONOMIC ASSESSMENT OF AIR POLLUTION DAMAGES TO SELECTED ANNUAL CROPS IN SOUTHERN CALIFORNIA

Agricultural production is strongly influenced by many factors beyond the control of individual producers. In agricultural regions within or surrounding urban areas, air pollution has in recent decades become one of these exogenous influential factors. When these agricultural regions, perhaps because of unique climatological requirements, dominate the national marketing for selected crops, output price increases may occur due to air pollution induced reductions in crop yields. These price increases will reduce the well-being of consumers. In addition, if increases in market price are insufficient to offset reductions in marketing, producers may also be made worse off.

On a seasonal basis (mainly winter and spring) southern California produces a major share of the nation’s vegetables and fruits. Moreover, large volumes of field crops such as cotton and sugar beets are also produced within the region. The adverse biological effects on many of these crops from the oxidant air pollution that intermittently spreads through the region are well documented. [1/] Attempts to assess the economic impacts of these effects have been few. Moreover, those attempts that have been made simply multiply the estimated reductions in yields by an invariant price. [2/] This method is inappropriate for crops having geographically concentrated production patterns since their market prices may vary with the quantity supplied from the region. Moreover, the method is unable to account for mitigative changes in cropping patterns and locations.

In this paper we employ a more general methodology to assess the economic impact in 1976 of air pollution upon fourteen annual vegetable and field crops in four agricultural subregions of central and southern California. The study is best characterized as an exercise in the analysis of changes in comparative economic advantage between and among crops and growing locations. In addition, we are able to distinguish between the impacts upon consumers and producers of these air pollution-induced changes.

While our results are limited in scope and are sometimes based upon sparse air pollution data and unsettled dose-response relations, they suggest that more comprehensive analyses then have been traditional are desirable for the economic assessment of fairly large-scale ecosystem impacts of human activities. That is, at least for the case we report here, the empirical results appear to be quite sensitive to the analytical comprehensiveness of the model one adopts.

THE PROBLEM

We assume that markets for each of the included fourteen crops operate so as to solve the following quadratic programming problem:

$$\begin{aligned} \text{Max: } & \pi = C^T Q + 1/2 \; Q^T D Q \quad H^T Q \\ \text{Subject to: } & A Q \leq b \\ & Q \geq 0 \end{aligned}$$

The symmetric matrix D in the objective function is negative definite, and the constraints are convex. The terms of (1) are defined as follows.

A is an m x n matrix of production coefficients indicating the invariant amount of each of a variety of inputs required to produce any single unit of a particular output.

Q is a n x 1 column vector of crop outputs.

D is a m x m matrix representing slope values of the linear demand structure for the fourteen included crops.

H is a n x 1 column vector of invariant unit costs of production for the included crops.

C is a n x 1 column vector of constants.

b is a m x 1 column vector of inputs.

As advocated by Harberger (1971), π is the sum of ordinary consumer surpluses and producer quasi-rents. The supply functions for all producer inputs purchased in the current period (seeds, labor, fertilizer, etc.) are assumed to be perfectly price-elastic. In addition, we invoke Willig's (1976) results and presume any differences between ordinary and compensated consumer surpluses to be trivial. Since neither income elasticities nor ordinary consumer surpluses or expenditures as a percentage of incomes are likely to large for the crops being studied, this invocation seems reasonable.

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The left-hand-side of the objective function in (1) can be stated in terms of observable by introducing a price forecasting expression:

$$P = C + 1/2\ DQ, \tag{2}$$

where P is a n x 1 vector of farm level crop prices. In matrix form, the objective function may then be expressed as:

$$P^TQ = C^TQ + 1/2\ Q^TDQ - H^TQ \tag{3}$$

In order to capture the impact of air pollution upon crop yields, we define a variable $Z^*(0 \leq Z^* \leq 1)$ for each included crop. The Q terms in (1), (2) and (3) can then be stated as:

$$Q^* = (I - Z^*)\ L^TY, \tag{4}$$

where:

Q* is a n x 1 column vector of yields of the n crops in the presence of air pollution.

Z* is a n x 1 column vector of indicies of yield reduction for the n crops.

I is a n x 1 column vector of unity.

L is a n x 1 column vector of the land acreage used for cultivating the n crops. The total land area available for all crops is assumed fixed.

Y is a n x 1 column vector of yields per acre of the n crops in the absence of air pollution.

Given L and Y constant, the value of Q* varies inversely with the value of Z*. Thus regions with higher ambient oxidant concentrations will have higher values for Z* and consequently lower values for Q*. The yield price effects of these reductions in Q* are then predicted by (3), the price forecasting expression. Impacts of these predicted price changes upon consumer surpluses, producer quasi-rents, and cropping patterns can then be calculated by solving the quadratic programming problem.

YIELD REDUCTION RELATIONS

The first requirement for empirical implementation of the above model is the establishment of Z* in (4) for each crop. To accomplish this, we adopted two approximation procedures, and then tested the robustness of the approximations by comparing them to the results obtained by a totally different third procedure.[3] Nevertheless, some fairly speculative leaps from a quite limited base of hard data relating to photochemical oxidant dose-response relations for the fourteen crops were required.

Except for cotton, a formulation of Larsen and Heck's (1976) was combined with a general rule-of-thumb of Millecan's (1971) to estimate yield reductions. After reviewing a large number of studies on ozone damages to plants,[4] Larsen and Heck (1976) formulated a general expression relating the intensity and duration of ozone exposures to leaf damages. They also published the coefficients of the parameters of the expression for a variety of crops. Leaf damages may not be linearly related to yield reductions, however. We, therefore, used a "rule-of-thumb" suggested by Millecan (1971) to translate percentage leaf damage to percentage yield reduction for the study crops. This perhaps rather questionable but unavoidable procedure was unnecessary for cotton given that Oshima (1973) has related cumulative ozone exposures directly to percentage yield reductions.

By region, Table 1 presents estimated air pollution-induced percentage yield reductions averaged over the 1972-76 period and for 1976 for the fourteen crops, given the actual 1976 cropping patterns and locations. Four vegetable crops, broccoli, cantaloupes, carrots, and cauliflower, displayed no yield effects. Reductions in lettuce yields occurred only in the South Coast and these effects were slight. However, lima beans, celery, and cotton appear to have suffered substantial yield reductions, while potatoes, tomatoes, and onions exhibit moderate losses at observed oxidant levels. Regionally, percentage yield reductions are by far the greatest in the South Coast, followed by the Southern San Joaquin, the Southern Desert, and the Central Coast regions. This ordering of regions by yield reductions corresponds to an ordering by ambient oxidant concentrations. Percentage yield reductions for some crops in some regions do not differ between 1972-76, and 1976, because of the discontinuous dose-response functions posited by Larsen and Heck (1976) and Oshima (1973). Those dissimilar crops such as potatoes and tomatoes in Table 1 said to have identical estimated percentage yield reductions were, on the basis of a review of the relevant literature, treated as having identical dose-response functions.

In order to provide an independent check of the estimates in Table 1, production functions for most crops were estimated by individual counties from annual time-series data extending from 1957 through 1976.[5] Using ordinary-least-squares, individual crop yields were assumed to be simple linear functions of exogenously determined levels of harvested acreage of the crop, annual average 24-hour maxima of oxidants, and a county agricultural

Table 2.1

Estimated Percentage Yield Reductions by Crop and Region Due to Arithmetic Mean 1972-76 and 1976 Ambient Oxidants Given Existing Cropping Patterns and Locations*

Crop	Region**							
	Southern Desert		South Coast		Central Coast		Southern San Joaquin	
	1972-76	1976	1972-76	1976	1972-76	1976	1972-76	1976
Vegetables								
Beans, processing green lima	*** —	—	22.26	15.71	1.57	1.57	9.45	9.45
Broccoli	—	—	0.00	0.00	0.00	0.00	—	—
Cantaloupes	0.00	0.00	0.00	0.00	n.a.	n.a.	0.00	0.00
Carrots	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cauliflower	—	—	0.00	0.00	0.00	0.00	—	—
Celery	—	—	18.11	12.57	1.23	1.23	—	—
Lettuce, head	0.00	0.00	0.27	0.03	0.00	0.00	0.00	0.00
Onions, fresh	1.00	0.00	6.80	1.99	0.40	0.40	—	—
Onions, processing	1.00	0.00	6.80	1.99	0.40	0.40	1.35	1.35
Potatoes	—	—	11.24	4.20	0.43	0.43	1.95	1.95
Tomatoes, fresh	1.10	0.00	11.24	4.20	0.43	0.43	1.95	1.95
Tomatoes, processing	1.10	0.00	11.24	4.20	0.43	0.43	1.95	1.95
Field								
Cotton	9.40	9.40	19.70	18.70	n.a.	n.a.	6.90	6.90
Sugar beets	0.80	0.00	5.66	1.63	0.33	0.33	1.10	1.10

Notes to Table

* Ambient oxidants are the arithmetic means of the 24-hour hourly maxima in parts per hundred million by volume as reported in California Air Resources Board (undated). Monitoring station locations were selected so as to be as close to crop production areas as possible. Exact locations of monitoring stations and crop production areas are depicted in Thanavibuchai (1979, P. 132).

** The Southern Desert is Imperial County; the South Coast is Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, San Diego, and Ventura

Table 2.1 (continued)

Counties; the Central Coast is Monterey, San Benito, San Luis Obispo, and Santa Cruz Counties; and the Southern San Joaquin is Kern and Tulare Counties.

*** A line indicates "not applicable" because the crop is not produced in the region.

productivity index. The latter is a composite measure of input productivities for all crops.[6] Cotton, cantaloupes, and carrots in Kern County; processing tomatoes, lima beans, and celery in Orange County; and fresh onions, lima beans, and fresh tomatoes in Riverside County had coefficients implying yield reductions similar to those predicted by the Larsen-Heck (1976) and Oshima (1973) methodologies. Given the time-series nature of the production function estimates, some discrepancies are not surprising. Nevertheless, the ordering of oxidant sensitivities by crop obtained for the latter methodologies corresponded to the ordering obtained by the production function estimates and can lend plausibility to the range of effects incorporated in the model.

PRICE FORECASTING RELATIONS

In order to capture air pollution-induced price changes and their consequent welfare effects, the problem in (1) incorporates a system of linear demand functions for the study crops in the quadratic objective function. Since interest here is in prediction of these price changes, an inverse function or price-forecasting expression for estimation purposes is employed.[7] With certain exceptions, the current quantities of the study crops produced can be treated as predetermined. Planting decisions for annual crops, once made and acted upon, are not readily altered. However, where a crop is widely grown under contract, as with processing tomatoes, or is generally acknowledged to be strongly influenced by government subsidy and quota programs, as with cotton and sugar beets, we employed the quantity-endogenous studies of others to establish a quantity coefficient. In addition, if the estimated quantity coefficient for any crop was statistically insignificant at the five percent level of the one-tailed t-test, we derived the incorporated coefficient from the price flexibilities of other seasons (e.g., spring, summer, fall) for the same crop at relevant price and quantity levels.

Table 2 gives the quantity coefficients as estimated from time-series data extending from 1955 through 1976.[8] Price flexibilities are included to facilitate comparisons with other studies, particularly King, et al., (1978).[9] Initially for each seasonal crop, the average price received by California farmers was regressed by ordinary-least-squares upon quantity produced in California, quantity produced in the rest of the United States, holdover stocks, and United States aggregate disposable income. To ease the computational burden involved in solving (l), an adjusted intercept term was then calculated by evaluating all independent variables, except for the quantity produced in California, at arithmetic mean (1955-1976) levels, summing, and adding the result to the initially estimated intercept term. The general price forecasting equation used in solving (1) was then:

Table 2.2

PRICE FLEXIBILITIES FOR THE SELECTED CROPS

Crop and Season	Adjusted Intercept[a] (1976)	Quantity Coefficient with Respect to California Production[b]	Price Flexibility with Respect to California Production, (1972-76)	$\bar{R}^2$
Vegetable				
Beans, gr. lima	333.29	-0.1543	-0.02′	0.91
Broccoli				
Early spring	15.85	-0.7247	-0.11	0.93
Fall	20.85	-2.9696	-0.34	0.96
Cantaloupes				
Spring	14.62	-1.6286	-0.18	0.89
Summer	12.40	-0.5355	-0.40	0.90
Carrots				
Winter	9.22	-1.4781	-0.83	0.56
Early summer	7.94	-0.1467	-0.10	0.47
Late fall	8.32	-0.1803	-0.10	0.68
Cauliflower				
Early spring	25.51	-6.3986	-0.30	0.93
Late fall	11.57	-2.4036[c]	[d]	0.96
Celery				
Winter	10.83	-1.3500	-0.48	0.69
Spring	11.43	-1.7608	-0.69	0.68
Early summer	8.09	-0.622s	-0.20	0.65
Late fall	13.97	-1.6232	-0.88	0.69
Lettuce				
Winter	6.36	-0.5857[c]	[d]	0.53
Early spring	16.72	-1.2690	-1.50	0.52
Summer	17.75	-0.8376	-1.30	0.75
Fall	12.57	-0.5047	-0.55	0.79
Onions				
Late spring	8.97	-0.5951	-0.14	0.36
Late summer	4.27	-0.0053	-0.01	0.71
Potatoes				
Winter	6.50	-0.8493	-0.18	0.71
Late spring	9.95	-0.2997	-0.69	0.62
Early summer	5.32	-1.2863	-0.23	0.65
Late summer	5.27	-0.1512	-0.05	0.66
Fall	4.00	-0.(3377	-0.05	0.77
Tomatoes, fresh				
Early spring	26.04	-5.4866[c]	[d]	0.70
Early summer	29.41	-1.0698	-0.19	0.93
Early fall	23.81	-1.2692	-0.18	0.93
Tomatoes, processing[e]	68.00	-2.4300		
Field				
Cotton[f]	70.17	-0.0296		
Sugar beets[g]	32.46	-0.2655		

Table 2.2 (continued)

[a] Independant variables, other than California production, were evaluated at mean (1955-76) levels and added to the intercept term. Units of the adjusted intercept terms are in dollars per hundredweight for all crops except processing tomatoes, lima beans and sugar beets (dollars per ton) and cotton (cents per pound).

