Journal of Environmental Management (1985) **20**, 321–331

Implications of Environmental Policy for U.S. Agriculture: the Case of Ambient Ozone Standards

Raymond J. Kopp, William J. Vaughan, Michael Hazilla and Richard Carson*

Resources for the Future, 1616 P Street, N.W. Washington, D.C. 20036, U.S.A.

Received 27 *September* 1984, *and in revised form* 12 *March* 1985

Biological experiments have revealed an adverse physical effect of increased photochemical air pollution on agricultural crops, and hence their yields, suggesting potentially serious economic losses. Integrating ozone exposure and crop yield data with farm cost of production information for five major U.S. crops, this paper develops an agricultural economic assessment model. The national monetary welfare effects on agriculture of alternative hypothetical levels of the primary ambient ozone standard are explored with the model. The effect of relaxing the model's restrictive fixed crop mix assumption is demonstrated in a regional setting, and found to be inconsequential. Data and modeling deficiencies are discussed, and the estimates compared with other, more *ad hoc*, approaches.

Keywords: U.S. agriculture, air pollution, ozone concentrations, crop yields, statistical dose–response functions, regional crop production cost, economic assessment of air pollution standards, monetary measures of welfare change.

1. Introduction

The injurious effect of photochemical air pollution, especially ozone, on vegetation was first observed in the U.S.A. in the Los Angeles area in 1944. Since then, both ambient oxidant and controlled (greenhouse or field chamber) studies have revealed the existence of acute and/or chronic oxidant injury to several important agricultural crops. The purpose of this paper is to present monetary estimates of social welfare gain or loss

---

*Quality of the Environment Division, Resources for the Future.

The authors wish to express their appreciation to Thomas Walton, Allen Basala, John Mullahy and Paul Portney for helpful comments at all stages of this research and especially to David Fawcett of USDA for his help in manipulating the Firm Enterprise Data System. This research was supported by the United States Environmental Protection Agency, Office of Air Quality Planning and Standards, under contract No. 68-02-35-82. Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through Contract No. 68-02-35-82 to Resources for the Future, it has not been subject to the Agency's peer and administrative review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

0301–4797/85/040321 + 11 $03.00/0

emanating from the agricultural production sector, as a result of policy actions which lead to changes in rural U.S. concentrations of ozone. The economic assessment model employed to calculate the welfare effects employs biological dose–response information obtained from controlled experiments conducted by the National Crop Loss Assessment Network, and a simple yet extraordinarily detailed microeconomic model of producer behavior.

The National Crop Loss Assessment Network (NCLAN) was initiated by the United States Environmental Protection Agency (U.S. EPA) to evaluate the significance of crop losses caused by air pollution. Working through five field sites located across the U.S.A., NCLAN researchers have conducted controlled experiments in an attempt to quantify the relationship between ozone concentration and crop yield (Heck *et al.*, 1981, 1982). To employ such yield relations in an economic model, one must assume that ozone concentrations neutrally displace crop-specific, agricultural production functions. If this assumed ozone neutrality obtains, then a neutral production function shift implies a neutral cost function shift, which determines the shift in agricultural producer supply functions. (A detailed discussion of ozone neutrality and other important concepts touched upon in this paper is found in Kopp *et al.*, 1984). Knowledge of these shifting supply functions in conjunction with demand estimates provides the information necessary to establish a link between the biological relationship of ozone to yield and estimates of the changes in producer and consumer surplus.

In the next section, we briefly discuss the dose–yield equations utilized in the study, referring the reader to Kopp *et al.* (1984) for a more complete discussion. The economic assessment model is presented in Section 3, and the underlying agricultural cost and production data are reviewed in Section 4. Section 5 presents estimates of welfare gain or loss associated with six hypothetical ozone regulatory standards. In Section 5, we relax the assumption of a fixed crop mix and develop an assessment model in which crop mix is an endogenous variable responding to changes in ozone concentrations. Section 6 presents some concluding remarks.

