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ESTIMATING THE PRODUCTIVITY OF PESTICIDES IN CONTROLLING YIELD AND QUALITY DAMAGE

Bruce A. Babcock
North Carolina State University

Erik Lichtenberg
University of Maryland

David Zilberman
University of California, Berkeley

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Pesticides

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ESTIMATING THE PRODUCTIVITY OF PESTICIDES IN CONTROLLING YIELD AND QUALITY DAMAGE

Pesticides in agriculture belong to the class of production inputs Lichtenberg and Zilberman have termed damage control inputs. This type of input does not increase potential output. Rather, damage control inputs act to increase realized output by reducing damage from natural, mechanical, or human sources. In the absence of damage, such inputs have no effect on output. This special characteristic of damage and damage control inputs suggests that production models must be specified carefully. In the absence of damaging forces, realized output equals potential output and the marginal productivity of damage control inputs is zero. When damage is complete, actual output will equal its minimum value (given levels of standard production inputs). Failure to specify quantity production functions in this manner can lead to the conclusion that farmers are not using enough pesticides (see e.g., Campbell). This runs contrary to the long-held views of most agronomists and entomologists that pesticides are often overutilized in agriculture.

Another potential problem with estimating the productivity of pesticides with standard production models is that improvements in the quality of output from the application of pesticides can be ignored quite easily. Ignoring the quality effects will tend to underestimate the value of some pesticides, especially those used on fruits and vegetables where the appearance of output is often more important to farmers than the quantity of output.

This paper introduces a new approach to estimating the impacts of pesticide on productivity - an approach that has the potential of overcoming both the problem of misspecification as well as the problem of failing to take into account the quality effects of pesticides. The framework is applied to data on the use of insecticides and fungicides by apple growers in North Carolina.

Specifying Pesticide Production Functions

Lichtenberg and Zilberman have proposed a method of specifying production functions that incorporates a priori knowledge about how pesticides affect measured output. The quantity production function estimated in this paper is formulated following their method. Only a brief summary of their work will be presented here. For more details see their paper.

The basic motivation for the work of Lichtenberg and Zilberman is that the contribution of some inputs (e.g., pesticides) to production may be understood best if one conceives of actual (realized) output as a combination of two components: potential output (the maximum quantity of product obtainable from any given combination of standard inputs) and losses caused by damaging agents (insects, weeds, diseases) present in the environment. These losses can sometimes be reduced by using damage control inputs. Damage control effectiveness is limited by two factors. Damage can be at most equal to potential output and no smaller than zero, and abatement can be at most equal to total destructive capacity (implying that production will equal some minimum value) and no smaller than zero (implying that production will equal potential output). The productivity of damage control inputs is measured by their effectiveness in controlling damage.

These natural restrictions on damage abatement can be captured by defining an abatement function G(X). This function gives the proportion of the destructive capacity of the damaging agent eliminated by the application of a level of control agent X. The derivative of G with respect to X represents marginal damage control agent effectiveness or marginal productivity; it is simply the density of G(X).

Characterizing actual output, Y, as a function of standard inputs, Z (inputs that increase potential output), and damage abatement, G(X), allows the production function to be written as:

(1) $$Y = F[Z,G(X)],$$

with F(•) possessing the standard properties of production functions, notably concavity in Z and X.

Incorporating Product Quality

Producers have an interest in maintaining and/or enhancing product quality as well as the quantity of output, since for many products the value of goods produced may depend on their quality. The distinction that can be made between standard inputs and damage control agents can hold for product quality as well. In such cases realized product quality must be modeled as a function of potential quality, which is increasing in standard inputs Z, and damage L(X), which is a decreasing function of damage control agents X. Realized quality, Q, can thus be written

(2) $$Q = H[Z,L(X)].$$

Because both price received and volume of output sold may depend on quality, revenue can be written as a function, R(Q,Y), of quality, Q, and quantity, Y. Thus profits are

(3) $$\pi = R(Q,Y) - wX - rZ$$

where w and r are the prices of the damage control agent X and the standard input Z, respectively. Profit maximization with respect to X implies

(4) $$R_Q H_L L_X + R_Y F_G G_X = w.$$

It is evident from equation (4) that the damage control agent X has both a quantity effect, $R_Y F_G G_X$, and a quality effect, $R_Q H_L L_X$. It is clear that ignoring product quality results in underestimation of damage control agent productivity and, therefore, underestimation of optimal levels of these inputs.