[b] Units in the slope coefficients are million hundredweight for all crops except processing tomatoes and sugar beets which are in million tons, lima beans in thousand tons, and cotton in million 500-lb bales.

[c] Due to the statistical insignificance of the estimated slope coefficients, the incorporated slope coefficient is derived from price flexiblities of other seasons for the same crop at relevant price and quantity levels.

[d] Not applicable due to reasons given in footnote c.

[e] Slope coefficient is derived from King, et.al. (1973, Tables 5.2-5.6)

[f] Slope coefficient is derived from Blakley (1962).

[g] Slope coefficient is derived from Bates and Schmitz (1969).

$$P = (a + \sum_{i} b_i \bar{X}_i) + cQ, \qquad i + 1 \qquad (5)$$

where P is the average seasonal price for the crop in question, b is the initially estimated coefficient for the ith explanatory variable, X^1 is the arithmetic mean value of the ith explanatory variable over the 1$55-1976 interval, and c is the initially estimated coefficient for the quantity Q of the crop produced in California.

TECHNICAL COEFFICIENTS AND INPUT CONSTRAINTS

On the presumption that the annual crops being studied require given input combinations, a linear technology is adopted for each crop and region. Once planting has taken place, input combinations for these annual crops are not easily altered. Moreover, since the estimated input-output coefficients represent grower and county averages within a region, major shifts in relative input usages within a single season would have to occur to bring about a discernible change in the overall input-output coefficients.[10]

Input-output coefficients for soil type, water, fertilizer, pesticides, and labor were estimated by crop within the individual regions. Units were defined so as to be consistent with those employed for the price-forecasting expressions. Finally, in order to constrain the programming problem, available input stocks were set at 1976 levels.[11]

BASE PERIOD RESULTS

Using the price-forecasting intercepts and quantity coefficients of Table 2, the estimated input-output coefficients and resource constraints, and 1976 air pollution levels, the programming problem was solved by crop and region for the 1976 crop year. The solution results are presented in Table 3.

Even though the programming problem is normative, a comparison of these estimated 1976 results with what actually occurred in the same year provides an impression of the credibility of the adopted formulation. Since the estimated economic losses from air pollution will be the difference between these base results obtained in the presence of 1976 air pollution and what these results would have been in the absence of any oxidant air pollution in 1976, a check on the accuracy of the base results seems warranted.

The estimated 1976 production for most of the study crops in the four regions appears reasonably close to the actual 1976 production. For most crops, the differences between estimated and actual levels of crop production are substantially less then ± 10 percent. Exceptions are processing tomatoes (18 percent) in the Southern Desert region and fresh onions (-16 percent) in

Table 2.3

Estimated and Actual Crop Production[a] in Presence of Air Pollution by Crop and Region for 1976

Crop	Unit	Southern Desert		South Coast		Central Coast		Southern San Joaquin	
		Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated
egetable									
Processing green lima Beans	Tons	-	-	14.1	14.0	2.5	2.5	9.0	9.9
Broccoli	Cwt	-	-	1,071.1	1,129.5	2,089.4	2,087.3	-	-
Cantaloupes	Cwt	1,128.0	1,120.0	461.3	435.6	-	-	468.0	511.2
Carrots	Cwt	2,215.0	2,213.8	2,903.0	2,949.0	1,476.4	1,476.9	3,500.0	3,457.0
Cauliflower	Cwt	-	-	864.3	864.0	1,144.1	1,120.5	-	-
Celery	Cwt	-	-	6,478.1	6,277.3	4,529.8	4,454.9	-	-
Lettuce, head	Cwt	11,720.0	11,725.0	4,950.1	4,854.9	20,535.2	20,606.3	1,490.0	1,438.2
Onions, fresh	Cwt	374.0	373.4	277.3	232.0	596.6	536.2	-	-
Onions, processin	Cwt	300.0	354.0	1,400.0	1,398.3	393.3	424.0	2,580.0	2,667.3
Potatoes	Cwt	-	-	2,930.2	3,037.0	1,428.6	1,423.5	0,630.9	10,661.5
Tomatoes, fresh	Cwt	334.0	377.4	5,020.4	5,098.0	872.0	805.4	403.5	338.7
Tomatoes, processing	Tons	36.0	35.0	178.5	179.1	189.0	198.5	195.0	206.4
ield									
Cotton	Bales[b]	141.5	141.0	51.1	50.6	-	-	972.8	970.8
Sugar Beets	Tons	1,476.0	1,475.0	256.6	257.0	867.0	866.2	849.6	849.0

[a] All figures are in 1,000 units for each crop

[b] 500 lb. bales

the South Coast region. These differences are partially due to the tendency of the model to overestimate production of the relatively more profitable crops. Overall, however, the results in Table 3 suggest that the model and its price forecasting expressions provide a quite accurate prediction of actual 1976 production patterns for the study crops.

AIR POLLUTION DAMAGES

Potential Production in a Regional Context

To determine the extent to which air pollution reduced crop production in the individual study regions, the estimated 1976 percentage yield reductions in Table 1 were used to calculate what per acre yields for each crop in each region would have been in the absence of air pollution. Given these new per acre yields, the input-output coefficients for each input used were then recalculated, presuming that the absolute levels of input usage were unchanged. The programming model was then recast in terms of these altered production coefficients and solved separately for each region. Table 4 presents the results of this recasting and compares them with the estimated yields in Table 3, where 1976 air pollution levels were present.

The results of Table 4 show that the Southern Desert region would experience a slight increase in production of most crops susceptible to air pollution damages, with significant increases in the production of processing onions and cotton. Those crops more resistant to air pollution damages, such as carrots and lettuce, exhibit slight declines in production.

For the other three regions, some crops such as cauliflower, lettuce, and broccoli, that are rather tolerant of oxidant air pollution record minimal changes in production levels. However, broccoli and cantaloupes in the South Coast region are two exceptions. The very significant decrease in the production of these air pollution tolerant crops is due to their substantially reduced profitability relative to crops that are more sensitive to air pollution. Production of these air pollution sensitive crops, such as lima beans, potatoes, tomatoes, cotton and onions, generally tends to increase in each region. Exceptions are lettuce in the South Coast region and processing onions in the San Joaquin Valley region. Even though these two crops are fairly intolerant of oxidant air pollution, their estimated production in the absence of air pollution is actually lower than in its presence. These results appear to stem from the significant and dominating increases in production of fresh onions, lima beans, processing tomatoes, and cotton in the South Coast region, and lima beans and cotton in the Southern San Joaquin. As expected, there are only minimal changes in crop production in the Central Coast region since 1976 air pollution levels were relatively small.

Table 2.4

Crop Production Patterns in the Absence of Air Pollution
Regional Analysis for 1976

Crop	Southern	sert		S	h Coast		Central Coast			Sout hem San Joaquin			Tots l	
	Potential Production	Differences[a]		Potential Production	Differences[a]		Potential Production	Differences[a]		Potential Production	Differences		Potential Production	Differences[a]
		uantity	%		Quantity	%		Quantity	%		“ant, t	%		
getable														
Beans, Lima				17,164	3,164	22.6	2,550	50	2.00	10,567	710	7.20	30,281	3,924
Broccoli				1,018,129	-111,364	. 9.8	2,072,893	-14,376	- 0.69	-		-	3,091,022	-125,740
Cantaloupe	1,120,010		0.00	416,675	-18,924	- 4.34				503,892	- 7,324	1.43	2,040,577	-26,238
Carrots	2,216,658	2,1%	- 0.10	2,924,409	-24,569	- 0.8	1,473,525	- 3,360	- 0.23	3,480,131	23,134	0.67	10,094,723	-6,965
Cauliflowe				863.853	- 147	-0.02	1,121,352	829	0.07	-		-	1,985,209	682
Celery				6,613,678	336,424	5.36	4,482,108	27,178	0.61	-		-	11,095,786	363,602
lettuce	1,709,770	15,220	- 0.13	4,838,876	-57,407	-1.17	20,624,005	17,725	0.08	1,428,242	-9,956	0.69	38,600,893	-64,938
On Ions, fresh	377,200	3,831	1.03	414.900	182,906	78.84	585.776	-435	- 0.07	-			[illegible]77,876	186,302
Onions, processi	373.550	19,550	5.52	1,493,326	95,076	6.70	4)9,882	-4,103	- 0.97	2,520,444	-146,910	5 50	4,[illegible]07,202	-36,387
Potatoes				3,248,317	211,320	6.96	1,430,512	7,012	0.49	10,897,512	236,024	2“21	15,576,341	254,356
Tomatoes, fresh	381,533	4,108	1.09	5.177,999	180,029	3.53	80s ,505	130	0.02	405,298	16,628	4.28	6,870,335	200,895
Tomatoes processi	35,363	351	1.00	273,750	94,619	52.82	204,338	5,878	2.96	210,756	4,315	2.09	724,207	105,163
ield														
Cotton	154,354	13,354	9.47	60,150	9,510	18.78	-	-		1,037,822	67,062	6.91	1,252,326	89,926
Sugar Beet	1,486,812	11,802	0.80	271,500	14,500	5.64	868,850	2,650	0.31	868,324	19,324	2.28	3,495,486	48,276

[a] Difference from the estimated production with air pollution effects of Table 3.

NOTE: Quantity is tons for 1 ima beans, processing tomatoes and sugar beets; bales for cotton and hundredweight for all other crops.

COMBINED REGIONAL ANALYSIS

The above analysis treats the air pollution-induced changes in price, production levels, and input usages for the crops within a region as being independent of similar changes in other regions. In this section, we obtain the optimal levels of production for each crop within each region by maximizing the- objective function over the combined four regions. All inputs except land were aggregated over the regions to arrive at a total resource constraint. Since land is immobile, a maximum constraint based on the actual 1976 regional acreage planted for all crops was imposed separately in each region. The base input-output coefficients and price forecasting expressions employed are identical to those used to establish the results of Table 3.

Table 5 serves as a check on the creditability of the combined regional analysis. As was true for Table 3, the estimated yields for most crops are quite close to actual yields, although the correspondences are not as good as in Table 3. Substantial discrepancies between estimated and actual yields occur with fresh tomatoes in the Southern Desert region, with carrots and fresh tomatoes in the Central Coast, with carrots and processing onions in the Southern San Joaquin region, and with broccoli in the South Coast region. Since close correspondences were present in the regional analysis summarized in Table 3 between the actual and estimated yields for these crops, discrepancies in Table 5 are perhaps due to the implicit assumption of the programming model that locational adjustments across regions take place instantaneously and costlessly.

Table 6 shows how the estimated 1976 yields of Table 5 would be altered in the absence of air pollution. The Southern Desert region experiences increases in the production of all crops except lettuce. Carrots, fresh tomatoes, and cotton exhibit major increases. Only plants of the latter group are sensitive to air pollution damages. With the exception of carrots, there are no major changes in crop yields in the Central Coast region. Carrots show a nearly 30 percent decline, with most of the production apparently shifting to the Southern Desert region.

In the South Coast and Southern San Joaquin regions, crops whose plants are sensitive to air pollution damages (lima beans, celery, onions, tomatoes, cotton, and sugar beets) generally have increases in production when air pollution is not present. Crops resistant to oxidant air pollution, such as broccoli, cantaloupes, and carrots, show a reduction or no major change in production.

