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CHAPTER III

SOME METHODOLOGICAL CONSIDERATIONS ON THE ASSESSMENT OF AIR POLLUTION DAMAGES: A PROPOSED MATHEMATICAL FRAMEWORK

3.1 Introduction

One important aspect of economic analysis concerns the definition of methods or procedures that may be used in addressing a problem or set of problems at hand. When integrated with appropriate assumptions, methodologies constitute the conceptual framework within which to achieve possible solution(s) or provide suggestions for sclving such problem(s). The problem statement and justification for this study has been set forth in Chapter 1. Given these problem statements and objectives concerning the relationship between air pollution and vegetation, the intent of the analysis is to determine the consequences and the magnitude of such air pollution damage. This quantitative assessment of air pollution damage occurs within the methodological framework defined for this study. Thus , specification of the appropriate technique is central to the success of the analysis.

A number of conceptual issues have been raised implicitly concerning a methodology for estimating agricultural damages associated with air pollution. The approach should have a general equilibrium flavor, in that both producing and consuming sectors are assessed simultaneously. Further, interregional competition and comparative advantage constructs are required, given that all regions considered compete to some extent for shares of national commodity markets. In addition, substitution effects on the production side need to be considered. All of these relationships are dependent to some degree on the physical environment surrounding crop production, including ambient air quality. This section discusses these concepts or components required for such an analysis. The concepts are then extended into a tractible mathematical model.

3,2 Methodological Framework

The conceptual issues outlined above involve a wide range of economic relationships suggested by theory. For the methodology to be tractable in terms of empirical analysis, these relationships must be combined in a logical sequence and given a quantitative interpretation. This section provides a more detailed methodological framework with which the concepts discussed earlier may be quantified.

1. Production Section

a. Production Functions

Assume that a specified area is divided into r heterogeneous regions where r = 1,2, . . ., R. Regions are differentiated by such factors as climatological conditions, soil quality and levels of ambient air quality. Climatological conditions and soil quality determine jointly or separately type(s) of crop(s) suitable for each region, whereas ambient air quality is assumed to have different effects (favorable or unfavorable) on crops. In each region there are i(i = 1,2,.. .,1) farmers (processes) producing j (j = 1,2, . . .,J) agricultural. crops. However, it is possible for a region to produce one or more crops and many regions to produce the same crop. Thus, two regions may be viewed as homogeneous; each has identical cropping alternatives, i.e. , the same set of crops. Perfect competition is assumed to prevail in the sense that each producer and each consumer acting alone cannot affect the market price of a commodity, regardless of the amount each one supplies and demands; but aggregate supply put forth by all farmers (processes) in the area, due to the nature of the commodity described in the earlier section can affect the market price of that commodity. Assume further that, in the short run, farmers use both fixed and variable inputs. Fixed inputs are land (measured in acreage used in cultivation) and irrigation water. The factor supply function for such inputs may be assumed to be perfectly inelastic. Variable inputs include labor, seeds, fertilizer, and insecticide. These inputs are used in different amounts from one stage of production to another. The factor supply functions for these inputs may be assumed to be perfectly elastic for some (e.g., seed). Labor is a special case, since unskilled labor is assumed to be available at any time and thus has a perfectly elastic supply curve, whereas skilled labor required for some processes of production is relatively scarce. Consequently, its factor supply curve is rather inelastic.

There is another type of input, ambient air quality, which enters into the production function. It would appear reasonable to assume that if air quality deteriorates, production (yield) may be reduced or the costs of production increased. Some of the crops produced are assumed to be perishable and thus have to be sold within a certain period of time, limiting the use of carryover or buffer stocks across seasons. Transportation cost is excluded under the assumption that it is treated as a fixed cost of comparable magnitude for producers and regions within the analysis. Thus, its exclusion from the model may not significantly alter the result of the analysis.

Let lower case letters denote individual units and capital letters aggregate units. Thus, q_{ji}^{rm} denotes total production of crop j at the end of the current season by farmer i in region r using soil type m where m = 1,2, . . .,M. Let l, la, f, is, w, se, k and z be total land, labor, fertilizer, insecticide, irrigation water, seed, capital, and environmental quality, respectively, associated with the production of crop j. The production function of crop j can then be expressed as:

$$Y_{ji}^{rm} = q_{ji}^{rm} (l, la, f, is, w, se, k, z) \qquad (3.1)$$

If one assumes that the above production function is linear, one will, by taking the first-order partial derivative of q with respect to each input, obtain a constant marginal productivity of each input included in the model. Such a result might be interpreted as the shadow price of each input. This general class of production functions is said to be homogeneous of degree one, i.e. , a constant returns to scale production function in which output will be increased by the same proportion as an increase in inputs.

Let P_j be the market price of commodity j. Assume one market price across all regions. $Q_j = \Sigma\Sigma\Sigma_{irm} q_{ji}^{rm}$ is the aggregate production of commodity j. S_j, P_l, and O_j are stocks of commodity j, prices of all other commodities, and all other factors such as income associated with the price of commodity j. We can express the price forecasting equation for commodity j as:

$$P_j = P_j(Q_j, S_j, P_l, O_j), \qquad l = 1,2, \ldots, L. \qquad (3.2)$$

For analytical purposes, assume that the effects of all variables except Q_j in the price forecasting equation can be summed together into the intercept term (by using the mean value of each variable multiplied by its corresponding estimated parameters), yielding a new equation for the price of commodity j:

$$P'_j = P'_j(Q_j) = c + dQ_j, \qquad d < 0 \qquad (3.3)$$

i.e., it is strictly a function of quantity. Such an equation can then be used to estimate changes in commodity price associated with changes in the level of production.

Assuming that each farmer in the area has the same objective of maximizing total revenue (above variable costs) subject to certain constraints, the analytical problem then becomes a quadratic objective function with linear constraints as follows:

$$\max \quad TR = PQ = CQ_j + dQ_j^2. \qquad (3.4)$$

subject to:

$$Y_j = a_1 L_j + a_2 N_j + a_3 F_j + a_4 Is_j + a_5 W_j + a_6 Se_j + a_7 K_j + a_8 Z_j \qquad (3.5)$$

$$Y_j = \Sigma_g Y_{jg} = L_j + W_j \qquad (3.6)$$

$$Z_j = \bar{Z}_j \qquad (3.7)$$

$$Q_j \geq 0 \qquad (3.8)$$

Equation (3.5) represents the production function for commodity j. All variables in that equation are the aggregate of those defined earlier. The expectation is that all the estimated parameters will be positive except those for Z_j (environmental quality--ambient air quality). The sign of the estimated coefficient of Z_j, as mentioned earlier, is uncertain. Equation (3.6) states that the amount of fixed inputs available, Y_j, is simply the summation of various fixed inputs (in this analysis only land and irrigation water) used by producing commodity j. Equation (3.7) indicates that environmental. quality (as measured by the degree of concentration of specific air quality parameters) is assumed to be given. Finally, Equation (3.8) states that the output of all commodities must be non-negative.

If each producer takes price as given, i.e., the economy is perfectly competitive, the objective function must be modified by the use of the scaler value of "1/2," i.e.,

$$\max \quad TR = cQ_j + 1/2\ dQ_j^2 \qquad (3.9)$$

which then yields the following first-order condition,

$$\frac{dTR}{dQ_j} = MR = c + dQ_j = P_j \qquad (3.10)$$

as required for perfect competition.