Application to Pesticide Use on Apples in North Carolina

North Carolina apple growers use pesticides--primarily insecticides and fungicides--to control damage to both yield (manifested as premature fruit drop) and quality. The principal quality distinction revolves around market disposition. Lower quality fruit is used for processing while higher quality fruit is sold on the fresh market at a premium price. Attributes of apples that affect quality include size, color and visible damage from insects and diseases (primarily fungal).

Damage to both quantity and quality can be diminished by the use of chemical and non-chemical damage control agents. Insecticides are the principal mechanism for reducing insect damage. Fungal diseases are treated by applying fungicides and by tree pruning. Pruning permits greater penetration of sunlight into the interior of the tree and superior air circulation, conditions that retard fungal growth and enhance size and color.

Data

The data used in the analysis were collected from a random sample of 47 North Carolina apple orchards during 1976-1979 by the North Carolina Agricultural Research Service. The names and descriptions of the variables used in this analysis are given at the bottom of Table 1. This particular data set is perhaps the richest and most detailed collection of farm level data for any horticultural crop in the U. S. For a detailed summary of how the data were collected and a more detailed description of what the entire data set contains, see Rock and Apple.

Estimation Methods

The technical relationships of primary importance are the effects of insect and disease damage on yield and quality, and how these sources of damage are affected by apple orchard characteristics, weather variables and the use of damage control inputs. Damage manifests itself differently on yield and quality. Yield damage shows up as premature fruit drop, whereas quality damage is measured only after the fruit is harvested. It is relatively easy to collect data on quality damage. Fruit is harvested and then inspected for signs of insect or disease damage. However, without heroic efforts, observations on yield damage cannot be obtained. It would take season-long collection of fruit drop in combination with fruit growth models (to predict how the dropped fruit would have developed) to measure yield damage. Such data is not available.

This difference in data availability suggests two different estimation approaches. Separate quality and quality damage equations can be estimated to predict how well damage control inputs work to increase quality. Quality is a function of damage and damage is a function of damage control inputs. Such separation is not possible for the yield equation. In the absence of data on yield losses, only reduced form relationships linking yield with damage control agent use can be estimated.

Estimating the Quantity Function

Following Lichtenberg and Zilberman, potential yield is assumed to be Cobb-Douglas in standard inputs Z, and that yield losses are proportional to damage. Yield damage is assumed to be an exponential function of damage control inputs. Discussions with apple production experts led to the expectation that insect damage has relatively minor impact on yields. Various unsuccessful attempts at estimating an insect abatement function supported this conclusion. Hence, only a disease abatement function, with fungicides and tree pruning (denoted by X_1 and X_2) as damage control inputs was included in the estimated model. That is, the production function can be written as

$$(5)\ y = \alpha_0 + \sum_{j=1}^{n} \alpha_j z_j + \log(1-\exp(\gamma_0^d + \gamma_1^d X_1 + \gamma_2^d X_2)) + u$$

where y and $z....z_n$ represent the natural logarithms of Y and $Z_1....Z_2$, and u is a mean zero error term. This function is intrinsically nonlinear in the parameters and must therefore be estimated using nonlinear estimation techniques. The parameter estimates along with their asymptotic t-values are reported in the first column of Table 1.

Interest here is on estimating the productivity of damage control inputs, hence the discussion will focus on this aspect of the estimated model. As expected, damage abatement increases as the number of pounds of fungicide applied increases. Also, one effect of tree pruning is to increase harvested yields through its abatement effect. Thus, the estimated abatement function gives evidence that reductions in disease damage on apple yields can be accomplished either chemically, through the use of fungicide, or biologically by pruning the apple trees more intensively. In addition, tree pruning seems to play another role besides decreasing damage. A better canopy rating is correlated with lower potential yields. This result can be explained by noting that tree pruning reduces the amount of fruit bearing wood.