The last column of Table 6 shows estimated increases and decreases in combined regional 1976 production in the absence of oxidant air pollution.

Table 2.5

Estimated and Actual Crop Production in Presence of Air Pollution
Combined Regional Analysis for 1976

Crop	Unit	Southern Desert			South Coast			Central Coast			Southern San Joaquin Valley			Total	
		Season	Actual	Estimated	Season	Actual	Estimated	Season	Actual	Estimated	Season	Actual	Estimated	Actual	Estimated
Vegetable															
Beans, pmt.															
green lima	Tons					14.1	14.1		2.5	2.5		9.0	9.0.	25.592	25.538
Broccoli	list				ES	,071.1	1,616.3	F	2,089.4	1,833.9				3,160.530	3,4$0.250
	Cwt	S	1.128. O	1,127.4	S	461.3	482.5			-	Su	468.0	524.6	2,057.332	2,134.452
Carrots ″	Cwt	u	2,215.0	2,207.6	LF	,908.0	2,643.6	ESU	1,476.4	646.7	ESU	1,500.0	4.531.9	0,099.412	0,029.752
Cauliflower	Cwt				LF	864.3	876.1	ES	1,144.1	1,399.5				2,008.380	2,275.631
Celery	Cwt				S		4,588.5								
					LF		1,313.9								
						,478.1	5,902.4	W	4,529.8	4.456.6				1,007.900	0,358.955
Lettuce	Cwt				-			ES	N.A.	7,018.2					
								Su	N.A.	15,262.5					
		W	1,720.0	12,076.6	ES	,950.1	4.800.2	Total	0,535.2	22,280.7	ES	1,490.0	1,536.0	8,695.300	0,693.571
onions,															
fresh	Cwt	LS	374.0	373.9	LS	277.3	275.3	LS	596.6	595.4	-			1,247.928	1,244.530
Onions,															
processing	Cwt	LSU	300.0	286.4	LSu	,400.0	1,398.1	LSu	393.3	393.5	LS	!,580.0	3,615.2	4,673.260	5,693.130
Potatoes	Cwt				W	,980.2	3,390.0	LSu	1,428.6	1,425.7	LS	),630.9	12,178.7	5,039.700	6,.988.379
Tomatoes,															
fresh	Cwt	ES	384.0	148.3	ESu	,020.4	4,583.8	ESu	872.0	628.7	ES	403.5	457.2	6,679.896	5.818.097
Tomatoes,															
processing	Tons		36.0	35.4		178.5	165.8		189.0	190.2		195.0	233.1	598.518	624.537
Field															
Cotton	Bale		141.5	141.2		51.1	51.3					972.8	935.4	1,165.382	1,127.973
Sugar Beets	Tons		1.476.0	1,475.3		256.6	256.1		867.0	866.4		849.6	850.1	3,449.292	3.447.962

*All figures are in 1,000 units for each crop.

NOTE: Season is abreviated as follows: ES - Early Spring; ESU - Early Summer; F - Fall; LS - Late Spring; LSu - Late Summer; S - Spring; Su - Summer; and W - Winter.

Table 2.6

Crop Production Patterns in the Absence of Air Pollution

Combined Regional Analysis for 1976

Crop	Southern Desert			South Coast			Central Coast			Southern San Joaquin			Total		
	Potential Production	Differences		Potential Production	Differences		Potential Production	Differences		Potential Production	Differences		Potential Production	Differences	
		Quantity	%		Quantity	%		Quantity	%		Quantity	%		Quantity	%
Vegetable															
Beans, lima				17,226	3,126	22.1	2,553	67	2.70	9,912	960	0.72	29,691	4,153	14.00
Broccoli				1,461,084	1ss,246	-9.6	1,927,896	93,976	5.12	-	-	-	3,388,980	-61,270	-1.81
Cantaloupes	1,128,103	736	0.06	466,976	-15,539	-3.22		-	·	514,826	-9,744	1.86	2,109,905	-24,547	1.16
Carrots	2,907,11!	$99,551	1.69	1,451,579	191,980	-7.2	456,724	-190> 010	-29.38	4,217,063	-314,833	6.9	10,032,480	2,728	.00
Cauliflower				863,523	-12,605	-1.4	1,368,086	-31,467	-2.25	-	-	-	2,231,609	-44,072	-1.97
Celery				$,286,905	384,544	6.5	4,489,592	32,998	0.74	-	-	-	10,776,497	417,542	3.87
Lettuce	1,575,267	501,335	4.15	4,790,808	- 9,425	-0.20	22,146,294	-134,407	-0.60	1,551,698	15,663	1.02	40,064,067	629,504	-1.57
Onions, fresh	377,360	3,504	0.94	296,182	20,860	7.5	598,300	2,948	0.50			-	1,271,842	27,312	2.15
Onions, processing	289,461	3,111	1.09	1,494,126	96,023	6.8	395,054	1,582	0.40	3,500,347	-114,857	3.18	5,678,989	-14,141	- .02!
Potatoes				3,499,088	110, I32	3.2	,431,523	5,841	0.41	12,399,950	226,2o9	1.86	17,330,561	342,182	1.97
Tomatoes, fresh	162,02(	13,688	9.23	4,822,777	238,937	5.2	634,210	5,535	0.88	502,629	45,383	9.	6,121,64	303,543	4.96
Tomatoes, processing	35,44	7	0.02	202,650	36,899	22.2	197,826	7,610	4.00	248,595	15,464	6.6	684>51;	59,980	8.76
Field															
Cotton	154,75!	13,523	9.58	60,246	8,918	17.				1,001,036	65,616	7.01	1,216,035	88,057	7.24
Sugar Beets	1,486, 99!	11,669	0.79	272,123	15,988	6.	868,653	2,284	0.26	868,416	18,284	2.1	3,496,187	48,225	1.38

'Difference from the estimated production with air pollution effects of Table 5.

NOTE: quantity is tons for lima beans, processing tomatoes and sugar beets, bales for cotton and hundredweight for all other crops.

Major percentage increases are estimated to occur in the production of lima beans, tomatoes, cotton, and celery. Relatively small estimated declines in the production of broccoli, cantaloupes, cauliflower, and lettuce are seen. Furthermore, consistent with changes in comparative advantage among regions, some increases in the production of air pollution-resistant crops are observed in regions that have always had relatively low levels of air pollution.

WELFARE EFFECTS

In this section, we present for both the separate and combined regional analyses estimated differences in the value of the objective function “with” and “without” 1976 levels of oxidant air pollution, as well as the distributional consequences of these differences for producers and consumers. Table 7 displays these estimated differences by region for the separate regional analyses. Total 1976 air pollution-induced losses for the fourteen study crops are estimated to be $43.6 million, with 32.2 million of this total being losses in producer quasi-rents. Although it is not the most heavily polluted location, more than half of the total losses are suffered by the Southern San Joaquin region. This is mainly due to estimated reductions in cotton yields.

Differences in the objective function with and without 1976 air pollution for the combined regional analysis are presented in Table 8. The elimination of 1976 oxidant air pollution and attendant net increases in aggregate production would have increased 1976 producer quasi-rents by $35.1 million and ordinary consumer surpluses by $10.1 million, resulting in an increase of $45.2 million in the objective function total. This latter figure represents about 3.7 percent of the $1.22 billion total on gross farm value of the fourteen crops produced in the four regions in 1976. About $30.0 million of the estimated potential increase in the total is due to an improvement in cotton yields.

CONCLUSIONS

Aside from attempts to resolve the data limitation issues inherent in any study of this sort, there are several feasible avenues available whereby one might make the study more analytically complete. For example, non-zero cross-price effects across crops might be allowed, variable marginal costs of production might be introduced, and risk measured as historical yield variability might be incorporated. Any declines in soil fertility induced by oxidant air pollution could be taken into account.[12] Finally, in order to recognize a broader set of adjustments, the set of crops and regions considered could be expanded. These elaborations would, however, require substantial additional effort. It is, therefore, worthwhile to consider whether

Table 2.7

A Summary of Objective Function Values by Region With and Without 1976 Air Pollution
Regional Analysis for 1976

		Southern Desert ($000)	South Coast ($000)	Central coast ($000)	Southern San Joaquin ($000)	Total ($000)
objective total	With air pollution	216,213.5	299,904.5	413,870.3	520,998.7	1,450,987.0
	Without air pollution	221,305.7	313,431.6	416,263.9	545,557.0	1,494,563.2
	Estimated loss due to air pollution	5,092.2	13,527.1	399.6	24,558.3	43,576.2
Producer surplus	With air pollution	206,605.6	163,896.1	255,553.5	469,787.9	1,095,843.1
	Without air pollution	211,590.0	168,560.3	255,S31.5	492,081.9	1,128,063.7
	Estimated loss due to air pollution	4,984.4	4,664.2	278.0	22,294.0	32,220.6
Consumer surplus	With air pollution	9,607.8	136,008.4	158,316.8	51,210.8	355,143.8
	Without air pollution	9,715.7	144,871.3	158,437.4	53,475.1	366,499.5
	Estimated loss due to air pollution	107.9	8,862.9	120.6	2,264.3	11,355.7

Table 2.8

A Summary Result of Estimated Objective Function and With and Without 1976 Air Pollution Combined Regional Analysis for 1976

($)

	Objective Total	Producer Surplus	Consumer Surplus
With air pollution effects	1,457,733,227	1,036,788,371	370,944,856
Without air pollution effects	1,503,024,714	1,122,024,497	381,000,217
Estimated losses due to air pollution	45,291,487	35,236,126	10,055,361

the additional information acquired would merit this effort. Although it is impossible to resolve this question here, some insight can be gained from the material presented in the preceding pages.

Until this study, efforts to assess the value of crop losses due to air pollution simply multiplied air pollution-induced yield reductions by existing market prices. Shifts in cropping patterns and locations were implicitly assumed away. Any accounting of the losses suffered by consumers was unattainable since the response of market price to quantity variations was disregarded. The present study does not neglect these phenomena. If distributional consequences are of policy interest, measures of the differential effects of yield reductions upon producers and consumers are of consequence. One might reasonably doubt, nevertheless, whether similar estimates of crop losses might have been obtained by employing the traditional and easy course of multiplying yield reductions associated with the existing cropping and location pattern by an invariant price.

For the set of crops being studied, the traditional course consists of multiplying the actual 1976 yields of Table 6 by unity plus the percentage yield reductions of Table 1, and then multiplying again by the 1976 market prices. Upon doing so, a total loss estimate of $43.0 million is obtained. This total is not significantly different from the estimated losses obtained from the previous separate regional ($43.6 million) or combined regional ($45.2 million) analyses.[13] Given this result, the effort expended in doing the more elaborate analysis may appear unjustified.

Further inspection of Tables 6 and 1 soon negates the above conclusion, however. The traditional and the more elaborate estimates of reductions in cotton yields are nearly identical, apparently because air pollution had only trivial effects upon the amounts or the locations of lands devoted to cotton production. This combined with the low flexibility (-0.0296 in Table 2) of farm-level cotton prices with respect to variations in cotton yields, eliminated all possible sources of difference in the estimates of the value of cotton losses provided by the two types of analyses. When cotton is removed, an examination of the estimated percentage changes in production in Tables 1 and 6 makes evident that the two analyses provide quite different results in terms of total losses as well as with the crops and regions where these losses are thought to occur. Total estimated losses by the traditional analysis are then only $12.5 million, as opposed to the $15.6 million obtained using the more elaborate analysis. Moreover, such crops as broccoli, carrots, lettuce, fresh tomatoes, processing tomatoes, and sugar beets, which exhibit small or no percentage declines in Table 1, show large percentage increases or decreases in Table 6. These shifts in cropping patterns within and across regions as well as distributional as sequences of environmental degradations, seem likely to be of considerable interest to local and state policymakers. The traditional analysis is incapable of capturing them.

The economic modeling and assessment of perturbations to a complex ecosystem remains an imprecise exercise plagued by conceptual as well as data problems. While agriculture may be viewed as a managed system, difficult analytical issues must still be recognized. This study has suggested a partial equilibrium approach featuring elements of general equilibrium analysis to assess the effects of one aspect of environmental change on the agricultural system of Southern California. We believe that the model results, while conditional, appear sufficiently secure to suggest that this more comprehensive approach to economic damage assessment is capable of providing a theoretically consistent framework yielding policy relevant information.

REFERENCES

1 See, for example Middleton, et al. (1950); Middleton (1961); Oshima (1973); Brewer and Ferry (1974); Oshima, et al. (1976), (1977); Millecan (1976); and Thompson, et al. (1976).

2 Examples are: Barret and Waddell (1973); Lacasse, et al. (1970); Benedict, et al. (1975). Typically these studies conclude that economic losses are rather small, if not trivial. For example, Pen (1973) estimated that economic losses in New Jersey during the 1972-73 crop year amounted to only $130,000. Millecan (1976), using a similar but not identical geographic area as the present study, and covering all fruit and nut, field, vegetable, and nursery and cut flower crops, estimated that 1974 losses in this area were $55.1 million.