The Lagrangian equation is:

$$L = cQ_j + 1/2\ dQ_j^2 + \lambda[Q_j - (\cdot)] + \mu[Y_j - \sum_g Y_{jg}] + \delta[Z_j - \bar{Z}_j] \qquad (3.11)$$

Revenue maximization requires that the following first-order partial derivatives

$$\frac{\partial L}{\partial Q_j} = c + dQ_j + \quad = 0 \qquad (3.12)$$

$$\frac{\partial L}{\partial \lambda} = Q_j - (\cdot) = 0 \qquad (3.13)$$

$$\frac{\partial L}{\partial \mu} = Y_j - \sum_g Y_{jg} = 0 \qquad (3.14)$$

$$\frac{\partial L}{\partial \delta} = Z_j - \bar{Z}_j = 0 \qquad (3.15)$$

be fulfilled and the Bordered Hessian be negative definite or negative semi-definite.

Using the above procedure, variations in the level of Z should translate into different levels of Q and thus changes in TR, as a result of changes in prices due to such changes in Q. Moreover, it might also be possible to calculate changes in Q resulting from tradeoffs between or among inputs and Z, e.g., mitigative effects of fertilizer. Thus, air pollution damages, as measured by changes in output and price, may be assessed by crop and region.

Another means of measuring damages of air pollution to an agricultural crop is the use of a cost concept. In the presence of air pollution, farmers may increase some other variable inputs such as fertilizer or labor to compensate for the yield-depressing effect of some pollutants. Under such a situation, marginal cost and thus total cost will increase, while total yield might decrease, remain constant, or increase, depending upon whether such input adjustments are less than, equal to, or more than offsetting in terms of the impact of air pollution. Assume that the objective function of producers is to maximize total profit, which is defined as the difference between total revenue and total cost where total revenue remains as defined earlier, but total cost is a function of total production and different levels of ambient air pollution concentration in the specified area. In other words, the higher such concentrations, the greater the additional costs producers must bear, in addition to the "normal" cost of production. Mathematically, this again may be expressed as a non-linear objective function with linear constraints, i.e.,

$$\max \quad \pi = TR - TC = cQ_j + 1/2\, dQ_j^2 - C(Q_j, Z_j) \qquad (3.16)$$

subject to:

$$Q_j = a_1 L_j + a_2 N_j + a_3 F_j + a_4 Is_j + a_5 W_j + a_6 Se_j + a_7 K_j + a_8 Z_j \qquad (3.17)$$

$$Y_j = \sum_g Y_{jg} \qquad (3.18)$$

$$C_j = b_1 A_j + b_2 B_j + b_3 Z_j \qquad (3.19)$$

$$Q_j \geq 0 \qquad (3.20)$$

where C_j = total cost of producing commodity j

A_j = total fixed cost of producing commodity j

B_j = total variable cost of producing commodity j

Z_j = levels of air pollution concentration (per unit of measurement)

b_1, b_2, b_3 are estimated parameters where $b_1, b_2 > 0$, $b_3 \geq 0$.

All other variables and parameters are as defined earlier.

The Lagrangian equation is:

$$L = cQ_j + 1/2\, dQ_j^2 - C(Q_j, Z_j) + \lambda[Q_j - (a_1 L_j + a_2 N_j + a_3 F_j + a_4 Is_j + a_5 W_j + a_6 Se_j + a_7 K_j + a_8 Z_j)] + \mu[Y_j - \sum_g Y_{jg}] + \gamma[C_j - (b_1 A_j + b_2 B_j + b_3 Z_j)] \qquad (3.21)$$

The first-order conditions for profit maximization require that the following partial derivatives:

$$\frac{\partial L}{\partial Q_j} = c + dQ_j - \frac{\partial C}{\partial Q_j} + \lambda = 0 \qquad (3.22)$$

$$\frac{\partial L}{\partial Z_j} = -\frac{\partial C}{\partial Z_j} - \lambda a_8 - \gamma b_3 = 0 \qquad (3.23)$$

and the constant maximization equations stated above be fulfilled. The second-order conditions for profit maximization require that the Bordered Hessian be either negative definite or negative semi-definite.

From the first-order partial derivatives obtained above, one will then be able to solve for Q_j by varying the value of Z_j. After solving for the value of Q_j, the values of cost, revenue, and profit can then be obtained. Such results will provide a measure of the damages of air pollution to commodity j.

Risk and Uncertainty

Quadratic risk programming is usually regarded as a theoretically appealing technique for analyzing impacts of risk aversion on farm planning.

Let M be the gross income associated with agricultural crop j. Then $M = P_j q_j$ where P_j is the market price of commodity j and it is assumed to be distributed normally with mean μ and variance σ^2, i.e., $P \sim N(\mu, \sigma^2)$.

Let the utility-of-income function be exponential in the form:

$$U(M) = \alpha - \beta \exp(-\lambda M) \text{ where } \alpha, \beta, \lambda > 0 \qquad (3.25)$$

α, β are estimated parameters and λ is an arbitrarily assigned degree of risk aversion of the decisionmaker(s) toward commodity j. However, it is possible to directly estimate the value of λ. Wiens (1976) has suggested the following procedure to estimate λ:

Define a quadratic programming problem of maximizing:

$$W = \mu' X - (\lambda/2)\, X' \Sigma X = E(R) - (\lambda/2) \sigma(R)^2 \qquad (3.25)$$

subject to:

$$AX \leq C^* \qquad (3.26)$$

where X is a vector of activities; R is net income; A is the technology matrix relating units of inputs to one unit of output (activity); C* is the level of resource use; λ is degree of risk aversion; and μ is the mean of income.

The Kuhn-Tucker conditions for an optimal solution to the above quadratic programming problem require that:

$$\mu_i - \lambda \Sigma_i X - A'_i \emptyset = 0 \qquad (3.27)$$

for all non-zero activities i in the solution, where Σ_i, μ_i and A_i are, respectively, the ith row of Σ, the ith element of μ, and the ith column of A. Substituting X*, the actual activity level, for X and r, the actual market prices, for $\emptyset$, λ can be estimated as:

$$A^* = {}^e(\mu_i - A'_i r)/\Sigma_i X^* \qquad (3.28)$$

While this should hold for each production activity if all assumptions are exactly fulfilled, empirically an average overall production activity will suffice.

Following the method suggested by Wiens (1976), the expected value of the utility of income function is:

$$E(U(M)] = \alpha - \beta \exp[-\lambda \mu q_j + (\lambda^2/2)\sigma^2 q_j^2] \qquad (3.29)$$

To maximize equation (3.29) with respect to q_j is equivalent to maximizing:

$$W = \mu q_j - (\lambda/2) \text{ var } (q_j) = E(M) - (\lambda/2) \text{ var } (M) \qquad (3.30)$$

where μ can be interpreted as the shadow price of q_j. This is a conventional E,V objective function. Applying Weins' method described above, the values of λ can then be estimated. Hazell (1971) points out the following advantages of using the EV criterion for farm management research:

"(a) The criterion is consistent with probability statements with respect to the likelihood of occurrence of different levels of income for any given farm plan. If total gross margins can be expected to be approximately normally distributed, and if the variance-covariance coefficients used can be regarded as non-stochastic or subjective parameters, then such probability statements are easily derived by using tables for the normal deviate statistic . . .