2. Dose–yield equations

Explicit dose–yield functions for several major field crops grown in the U.S.A. are available in Heck *et al.* (1982). However, for the majority of crops reported, linear or plateau linear functions were estimated without *a priori* theoretical justification and only minimal statistical analysis of functional specification. Using summary data from the experiments as reported by Heck *et al.*, we have estimated a more general specification for the dose–yield relationship for each of five crops: soybeans, corn, wheat, cotton and peanuts. The functional specification is Box–Tidwell (see Box and Tidwell, 1962) and its general form is

$$Y = b_0 + b_1 X^{\lambda} + \varepsilon, \tag{1}$$

where Y is a measure of crop yield, X is 7 hour (09·00–16·00 h standard time) seasonal ozone concentration, b_0, b_1 and λ are parameters to be estimated, and ε is a stochastic error term.

The Box–Tidwell has the desirable properties that it is parsimonious in parameters, takes on either a concave or convex shape as $\lambda > 1$ or $\lambda < 1$ (for $b_1 \leqslant 0$), and is linear in the special case when $\lambda = 1$. The undesirable property of equation (1) is its parameter non-linearity, thus necessitating non-linear estimation procedures. Such non-linear procedures are discussed by Kopp *et al.* (1984).

The estimated value of λ indicates that dose–yield functions are concave for soybeans, corn, wheat and peanuts, but convex for cotton. This concavity is suggestive of a threshold ozone effect at concentrations near or below ambient level (approximately 0·045 parts per million), but increased plant sensitivity as concentrations increase.

3. Economic assessment model

The economic assessment model quantifies the change in societal welfare as the change in net consumer and producer surplus. The change in this surplus is due to changes in ambient ozone concentrations which bring about a shift in agricultural production functions, and thereby a shift in producer supply functions. Throughout the analysis, we assume that factor prices remain constant while the equilibrium prices and quantities of the crops affected by ozone change.

The cornerstone of the model is the characterization of the crop-specific producer supply functions which, under competitive assumptions, we take to be the crop-specific marginal cost functions. Given the ozone neutrality assumption, derivation of the supply functions and the integration of the dose–yield relations into the functions are straightforward.

Consider, for the moment, a simple agricultural production function for a single crop,

$$Y=f(x). \tag{2}$$

Denote the output of this crop Y and let the n-vector x represent inputs. Let e be a scalar measuring ozone concentrations, and $\varphi(e)$ be a function of e. We rewrite equation (2) to permit ozone concentration to affect the production of Y,

$$Y=f[x,\varphi(e)]. \tag{3}$$

If ozone neutrally affects the production function, then equation (3) can be written as

$$Y=f(x)\varphi(e), \tag{4}$$

and the corresponding cost function written as

$$C=[C(P,Y)\varphi(e)], \tag{5}$$

where P is an n-vector of input prices.

Assuming $f(x)$ is characterized by constant returns to scale, we may draw a two-input unit isoquant for $f(x)$ at two ozone concentrations, e_0 and e_1, where $e_0>e_1$, as shown in Figure 1. The lines PP and P′P′ are isocost lines at constant input prices and the points A^0 and A^1 depict the cost minimizing equilibrium quantities of x_1 and x_2 under the two ozone regimes. From the figure, one can see that neutral shifts in the production function, due to changes in ozone concentrations, imply, in the case of ozone reductions, proportional decreases in all inputs, while leaving the mix of inputs unchanged.

Hypothesized ozone neutrality combined with the assumption of constant factor prices implies that all factor demand equilibria lie on a ray from the origin. Moreover, the ray may be determined from a single observed factor demand equilibrium. As the neutrality of ozone will not induce any factor substitution if factor prices are held constant, the production and cost functions [equations (4) and (5)] may be treated as if they were generated from a linear, fixed input coefficient (Leontief) production process. This construct forms the foundations of our economic assessment model.

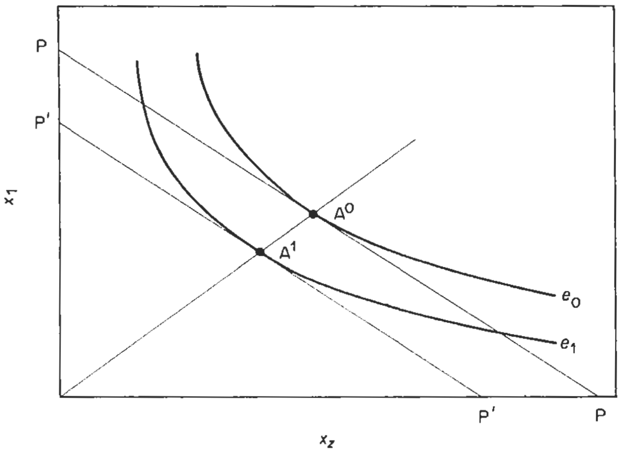

Figure 1. Ozone neutral isoquant shift.