3 The exact procedures followed are detailed in Thanvibulchai (1979, 115-143).

4 Ozone (0_3) is the major constituent of photochemical oxidants.

5 See Thanavibulchai (1979, 115-125) for particulars.

6 See the chapter on “Farm Resources, Income, and Expenses” in U.S. Department of Agriculture (1978) for an explanation of the construction of the index.

7 According to the California Crop and Livestock Reporting Service (1977), with the exceptions of fresh tomatoes (32%), fresh onions (23%), and potatoes (7%), all the vegetable crops studied in the four regions constitute no less than 50% and as much as 97% of the 1976 U.S. production. Cotton in the four regions makes up 24% and sugar beets 30% of 1976 U.S. production.

8 For the 1955-1972 period, the data were obtained from Adams (1975), and for the 1973-1976 period they were taken from U.S. Department of Agriculture Agricultural Hazard Statistics (various issues).

9 The price flexibility is the reciprocal of the price elasticity of demand under restrictive assumptions.

10 County agents and agricultural researchers in the area commonly assert that growers mainly adapt to the presence of air pollution by altering their mixes of crops and crop varieties across seasons.

11 The estimated input-output coefficients are reported in Thanavibulchai (1979, 333-336). Except for water, data for the estimation were taken from annual reports of the various County Agricultural Commissioners, and publications of the California Department of Agriculture, and the California Employment Development Department. Since pesticide data were available only on a statewide basis by crop, regional usage was assumed to be proportional to each region's production share of each crop. Water use data were taken from Adams (1975).

12 For evidence that oxidants can reduce soil fertility, see Westman and Corm (1977).

13 An extension of the traditional procedure to all crops, including perennials, in the four regions yielded an estimated total 1976 loss of $217.6 million inclusive of the fourteen crops studied in the text. See Thanvibulchai (1979, 344-358) for details.

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CHAPTER III

HOURS OF WORK, LABOR PRODUCTIVITY, AND ENVIRONMENTAL CONDITIONS: A CASE STUDY

Livelihood measures of foregone and compensating earnings are frequently used as measures of economic losses due to realized or potential damages to the health of labor inputs. Both measures as they have been used are incomplete, though for quite different reasons. The narrowness of the foregone earnings measure is widely acknowledged.[1] As set forth in Smith (1974), Thaler and Rosen (1976), and Viscusi (1979), the compensating earnings measure, with its emphasis upon the earnings premia workers require to be willing to be exposed to job hazards they perceive, certainly has broader analytical appeal. However, as empirically implemented, these latter studies too are incomplete: they deal with worker and time aggregates allowing only crude measures of differences in reward structures, mixes of complementary inputs, work-day lengths, risk aversions, worker effort, and other dissimilar factors across individuals, firms, and industries.

In this paper, the productivity changes and consequent earnings adjustments that occur under differing work conditions for 17 individual citrus pickers in southern California are assessed. Interest is centered upon the acute effects of two environmental factors, ambient ozone (O_3) and ambient temperature, upon the daily work performances of these individuals.[2] Since each individual is separately analyzed, the host of plausible confounding influences (e.g. , experience, biological endowments, health histories, etc.) to which one must devote attention when dealing with the fictional "representative" individual are relevant here only insofar as they change within the short time periods being considered.

THE PICKER'S SUPPLY OF EFFORT

The occupation of citrus harvesting has that ease of entry and exit, geographical and numerical scope, and absence of idiosyncratic (i.e., heterogeneous, highly-differentiated, task-specific skills enabling the current occupant to possess a degree of monopolistic advantage) characteristics that Doeringer and Piore (1971) term the secondary labor market. Harvesting operations in citrus groves are highly labor-intensive. Except for standardized ladders, cutting shears, and bags in which to deposit picked fruit, complementary capital inputs exercise no influence on the individual picker's output. Moreover, there are no good economic or even technical substitutes for the picker. His output, boxes of fruit picked, is readily defined, measured, and monitored, and is independent of the activities of other members of his picking crew.[3] Picking procedures, which are standardized from one grove to another, do not require the picker to take involuntary leisure. In each grove, he is paid a predetermined piecework wage rate that varies directly with the difficulty of the picking opportunity, as determined by fruit type, size, and density, and tree height. A picker's earnings in a grove are the number of boxes of fruit he picks multiplied by the per box wage rate. Since all fruit meeting prespecified conditions for ripeness and size is to be picked, pickers have little, if any, incentive on a particular day to urge each other to slow the rate of pick, given that all pickers are at least earning the minimum wage. To do so would reduce the earnings of the better pickers without enhancing the earnings or reducing required work effort of the slower pickers. Since there are several thousand pickers employed in any one crop season, we view the picker as a wage-taker.[4]

The Lagrangian for the utility maximization problem the picker faces daily is:

$$L = U(I,H) + \lambda[I-w(G)\cdot B(E,G,H(E,G))-\bar{M}], \tag{1}$$

where $U(o)$ is concave and all partial derivatives are twice continuously differentiable. We assume that $U_I>0$, $U_H<0$, $U_{II}<0$, $U_{HH}<0$, and $U_{IH}<0$. This formulation states that the picker's level of utility varies positively each day with his consumption expenditures and savings, I, for that day, and negatively with the number of hours, H, he harvests fruit that same day. His daily consumption expenditures and savings are equal to his daily earnings from harvesting fruit plus whatever nonharvesting income, $\bar{M}$, he obtains. Nonharvesting income is fixed for the day in question. The amount of fruit, B, the picker harvests depends on the hours he practices harvesting, with both the amount and the hours depending on environmental, E, and grove conditions, G. The wage, w, for each box of fruit he harvests varies only with grove conditions. Finally, income taxes and minimum wages are assumed to have no effect upon his work effort.[5]

The necessary conditions for an interior utility maximum of (1) are:

$$u_I + \lambda = 0, \tag{2}$$

$$u_H - \lambda w B_H = 0, \tag{3}$$

and the constraint.

Expressions (2) and (3) are, respectively, the marginal utility of earnings and the marginal disutility of work-hours, presuming that the opportunity to acquire earnings by harvesting fruit exists, Taken together (2) and (3) imply:

$$\frac{U_H}{U_I} = -wB_H \qquad (4)$$

which is the value of work to the picker and the rate at which he is willing to substitute leisure for earnings. Simultaneous individual fruit grower and individual picker utility maximization requires that:

$$C_B = -wB_H \qquad (5)$$

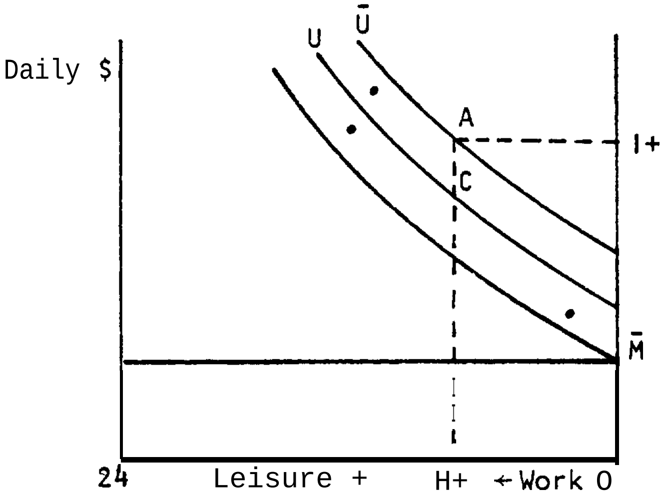
where C_B is the rate at which the grower's expected income changes in response to changes in boxes of fruit harvested.[6]

From the picker's perspective, w is predetermined. Temporarily assume that all groves are identical, except that they differ in size and therefore require differing numbers of hours for the picker's crew to harvest. This implies that the piece work wage rate will be constant across groves and that the picker's earnings opportunities in fruit harvesting will differ only according to the number of hours it will take his crew to harvest each grove.

At the beginning of any given day, the picker faces the situation depicted in Figure 1. Each point in the figure represents an hours-earnings opportunity, one point to an opportunity. The opportunities need not involve citrus picking. Presume that $\bar{U}$, which passes through point A, is the highest indifference curve passing through any of these points. Point A, where the picker expects to earn I^+ dollars for H^+ hours of work, is therefore the earnings opportunity the picker will select for the day in question. On some days the opportunity set may not have any points lying on an indifference curve above that intersecting $\bar{M}$, the daily income the picker receives when he does not work. Given that the picker's hours-earnings opportunities differ from day to day, the level of utility he expects to attain will also differ daily.

The above reasoning is not altered by the fact that grove attributes are dissimilar across groves. Growers attempt to adjust per box wage rates so that for any particular expenditure of his hours over the picking day, the picker expects his earnings, for given environmental conditions, to be (nearly) equal from one grove to another.

Figure 3.1 HOURS - EARNINGS OPPORTUNITIES



Once the picker is in a grove, he may discover that his initial perception of the hours-earnings opportunity was mistaken. For example, he may find that his earnings are distressingly low because unexpectedly severe environmental conditions are reducing his picking prowess. Similarly, he may find that the per box wage rate being paid is imperfectly adjusted to grove attributes so that his earnings for a given time expenditure are different than he had been led to expect. As a result, the level of utility he achieves may only be U, rather than $\bar{U}$. If the cause of this is air pollution and if the picker has disregarded air pollution in his original assessment of the earnings opportunity, the additional earnings while working H^+ hours he must receive in order to remain on ;, his expected levels of utility, are AC. AC thus represents a measure of the Hicksian compensating surplus. It is the economic loss caused by poor environmental conditions that attaches to the picker. In our empirical results, we obtain a measure of AC for air pollution and temperature differences. Assuming that crew work-hours on the day in question do not change, AC overstates the required compensation since the picker is constrained to work the same hours as the crew.

THE DATA

Data on the daily work performances and working conditions in 1973 and/or 1974 for more than 200 individual pickers were collected from citrus packing houses and labor camps in southern California.[77] Daily or hour-by- hour air pollution and temperature data were obtained for the single monitoring sites closest to picking locations from records maintained by the Statewide Air Pollution Research Center at the University of California, Riverside. Several possible sources of measurement error are present in the environmental conditions data as well as the work performance data. These errors seem most important in the environmental conditions data, particularly the air pollution data. For example, it is not known whether the levels of air pollution recorded at the monitoring sites have a positive or negative bias, or even if they are biased at all. Furthermore, most of the monitoring stations used to determine air pollution and temperature levels for the grove locations are five to eight miles away. The stations are typically in downtown areas and at somewhat lower elevations than the groves.

In the work performance data, only the daily number of hours worked by a picker seems a possible nontrivial source of error. This number of hours is rounded off to the nearest half-hour in the picking records. In circumstances where the work-day has been rather short, this could lead to some bias in estimates, although it seems likely there is no systematic bias with respect to the sign of the error.

ESTIMATION

In order to estimate the model of Section 2, it is convenient to use the picker's inverse supply function, the function in which earnings are determined by hours worked and exogenous factors, such as air pollution, that can be responsible for discrepancies between expected and realized earnings.[8] After some experimentation with the picking histories of four experienced pickers who worked more-or-less continuously harvesting lemons over an entire year, a number of empirically inspired restrictions were placed upon the separate earnings expressions finally estimated for seventeen other pickers. The basic specification selected for estimation was multiplicative. This daily earnings expression can be estimated by ordinary-least-squares since values of the dependent variable are fairly evenly distributed over a wide interval for each picker and since, as explained in the next section, all the independent variables, including work hours, are exogenously determined.

Table 1 gives the variable descriptions, while Table 2 gives ordinary-least-squares estimates of the earnings expressions for 17 pickers. The four preliminary test pickers are not included.[9]

Of the 17 pickers for whom earnings expressions are presented in Table 2, nine (1,3,5,7,9,10,15,16,17) have statistically significant air pollution coefficients at the 0.10 level or better of the one-tailed t-test. six (3,5,6,8,10,12) of the temperature coefficients are significant, but only three (3,5,10) pickers have both coefficients significant. With but one exception (daily ozone for 12), air pollution and temperature have the negative signs consistent with the maintained hypotheses that higher levels of each have detrimental effects upon picker earnings.[10] The standard errors of both coefficients are probably somewhat inflated since the simple correlation coefficients between the two are typically between 0.5 and 0.8, with the bulk being around 0.6. Since air pollution appears to be somewhat more statistically robust, subsequent discussion concentrates upon it.

A substantial literature now exists demonstrating declining marginal productivity of increased hours within the work-day.[11] The cases studied in this paper are not representative of most jobs. Nevertheless, the individuals in Table 2 do engage in strenuous physical activity over work- days that can vary from 2 to 12 hours. In spite of the strenuousness of their activity, the marginal value product of hours for nearly all the pickers in Table 2 is very close to being a constant.