(b) The variance V is totally specified by the variance-covariance coefficients; and when subjective values of these parameters are available or can be found, the variance is no longer estimated from the sample of observed gross margin outcomes . . .

(c) The criterion is consistent with the Separation Theorem (see Johnson, 1967, pp. 614-620) and allows more general solution to the farm diversification problem given a riskless option (for the decisionmakers) ." [pp. 55-56, expression in the parentheses is added]

Due to the fact that use of EV method requires a special computer algorithm, Thomson and Hazell (1972) suggest that it be replaced by the mean absolute income deviation (MAD) and used to obtain a solution through standard linear programming codes with the parametric option. However, when the sample mean absolute deviation is used rather than the sample variance, the reliability of the estimated efficient, EV, farm plans is necessarily weakened [Thomson and Hazell, 1972, p. 503]. Nevertheless, MAD is still a best substitute when access to such a special computer algorithm is not possible and provided that certain adjustments are also used in order to reduce error due to the use of sample MAD rather than the sample variance. Such an adjustment has been suggested by Thomson and Hazell (1972) by using:

$$\frac{\sum_i (\hat{P}_{1i} - \hat{P}_{2i})(1 - V_i)}{\sum_i (1 - \hat{P}_{1i})(1 - V_i)} \times 100 \text{ percent} \qquad (3.31)$$

where $\hat{P}_{1i}$ and $\hat{P}_{2i}$ are the estimated probabilities of the correct ranking of the ith farm plan for the sample MAD and variance respectively and V_i is the ith variance ratio as a weight in the MAD model.

Consumer Sector

In aggregate models of the consuming sector, it is convenient to assume that there are n individuals with similar taste and preferences. Each individual has a utility function which is concave and is the function of various goods and services consumed, i.e.,

$$u_n = u_n(q_{n1}, q_{n2}, \ldots, q_{nJ}), \quad n = 1,2, \ldots, N \qquad (3.32)$$

where u_n is the utility of individual n and q_{nj} ($j = 1,2, \ldots, J$) is the jth commodity or service consumed by individual n. q_{nj} is, of course, a function of the price of commodity j, prices of all other commodities or services, and income associated with individual n, i.e.,

$$q_{nj} = q_{nj}(P_j, P_o, M_n) \qquad o = 1,2, \ldots, O \qquad (3.33)$$

Total demand for commodity j is given by:

$$Q_j = \sum_{n=1}^{N} q_{nj}(P_j, P_o, M_n) \qquad (3.34)$$

Individual n then maximizes his utility subject to his budget constraint, i.e.,

$$\max \quad u_n = (q_{n1}, \ldots, q_{nj}) \qquad (3.35)$$

subject to:

$$P_1 q_{n1} + P_2 q_{n2} + \ldots P_j q_{nj} = M_n \qquad (3.36)$$

The Lagrangian equation is:

$$L = u_n(q_{n1}, \ldots, q_{nj}) + \mu[M_n - (P_1 q_{n1} + P_2 q_{n2} + \ldots P_j q_{nj})] \qquad (3.37)$$

The necessary conditions for utility maximization require that:

$$\partial L/\partial q_{nj} = \partial u_n/\partial q_{nj} - \mu P_j = 0 \qquad (3.38)$$

$$\partial L/\partial \mu = \sum_{j=1}^{J} P_j q_{nj} = M_n \qquad (3.39)$$

and the associated sufficient conditions will be fulfilled if the Bordered Hessian is either negative definite or negative semi-definite.

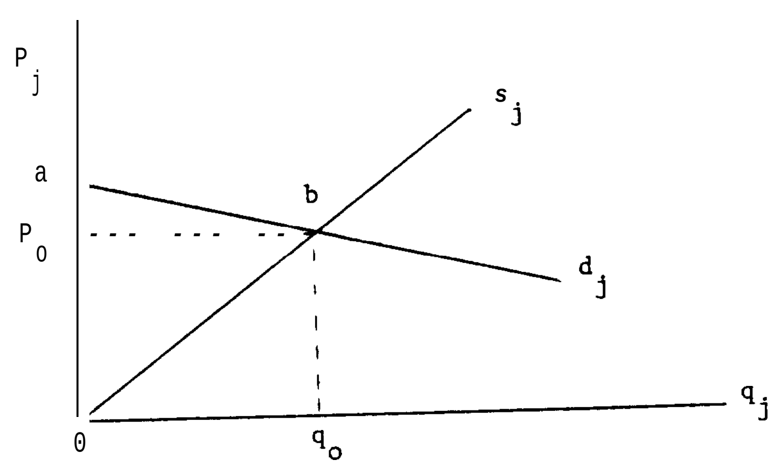
With changes in price due to effects of air pollution on crop production, individual n's demand function will change. If there is no change in his income level (i.e., uncompensated in the case of price increase or taxed in the case of price decrease), his level of well-being will be altered. This alteration of consumer welfare may then be approximated by changes in "consumer's surplus" which will be introduced in the next section.

Consumer's and Producer's Surpluses

Of the three concepts of economic rent the Marshallian concept of consumer's and producer's surpluses is most applicable if one assumes that all other prices and incomes of all individuals concerned are constant. Let:

$$P_j = F(q_j, \theta_j) \qquad (3.40)$$

be the demand function of commodity j denoted by d_j in the following diagram where P_j and q_j are the price and quantity respectively. θ_j is the shift parameter denoting changes in Price of commodity j due to, say, changes in total supply arising from air pollution. It is assumed that the demand curve, d_j, is downward sloping.



Let the supply function of commodity j be represented by:

$$P_j = G(q_j, \theta_j) \tag{3.41}$$

The supply curve, s_j, is assumed to be upward sloping. It starts from the origin under the assumption that farmers will not supply any of commodity j if its price is zero. ● 'Fer simplicity the subscript j will be dropped. Market equilibrium for commodity j, as shown in the above diagram, will be obtained when the quantity supplied and demanded is q_0 and the market price is P_0. Consumerrs surplus is then defined as the area under the demand curve, d_j, and above the equilibrium price, P_0, or the triangle P_0ab. Producer's surplus or net return to factor owners is the area under the equilibrium price but above the supply curve or the triangle OP_0b. The sum of consumer's and producer's surpluses is given by:

$$R(\theta) = \int_0^{q_0} [F(q,\theta) - G(q,\theta)]dq \tag{3.42}$$

$$= Oabq_0 - Obq_0 = Oab \tag{3.43}$$

Frcm the above equation one can compare the value of R associated with different values of 9, e.g., if we let $\theta_0 = \theta(o)$ be the initial situation when there is no air pollution and θ_1 be the situation with some level of air pollution then the difference between $R(\theta_1) - R(o)$ will measure changes in consumer's and producer's surpluses due to increase in level of air pollution.

This method when applied via the mathematical concepts developed earlier in this report is analogous to Samuelson's (1952) "net social payoff" theory in which he relates Enke's formulation [Enke, 1951] to a standard problem in linear programming, the so-called Koopmans-Hitchcock (1941, 1949) minimum transport cost problem. Basically, the Samuelson's net social payoff is defined as the sum of the algebraic area under the excess demand curves of n individuals minus the total transport costs of all shipments [Takayama and Judge, 1964a, 1964b]. The objective is to artificially convert the descriptive price behavior into a maximization problem which can then be solved by using trial and error or a systematic procedure of varying shipments in the direction of increasing social payoff [Takayama and Judge, 1964b, p. 510]. However, in the formulation outlined in this section, quadratic programming can be used to approximate (see the subsequent section on analytical model) such a payoff.