Estimating the Quality System

The measure of apple quality in the data used for this study is the percentage of harvested apples that did not qualify for the high-priced fresh market. The probability that an apple qualifies for the fresh market decreases with increases in skin blemishes or other damage from disease and insects. The probability of a fresh market apple increases as size and color attributes increase.

The incidence of insect damage and disease damage was measured separately. After harvest, each apple was inspected for damage. The percentage of apples that showed some sign of insect damage and the percentage that had some disease damage were recorded. This suggests that quality can be specified generally as

(6) $Q = g(D_i, D_d, A)$,

where D_i, D_d denote damage from insects and disease, and A denotes other quality attributes, most notably, size and color.

Farmers take actions to control quality damage by long-term manipulation of orchard characteristics and short-term applications of pesticides. Denoting X as damage control inputs and Z as other inputs allows the two damage equations to be written as

(7) $D_j = h_j(X_j, Z_j) \quad j = i \text{ or } d.$

Both quality and damage are measured as percentages. One goal of this study is to predict how well damage can be reduced, and quality increased by the application of pesticides. To insure that these predictions lie between zero and one, g in (6) and the h_j in (7) should take the form of cumulative distribution functions. The logistic function was used for estimation because of its computational simplicity. Following the recommendation in Amemiya, the dependent variables were transformed using the Cox modification of the standard logit transformation. Thus transformed, the dependent variables are assumed to be linear functions of the explanatory variables. The three equations therefore can be written as

(8) $Q^* = B_o + B_1 D_d + B_2 D_i + B_3 A + e_q$

(9) $D_j^* = \sum_{k=1}^{K} \alpha_{jk} Z_{jk} + \sum_{m=1}^{M} \theta_{jm} X_{jm} + e_j \quad j = i \text{ or } d,$

where Q^* and D_j^*, are modified logit transformations of Q and D_j.

A Hausman specification test was used to test for correlation between the error terms in (8) with the error term in (9). The null hypothesis of zero correlation could not be rejected so single equation estimated methods can be used to estimate (8). The method used followed Amemiya. The parameter estimates and their asymptotic t-values for the quality equation are given in the last column of Table 1.

That there is no evidence of correlated error terms between the damage equations and the quality equation does not mean that the two damage equation error terms are uncorrelated. To obtain asymptotic efficiency when $E(e_i \, e_d) \neq 0$ requires that the two equations be estimated as seemingly unrelated regressions. The null hypothesis of zero correlation between e_i and e_d in (9) was rejected using a Breusch-Pagan test. The parameter estimates from estimating the two equations together are reported in columns 3 and 4 of Table 1.

Once again, there is evidence that disease damage can be controlled by either of two methods. The results give strong evidence that biological control can be attained with tree pruning, and chemical control can be obtained by spraying the orchards with fungicides. Chemical control of insect damage can also achieved by the use of insecticides.

The estimated damage system gives strong evidence that disease and insect damage can be reduced by the use of damage control agents. The degree to which these agents can increase the quality of harvested apples depends on how strongly quality is affected by the two sources of damage. Increases in either disease damage or insect damage are strongly associated with decreases in quality.

Economic Implications

Several conclusions regarding the preceding econometric analysis of damage control agents in the context of apple production can be drawn. Briefly, they are: (1) estimating damage control specifications such as those suggested by Lichtenberg and Zilberman is feasible; (2) quality effects play a major role in fungicide use decisions in North Carolina apple production; (3) there is substantial scope for substitution between chemical and mechanical controls, both for quality and quantity; and (4) the bias in estimates of pesticide productivity due to the use of generic functional forms like the Cobb-Douglas can be quite large.

First, the estimates discussed in the preceding section demonstrate that estimating pesticide productivity using damage abatement specifications is feasible. Information about the biological, chemical and/or physical processes affecting production can be incorporated into econometric production models. The yield specification used here incorporated an entomological "kill" function. This meant using nonlinear estimation methods. For both the quantity function and the quality function, sets of statistically significant coefficients estimates in accord with a priori expectations were obtained.