In spite of the near-unitary elasticity of earnings with respect to hours in Table 2, it is possible that poor environmental conditions and hours interact to result in a declining marginal value product. The hypothesis is that picker responsiveness to air pollution increases with the length of the work-day. Rather than arbitrarily specifying the form of the interaction

Table 3.1 - VARIABLE DESCRIPTIONS

Daily Earnings = the picker's daily gross earnings from picking activities for each grove worked.

Boxes per tree = the mean number of field boxes picked per tree during the work-day by the picker's crew in a specific grove. The fewer the boxes per tree, the greater the difficulty of the picking opportunity and, therefore, the fewer the boxes the individual will be able to harvest. However, the wage rate per box picked is adjusted with crew boxes per tree, fruit size, and tree height according to a standard formula in order to keep the representative picker's earnings similar across groves. The regression coefficients attached to this and the other two grove attribute variables therefore represent the deviation in the individual picker's adjustment to the change in the variables from the adjustment of the representative picker. If the picker were the representative picker, the variables would have zero coefficients since his earnings (the product of boxes he picks and the pay per box) would be identical across groves.

Fruit size = the number of fruit required to fill a field box. Since picking is reputed to be easier with larger fruit, the pay per box declines with increases in the variable.

Tree height = an index which monotonically increases with tree height. The respective tree heights assigned, one to a grove, are 4.5 feet, 7.0 feet, 10.5 feet, and 15.0 feet.

Hours worked = the number of hours worked by the crew and the picker during the day. All days in which the picker worked fewer hours harvesting fruit than did the crew were excised from the sample. No days in which the crew worked less than 2 hours were included in any picker's sample.

Daily ozone = the arithmetic mean 24-hour ambient concentration on the work day of O_3 in parts per million by volume as measured by the CHEMILUM method.

Hourly ozone = the arithmetic mean of the hourly ambient concentration of O_3 occuring during the time interval the picker w-as engaged in citrus harvesting.

Temperature = the maximum hourly arithmetic mean ambient dry-bulb temperature in F“ on the work day.

Table 3.2 1n(DAILY EARNINGS) ESTIMATES BY ORDINARY LEAST-SQUARES FOR SEVENTEEN CITRUS PICKERS

Picker / Independent Variables	1	2	3	4	5	6	7	8	9
Constant	1.671 (0.679)	1.908 (1.822)	1.460 (0.675)	0.243 (0.091)	1.343 (3.177)	0.155 (0.133)	0.221 (0.163)	1.213 (1.128)	0.745 (0.871)
ln (Boxes per tree)	-0.289 (-2.344)	0.045 (1.876)	0.016 (5.108)	0.147 (1.682)	-0.008 (-0.238)	0.046 (2.318)	0.217 (1.512)	-0.071 (-0.438)	-13.06? (-0.216)
in (Fruit size)	0.223 (0.762)	-0.342 (-1.198)	-0.025 (-0.160)	0.089 (0.921)	-0.064 (-0.329)	0.036 (0.175)	-0.221 (-0.359)	-0.125 (-0.764)	0.264 (0.719)
in (Tree height)	0.055 (0.904)	-0.027 (-0.207)	0.011 (0.149)	0.051 (1.068)	-0.337 (-0.454)	0.208 (2.008)	0.036 (0.658)	0.018 (0.461)	0.029 (0.625)
ln (Hours worked)	0.982 (10.063)	1.137 (34.166)	1.119 (30.343)	1.343 (13.411)	0.885 (4.184)	1.032 (29.571)	1.083 (22.133)	1.024 (32.743)	1.001 (25.696)
in (Daily ozone)	-0.243 (-1.909)			-0.281 (1.042)					
in (Hourly ozone)		-0.010 (-0.640)	-0.035 (-1.342)		-0.038 (-1.583)	-0.001 (-0.801)	-0.047 (-1.624)	-0.018 (-0.683)	-0.029 (-1.611)
in (Tempecature)	-0.381 (-0.895)	-0.183 (-1.126)	-0.076 (-1.321)	-0.269 (-1.080)	-0.031 (-1.747)	-0.076 (-1.738)	-0.046 (0.174)	-0.361 (-2.734)	-0.093 (-0.484)
$\bar{R}^2$	0.636	0.372	0.859	0.760	0.661	0.883	0.792	0.814	0.849
S.E.	0.288	0.273	0.315	0.179	0.295	0.195	0.251	0.212	0.219
F	17.314	257.607	200.959	45.539	22.776	235.023	98.736	117.439	125.364
D-W	1.732	1.668	2.226	2.314	1.607	1.898	1.830	1.870	1.917
R-pie Size	57	189	208	57	112	162	143	156	136
Sample Period	June 18 - Sept. 9, '73	March 17 - Dec. 1, '73	March 1 - Dec. 17, '73	June 18 - Sept. 9, '73	April 1 - Nov. 2, '74	April 1 - Dec. 12, '73	April 17 - Nov. ?, '74	April 1 - Nov. 2, '71.	March 17 - Dec. 20, '73
Crop	Orange.	Lemons	Lemons	Oranges	Lemons	Lemons	Lemons	Lemons	Lemons

Table 3.2 (con=inued)

Picker / Independent Variables	10	11	12	13	14	15	16	17
Constant	3.583 (3.012)	1.279 (1.000)	2.387 (2.031)	-0.694 (0.784)	-0.743 (0.674)	3.642 (1.458)	0.907 (2.174)	2.191 (1.603)
ln (Boxes [illegible]				-0.048 [illegible]	0.150 [illegible]	-0.326 [illegible]	-0.086 [illegible]	-0.020 [illegible]
[illegible]				[illegible] (0.729)	[illegible] (0.192)	[illegible] (1.932)	[illegible] (0.397)	[illegible] (-0.890)
[illegible]				[illegible]	[illegible]	[illegible]	[illegible] (0.751)	[illegible]
ln (Hours worked)	1.001 (14.941)	1.146 (21.794)	1.172 (17.764)	0.926 (10.568)	1.032 (10.769)	1.114 (22.862)	1.007 (48.663)	1.134 (31.683)
ln (Daily [illegible]	-0.081 (-1.775)	-0.027 (0.449)	0.065 (1.140)		-0.054 (-1.036)	-0.239 (-2.155)	-0.032 (-1.971)	-0.151 (-2.145)
[illegible]				[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] (-0.893)	[illegible] (-0.080)
R^2	[illegible]	0.759	0.756	0.717	[illegible]	0.888	0.892	0.948
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.165	0.188
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	88.166	480.743	100.660
[illegible]	[illegible]	1.557	1.611	1.845	1.560	[illegible]	1.933	969
Sample Size	114	115	114	116	152	67	297	64
Sample Period	April 4 - Aug. 28, '74	April 4 - Aug. 28, '74	April 4 - Aug. 28, '74	Feb. 29 - Dec. 31, '73	March 4 - Oct. 18, '73	June 5 - Sept. 13, '73	Jan. 6 - Dec. 20, '74	June 6 - Dec. 20 '7[illegible]
[illegible]	Oranges	Oranges	Oranges	Oranges	Lemons	Lemons	Lemons	Lemon[illegible]

Notes:
Pickers 1-9 worked in the Upland area, pickers 10-12 in the Irvine area, 13-14 in the San Bernardino area, and 15-17 in the Sant Paula area. Grove attribute data is not recorded in the Irvine area because all groves are very similar. The figures in parentheses are t-values.

Table 3.3 AIR POLLUTION COEFFICIENTS (AND SAMPLE SIZE) FOR HOURS WORKED PARTITIONINGS

Partitioning \ Picker	1[a]	2	3[a]	4	5	6[a]	7[a]	8
$2.0 \le$ Hours worked < 7.0	-0.074 (14)	-0.063 (122)	-0.022 (148)	-0.189 (22)	-0.012 (48)	0.031 (100)	0.008 (81)	0.051 (101)
Hours worked ≥ 7.0	-0.346* (43)	-0.075 (67)	-0.097* (60)	-0.263 (35)	-0.038* (64)	-0.087* (62)	-0.081* (62)	-0.035 (55)

Partitioning \ Picker	9[a]	10[a]	11[a]	12[a]	13[a]	14[a]	15	16[a]	17[a]
$2.0 \le$ Hours worked ≤ 7.0	-0.011 (76)	-0.143* (53)	-0.100* (51)	-0.171* (48)	-0.093* (74)	0.032 (57)	-0.263 (30)	0.003 (207)	-0.036 (30)
Hours worked ≥ 7.0	-0.096* (60)	0.080 (61)	0.027 (64)	0.164 (66)	-0.031 (42)	-0.064* (95)	-0.108* (37)	-0.056* (90)	-0.294* (34)

Note:

[a] indicates that the two coefficients are significantly different at the 0.10 level of the F-test.

*indicates that the coefficient is significant at least at the 0.10 level of the one-tailed t-test.

between hours and air pollution by adding a combined variable to the expressions of Table 2, we have partitioned the work-day for each picker by the number of hours he worked. The specifications are identical to those of Table 2. To test for statistically significant differences in the air pollution coefficients across partitions, the covariance F-test for single coefficients developed by Tiao and Goldberger (1962) was used. The results of the test are presented in Table 3.

At best, the evidence in Table 3 for longer hours worsening the negative effects of air pollution upon picker productivity is mixed. Fourteen of the pickers now have a significant air pollution coefficient, including five (6,11,12,13,14) for whom the Table 2 coefficient was not significant. Twelve of the seventeen pickers have coefficients of greater negative magnitude for days in which they worked 7 hours or more. However, of the twelve, four (2,4,5,8) do not have a significant difference between the coefficients. Finally, four pickers (10,11,12,13) have negative and significant coefficients only for days when they worked less than 7 hours. These coefficients are significantly different from those applying to work- days of 7 or more hours.

MEASURES OF REQUIRED COMPENSATION

Here we use the results of Table 3 to calculate the compensation the picker requires to make him indifferent between the presence or absence of ozone air pollution. Assuming that the elasticity of the picker’s earnings with respect to air pollution is a constant, his required income compensation, $\bar{V}$, per grove he picked during the period of observation is:

$$\bar{V} = \frac{\hat{b}}{n} \sum_{i=1}^{n} \frac{I_i}{\text{ith ozone observation}},$$

where $\hat{b}$ is the elasticity of earnings with respect to air pollution, n is the number of earnings observations, I is earnings in a grove, and i indexes the groves in which the picker harvested fruit.

Only “those partitionings of Table 3 yielding significant and negative air pollution coefficients are employed to perform the calculations embodied in Table 4. However, $n\bar{V}$ and $(n\bar{V}/(I+n\bar{V}))100$, which respectively represent the total required compensation, and this required compensation as a percentage of what the picker’s harvest earnings would have been in the absence of air pollution, use earnings over all work-day lengths for the entire period of observation as the basis for the calculations. The calculations reveal that required picker compensation ranges from zero percent to 7.4 percent of what

Table 3.4 REQUIRED PICKER COMPENSATION

Picker	$\hat{b}$	ΣI_i	$\bar{V}$	$n\bar{V}$	$\left(\frac{n\bar{V}}{I_i+n\bar{V}}\right)100$
1	-0.346	$,213.50	$1.695	$ 96.62	7.4%
2[a]					
3	-0.097	,586.13	0,496	103.17	2.9%
4[a]					
5	-0.038	1,134.59	0.127	16.22	1.1%
6	-0.087	3,163.33	0.685	110.97	3.4%
7	-0.081	2,619.37	0.197	28.17	1.1%
8[a]					
9	-0.096	1,821.46	0.121	16.46	0.92
10	-0.143	2,063.40	0,685	78.09	3.6%
11	-0.100	2,313.10	0.418	48.07	2.0%
12	-0.171	2,650.36	0.877	99.98	3.6%
13	-0.093	1,239.08	0.080	9.28	0.7%
14	-0.064	3,529.50	0,173	26.30	0.7%
15	-0.108	1,033.85	0.527	35.31	3.3%
16	-0.056	4,861.93	0.408	121.18	2.4%
17	-0.294	1,174.40	0.742	47.49	3.9%

[a] One can reject the hypothesis that this picker's earnings were reduced by air pollution.

earnings would have been in the absence of air pollution. The arithmetic mean required compensation for the seventeen pickers is 2.2%, with the median being 2.0%. The weighted mean is 2.1%, where the weights are the number of daily earnings observations on each picker. Assuming that the representative picker could earn approximately $5,000 in 1974 by working full-time, this implies that prevailing levels of air pollution in southern California in 1974 might have cost him as much as the utility equivalent of $100-110. This is probably an upper bound on his losses since we have limited our inquiry to circumstances where the picker never chose to substitute leisure for earnings.