3.3 An Analytical Model for Measuring Impacts of Air Pollution on Agricultural Crops

The conceptual model and mathematical concepts developed earlier in these sections can he used to construct a mathematical programming model capable of achieving some of the goals set forth in this study. This model can be explanded further by incorporating into it some additional concepts such as technical substitution possibilities, endogenous air pollution response functions and risk. The derived model will, it is hoped, present a realistic example of the agricultural sector within the constraints imposed by data limitations. Data requirements are extensive for such programming techniques and some of them, such as quadratic programming, require special computer algorithms. Nevertheless, the incorporated model should be analytically feasible and mathematically tractable. The degree of sophistication will be dependent on the availability of the required data and computer software.

In order to simplify some of the notations given in the earlier sections, matrix notation will be used in the models proposed below. However, all notations will remain as described earlier. It is assumed that air pollution in the specified area adversely affects crop production, and, consequently, may affect producers and consumers. Mathematically, the objective of the model is to maximize a "quasi-net social payoff" which is defined as the summation of consumers' and producers' surpluses and subject to certain constraints, i.e.,

$$\text{Max} \quad QNSP = C^T Q + 1/2\, Q^T D Q - E^T Q \tag{3.44}$$

subject to:

$$AQ \leq b \tag{3.45}$$

$$Q \geq 0 \tag{3.46}$$

where

QNSP = quasi-net social payoff (a scaler).
Q = jxl column vector of agricultural crop production, where production equals yield per acre times acreage planted.
c = jxl column vector of constants (intercepts in a linear demand structure).
D = jxj negative diagonal matrix (negative definite of coefficients representing slope values with the linear demand structure).
E = jxl column vector of unit cost of production.
A = gxj technology matrix relating units of inputs to one unit of output (g constraints and j variables).
b = gxl column vector of fixed inputs (land, water).
and T denotes matrix transportation.

The summation of the first two terms on the right-hand side of equation (3.44) is the total revenue for commodities Q. When integrated it represents the area under the demand curve but shove the horizontal axis from the origin to the equilibrium amount demanded. The last term in the right-hand side of equation (3.44) is the total cost of production whose first-order derivative is the marginal cost. The rising portion of the marginal cost curve can then be treated as the short-run supply curve. Therefore, total cost of production can be considered as the returns to factor owners. The difference between the sum of the first two terms and the third term is the sum of producers' and consumers' surpluses over all commodities. It is equivalent to the quasi-net social payoff. Maximizing the objective function is analogous to maximizing a quadratic "quasi-net social payoff" subject to linear constraints.

The above price endogenous model can be expressed as a quadratic programming economic model. Such a model formulation will result in solution values for price and quantity of each commodity which maximize the value of QNSP.

In order to assess the impacts of air pollution upon agricultural crops, one may either introduce a variable, $Z^*_j (0 \leq Z^*_j \leq 1)$, defined as an index of crop yield reduction (% of yield reduction divided by 100) associated with crop j , into the production function (yield) or the cost function. If Z^*_j enters directly into the production function, it may affect crop yield but not necessarily total cost. Alternatively, Z^*_j may be treated through the cost function as an investment in ameliorating air pollution effects on agricultural crops by means of either increasing use of other variable inputs or relocating the site of production. The former involves the problem of technical substitution possibilities. For example, can fertilizer application rates be increased to partially offset the negative impact of air pollution? The latter can be achieved by comparing two neighboring areas, one with and the other without air pollution, using the same technique of measuring crop yield for same type(s) of crop(s). If total yield in the area with air pollution is lower than yields in adjacent areas, (keeping all other factors constant) one might suspect that such a reduction in yield is caused by air pollution. Thus, it might be possible to compare cost of relocation vs. investment in air pollution abatement.

Consider the case when Z^*_j enters directly into the production function. If one lets Z_j represent air pollution concentration, in parts per hundred million, associated with agricultural crop j, Z_j can then be calculated, by using the formulas given by Larsen and Heck (1976), Oshima (1975), Oshima, et. al. (1976, 1977) or others. Applying this method to all other crops under study will provide a vector of Z* which is a jxl column vector for j crops. Then calculate total production of each crop by the following formula:

$$Q^* = (I - Z^*)L^T Y \qquad (3.47)$$

where

Q^* = jxl column vector of total production of j crops with air pollution.
Z^* = jxl column vector of yield reduction index.
I = jxl vector of unity.
L = jxl column vector of acre of land used for cultivating j crops.
Y = jxl column vector of yield of j crops.

The model given under equations (.3.44) through (.3.46) will then be modified to be:

$$\text{Max} \quad QNSP = C^T Q^* + 1/2\, Q^{*T} D Q^* - E^T Q^* \qquad (3.48)$$

subject to:

$$AQ \leq b \tag{3.53}$$

$$Q \geq 0 \tag{3.54}$$

As mentioned earlier, agricultural production involves various degrees of uncertainty. If farmers are assumed risk averse then their production decisions will reflect the uncertainty of climatological conditions for the coming season, and hence the total quantity supplied, and thus prices in the next season. Thus, production risks are multiplicative in nature, meaning that it is the slope of the supply curve which contains the important stochastics [Hazell and Scandizzo, 1975, p. 641]. Therefore, the traditional method of treating the risky component of supply as a constant added to the intercept term may not be appropriate. Hazell and Scandizzo (1974) use linear programming models with multiplicative supply function. Other methods frequently used in the empirical supply analysis are the econometric estimation of constant elasticity of substitution and Cobb-Douglas functions.

Another method that is widely used in farm management is the EV criterion described earlier. The analytical model may be further modified to be the following form:

$$\text{Max} \quad QNSP = C^T Q^* + 1/2\, Q^{*T} D Q^* - E^T Q^* - \lambda (Q^{*T} \Omega Q^*) \tag{3.55}$$

subject to:

$$AQ^* \leq b \tag{3.56}$$

$$Q^* \geq 0 \tag{3.57}$$

where

λ = a constant value of risk aversion coefficient.

Ω = jxj matrix of variance-covariance of income associated with each type of crop.

if Z* enters only into the yield function.

If Z* enters directly into the cost function, then the formulation becomes:

$$\text{Max} \quad QNSP = C^T Q + 1/2\, Q^T D Q - E^{*T} Q - \lambda (Q^T \Omega Q) \tag{3.58}$$

subject to:

$$AQ \leq b \tag{3.59}$$

$$Q \geq 0 \tag{3.60}$$

Thus, the quasi-net social payoff will be lower for higher values of the risk aversion coefficient given no change in income and vice versa. In the above formulations all hut λ can be observed. However, the values of λ can be as-signed arbitrarily or can also be estimated by using the method suggested earlier.

CHAPTER IV

AIR POLLUTION YIELD RESPONSE RELATIONSHIPS

4.1 Introduction

Effects of air pollution on agricultural crops, such as vegetables and field crops, have been well documented, as discussed in Chapter II. Although results obtained by various researchers are mixed, depending in part upon different methodologies and varieties of crops chosen for each study, the effects on some vegetable crops appear to be particularly acute. Controlled experiments performed in laboratories and greenhouse tests tend to indicate consistent adversary effects of air pollution on crop yield. However, similar results may not always be obtained in actual field tests due to the fact that various factors such as climatological conditions are either difficult or impossible to control and are capable of moderating impacts of air pollution on yield. Given the importance of selected vegetable and field crops to the agricultural sector of the study region and the significant share of the national market held by the region, the relationship between ozone and vegetable yields is a critical component of this analysis.