Pursuing the supply function derivation under the Leontief specification, let us consider the producer cost minimization problem. Following Ferguson (1969):

$$\underset{x}{\text{Min:}} \sum_i P_i x_i \tag{6}$$

$$\text{ST: } Y = \min(x_1/a_1, x_2/a_2, \ldots, x_n/a_n),$$

where x_i are the physical quantities of the n productive factors; a_i are technological constants measuring input requirements per unit of output conditioned upon variables such as weather, soil characteristics, ozone concentrations, etc.; Y is the output rate of a single crop; and P_i are the n input prices.

The solution to the above problem implies

$$x_1/a_1 = x_2/a_2 = \ldots = x_n/a_n = Y. \tag{7}$$

The optimal factor demands are

$$x_i = a_i Y, \tag{8}$$

which lead to the minimum cost function

$$C = Y(\sum_i P_i a_i), \tag{9}$$

and the output supply (marginal cost) equation

$$S_Y = \partial C/\partial Y = \textstyle\sum_i P_i a_i. \tag{10}$$

If a change in the set of conditioning variables occurs due to, say, a change in ambient ozone concentrations, the productivity of some or all factor inputs is affected. Analytically, this effect is captured by a change in the technology constants a_i. We represent this productivity effect by an augmentation term ∂, which equals unity under baseline conditions.

$\hat{a}_i = \delta a_i$, for all i, where $0 \leqslant \delta \leqslant 1$ for decreases in ozone concentrations, and $\delta \geqslant 1$ for increases in ozone concentrations. (11)

After a change in environmental conditions, the output supply equation becomes

$$\hat{S}_Y = \sum_i P_i \delta a_{i\cdot} \tag{12}$$

Finally, for any given region, an upper bound on cultivatable acreage exists. This upper bound determines the maximum output Y^* denoted,

$$Y^* = \bar{x}_1 / a_1, \tag{13}$$

where $\bar{x}_1$ is the upper bound on acreage. Given the upper bound on acreage, the region-specific output supply function is perfectly elastic (due to the constant returns to scale assumption of the Leontief technology) up to Y^*, and then becomes perfectly inelastic at Y^*.

Given the productivity augmentation conditions defined by equation (11), maximum producible output is

$$\hat{Y}^* = \bar{x}_1 / \partial a_1 \tag{14}$$

where Y^* is maximum output before the change in ozone, and $\hat{Y}^*$ the maximum output after the change. Employing the dose–yield equations estimated using (1), Y^* and $\hat{Y}^*$ are easily calculated. Solving equation (14) for δ and using equation (13) yields

$$\delta = Y^* / \hat{Y}^* \tag{15}$$

Thus, the dose–yield functions obtained from the biological field experiment data may be incorporated directly into the agricultural supply equations, and thereby determine the supply response to different ambient ozone concentrations.

To perform the welfare calculations, all pre-policy, region-specific, producer supply functions are aggregated to obtain the pre-policy aggregate supply relationship. The aggregate demand relations are drawn from House's (1982) elasticity of demand estimates, in conjunction with assumed demand linearity and zero cross-price effects. Consumer and producer surplus estimates based on the pre-policy supply functions are calculated as the area below the demand curve above the equilibrium price line, and the area above the supply curve below the price line. Post-policy ozone concentrations are then passed as arguments to the dose–yield functions embedded in the regional supply equation, and the post-policy supply equations are, once again, aggregated. Post-policy consumer and producer surplus estimates are used to evaluate the net change in economic welfare from pre- to post-policy.

4. Cost of production data

The economic assessment model described in the previous section relies on regionally specific cost and production information. The regional detail is necessary for several reasons. First, ozone concentrations vary significantly from one area of the country to another. This variation, coupled with the nonlinear nature of the dose–yield equations, implies that any percentage change in ozone concentration will have region-specific welfare effects. Second, as costs of production for specific crops vary by region, any given percentage change in input productivity due to changing ozone concentrations will yield regionally differentiated producer surplus changes. Finally, in many instances, the biological experiments produce relationships between ozone and crop yield that are also region-specific, necessitating regional producer models.