Second, the estimated functions imply that quality effects can have substantial influence on total pesticide demand. Increased pesticide use decreases pest damage, which, in turn, increases the quality of North Carolina apples. Increases in the value of fresh market apples thus leads to increases in fungicide use. Value can be increased by either increasing the average price for all apples, or by holding average price constant and increasing the price differential between fresh and process grade apples. Using the second method allows the quality effects to be more clearly identified. The implied profit function from the estimated quantity and quality functions can be solved for profit maximizing levels of fungicide use given levels of all other inputs. By holding average price constant and varying the price differential between fresh and process apples, the percent of fungicide use due to quality considerations can be evaluated. At a price differential of zero, the quality effects are, of course, zero. When the profit function is evaluated at the sample means of all variables except for fungicide, and the average price for apples is held constant at $150.00 per ton, then quality considerations account for 20 percent of total fungicide use when the price differential is $250.00, and for 33 percent when the price differential is $400.00 per ton. These results are for a fungicide price of $4.00 per pound of active ingredient.

Third, it is evident from the estimated functions that there is considerable scope for substitution between chemical and mechanical controls in reducing both yield and quality damage. The expected marginal rate of substitution for damage abatement between tree pruning and fungicides is around 34 for yield damage and almost 53 for quality damage, indicating that one step in the pruning rate is about as effective as 34 or 53 pounds of fungicides applied annually.

Another way of illustrating this substitution is to calculate the impact of tree pruning on the value of marginal product of fungicide. Assuming that the process and fresh market prices are $106 per ton and $400 per ton respectively, an increase in pruning from below average (a rating of 4.0) to average (a rating about 3.0) reduces the marginal value from $50 per acre to $10 for fungicide applications of ten pounds annually and from around $8 per acre to $3 for applications of 55 pounds annually. If the price of fungicide is $4.00 per pound active ingredient, the optimal level of fungicide use is about 45 pounds per acre for below average pruning, about 6 pounds for average pruning, and zero pounds for above average pruning (a rating of 2.0). These figures suggest that pruning can reduce average chemical use substantially while maintaining control over yield losses. The extent to which damage control should be accomplished with tree pruning should be determined by the relative prices of tree pruning and fungicides.

The last point to be made is that the North Carolina data suggest that the bias in pesticide productivity estimates from using generic production function specifications may be quite substantial. A standard Cobb-Douglas version of the yield equation was estimated for this purpose. The resulting parameter estimates are shown in column 2 of Table 1. Again, evaluating the two functions at the sample means implies that at low levels of fungicide use the Cobb-Douglas function underestimates the marginal productivity of fungicides by about one-half, whereas at higher levels of fungicide use (over 40 pounds) the Cobb-Douglas function overestimates the marginal product by up to 500 percent. The absolute size of the bias, while smaller, is still quite substantial. The Cobb-Douglas estimate exceeds the "damage control" estimate by 0.06 tons per acre at application rates of 12 pounds per year, 0.03 tons per acre at 100 pounds.

A last point to be made in comparing the two specifications concerns the effect of tree pruning on yields. It is not surprising that the estimated canopy rating parameter in the Cobb-Douglas version is both small and insignificant. Using the abatement specification and accounting for the dual role played by tree pruning reveals that a better pruned tree both increases yields, by preventing fruit drop, and decreases yields, by removing potential yield bearing wood. The Cobb-Douglas version masks the separate, significant effects, thereby leading to the erroneous conclusion that tree pruning has no effect on yields.

Conclusions

This paper has shown that production functions that incorporate information about biological processes can be estimated fairly reliably. The restrictions on how damage control inputs affect yields were captured in an abatement function. It was demonstrated that failure to specify production functions in this manner can lead to a large bias in estimating marginal products. Damage control inputs were also shown to reduce quality damage, suggesting that quality effects should be taken into account in both normative and positive studies of pesticide effectiveness. Of particular interest to advocates of less pesticide use on food crops is the evidence that disease damage can be controlled chemically or biologically. These two methods were estimated to be strong substitutes in controlling yield and quality losses.