This chapter discusses the development of a set of yield-ozone relationships for the study area in general and the four production regions in particular. These relationships are derived from research discussed in Chapter 11 and some specific concepts presented in this chapter. The following subsection presents a hypothetical relationship between air pollution and yield. A quantitative relationship is obtained by using methods which will be more fully described in another subsection. The last subsection in this chapter provides estimated yield effects by crop and production region.

4.2 A Hypothetical Relationship Between Air Pollution and Yield

Most studies concerning the effects of air pollution on agricultural crops concentrate largely on physical damages such as leaf-drop and growth retardation of plants. Analyses of the specific relationship between air pollution concentration levels and yield reduction have been limited. Obviously, such a relationship is important in economic analysis of the impact of air pollution, given the need to directly estimate a market value or loss associated with air pollution.

Based on research discussed above, one may hypothesize that a negative relationship exists between ozone concentration and crop yields. A simple method for testing such a relationship is to examine the correlation coefficient between the level of air pollution and yield over a certain period of time for each crop. Again, one would hypothesize that cet. par. an increase in the level of air pollution concentration will lower yield. In other words the correlation coefficient between air pollution and yield should be negative. Further, the higher the coefficient the greater is the degree of relationship between air pollution and the crop, assuming the relationship is statistically significant.

To obtain correlation coefficients for the entire set of crops and regions, data on yield per acre for the 12 vegetable and 2 field crops were collected, covering the period from 1957 to 1976 for each county in the 4 major vegetable growing regions.1/ The yield per acre was then correlated against the maximum level of oxidant/ozone concentration taken from the publication "California Air Quality Data" for each county for the same period. However, due to a lack of complete data on ozone concentration and crop yields, only three counties (Orange, Riverside and Kern) and some crops were included in the correlation analysis. Orange and Riverside counties represent an area of more severe air pollution, whereas Kern County, a major agricultural county, was selected to represent an area of relatively low ozone concentration. The correlation coefficients between air pollution concentration (annual maximum level of oxidant/ozone concentration in parts per hundred million) and yield for these three counties are given in Table 4.1.

The correlation coefficients presented in Table 4.1 tend to conform to a priori expectations; that is, most of the coefficients have the expected sign although not all are statistically significant. This tends to suggest that air pollution in these areas has had some adverse effects on yield. However, correlation analysis does not imply causality, thus these results only lend support to the earlier supposition concerning yield and air pollution.

In order to further test the effects of air pollution on yield a simple production function relationship between yield per acre, the hourly maximum of oxidant/ozone concentrations and the crop acreage harvested for the three counties from 1957 to 1976 was estimated for some crops. The relationship was estimated via ordinary least squares, assuming a linear functional relationship. The production relationship was first estimated as strictly a function of ozone concentration, then acreage only and finally as a function of both variables.

Results obtained, as shown in Tables 4.2a, 4.2b, and 4.2c were generally not statistically significant, although the estimated coefficients for ozone had the expected negative sign in most equations. The coefficients of determination ($\bar{R}^2$) are very low with insignificant F-statistics. The Durbin-Watson in some equations are inconclusive. This means that variations in crop yield per acre can only be slightly explained by changes in the levels of oxidant/ozone concentration. As expected, the multiple regression had slightly higher levels of significance than the simple regressions.

4.3 Methods of Estimating Effects of Air Pollution Concentration on Yield

Earlier analysis suggests that air pollution (ozone) does indeed have a negative effect on yield. In order to estimate more precisely the effect of air pollution on yield, the Larsen and Heck and the Oshima equations as

Table 4.1

Correlation Values between Level of Oxidant and Yield

Crops	Oxidant, average of hourly maximum (pphm)		
	Orange County	Riverside County	Kern County
Beans, Lima	-0.13626	0.05014	
Cantaloupes		-0.23151*	-0.16470*
Carrots		0.42106*	-0.33044*
Cauliflower	0.62585*		
Celery	-0.29654*		
Lettuce	-0.19098*	0.10914	
Onion, Green		0.01628	
Potatoes		0.01481	-0.3933?*
Tomatoes, Fresh	-0.13500	-0.28838*	
Tomatoes, Process	-0.30188*		
Cotton		-0.23089*	-0.05636
Sugarbeets		0.19790*	-0.30327*

*Denotes those coefficients significant at the 20% level.

Table 4.2a

Regression Coefficients for Selected Crops, Orange County, 1957-76

Dependent Variables	Constant	Independent Variables: Oxidant (pphm) Est. Coef.	Oxidant (pphm) T-Value	Acreage Est. Coef.	Acreage T-Value	Summary Statistics: $\bar{R}^2$	F	DW
Beans, Lima Yield (Tons/acre)	4.614	-0.0187	-0.58			0.0186	0.34	0.59
	5.018			-0.0012	-1.38	0.0954	1.90	0.72
	5.159	-0.0052	-0.15	-0.0011	-1.21	0.0966	0.91	0.71
Cauliflower Yield (CWT/acre)	144.119	2.1054	3.40			0.3917	11.59	1.51
	235.003			-0.0150	-0.77	0.0321	0.60	1.37
	155.092	2.0625	3.24	-0.0087	-0.55	0.4023	5.72	1.53
Celery Yield (CWT/acre)	589.803	-1.6592	-1.32			0.0879	1.74	1.00
	499.655			0.0189	0.03	0.0299	0.55	1.05
	557.367	-1.7191	-1.35	0.0208	0.84	0.1240	1.20	1.14
Lettuce, Head Yield (CWT/acre)	295.236	-1.2048	-0.83			0.0365	0.68	0.88
	231.671			0.0325	1.18	0.0713	1.38	0.74
	283.851	-1.5784	-1.09	0.0383	1.37	0.1317	1.29	0.99
Tomato, Fresh yield (CWT/acre)	524.710	-1.5756	-0.58			0.0182	0.33	1.25
	740.489			-0.4807	-4.78	0.5592	22.84	1.15
	744.570	-0.1349	-0.07	-0.4794	-4.57	0.5594	10.79	1.15
Tomatoe, Processing Yield (Tons/acre)	24.838	-0.1205	-1.34			0.0911	1.80	1.26
	19.928			0.0002	0.22	0.0028	0.05	0.89
	24.085	-0.1215	-1.32	0.0003	0,28	0.0953	0.90	1.25