The database containing the requisite production information is the Firm Enterprise

Data System (FEDS), developed and maintained by the United States Department of Agriculture (USDA). Sample operating budgets, which describe the complete cost structure for producing an acre of a particular crop in a specific region of the U.S.A., are provided by FEDS. The budget represents the dominant agricultural practice in the region and is verified with farm level surveys every four years. The Firm Enterprise Data System divides the U.S.A. into over 200 producing areas; thus, when examining the cost of producing wheat, for example, FEDS allows for production cost variation across more than 160 wheat producing areas of the U.S.A. This extremely fine disaggregation of the cost structure of production by region and crop is one of the major strengths of FEDS and permits separate regional estimation of the pre- and post-policy supply functions. Thus, the resulting regional welfare calculations are not subject to regional aggregation biases and permit a detailed analysis of regionally distributed welfare changes.

Each crop- and region-specific pre-policy supply curve in our economic assessment model is based on the technology, factor prices, ozone concentrations and planted acreage prevailing in 1978. Employing the 1978 FEDS data (the latest available data based on actual farm surveys), a producer supply curve segment is constructed for each crop/region combination, leading to 72 producer supply relations for soybeans, 84 for corn, 163 for wheat, 35 for cotton and 12 for peanuts. The horizontal summation of these micro supply curve segments by crop provides a step-function aggregate supply relationship.

5. Welfare calculations

Calculating changes in societal welfare using the economic assessment model described in the preceding sections is relatively straightforward. Our objective is to measure the compensating variation for both the producers and consumers of the crops under study. We use traditional measures of producer and consumer surplus as approximate measures of compensating variation. It is well known that producer surplus (the area above the supply function and below the price line) is equivalent to producer compensating variation; however, consumer surplus measured from a Marshallian demand curve is not equal to compensating variation, unless the income effects are zero. For the purposes of our welfare calculations, we assume that the income effects of the policy change on consumers are negligible.

Table 1 displays welfare estimates on a crop-specific basis for six alternative policy scenarios. Each welfare calculation is measured as the difference in consumer and

TABLE 1. Welfare Gain/Loss in U.S.$ millions (1978)

Standard (ppm)	Agricultural crop				
	Soybeans	Corn	Wheat	Cotton	Peanuts
0·09	529	90	112	225	60
0·10	392	69	79	155	46
0·11	203	38	38	74	25
0·12	0	0	0	0	0
0·13	−226	−47	−41	−80	−27
0·14	−498	−110	−90	−182	−50
0·15	−708	−176	−137	−283	−67

producer surplus between 1978 ambient ozone concentrations (mean 7 hour concentrations during growing season) and the ambient concentrations which would prevail if the current U.S. primary National Ambient Air Quality Standards [0·12 parts per million (ppm), hourly, one expected exceedance per year] were changed.

The policy scenarios considered in this study range from 0·09 ppm (hourly, one expected exceedance per year) to 0·15 ppm, but we hasten to point out that these are not the concentrations that would prevail in the major agricultural production regions. Ozone standards are to be met at monitoring sites which are predominantly urban, and thus a mechanism must be established which determines likely rural seasonal 7 hour mean ozone concentrations from urban one hour concentrations prevailing under alternative standards. Ideally, one would calculate the degree of regional compliance with the alternative standards, thereby determining the most likely average monthly urban concentrations.

For the purpose of this paper, we make some simplifying assumptions regarding compliance and dispersion. Specifically, we assume that the hourly ozone concentrations at monitoring sites are just equal to the value of the standard, and that a linear dispersion model may be used to determine rural 7 hour seasonal mean concentrations. The dispersion model is shown below.

$$O_3^i = a_i^j + b_i^j \, O_3^j, \tag{16}$$

where O_3^i = the hourly ozone concentration in rural area i; a_i^j, b_i^j are dispersion model parameters which map concentrations at urban monitor j to rural area i, and O_3^j is the 7 hour seasonal mean ozone concentration at urban monitor j.

The dispersion model parameters are estimated from 1978 county level ozone concentrations supplied by the U.S. EPA.