SUMMARY AND CONCLUSIONS

The extent to which citrus harvesting has little or much in common with other occupations is arguable. At a minimum, it nevertheless has those attributes of strenuous physical activity and repetition found in a fairly wide variety of other semi-skilled jobs. It is in these jobs where one might reasonably expect to find declining marginal value productivity as fatigue and ennui set in with extensions of the work day. For the limited but well-defined case studied here, we found no evidence that the marginal value product, as registered in daily earnings, declines as more hours are worked each day. We did find, however, that the ozone air pollution prevalent in southern California does reduce daily earnings, perhaps by as much as 2.0 percent on the average. However, there exist order-of-magnitude differences in the losses among pickers. These results have been obtained on the presumption that air pollution and other environmental conditions influence only the picker’s ability to harvest fruit. No account has been taken of the possibility that he may simply dislike the presence of a poor environment and thereby be induced to reduce his work effort.

Similarly detailed data sets might allow more ambitious applications to other occupations of the basic model used here to estimate the compensating surpluses or variations that workers require for changes in workplace conditions. Though we have not attempted to explain the wide differences in compensating surpluses for air pollution exposures that we obtained as between and among the workers in our sample, the fact of these differences suggests that studies which employ worker and/or time aggregates might err: it could be that estimates derived from aggregated data represent the behavior of neither sensitive nor insensitive individuals but rather a weighted sum of the two for which it is impossible to disentangle the distinct contribution of each type of individual. For many policy questions involving workplace and environmental conditions, it is the sensitive individual, rather than the “representative” individual, who must be identified.

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1 See Freeman (1979, Chapter 7) for a discussion.

2 In a laboratory experiment, Raven, et al. (1976) found that lung function of nineteen adult males had declined by four to seven percent following four hours of physical exertion in an environment resembling frequent ambient air conditions in southern California. No interactions between ambient temperature, ambient pollutants, or smoking habits were evident. Younger subjects appeared to be more sensitive to pollution and temperature than did older subjects. Qualitatively similar findings are presented in Kagawa and Toyama (1975).

3 See Crocker and Horst (1977, pp. 9-12) for a description of the procedures used to assign pickers to rows.

4 Rosendale and Mamer (1974, p. 19) state that in 1973, 3,335 pickers were employed by the Coastal Growers Association of Ventura County alone.

5 All pickers studied regularly earned more than the minimum wage, although since they were in the lowest tax bracket, marginal income tax rates seem unlikely to have exercised a major influence upon work effort.

6 See Crocker and Horst (1977, pp. 27-31) for a development of the grower's harvest decision problem.

7 Worker performance data were obtained from the San Gabriel Valley Labor Association of Fucumonga, the Lemoneira Ranch of Santa Paula, the River Growers Association of East Highlands, and Irvine Valencia Growers of Irvine. Grove condition data were provided by Upland Lemon Growers of Upland, Lemoneira Ranch of Santa Paula, Western Fruit Growers Packing Company of Mentone, Irvine Valencia Growers of Irvine and Corona College Heights Citrus Company of Riverside.

8 This supply function is simply the mirror image of the hours-earnings indifference locus in Figure 1. Since the indifference locus has a

negative slope throughout, the slope of the supply function if the negative of the picker's marginal rate of substitution between earnings and leisure.

9 In addition to the independent variables of Table 2, several other variables were investigated for the four test pickers. The introduction of most of these other variables was motivated by conversations with labor camp managers rather than from properties of our model of the picker's decision problem. For example, managers widely believe that, because of planned and realized picker weekend activities, picker performance decreases markedly on Fridays and Mondays. For the four test workers, however, the estimated coefficient for Friday and Monday dummy variables were not significantly different from zero. A second common managers' observation is that many pickers set an earnings goal and will not work as productively once this goal is achieved. The validity of this hypothesis was checked by including a measure of the picker's total earnings in previous weeks. Again, statistically significant coefficients were not obtained. Finally, the managers believe that having multiple groves worked in a day seriously impairs the picker's productivity. It is thought that each move to a different grove causes the picker to go through another "warn-up" period, thus slowing down his picking output. Inclusion of a variable representing the daily number of groves picked did not result in a significant coefficient for any test picker.

Measure of the daily variances and maxima hourly ozone faced by the four test pickers were also calculated. They were highly collinear with the arithmetic mean measures and, when included in the four pickers' earnings expressions, were not significant.

10 It is practically unheard of for daytime temperatures in the citrus growing areas of southern California to approach freezing. In the summertime, daytime temperatures exceeding one hundred degrees are common.

11 See Feldstein (1967), Barzel (1973), and Rosen (1976), for example.

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CHAPTER IV
YIELD VARIABILITY, AIR POLLUTION, AND PRODUCER RISK: SOME OBSERVED ASSOCIATIONS

INTRODUCTION

It is well-known that air pollution has severe negative effects upon some crops while having only trivial effects upon others.[1/] High concentrations of oxidants or other air pollutants weaken some plants and thus increase disease incidence or otherwise decrease the plants' abilities to withstand stress. As a result, air pollution may affect both the absolute levels and the variabilities of crop yields.

Our purpose in this essay is limited to demonstrating the existence of a moderately strong positive association between a frequently employed measure of the risks faced by agriculturists and increases across space and time in southern California air pollution. No attempt is made to show that ambient oxidants are the cause of the spatial and temporal increases in the risk measure, nor to trying to assign pecuniary equivalents to variations in this measure. We do, however, present a simple model intended to show why air pollution which increases the risks faced by agricultural producers is costly.

A SIMPLE MODEL

Assume that an agricultural producer must make all input commitments prior to the growing season and that air pollution levels during the growing season are his only source of uncertainty. If the prices for his outputs are exogenously determined, the quantities of outputs and thus the net revenues, π, he will obtain from any particular commitment of inputs are uncertain and will vary inversely with realized levels of air pollution. For simplicity, we assume that net revenues are the sole argument in the producer's utility function and that his marginal utility of money is positive and a constant. Thus, without loss of generality, we can write:

$$\pi = \pi(p), \text{ and } \pi' < 0 \qquad (1)$$

where p is the ambient concentration of pollutants. Expanding (1) in a Taylor series about a mean value, $\bar{p}$, ignoring moments above the third, and taking the expected value gives:

$$E[\pi(p)] = \pi(\bar{p}) + \left(\frac{\sigma^2}{2}\right)\left(\frac{\partial^2\pi}{\partial\bar{p}^2}\right) + \left(\frac{\sigma^3}{6}\right)\left(\frac{\partial^3\pi}{\partial\bar{p}^2}\right) \qquad (2)$$

where E is the expectation operator, and

$$\sigma^2 = E(p-\bar{p})^2$$

$$\sigma^3 = E(p-\bar{p})^3$$

since p is a random variable for the producer.[2]

Taking the producer’s net revenues to be a function of the first three moments of p’s distribution about its mean is equivalent to assuming $\pi(p)$ in (1) to be cubic. Thus:

$$\pi(p) = p + bp^2 + gp^3 \qquad (3)$$

Upon taking the expected value of (3), we obtain:

$$E[\pi(p)] = E(p) + bE(p)^2 + gE(p)^3 \qquad (4)$$

where

$$E(p)^2 = \sigma^2 + [E(p)]^2 \qquad (5)$$

and

$$E(p)^3 = \sigma^3 - 2[E(p)]^3 + 3E(p)^2\, E(p) \qquad (6)$$

Substitution of (5) and (6) into (4) gives:

$$E[\pi(p)] = E(p) + b[E(p)]^2 + g[E(p)]^3 + [3gE(p) + b]\sigma^2 + g\sigma^3 \qquad (7)$$

Taking the derivative of (7) with respect to E(p), we have:

$$\begin{aligned}\frac{\partial E[\pi(p)]}{\partial E(p)} &= 1 + 2bE(p) + 3g[E(p)]^2 + 3g\sigma^2 \qquad (8)\\ &= 1 + 2bE(p) + 3g[E(p)]^2 + 3g(E(p)^2 - [E(p)]^2)\end{aligned}$$

$$= 1 + 2bE(p) + 3gE(p)^2$$

This is a quadratic having roots:

$$\frac{-2b \pm [2b^2 - 4(3g)]^{1/2}}{6g}$$

Thus if the expected marginal effect of dirtier air on net revenues is to be negative, then:

$$b^2 < 6g \tag{10}$$

Since b^2 is always positive, g must also be positive if (10) is to hold. Given that g must be positive, the sign for $\partial^2\pi/\partial\bar{p}^2$ comes from (2) and (7) where:

$$\frac{\partial E[\pi(p)]}{\partial\sigma^3} = \frac{\partial^2\pi/\partial\bar{p}^2}{2} = 3gE(p) + b \tag{11}$$

$$= 3g\bar{p} + b$$

Clearly in (11), if $\bar{p} \leq -b/3g$, then $\partial^2\pi/\partial\bar{p}^2 \leq 0$, which implies that increasing uncertainty, as measured by the variance of air pollution dosages, decreases the producer's net revenues.

The correct sign for $\partial^3\pi/\partial\bar{p}^3$ can also be obtained from (2) and (7) since

$$\frac{\partial E[\pi(p)]}{\partial\sigma^3} = \frac{\partial^3\pi/\partial\bar{p}^3}{6} = g \tag{12}$$

The requirement from (10) that g be positive therefore assures that $\partial^3\pi/\partial\bar{p}^3 < 0$. Thus, given similar expected values and variances among air pollution frequency distributions, the producer will prefer those distributions skewed toward the lower ranges.

A SCENARIO IN WHICH INCREASING AIR POLLUTION INCREASES YIELD VARIABILITY

The preceding section demonstrates under reasonable assumptions that air pollution which increases the variability of the outputs to be obtained from a preselected mix and magnitude of inputs is costly to the producer. No justification is provided, however, as to why air pollution increases the variability. In fact, it is certainly possible that increased air pollution might reduce expected yields while also compressing the range of physiologically possible yields. Air pollution could thus reduce rather than increase one facet of producer costs. There are at least two related factors which make a compression unlikely, however.

As Larsen and Heck (1976) note, air pollution damages to plants are functions of both the magnitude of instantaneous exposures and the duration of any particular magnitude. Young plant tissues are thought to be particularly sensitive to high instantaneous exposures.

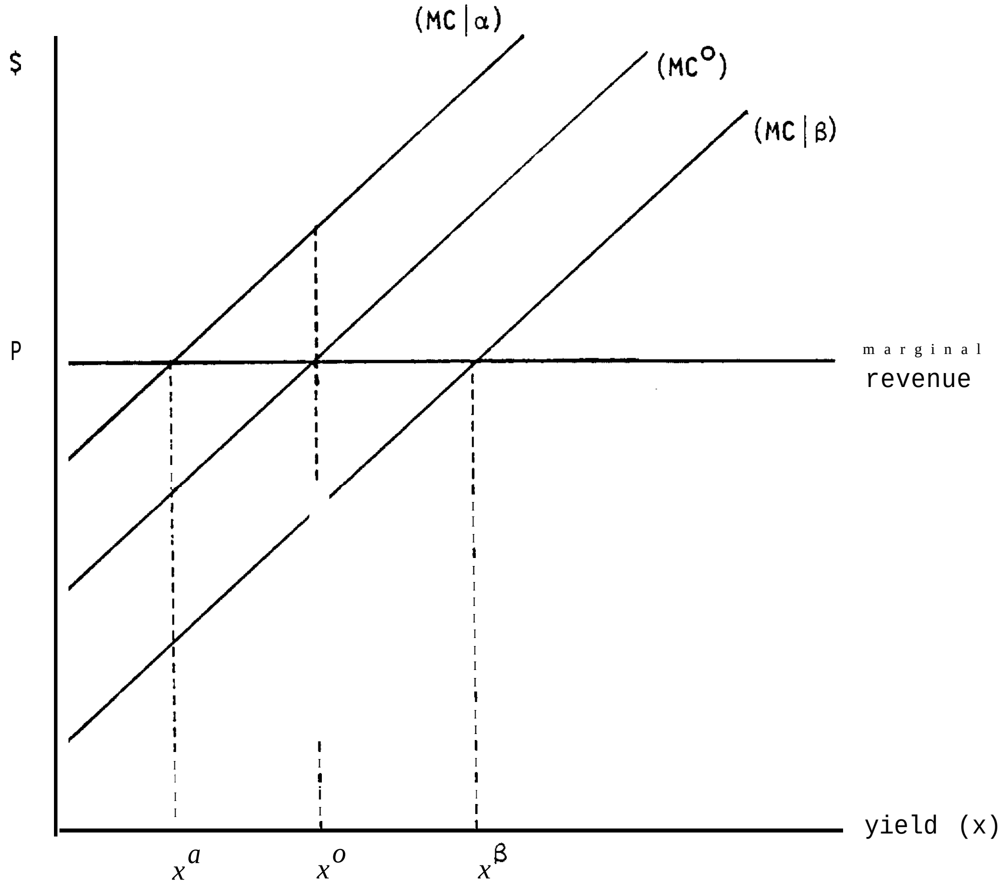
High instantaneous exposures of young plants to air pollution can occur in a location, but one would expect the frequency of these high exposures to be greater in areas with relatively high average ambient pollution concentrations. Nevertheless, because of temporarily favorable meteorological conditions, even these generally high pollution areas may experience periods, when ambient pollution concentrations are no higher than in the more favored locations. If one of these low pollution periods happened to coincide with a time in the growing season when plants are highly sensitive to air pollution, then an otherwise polluted area may exhibit little plant damage over one growing season. In another year when pollution was high at the times of greatest plant sensitivity, major damages may appear. Since meteorological conditions will provide even the most highly polluted areas with occasional periods of relief, areas growing crops sensitive to instantaneously higher ambient pollution levels are likely to exhibit greater variability in their yields from year to year.