Table 4.2b

Regression Coefficients for Selected Crops, Riverside County, 1957-76

Dependent Variables	Constant	Independent Variables				$\bar{R}^2$	F	DW
		Oxidant (pphm)		Acreage				
		Eet. Coef.	T-Value	Est. Coef.	T-Valu			
Beans, Green Lima Yield (Tone/acre)	2.4161	0.0159	0.21			0.0025	0.0454	2.30
	5.0358			-0.0078	-1.65	0.1320	2.74	2.42
	5.6386	-0.0126	-0.17	-0.0080	-1.60	0.1335	1.31	2.49
Cantalope Yield (CWT/acre)	164.457	-0.5960	-1.01			0.0536	1.02	1.56
	163.975			-0.0069	-3.13	0.3529	9.82	2.03
	213.048	-1.0226	-2.2s	-0.0080	-3.91	0.5016	8.55	2.53
Carrots Yield (CWT/acre)	122,741	3.6983	1.97			0.1773	3.88	1.62
	212.491			0.0137	1.92	0.1706	3.70	1.07
	45.298	3.7706	2.20	0.0140	2.16	0.3548	4.67	1.95
Lettuce, Head Yield (CWT/acre)	185.394	0.4628	0.47			0.0119	0.22	1.18
	211.929			-0.0009	-0.13	0.0009	0.02	1.16
	189.710	0.4541	0.44	-0,0006	-0.08	0.0123	0.11	1.16
Onion, Green Yield (CWT/acre)	251.105	0.1616	0.07			0.0003	0.01	0.56
	119.844			0.1657	7.03	0.7330	49.41	2.00
	110.930	0.2024	0.16	0.1657	6.84	0.7334	23.38	2.02
Potatoes Yield (CWT/acre)	270.514	0.0575	0.06			0.0002	0.01	1.06
	332.465			-0.0061	-3.27	0.3728	0.70	1.74
	366.201	-0.6614	-0.87	-0.0066	-3.36	0.3995	5.66	1.91
Tomato, Fresh Yield (CWT/acre)	340.654	-2.6267	-1.28			0.0832	1.63	1.10
	162.343			0.1470	4.62	0.5430	21.38	2.18
	195.421	-0.7081	-0.46	0.1424	4.19	0.5485	10.32	2.12
Cotton Yield (lbs/acre)	316.92	-5.9587	-1.01			0.0533	1.01	1.65
	478.02			0.0310	3.02	0.3362	9.12	1.58
	392.62	1.3758	0.24	0.0323	2.71	0.3384	4.35	1.56
Sugarbeets Yield (Tons/acre)	16.1126	0.1604	0.86			0.0392	0.73	1.63
	22.3874	-		0.0003	0.36	0.0072	0.13	1.58
	16.1528	0.1579	0.75	0.00003	0.03	0.0392	0.35	1.64

Table 4.2c

Regression Coefficients for Selected Crops, Kern County, 1957-76

		Independent Variables						
		Oxidant (pphm)		Acreage				
Dependent Variable	Constant	Est. Coef.	T-Value	Est. Coef.	T-Value	$\bar{R}^2$	F	DW
Cantalope Yield (CWT/acre)	189.936	-1.2713	-0.71			0.0271	0.50	1.91
	225.148			-0.0149	-1.63	0.1290	2.67	1.97
	247.578	-1.2876	-0.75	-0.0149	-1.62	0.1568	1.58	2.14
Carrots Yield (CWT/acre)	415.033	-4.9290	-1.49			0.1092	2.21	1.43
	303.150			0.0067	1.45	0.1050	2.11	1.36
	370.558	-3.3722	-0.88	0.0044	0.83	0.1439	1.43	1.44
Potato Yield (CWT/acre)	396.505	-3.9781	-1.82			0.1547	3.30	0.73
	515.002			-0.0042	-4.44	0.5225	19.70	0.94
	518.229	-0.6357	-0.33	-0.0040	-3.65	0.5255	9.42	0.94
Cotton Yield (lbs/acre)	1122.86	-1.5612	-0.24			0.0032	0.06	1.02
	1146.15			-0.0002	-0.35	0.0069	0.13	1.08
	1189.35	-2.0374	-0.30	-0.0003	-0.39	0.0121	0.10	1.03
Sugarbeets Yield (Tons/acre)	25.827	-0.1965	-1.35			0.0920	1.82	0.82
	19.102			0.0002	2.40	0.2428	5.77	1.03
	19.823	-0.0314	-0.19	0.0002	1.85	0.2445	2.75	1.03

described in Section 4.2 are used. The Larsen and Heck relationships measure percentage leaf damage associated with different levels of air pollution concentration (ozone) and hours of exposure. They thus take into account the intuitively obvious fact that leaf damages may be more serious if a given plant is exposed to either higher levels of air pollution or a constant level for longer duration. There is one difficulty attendant to the use of the Larsen and Heck relationship, that being leaf damage may not correspond to yield reduction, especially for fruit or root crops. Thus, certain adjustments must then be made to translate leaf damage to yield reduction. Based on empirical results reported by Millecan, a general "rule-of-thumb" can be used to relate leaf damage to percentage of yield reduction. These translations are presented in Table 4.3.

An additional problem concerning the use of the Larsen and Heck methodology is that only a limited set of equations has been estimated. Of these, very few correspond to the set of crops included in the study. To circumvent this problem certain equations have been selected from the Larsen and Heck set to serve as "proxies" for general classes of crops. This assignment of equations to represent groups of included crops is based on a review of secondary information concerning degree of susceptibility of each plant or plant group to air pollution to establish some consistency of response. The representative crop equations used in this study are presented below.

Larsen and Heck equation		Study Crops
1. Pinto Beans	approximates	Green Lima Beans Celery (times 0.8)
2. Radish	"	Onion, Fresh (times 1.2) Onion, Processing (times 1.2) Sugarbeets
3. Spinach	"	Head Lettuce (times 0.6)
4. Summer Squash	"	Broccoli Cantaloupes Carrots Cauliflower
5. Tomato	"	Tomato, Fresh Tomato, Processing Potato

After the selection of a specific equation to serve as a proxy for a particular study crop, a table of leaf damage (percent) associated with actual levels of air pollution concentration (ozone) as measured at representative air monitoring stations for each county and hours of exposure (8, 10, 12 hours) are calculated. For the purposes of this study, the level of air pollution concentration is classified into three categories: (1) Air pollution concentration level A represents the annual hourly maximum recorded at the county monitoring station. It is thus the highest level of oxidant/ozone concentration in each year; (2) Level B is the annual average

Table 4.3

A "Rule-of-Thumb"* Relating Leaf Damage to Yield Reduction

% of Leaf Damage						% of Yield Reduction				
1	2	3	4	5	corresponds to	0	0.1	0.4	0.8	1.0
6	7	8	9	10		1.1	1.2	1.5	1.7	2.0
11	12	13	14	15		2.3	2.7	3.0	3.5	4.0
16	17	18	19	20		4.5	5.1	6.0	7.0	8.0
21	22	23	24	25		9.0	10.1	11.2	12.5	14.0
26	27	28	29	30		15.0	16.0	17.0	18.0	19.0
31	32	33	34	35		19.9	20.9	21.7	22.5	23.0
36	37	38	39	40		23.8	24.7	25.5	26.3	27.0
41	42	43	44	45		27.6	28.2	28.8	29.4	30.0
46	47	48	49	50		30.6	31.2	31.7	32.3	33.0
51	52	53	54	55		33.6	34.2	34.8	35.4	36.0
56	57	58	59	60		36.6	37.2	37.8	38.4	39.0

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*It should be noted that Millecan's "rule-of-thumb," as cited, applies only to 20% leaf damage. For damage in excess of 20%, yield reduction was derived from secondary sources concerning general crop sensitivity as well as information relating to yield reduction at high levels of physical damage.

of the hourly maximum;2/ (3) Level C is the annual average of the average hourly maximum.3/ Table 4.4 contains the levels of oxidant/ozone concentration by station and region for the period 1972 to 1976 and the average of that period classified according to the three levels mentioned above.