Table 1 is self-explanatory, but it is useful to consider a single calculation in more detail. For example, the assessment model estimates the increase in welfare brought about by a tightening of the standard to 0·09 ppm at $90 million, due to the beneficial effect on corn production alone. Without any economic adjustments, the biological relations between ozone and corn yield suggest that an additional 52 million bushels of corn could be raised under the new standard. If one employed an *ad hoc* valuation rule to this yield increase, e.g. evaluating the bushels by the pre-policy market price (see Jacobson and Millen, 1982), which in 1978 was approximately $3·30 per bushel, one would arrive at a welfare gain of approximately $172 million, compared to our estimate of $90 million.

The difference between the *ad hoc* methodology and ours is that the former neglects both the change in market price due to demand–supply interactions and changes in production cost. Our assessment model suggests that the additional bushels could only clear the market at $3·05 per bushel, not $3·30. Furthermore, while yield increases do not increase pre-harvest cost, total harvest cost rises in response to the increased yield. This additional harvest cost is predicted by the model to be in the neighbourhood of $70 million or approximately $1·30 per bushel. If we deduct from the *ad hoc* valuation the decline in market price and the increased cost of production, we arrive at a valuation of approximately $80 million.

6. Endogenous crop choice decisions

The welfare estimates presented in the preceding section assume that the mix of acres planted in a particular crop is unaffected by changes in ambient ozone. That is, producers do not engage in mitigating crop-switching behavior in response to yield changes due to ozone. Such an assumption is clearly unrealistic, because the yields of major field crops are differentially sensitive to ozone; moreover, crop switching among the major grains is technically and economically feasible for many areas of the U.S.A. Whether the unrealistic nature of this assumption seriously biases the benefit estimates of the previous section is an empirical issue which we have investigated.

To examine the sensitivity of our welfare estimates to relaxation of the fixed crop acreage mix assumption, we employ a more general producer model, where the behavioral assumption is profit maximization rather than cost minimization. In this model, producers are able to choose among three crops, wheat, soybeans and corn, and decide on the total number of acres to be planted in each crop, subject to an overall acreage constraint. Each crop-specific production function is again of the Leontief type discussed in Section 3, and is driven by the same ozone dose–yield functions.

To illustrate the impact of relaxing the assumption of a fixed crop mix, we focus on the U.S. corn belt area, comprised of the following states: Illinois, Indiana, Iowa, Ohio and Missouri. In 1978, a total of 69 million acres were planted in wheat, corn and soybeans in the corn belt, with approximately 3·75 million in wheat, 30·00 million in soybeans and 35·25 million in corn. Our intention is to determine the profit maximizing crop mixes that would have prevailed in this area under the two most extreme ozone scenarios (0·09 ppm and 0·15 ppm), to calculate the welfare gains and losses, and then to compare these welfare estimates to a similar set of estimates for the same area, but without the mitigating effects of crop switching.

If we accept the assumption implicit in the FEDS data that the production activities for wheat, soybeans and corn are nonjoint (i.e. production costs are allocatable by crop), it is a relatively simple task to calculate the net profit crop by crop, as a function of acres planted, by subtracting the marginal cost of production given by equation (10) from market output price. Using these three net profit relationships, we allocate the 69 million acres in such a way that total corn belt profit is maximized. In order to permit the possibility that plantings of any one of the three crops might be expanded beyond the 1978 figures, we fit by ordinary least squares a linear relationship between acres planted and marginal cost for each crop, and then calculate the net profits per acre from this fitted relationship. The fitted relationship allows us to predict marginal cost for unplanted acres.

The analysis outlined above is conducted under two alternative characterizations of the market prices for each of the crops. In the first characterization, we assume that the agricultural producers in the corn belt take the market prices for wheat, soybeans and corn as given, and adjust their crop–acre mixes in response to ozone induced-yield changes under the impression that their actions have no effect on market prices. This assumption is legitimate if the yield changes do not induce massive crop switching; in the event that they do induce considerable switching, we substitute the inverse demand functions (price as a function of output) for the market prices used to calculate the net profits. If crop switching is prevalent, the price-taking behavior characterization will not lead to a market clearing equilibrium, while the explicit recognition of the demand functions in the second characterization does.