The greater year-to-year variability in yields which the above scenario generates for more polluted areas can be exacerbated by the preplant and cultural management decisions the producers make on the basis of their expectations about ambient pollution behavior.[3] Figure 1 illustrates the relevant reasoning. As before, we assume that the marginal utility of money is constant for the producer and that net revenues is the sole argument in his utility function.

Assume that the producer must make all input commitments before the actual start of the growing season and that air pollution is his only source of uncertainty. For simplicity, further assume that air pollution over the growing season is expected to be either "high" (a) or "low" (β). If air pollution is "high", the marginal cost of supplying various yields, given the input commitments already made, will be represented by the curve ($MC|\alpha$) in Figure 1. This curve is the highest of the three marginal cost curves in Figure 1 because the actual occurrence of the a level of air pollution will reduce the marginal product of the preselected mix of inputs, and thereby increase the marginal cost of producing any particular yield. On the other hand, if <u>realized</u> air pollution levels during the growing season were β, then,

Figure 4.1

EFFECT OF AIR POLLUTION RISK UPON YIELDS



in accordance with the $(MC|\beta)$ curve, the marginal cost of producing various yields would be reduced. The MC^o curve is the graphical representation of the probability weighted average of $(MC|\alpha)$ and $(MC|\beta)$.

Let the producer regard the occurrence of either a or β air pollution as equally likely. The MC^o is the marginal cost curve associated with the input mix maximizing hi's expected profits. Although this technology will, on average, yield X“ over several growing seasons, it will result in yields of either x^α or x^β during any one season. Thus if air pollution is high during one season, x^α will result, while if it is low, x^β will result. In effect, the variability across seasons in levels of air pollution causes yields to be more variable than in areas where air pollution never affects yields or where it is stable.

If maximum air pollution levels during the sensitive parts of the growing seasons have been increasing over time, while low levels of pollution still occasionally occur on some years during these sensitive parts, then yield variabilities for crops susceptible to being damaged by instantaneously high levels of pollution would increase. This is because the higher pollution levels cause the $(MC|\alpha)$ tune to shift upward. Unless the producer constantly lives in the darkest depths of despair about the air pollution problem, the MC^o curve, which is the probability weighteda average of the other two curves, will never shift upward as much as the MC curve. The result will be increasing yield variability over time in the progressively more polluted areas.

SCOPE OF THE EMPIRICAL ANALYSIS

The preceding section suggests that increasing levels could readily increase crop yield variabilities. In the next section, we empirically test whether or not locations with high air pollution levels relative to other locations or other times are associated with higher variabilities of crop yields. We do not dismiss other factors exogenous to the individual producer's decision problem, such as urban encroachment upon agricultural land, from being sources of any differences in yield variability we observe.

Given its documented history of high pollutant levels coupled with significant agricultural activity, southern California seems a suitable region for study . Because of a favorable mix of climate, soils, and irrigation water, southern California has assumed national importance in the production of a number of specialty crops, including citrus, fresh vegetables, and nursery crops. Thus any changes in yields and production patterns within the region may have implications for national commodity markets, and hence consumer's welfare. In addition, if a region produces a large share of national production, then significant fluctuations in yield will usually result in variations in market price and thus the gross and net earnings realized by producers and factory owners.

The crops included in the analysis are major vegetable and field crops, each having a 1974 gross value of production of over fourteen million dollars. The crops are: Lima beans, broccoli, cantaloupes, carrots, cauliflower, celery, lettuce, onions (fresh and processed), potatoes, tomatoes (fresh and processed) and cotton and sugar beets. Yield variability measures for each crop are presented for Santa Barbara, Ventura, Los Angeles, Orange, and San Diego Counties on the coast, and Riverside and San Bernardino Counties in the high desert. Although these counties, with the exception of San Bernardino, constitute a relatively small proportion of the total acreage in the state, they produce most of the supplies of California lima beans, carrots, celery, fresh onions and fresh tomatoes.[4/]

Among the counties in the region, a rank-ordering, from highest to lowest, of oxidant/ozone ambient air pollution (the overwhelmingly dominant pollutant class throughout the region), is: LOS Angeles, Riverside, San Bernardino, and Orange Counties, followed by San Diego, Santa Barbara, and Ventura Counties. The ranges of ambient air pollution for fairly representative agricultural locations in each county are presented in Table 1. Figure 2 shows the location of the oxidant/ozone monitoring stations used for this study relative to the major agricultural areas of each county.

YIELD VARIABILITY INDICES

For any given combination of market-purchased inputs, variations in crop yields are caused by a set of factors beyond the individual producer’s control. In terms of the producer’s decision problem, one can discriminate between the portion of the total yield variation attributable to “unpredictable” or “random” factors and the portion that is “predictable,” based on past experience and information. It is often assumed that producers will regard any deviation of crop yield from the long-run mean as an unpredictable event. However, most models of rational expectations [Muth (1961)] as well as practical observations of agricultural producer behavior [see, e.g., Cooley and De Canio (1977)] imply that the unpredictable element is that portion of the total variation that deviated from the “current” level (say, over the past few seasons) rather than the long-run mean. In effect, producers are generally depicted as giving more weight to more recent observations.

Carter and Dean (1960), suggest several alternative empirical procedures for determining the current level of a specific set of time series data and the deviations from this current level. An often used method is to approximate

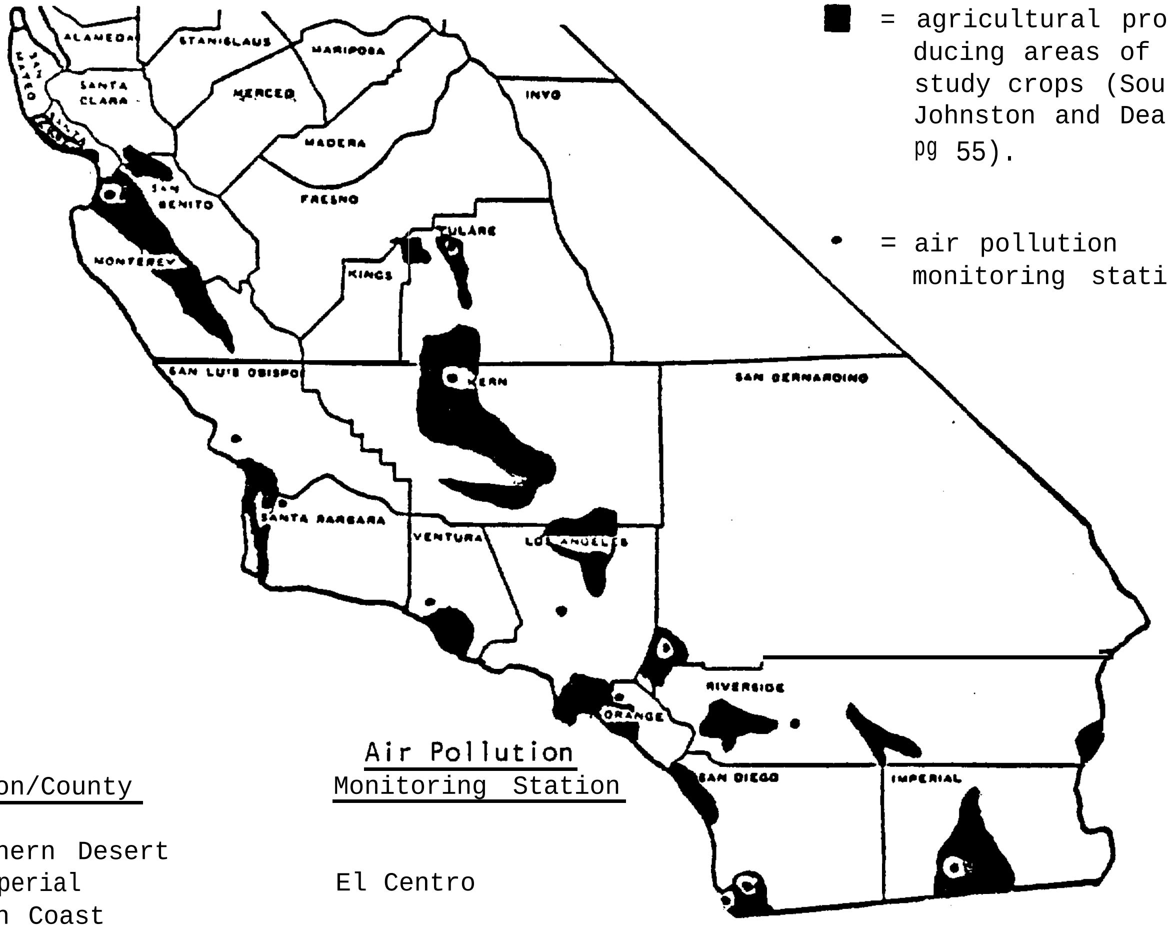
Table 4.1

Selected Measures of Ambient Air Pollution for South Coastal Counties, 1.957-1976

County and Period	Annual Average Concentration (oxidants/ozone)	Range Minimum/Maximum	3 year period of maximum concentration
Los Angeles (1.957-1976)	53 pphm	27 - 117 pphm	1957-59
Riverside (1957-1976)	44 pphm	35 - 62 pphm	1968-70
San Bernardino (1958-1976)	40 pphm	30 - 59 pphm	1959-61
Orange (1957-1976)	35 pphm	17 - 62 pphm	1965-67
San Diego (1957-1976)	30 pphm	15 - 80 pphm	1963-65
Ventura (1963-66, 1969-70, 1974-76)	22 pphm	11 - 31 pphm	1963-65
Santa Barbara (1959-66, 1971-76)	21 pphm	11 - 40 pphm	1959-61

Figure 4.2

Locations of Air Pollution Monitoring Stations and
Agricultural Producing Areas of Study Crops in Southern California



■ = agricultural producing areas of study crops (Source Johnston and Dean, pg 55).

• = air pollution monitoring stations

Region/County	Air Pollution Monitoring Station
Southern Desert	
Imperial	El Centro
South Coast	
Los Angeles	Pasadena
Orange	Anaheim
Riverside	Indio-Oasis
San Bernardino	San Bernardino
Santa Barbara	Santa Maria
San Diego	San Diego
Ventura	Ventura-Telegraph Road
Central Coast	
Monterey	Salinas
San Benito	Hollister
San Luis Obispo	San Luis Obispo
Santa Cruz	Salinas
Southern San Joaquin	
Kern	Delano
Tulare	Visalia-Old Jail

the current level of the time series data by fitting a trend line, and then to assume that a "random" component is any deviation from that trend line. A second method is to assume that there is no difference between the "current level" and that in the previous year so that the "random" element is identical with first differences in the data. A third procedure consists of approximating the "current level" by a moving average, and then assuming that any crop yield deviations' from the moving average are the "random" element. Finally, time series data might be deflated by some general index to arrive at "real" values of the series, with any crop yield deviations from the long run mean of the deflated data series classified as the "random" element.[57]

In the absence of detailed information about production functions, the learning reactions of producers, and other factors, any statistical method not requiring a priori specification of rigid functions should be preferable to alternative methods. Since the trend removal method assumes that the systematic component of time-series data can be characterized by any type of function, that version of the trend removal method (the variate difference technique) originally formulated by Tintner (1940) seems appropriate.

The basic assumption of the variate difference method is that time-series data consist of two additive parts: The mathematical expectation (or systematic component) of the time series in which consecutive observations are mutually and positively correlated; and a random component where consecutive items are assumed to be nonautocorrelated or uncorrelated with the systematic component. The procedure separates the systematic from the random component. Initially, the mean and variance for the original series of data and for each of a series of successive finite differences is calculated. Following this, the random standard deviations are calculated for each finite difference and from these, using procedures outlined in Tinter (1952), one selects that finite difference which has been purged of the systematic component. Total (systematic plus random) and random variability indices may then be calculated as:

$$\text{Total variability} = \frac{(\text{Total variance})^{\%}}{\text{Mean}} \quad \text{x } 100,$$

$$\text{Random variability} = \frac{(\text{Random variance})^{\%}}{\text{Mean}} \quad \text{x } 100,$$

where the denominator refers to the first moment of the data during some preselected time period. In this study, this preselected period will be 1972-1976.