The second type of equation used in the yield response analysis is that developed by Oshima, et. al. This equational structure is used to measure yield reductions in cotton, California's major field crop. The Oshima, et. al. equations, unlike those of Larsen and Heck, relate ozone doses directly to percentage of yield reduction. To date, this type of equation has been estimated for only three crops; alfalfa, cotton and tomato. In order to obtain an estimated percentage yield reduction, a cumulative ozone dose greater than 10 parts per hundred million (the required California standard) over the growing season in each year for each county is needed. Such data for 1976 were not available at the time of this study. However, the cumulative dose can be calculated for alternative levels (e.g., 8 and 20 parts per hundred million). The 8 pphm level was selected for use, with levels measured at air monitoring stations in or close to the growing regions for cotton. The stations include Indio-Oasis for Riverside and San Bernardino Counties; half the level of ozone doses observed in Indio-Oasis for Imperial County;4/ and Delano for Kern and Tulare Counties. The cumulative ozone dose is obtained by adding up total doses exceeding 8 pphm from March to September 1976 (representing the growing season) for each station, as reported in Table 1 in "California Air Quality Data, Summary of 1976 Air Quality Data Gaseous Pollutants." The average value of yield reduction across county is then used for each region producing cotton.

4.4 Estimated Results of Yield Reduction Due to Air Pollution

From the three levels of concentration in Table 4.4, concentration level C was selected for use in estimating the degree of yield reduction to be used in the study. Such a level is the most conservative level of the three, thus perhaps representing a lower bound on yield damage. In the South Coast region, the Pasadena, Anaheim, Indio-Oasis, San Bernardino, Santa Maria, San Diego, and Ventura air monitoring stations are used to calculate air pollution concentration for their respective counties. The Monterey station in the Central Coast was eliminated, as was the Bakerfield station in the Southern San Joaquin Valley on the assumption that levels at these stations are not representative of the levels in the actual growing areas.

In calculating the effect of air pollution on yield, two values of air pollution concentration (both representing level "C") are used. One is the average of 1972-1976 and the other is the 1976 level (for level C). The estimated yield reduction for a 12 hour exposure for the study crops is given in Tables 4.5 and 4.6. Table 4.7 is the average percentage of yield reduction across county in each region attributed to the presence of air pollution. Table 4.8 gives the actual yield per acre for the average of 1972-1976 and the 1976 crop year derived from Tables 1.2, 1.3 and 1.4 of Chapter 1. These yield figures thus represent actual yields, i.e., yields in the presence of air pollution. Finally, Table 4.7 is used to estimate Table 4.9, the production or yield per acre in the absence of air pollution

Table 4.4

Levels of Oxidant/Ozone Concentration (pphm)

Area/Station	County	Level A 72	73	74	75	76	Av.	Level B 72	73	74	75	76	Av.	Level C 72	73	74	75	76	Av.
Imperial Valley																			
El Centro	Imperial			17	13	8	13			11	9	6	7			6	6	3	5
South Coast																			
Downtown	Los Angeles	25	52	25	25	34	32	18	20	17	18	22	19	7	7	8	8	8	8
Pasadena	Los Angeles	38	45	34	32	34	36	23	23	24	22	24	23	10	10"	11	10	11	10
Anaheim	Orange	35	32	25	17	30	28	18	19	16	13	16	16	5	6	6	5	6	6
Riverside-Robidourr	Riverside	50	39	39	35	36	40	21	24	26	24	23	25	12	11	13	10	10	11
Indio-Oasis	Riverside	25	22	22	20	16	21	16	18	14	12	11	14	8	7	7	7	6	7
San Bernardino	San Bernardino	42	42	33	38	30	37	18	22	22	22	16	20	8	11	9	10	7	9
Santa Barbara	Santa Barbara	13	24	21	25	17	20	9	13	12	12	10	11	4	6	6	6	5	4
Santa Maria	Santa Barbara	15	13	15	6	12	12	8	7	7	5	9	7	4	4	4	3	5	4
San Diego	San Diego	17	2f,	18	15	16	18	12	11	12	11	13	12	4	5	6	6	6	5
Ventura-Telegraph Rd.	Ventura			20	16	19	18			14	11	13	13			7	5	5	6
Central Coast																			
Monterey	Monterey	11	14	14	8	7	11	7	9	7	6	5	7	3	4	4	3	3	3
Salinas	Monterey	9	15	12	8	11	11	7	9	8	5	6	7	4	4	4	3	4	4
Holliston	San Benito		13	14	13	15	14		10	10	9	9	10		5	5	5	5	5
San Luis Obispo	San Luis Obispo	12	11	15	11	11	12	8	8	9	7	8	8	4	4	5	4	4	4
Southern San Joaquin																			
Bakersfield	Kern	18	17	17	12	12	15	10	11	12	8	8	10	6	6	7	5	5	6
Delano	Kern				12	11	11				10	10	10				4	6	5
Visalia-Old Jail	Tulare	20	19	20	13	13	17	13	11	12	10	10	11	7	J	8	5	5	6

A - Maximum value for the year. It is the maximum of the month and also the maximum of each day. It is obtained by first obtaining the hourly maximum for each day (24 values) then pick the maximum to represent the maximum for each day and pick the maximum to represent each month (12 values). Then pick the maximum to represent each year (5 values) and the average over a 5-year period.

B = Average of the maximum of hourly max. It is obtained by the same procedure as In A but the final value for each year is obtained by averaging the monthly maximum and then the average over a 5-year period.

C = Average of the average of hourly maximum. It is obtained by averaging the average of the hourly-maximum. Then average over a 5-year period.

Table 4.5

Percentage Yield Reduction for 12 Hour Exposure,
Using the Average Value of Oxidant/Ozone
Concentration from 1972-1976, "C" Level

Region/Station	County	Oxidant/Ozone Concentration (pphm)	Crop											
			Green Lima Beans	Broccoli	Cantalopes	Carrot	Cauliflower	Celery	Head Lettuce	Onions	Potato	Tomato	Cotton	Sugarbeets
Imperial														
El Centro	Imperial	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	9.4	0.8
South Coast														
Pasadena	Los Angeles	10	49.9	a	o	0	0	39.9	1.1	23.9	34.3	34.3	-	19.9
Anaheim	Orange	6	15.8	0	C	o	o	12.6	0	1.7	2.8	2.8	-	1.4
Indio-Oasis	Riverside	1	28.2	0	0	0	0	22.6	0.1	3.4	9.4	9.4	18.7	2.6
San Bernardino	San Bernardino	9	45.0	Q	o	o	0	36.0	0.7	15.8	28.2	28.2	18.7	13.2
Santa Maria	Santa Barbara	4	0.8	0	0	o	0	0.6	0	0.1	0.1	0.1	-	0.1
San Diego	San Diego	5	3.1	o	o	0	0	2.s	o	1.0	1.1	1.1	-	0.8
Ventura-Telegraph Rd.	Ventura	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	-	1.4
Central Coast														
Salinas	Monterey	4	0.8	0	0	0	0	0.6	0	0.1	0. I	0.1	-	0.1
Hollister	San Benito	5	3.1	0	0	0	0	2.5	o	1.0	1.1	1.1	-	0.8
San Luis Obispo	San Luis Obispo	4	0.8	0	0	o	0	0.6	0	0.1	0.1	0.1	-	0.1
Southern San Joaquin														
Delano	Kern	S	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	6.9	0.8
Visalia-Old Jail	Tulare	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	6.9	1.4

Table 4.6

Percentage Yield Reduction for 12 Hour Exposure.
Using the "C" Level of Oxidant/Ozone Concentration for 1976