Table 2 displays the acres planted in each crop for three alternative ozone regimes, under the assumption that corn belt producers take the 1978 market prices as fixed. The first column, associated with the 0·12 ppm ozone standard, is representative of the actual acres planted in 1978. One notices that, as ozone concentrations increase, soybean plantings decline and corn plantings rise. This is due to the increased ozone sensitivity of

TABLE 2. Profit maximizing distribution of corn belt acres under price taking behavioral assumption (thousands of acres)

	Ozone scenarios		
Crop	0·09 ppm	0·12 ppm	0·15 ppm
Wheat	3 000	3 750	3 750
Soybeans	31 500	30 000	27 000
Corn	34 500	35 250	38 250

soybeans relative to corn. Should ozone concentrations decline, the crop mix favors soybeans over corn and wheat.

Relative to the actual 1978 plantings, a total of 3 million acres, which accounts for approximately 4% of the total corn belt acreage, is switched from one crop to another in response to changes in ozone concentrations. To examine the impact of this crop switching on the welfare calculations of the previous section, we compare the welfare gains under the 0·09 ppm scenario and the losses under the 0·15 ppm scenario to similar welfare estimates for the corn belt based upon a model of producer behavior which does not admit crop switching (fixed crop mix). In the case of the 0·09 ppm scenario, the assumption of a fixed crop mix leads to an understatement of benefits of 2% relative to the more general model which permits crop switching, while the 0·15 ppm scenario leads to a 4% overstatement of losses.

Given the fairly inelastic demands for soybeans and corn, one might expect that even a marginal 4% shift in corn belt planted acreage from one crop to another may produce output changes large enough to cause substantial price changes in the markets for these crops. If such price changes occur, the planted acreage decisions detailed in Table 2 are not reflective of an equilibrium situation, and thus the disequilibrium distorts the welfare measurements. To determine the partial equilibrium level of crop plantings more accurately, we substitute in the net profit equations the inverse demand functions for the fixed crop prices, and again solve for the configuration of crop plantings which maximizes net corn belt profits subject to the acreage constraint.

Table 3 displays the equilibrium profit maximizing acres for each of the three crops under each ozone scenario. There are three substantive differences between the equilibrium crop mixes shown in Table 3 and their disequilibrium counterparts in Table 2. First, relative to 1978 planting, a maximum of 0·75 million acres are switched from one crop to another in this equilibrium model, compared to 3 million for the disequilibrium case. Second, even though soybeans are more sensitive to ozone than the

TABLE 3. Profit maximizing distribution of corn belt acres under the market equilibrium assumption (thousands of acres)

	Ozone scenarios		
Crop	0·09 ppm	0·12 ppm	0·15 ppm
Wheat	4 500	3 750	3 000
Soybeans	29 250	30 000	30 750
Corn	35 250	35 250	35 250

other two crops, planted soybean acres *increase* as ozone concentrations increase within the range we consider. Finally, in contrast to the disequilibrium model where crop switching occurs between soybeans, corn and wheat, crop switching in the equilibrium case occurs only between soybeans and wheat. These three differences are the result of the interplay between the differential biological responses, the three crops to ozone, and the differential economic responses of crop prices to reductions in output.

If we compare the total welfare estimates calculated from this equilibrium crop switching model to an equilibrium fixed mix model, we find that the more restrictive fixed mix model understates the benefits associated with the 0·09 ppm scenario by 0·29% and overstates the losses generated by the 0·15 ppm scenario by 0·1%. Naturally, the fixed planted acreage mix model performs well in the equilibrium setting because of the smaller number of acres shifted between crops.

The above analysis suggests that the equilibrium fixed mix model used to generate the national welfare estimates presented in Section 5 is not seriously biased due to its fixed crop mix assumption. In the corn belt, where crop switching is potentially prevalent, the equilibrium fixed crop mix model overstates welfare losses emanating from a simulated 0·15 ppm ozone standard by merely 0·1%, and understates gains associated with a 0·09 ppm standard by 0·2%.