REFERENCES

Amemiya, T. "Qualitative Response Models: A Survey." Journal of Economic Literature, 19(1981):1483-1536.

Breusch, T. S. and A. R. Pagan. "The Lagrange Mutiplier Test and Its Applications to Model Specification in Econometrics." Review of Economic Studies, 47(1980):239-53.

Cox, D. R. The Analysis of Binary Data. London, Methuen, 1970.

Campbell, H. F. "Estimating the Maginal Productivity of Agricultural Pesticides: The Case of Tree-Fruit Farms in the Okanagan Valley." Canadian Journal of Agricultural Economics, 24(1976):23-30.

Hausman, J. A. "Specification Tests in Econometrics." Econometrica, 46(1978):1251-71.

Lichtenberg, E. and D. Zilberman. "The Econometrics of Damage Control: Why Specification Matters." American Journal of Agricultural Economics, 68(1986):261-73.

Rock, G. C. and J. L Apple, editors. Integrated Pest and Orchard Management Systems for Apples in North Carolina. Technical Bulletin 276, North Carolina Agricultural Research Service, December, 1983.

Table 1. Estimated Functions for Apple Quantity and Quality[a]

	YIELD		DISDAM	INSDAM	QUAL
	Damage-Control	Cobb-Douglas			
CONSTANT	-11.03 (1.98)	-7.23 (1.15)	-2.73 (1.43)	-1.80 (1.66)	3.13 (9.00)
HUMID	---	---	.031 (2.86)	.025 (4.27)	---
TEMP	-.274 (2.59)	-.261 (2.43)	---	---	---
RAIN	.76 (0.79)	.086 (.08)	---	---	---
HEIGHT	.810 (1.29)	.973 (1.53)	-.123 (1.49)	-.090 (1.93)	---
WIDTH	.922 (1.86)	.903 (1.67)	-.0062 (0.08)	.091 (2.71)	---
DIAM	1.14 (2.54)	1.37 (2.94)	-.133 (1.12)	-.092 (1.22)	---
SPACE	.242 (0.62)	.018 (0.04)	-.0009 (0.62)	-.0013 (1.57)	---
TPA	.132 (0.36)	.078 (0.20)	-.0098 (0.79)	-.0086 (1.22)	---
TAGE	-.159 (0.52)	-.283 (0.89)	.114 (2.35)	.0081 (0.31)	---
DVAR	.271 (2.48)	.350 (3.06)	-.0096 (1.28)	-.011 (2.56)	-.025 (6.44)
CRATING	.190[b] (0.99)	.011[b] (.058)	.589 (3.22)	---	---
FUNG	---	.176[b] (1.54)	-.0112 (1.60)	---	---
INS	---	---	---	-.0097 (2.69)	---
FUNG	-.0699 (1.83)	---	---	---	---
CRATING	2.37[c] (1.85)	---	---	---	---
CONSTANT	-9.45 (1.86)	---	---	---	---
DISDAM	---	---	---	---	5.25 (15.29)
INSDAM	---	---	---	---	4.56 (2.27)

NOTES: [a]The estimation procedures are described in the text. The variable definitions are as follows: YIELD-tons of harvested apples per acre; HUMID - Number of growing season days (March 1 to September 30) with relative humidity ≥ 85%; TEMP - Number of growing season days with temperature ≤ 32°; RAIN - Number of growing season days with rainfall > .01 inches; HEIGHT - Average tree height in feet; WIDTH - Average tree width (outer limb edge to outer limb edge cross row); DIAM - Average tree diameter in inches one foot above soil line; DVAR - Percent of trees planted to Golden or Red Delicious varieties; TAGE - Average tree age in years; SPACE - Average area of tree in square feet; TPA - Number of trees per acre; CRATING - Average tree canopy rating (1 = ideally pruned, 5 = no pruning); FUNG - Pounds of fungicide active material per acre; INS - Pounds of insecticide active material per acre; DISDAM - Fraction of apples with disease damage; INSDAM - Fraction of apples with insect damage; QUAL - Fraction of apples that did not qualify fresh market apples.[b]Affects potential yield. [c]Affects actual yield through disease abatement.