Region/Station	County	Oxidant/Ozone Concentration (pphm)	Crop											
			Green Lima Beans	Broccoli	Cantalopes	Carrots	Cauliflower	Celery	Head Lettuce	Onion	Potato	Tomato	Cotton	Sugarbeets
Imperial														
El Centro	Imperial	3	0	0	0	0	0	0	0	0	0	0	9.4	0
South Coast														
Pasadena	Los Angeles	7	?8.2	o	0	0	0	22.6	0. i	3.4	9.4	9.4	·	2.8
Anaheim	Orange	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8		1.4
Indio-Oasis	Riverside	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	18.7	1.4
San Bernardino	San Bernardino	7	28.2	0	0	0	0	22.6	0.1	3.4	9.4	9.4	18.7	2.8
Santa Maria	Santa Barbara	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1		0.8
San Diego	San Diego	6	1$.8	0	0	0	0	12.6	0	1.7	2.8	2.8		1.4
Ventura-Telegraph Rd.	Ventura	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1		0.5
Central Coast														
Salinas	Monterey	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1		0.1
Hollister	San Benito	J	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1		0.8
San Luis Obispo	San Luis Obispo	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1	·	0.1
Southern San Joaquin														
Daleno	Kern	6	15.8	0	0	0	0	12.6	0	1.1	2.8	2.8	6.9	1.4
Visalia-Old Jail	Tulare	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	6.9	0.8

Note: The Salinas Station is also used for Santa Cruz County.

Table 4.7

Percentage Yield Reduction Averaged Over County, for each Region, by Time Period

Crop	Southern Desert		South Coast		Central Coast		Southern San Joaquin		Total	
	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976
Vegetable Crop										
Beans			22.66	15.71	1.57	1.57	9.45	9.45	11.23	8.91
Broccoli			0	0	0	0			0	0
Cantaloupes	0	0	0	0			0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0
Cauliflower			0	0	0	0			0	0
Celery			18.11	12.57	1.23	1.23			9.67	6.90
Lettuce	0	0	0.27	0.03	0	0	0	0	0.068	0.01
Onion, Fresh	1.00	0	6.80	1.99	0.40	0.40			3.60	0.60
Onion, Process	1.00	0	6.80	1.99	0.40	0.40	1.35	1.35	2.387	0.94
Potato			11.24	4.20	0.43	0.43	1.95	1.95	4.54	2.19
Tomato, Fresh	1.10	0	11.24	4.20	0.43	0.43	1.95	1.95	3.68	1.65
Tomato, Process	1.10	0	11.24	4.20	0.43	0.43	1.95	1.95	3.68	1.65
Field Crop										
Cotton	9.40	9.40	18.70	18.70			6.90	6.90	11.67	11.67
Sugarbeets	0.80	0	5.66	1.63	0.33	0.33	1.10	1.10	1.97	0.77

Table 4.8

Actual Yield Per Acre (in the Presence of Air Pollution)

Crop	Unit	Southern Desert		Southern Coast		Central Coast		Southern San Joaquin		Study Region	
		1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976
Vegetable Crops											
Beans, Green Lima	Tons	·		2.16	2.04	2.23	2,52	2.96	3.00	2.29	2.35
Broccoli	CWT			81.62	83.72	54.09	60.67			57.81	64.12
Cantalopes	CWT	129.57	127.46	139.85	150.42	-		188.12	180.00	145.12	141.72
Carrots	CWT	333.87	402.00	312.12	257.30	292.03	303.12	341.10	350.00	321.86	318.87
Cauliflower	CWT			127.68	114.02	99.28	97.68			108.66	103.43
Celery	CWT			568.65	546.58	561.88	549.73			565.94	547.87
Lettuce, Head	CWT	250.65	266.97	253.57	261.37	265.14	279.14	259.95	292.16	258.73	273.46
Onion, Green	CWT	274.37	208.94	322.54	291.31	302.55	285.45			300.05	258.26
Onion, Dehydrated	CWT	273.04	324.32	318.66	350.00	335.05	314.61	340.03	396.92	323.70	368.70
Potatoes	CWT			319.47	31 5.77	327.12	326.46	275.34	295.11	28a. 50	301.78
Tomato, Fresh	CWT	217.72	217.44	469.96	505.89	307.67	201.29	288.12	199.45	372.81	370.18
Tomato, Process	Tons	'21.66	25.17	24.83	20.34	25.52	19.89	20.29	24.53	22.71	21.64
Field Crops											
Cotton	Lbs	1,144.98	996.48	1,019.12	1,084.84			1,026.16	1,088.10	1,039.19	1,075.95
Sugarbeets	Tons	25.53	25.45	27.86	28.47	32.87	35.55	26.50	28.42	27,08	28.44

Table 4.9

Potential Yield Per Acre (without Air Pollution Effects)

Crop	unit	Southern Desert		Southern Coast		Central Coast		Southern San Joaquin		Study Region	
		1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976
Vegetable Crops											
Beans, Green Lima	Tons			2.65	2.36	2.26	2.S6	3.24	3.28	2.55	2.56
Broccoli	CWT			81.62	83.72	54.09	60.67	- .		57.81	64.12
Cantalopes	CWT	128.57	127.66	139.85	150.42			188.12	180.00	145.12	141.72
Carrots	CWT	333.87	402.00	312.12	257.30	292.03	303.12	341.10	350.00	321.86	318.87
Cauliflower	CWT			127.68	114.02	99.28	97.68			108.66	103.43
Celery	CWT			671.63	615.28	568.79	556.49			620.67	585.67
Lettuce, Head	CWT	250.65	266,97	254.25	261.45	265.14	279.14	259.95	292.16	258.91	273.49
Onion, Green	CWT	277.11	208.94	344.47	297.11	303.76	286. S9			310.85	259.81
Onion, Dehydrated	CWT	275.77	32/,.]2	340.33	356.96	330.39	315.07	344.62	402.28	331.43	370.91
Potatoes	CWT			355.33	329.03	328.53	327.86	280.71	300.86	301.60	308 .39
Tomato, Fresh	CWT	220.11	217.44	522.78	527.14	308.99	202.16	293.74	203.34	386.53	376.29
Tomato, Process	Tons	21.90	25.17	27.62	21.19	25.63	19.98	20.69	25.01	23.55	22.00
Field Crops											
Cotton	Lbs	1,252.55	1,090.15	1,209.70	1,287.70			1,096.97	1,163.18	1,160.46	1,201.51
Sugarbeets	Tons	25.73	25.45	29.44	28.93	32.98	35.67	26.79	28.73	27.61	28.66

Southern Desert includes Imperial County
Southern Coast includes Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, San Diego, rind Ventura Counties
Central Coast includes Monterey, San Benito, San Luis Obispo, and Santa Cruz Counties
Southern San Joaquin Includes Kern and Tulare Counties

Sources: County Agricultural Commissioner Annual Crop Reports effects in the study area. Table 4.9 thus represents the potential or hypothetical yield that could be realized if the negative effects of air pollution were removed from the crop environment.

FOOTNOTES : CHAPTER IV

1/ The counties in each region as well as included crops in this study are discussed in Chapter 1.

2/ See the explanation on these levels at the bottom of Table 4.4.

3/ ibid

4/ El Centro, the monitoring station for Imperial County, typically has approximately one-half the ozone level observed at Indio-Oasis. Hence, the one-half value for cumulative doses.