7. Concluding remarks

To date, biological and economic information appears to have been combined in a rather cavalier manner to produce national monetary estimates of welfare changes in the agricultural sector occasioned by alternative air pollution policies. Where the applied economic analysis has been strong, the biological information has unfortunately been weak (e.g. Adams *et al.*, 1982). And, more frequently, detailed biological information has been integrated with extremely aggregated econometric models of supply and demand which display only a loose connection with regionally differentiated production conditions and producer behavior (e.g. Heck *et al.*, 1983). Consequently, it is hard to place much confidence in the welfare estimates thus produced for policy-making purposes.

The aim of this paper has been to produce benefit estimates of alternative ozone policies which are more firmly linked to the neoclassical theory of producer behavior, than previous national attempts (the regional work of Adams *et al.*, 1982, is an exception). Throughout this paper, we have emphasized that, in order to employ experimentally generated biological dose–response information in economic models of production and cost, air pollution effects must be treated conceptually as having neutral technological change effects on the (regionally differentiated) production technologies. Without this maintained hypothesis, the experimental biological information currently available is useless in agricultural economic welfare analysis of air pollution policies.

The national benefit estimates reported in this paper share several deficiencies with previous work. The demand side is only sketchily represented, and all cross-price effects are assumed to be zero. On the supply side, the optimal crop mix decision is not considered. Crop planting decisions and welfare estimates are treated as if they were independent. However, the regional endogenous crop choice estimates of Section 5 suggest that this assumption may not distort the national benefit estimates.

Finally, and perhaps most important, there does not yet exist an accurate and reliable method to translate air pollution standards imposed on urban areas into rural concentrations. There are very few rural air pollution monitors, and statistical extrapolations from urban to rural areas are likely to incorporate errors of unknown magnitude. Hence, it is not currently possible to estimate unbiased econometric cost or profit function models incorporating air pollution concentrations as arguments, even though the economic information is available from FEDS. While this situation drives us back to more simple economic models like the one presented here, it does not solve the problem because, in order to evaluate air pollution policies, unrealistic pre- and post-policy rural concentration values must currently be obtained by extrapolation.

A balanced approach to future research in this area is therefore required, if informative welfare estimates are to be produced and compared consistently with the costs of policy implementation. Specifically, no single area of inquiry, biological, meteorological or economic, can be overemphasized at the expense of any other, if benefit measures are to be forthcoming which command more than just academic interest.

References

Adams, R. M., Crocker, T. D. and Thanavibulchai, N. (1982). An economic assessment of air pollution damages to selected annual crops in southern California. *J. environ. Econ. Mgmt* **9,** 42–58.

Box, G. E. P. and Tidwell, P. H. (1962). Transformation of the independent variables. *Technometrics* **4,** 531–550.

Ferguson, C. E. (1969). *The Neoclassical Theory of Production and Distribution.* London: Cambridge University Press.

Heck, W. W., Taylor, O. C., Adams, R. M., Bingham, G., Miller, J. E. and Weinstein, L. H. (1981). *National Crop Loss Assessment Network 1980 Annual Report.* Corvallis, Oregon: Corvallis Environmental Research Laboratory, U.S. EPA.

Heck, W. W., Taylor, O. C., Adams, R. M., Bingham, G. Miller, J. E. and Weinstein, L. H. (1982). *National Crop Loss Assessment Network 1981 Annual Report.* Corvallis, Oregon: Corvallis Environmental Research Laboratory, U.S. EPA.

Heck, W., Adams, R. M., Cure, W. W., Heagle, A. S., Heggestad, H. E., Kohut, R. J., Kress. L. W., Rawlings, J. O. and Taylor O. C. (1983). A reassessment of crop loss from ozone. *Environ. Sci. Technol.* **9,** 572A–581A.

House, R. (1982). *A Mathematical Programing Model for Agricultural Sector Policy Analysis.* U.S. Department of Agriculture, Economic Research Service, National Economics Division, Food and Agricultural Policy.

Jacobson, J. S. and Millen, A. A. (1982). Effects of Air Pollution on Farm Commodities. *Proceedings of the Symposium,* Washington, D.C., 18 February 1982, sponsored by Izak Walton League of America, Arlington, Virginia.

Kopp R. J., Vaughan, W. J. and Hazilla, M. (1984). *Agricultural Sector Benefits Analysis for Ozone: Methods Evaluation and Demonstration.* Final report submitted to the Office of Air Quality Planning and Standards, U.S. EPA., Research Triangle Park, North Carolina 27711, U.S.A.