The simple models presented in previous sections are consistent with the presence of systematic as well as random variability. If, for a particular annual crop, input commitments are irreversible once the crop has been planted and/or input combinations are invariant, then the observed variability would be random, assuming that the producer is unable to forecast accurately fluctuations in exogenous variables. However, if over time the producer learns about the behavior of-the exogenous variables and is thereby able to improve his forecasts, if he is able to make input adjustments during the growing season, or if he adopts less pollution susceptible varieties of the same crop in response to learning, then the data will embody a systematic component that reflects the producer's optimizing adaptation to altered values of the exogenous variable. Since we do not know which component, if either, dominated for the region being studied, empirical results for both measures are presented.

EMPIRICAL RESULTS

In this section, yield variability indices in high pollution counties are compared for the same crop with low pollution counties.[6] To determine whether yield variabilities have increased over time as ambient levels of oxidants have increased, our results will also be compared with the variability indices obtained by Carter and Dean (1960) for the entire southern California region.

Estimated by crop and county of variability indices are presented in Table 2. Because of lack of data, not all crops have indices calculated for each county. Comparisons of the random indices for the same crop across counties indicate that they are generally higher for those counties with higher air pollution levels. This association is, in fact, quite strong for those crops (processed green lima beans, lettuce, fresh tomatoes, and sugar beets) for which most varieties are generally acknowledged to be quite susceptible to oxidant/ozone air pollution damages.[7] The association is substantially less strong for the total variability indices, but they nevertheless do not contradict the rank-orderings of the random indices. If, in fact, the frequency greater values of the random indices in Los Angeles, San Bernardino, and Riverside Counties are caused by their generally higher maximum air pollution levels, then those discrepancies which do exist between the rank-orderings of the variable and the total indices are consistent with an inability of producers in these counties to adapt fully by using less susceptible crop varieties and input combinations.

Whether the differences in indices among counties are caused by variations in air pollution levels, other environmental factors, or simply chance is impossible to determine with the data used for this study. However, annual crop yield data reported by the separate county commissioners show that

Table 4.2

Yield Variability Indicies for Selected Annual Vegetable and Field Crops
Southern California, 1957-76

Crop	County	Production Season	Yield Variability Indices	
			Random	Total
			Per Cent	
<u>Vegetables</u>				
Green Lima Beans (processed)				
	Orange	--	18,7	36.0
	Santa Barbara	--	10.7	26.7
Cantaloupes				
	San Bernardino	Spring	23.7	35.3
	Los Angeles	Summer	18.1	25.0
	Riverside	Spring	8.8	15.2
Carrots				
	Los Angeles	Late Fall	13,8	16.3
	Santa Barbara	Late Fall	11.9	22.0
	Riverside	Winter	11.0	24.6
Cauliflower				
	Riverside	Early Sprhg	35.3	98.8
	Orange	Early Spring	14.7	19.6
	Ventura	Early Spring	11.8	36.8
	Los Angeles	Early Spring	11.2	20.6
	Santa Barbara	Early Spring	11.0	39.5
	San Bernardino	Early Spring	3.8	31.7
	San Diego	Early Spring	5.0	33.9
Celery				
	San Diego	Winter	10.0	15.4
	Orange	Spring	7.3	12.0
	Santa Barbara	Early Summer	5.9	8.7
Lettuce				
	San Bernardino	Early Summer	26.6	39.2
	Riverside	Early Summer	13.4	18.2
	Los Angeles	Early Summer	12.8	45.0
	Orange	Early Summer	10.8	19.9
	Ventura	Early Spring	6.4	12.5
	Santa Barbara	Early Spring	5.0	20.3

Table 4.2

(continued)

Crop	County	Production Season	Yield Variability Indices	
			Random	Total
			Per Cent	
Vegetables				
Onion, Fresh				
	Los Angeles	Late Spring	12.5	28.8
	Riverside	Late Spring	10.9	27.2
Potatoes				
	Riverside	Early Summer	8.4	10.5
	Santa Barbara	Late Summer	8.2	10.6
Tomato, Fresh				
	Riverside	Early Spring	35.1	49.0
	Los Angeles	Early Spring	23.1	29.3
	Orange	Early Spring	17.5	24.8
	Santa Barbara	Early Fall	14.0	34.8
	San Diego	Early Summer	10.1	22.4
	Ventura	Early Summer	9.9	14.0
Tomato, Processed				
	Orange	--	12.0	17.3
	Ventura	--	11.5	13.6
	Santa Barbara	--	10.6	30.04
Field Crops				
Cotton				
	San Bernardino	--	15.7	44.5
	Riverside	--	13.0	21.4
Sugar Beets				
	Los Angeles	--	18.7	23.7
	San Bernardino	--	16.4	20.7
	Riverside	--	15.4	23.7
	Santa Barbara	--	10.0	--
	Ventura	--	5.2	

during 1972-76, the annual average crop yields for fresh tomatoes, potatoes, and lettuce have been much lower in Riverside, San Bernardino, and Los Angeles Counties than in the other counties. This obviously increases the variability indices, *cet.par.* It is possible that some portion of these lesser yields is caused by air pollution. The ambiguousness of the results in Table 2 can be reduced by ascertaining whether there has been an association between higher variability' 'indices and increasing levels of oxidant/ozone air pollution over time. We, therefore, compare the values of our random variability indices, which cover the 1955-76 period for the southern California region, with those obtained in two earlier efforts by Carter and Dean (1960, 1968). All three sets of indices are estimated by the same technique. The earlier Carter and Dean study embodies estimates of income, price, and yield variability indices for principal California crops from 1918 to 1957.[8] Estimation of the variability indices on vegetable crops is on a statewide and seasonal basis. Comparisons between selected counties and the entire State of California are possible only for some field crops. In the later study (1968), data for the same crops were extended through 1965. Also, the 1968 study has variability measures on both a state and county level for selected crops. The data used in these two studies span a period of relatively low ambient air pollution concentrations (1918-1957, 1918-1965). Only for the last decade of the data period (1947-1957) for the earlier study did air pollution become a significant problem in the study area. Thus, any variability measures estimated by Carter and Dean should be relatively free from the influence of air pollution effects.

Table 3 permits a comparison of our random Variability indices for a variety of crops with those of Carter and Dean.[9] Any comparison tends to support an association between temporal increases in the random variability indices and temporal increases in oxidant air pollution throughout southern California.[ur] In fact, one or more of all the vegetable and field crops (green lima beans, lettuce, fresh tomatoes, and sugar beets) that in Table 2 consistently exhibited higher random yield variabilities in high air pollution counties also exhibited higher variabilities in the 1955-1976 period than in the Carter and Dean periods. Cotton, another crop known to be very susceptible to oxidant air pollution damages, also appears to have suffered increased yield variability during the 1955-1976 period. However, because Table 2 does not contain a low pollution county for cotton, we do not know whether this type of county has experienced a similar increase in yield variability. Of those crops displaying a lower yield variability during 1955-1976, only celery is widely thought to be sensitive to air pollution damages. Nevertheless, that single variety of celery (winter) that is almost entirely grown in southern California does exhibit an increase in yield variability. Given these observations, the plausibility of our second hypothesis cannot reasonably be rejected, i.e., increasing levels of air pollution over time, are

Table 4.3

Random Yield Variability Coefficients: Comparison between Carter and Dean and Present Study Results

Crop/Season	Carter and Dean 1918 - 1957	 1918 - 1965	Current Study 1955 - 1976
Vegetables			
Tomatoes, early fall	2	5	14 (10)
Beans, green lima	4	4	15 (11)
Celery, winter	5	7	10 (7)
Tomatoes, processing	5	5	12 (9)
Onions, late summer	6	6	11 (8)
Celery, late fall	6	5	6 (4)
Celery, spring	6	16	7 (5)
Cauliflower, late spring	7	7	15 (11)
Onions, late spring	7	13	11 (8)
Lettuce, summer	9	12	15 (11)
Carrots, winter	9	10	11 (8)
Tomatoes, early summer	11	9	11 (8)
Tomatoes, early spring	11	13	23 (16)
Cantaloupes, summer	12	10	18 (13)
Broccoli, early spring	12	15	8 (8)
Carrots, late fall	13	7	12 (9)
Lettuce, early spring	15	9	6 ( )
Cantaloupes, spring	16	16	23 (16)
Field Crops			
Sugar Beets	9	11	16 (11)
Cotton Lint	7	5	13 (9)

Sources: Carter and Dean (1960, Tables 1 and 2; 1968, Tables 1 and 2).

associated, whether causally or otherwise, with increased yield variabilities for a number of crops.

SUMMARY AND CONCLUSIONS

Variability in agricultural yields is one measure of the risk faced by producers. This Variability can be a manifestation of numerous factors, including weather, disease and other environmental perturbations. Air pollution may be another factor which contributes to yield variability through the weakening of the plant at times in the growing season when it is particularly susceptible to stresses.

This paper is an exploratory attempt to deal with the effects of air pollution on producer behavior and the yield variability of selected crops within a major production region. The empirical analysis suggests that regional and temporal differences in air pollution are associated, though perhaps not causally related, with increased yield variability. Relative risk rankings across crops and regions may, therefore, be changed by spatial and temporal differences in air pollution, especially when there exists a lack of alternative economic strategies to mitigate for air pollution effects within crop groups and/or production region. Our analysis raises the possibility then that, in the absence of compensating adjustments in expected income, producers of several crops in southern California have been forced to bear increased risks due to the intensification in the last two decades of the region’s oxidant air pollution.

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1 See, for example, Committee on Medical and Biological Effects of Environmental Pollutants (1977, pp. 437-556).

2 Somewhat similar developments can be found in Levy (1969) and Hanoch and Levy (1970).

3 Similar conclusions can be drawn from an extension of the model of Ratti and Ullah (1976). They show that increasing uncertainty reduces the demand for inputs. Assuming the marginal products of these inputs to be everywhere positive, and since Just and Pope (1979) suggest that decreased input use increases the variability of the marginal product, it follows that greater air pollution will increase yield variability.

4 Some counties have recently experienced a rather sharp decline in acreage and the production has declined for some crops, such as carrots, cauliflower, celery and fresh tomatoes in Los Angeles County; carrots, lettuce, fresh tomatoes and sugar beets in Orange County; most of the crops included in this study in San Bernardino County; and celery, lettuce and cotton in San Diego County. Only Santa Barbara and Ventura Counties have shown an increase in acreage of the included crops. While this decline is probably due mainly to urban encroachment, it may also reflect some locational adjustment in response to air quality degradation.

5 This last procedure is considered useful when dealing with price series, e.g., prices are usually deflated by some measure of the general price level such as the Wholesale Price Index or Consumer Price Index.

6 All crop yield data were obtained from the respective County Agricultural Commissioner annual reports..

7 For a detailed review of literature on the relative susceptibilities of various crops to oxidant/ozone air pollution, see Adams, et al. (1979) , Chapters 11 and IV.

8 The variability indices in the 1960 study were estimated from the 1918-1957 period if there was no statistically significant difference between

the variances in the 1918-1937 and the 1938-1957 periods, or the 1938-1957 period if there was such a difference. Moreover, in the case of nonhomogenous variances, the variance of the most recent period was

then taken as the best estimate of future variance (Carter and Dean, 1969, p. 180). The mean yield used in the study was the average from 1953 to 1957.

9 To the list of obvious but unconsidered factors which could influence the values of the indices must now be added shifts in relative input prices across periods that differentially affect crop varieties and input combinations and productivities across counties. New crop varieties with greater yield variabilities may also have been introduced.

10 Most of the variability measures for vegetable crops reported in Carter and Dean represent average variability (across all producing counties) for a specific crop in a specific season; e.g., the random variability for winter celery is the average of variabilities for all counties producing winter celery. The results from the present study as reported in Table 3 are the average variabilities for that crop and season for southern California only. Comparisons between Carter and Dean results and those of this study appear empirically valid, given that the crops and seasons cited in Table 3 are primarily grown within southern California. Hence, the underlying geographical production areas should be consistent across the two sets of results.

For field crops (cotton and sugar beets), the Carter and Dean results are provided for selected counties, including Imperial County in the desert region of southern California. The Imperial County variabilities from Cater and Dean are compared with those of Riverside and San Bernardino Counties from the current study, since these latter counties encompass a sizable crop area within the same desert environmental zone.

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