A SIMULTANEOUS EQUATION MODEL OF THE ECONOMIC-ECOLOGIC SYSTEM IN CITRUS GROVES*

Jonq-Ying Lee and Max R. Langham

In 1964, 89 percent of the citrus acreage in the U.S. was treated with pesticides. The percentage increased to 97 percent in 1966. Total expenditures for pesticides during the two years were 13.8 and 21.3 million dollars, respectively. Expenditures on a per acre basis were $12.74 and $18.82, respectively, in these years [9, p. 9]. The trend in pesticide use on citrus pest control has been upward.

The increased usage indicates that pesticides are recognized by growers as important inputs to increase output and/or improve fruit quality. The negative side effects of pesticides on the environment are also being increasingly recognized.

Insect populations and fruit yield of citrus trees are determined simultaneously by physiological factors and the environment of the citrus tree. In addition to the physical and climatic characteristics of the tree's site, the environment includes inputs (such as pesticides and fertilizers) that are applied by management. This study utilized a stochastic simultaneous equation system [3, pp. 288-388] to estimate the effect of a change in the amount of pesticides and other productive inputs on pest populations and on the yields of fruit produced.

THE SIMULTANEOUS EQUATION METHOD

Ecology is defined as the study of interrelationships of plants and animals with their environment [1, p. 2], or a science which probes the secrets of living systems at the levels of organisms, the populations, and the ecosystem[1] [8, p. 4]. The study of an economic-ecologic system thus places emphasis on the interrelationships of economic plants and animals with their environment. In a citrus grove, the living organisms include the citrus trees, insects, disease pathogens, and plants. Organisms included in this study were the citrus tree and insects thought to be of economic consequence. Emphasis was placed on the insect populations and the yield of citrus trees. The structural form of this system can be written as:

Citrus production = f (physical attributes of the grove, weather conditions, management and cultural practices, pest populations);

Pest populations = g (physical attributes of the grove, weather conditions, management and cultural practices, citrus production);

where citrus production and pest populations are endogenous variables and the other variables in the two equations are exogenous (including predetermined) variables.

Suppose we are interested in the yield of a citrus tree and its habitat. Figure 1 depicts a simplified hypothetical causal network between five "inputs" (fertilizers, age of the tree, planting density, pesticides, and weather conditions), and yield per tree and pest infestation. The time period can be thought of as a crop year and is basic relative to the production process. The arrows indicate directions of causation, for example, fertilizers, age of the tree, weather conditions, and pest infestation have direct

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[1]Organisms and the physical features of the habitat form an ecosystem. The habitat is the surroundings where an organism lives.

effects on yield per tree, as indicated by solid lines; yield per tree in time period t-1, has indirect effects on the yield per tree in time period t, which is indicated by a dotted line, and so on.

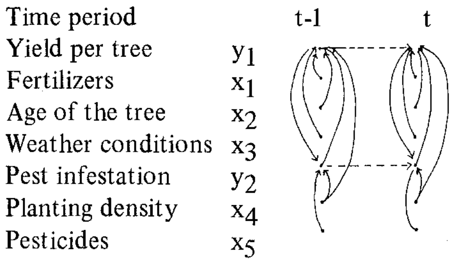

Figure 1. ARROW SCHEME OF A SIMPLE SIMULTANEOUS EQUATIONS MODEL OF A CITRUS GROVE.

Figure 1 may be represented by the equations (1) and (2). In these equations the second subscript denotes the grove, and the third subscript denotes the time period in which the value of the variable was determined.

(1) $y_{1st} = f(y_{2st}, x_{1st}, x_{2st}, x_{3st}, x_{4st}, y_{1s,t-1}, u_{1st})$

(2) $y_{2st} = g(y_{1st}, x_{3st}, x_{4st}, x_{5st}, y_{2s,t-1}, u_{2st})$

THE SAMPLE AND THE DATA

Information for this study came primarily from monthly ecological survey data collected under the direction of Dr. W. A. Simanton [6, 7]. These data are available for a period beginning in December 1955 for approximately 130 commercial groves scattered over the major citrus producing areas of Florida. This survey was designed primarily to furnish information to growers on insect and disease infestation. The survey provides the following kinds of data:

1. population density of insects and diseases,
2. spray programs – both nutritional and pest control sprays,
3. fertilizer applications, and
4. physical attributes of the grove.

The yield data for the groves used in this study were collected in a separate survey by Dr. W. A. Simanton. Parvin's weather indexes [5, p. 107] were used to express weather conditions. Indexes greater than one indicate favorable weather for fruit, and the larger the index the more favorable the weather conditions.

Eleven Valencia orange groves for which there were complete yield records and other required data (since the 1964-65 season) were chosen for the study.

EMPIRICAL RESULTS

The structural form equations of the model were estimated by the method of two-stage least squares.[2] The estimated structural form equations over the sample period (1964-65 to the 1967-68 season) were as follows:

$$(3)\ y_{1st} = \underset{(2.6277)}{3.226} + \underset{(.0793)}{.0063}\, x_{1st} + \underset{(.0730)}{.0377}\, x_{2st} + \underset{(.4753)}{1.868}\, x_{3st} - \underset{(.4517)}{.8263}\, y_{2st} + \underset{(.2058)}{.4807}\, y_{1s,t-1}$$

$$(4)\ y_{2st} = \underset{(4.7660)}{-2.642} + \underset{(.1565)}{1.636}\, x_{3st} + \underset{(.0545)}{.0708}\, x_{4st} - \underset{(.0328)}{.0255}\, x_{5st} + \underset{(.4402)}{.1042}\, y_{1st} + \underset{(.1699)}{.0311}\, y_{2s,t-1}$$

where:

y_{1st} = number of 90 pound boxes of fruit produced per tree in the s^{th} grove and t^{th} year,

y_{2st} = average monthly pest infestation[3] in the s^{th} grove and t^{th} year in percent,

x_{1st} = pounds of active ingredients of fertilizer[4] applied per tree to the s^{th} grove and t^{th} year,

x_{2st} = age of the trees in the s^{th} grove and t^{th} year,

x_{3st} = Parvin's weather index for the s^{th} grove and t^{th} year,

x_{4st} = number of trees per acre in the s^{th} grove and t^{th} year,

[2] Two kinds of models were estimated--the larger of the two used more disaggregated data and was specified with six endogenous variables--yield, black scale, glover scale, rust mite, Texas C. mite, and melanose. Predetermined variables include six lagged endogenous variables, eight kinds of pesticides, three kinds of fertilizers, three kinds of physical attributes of the grove, seven weather variables, and one predator population density [4, pp. 33-36]. For both models different functional specifications (i.e., linear, quadratic, semi-logarithmic, and logarithmic) and different variable combinations were fitted. Only the results from fitting the more aggregative model in simple linear form is presented for discussion in this paper.

[3] Calculated by the formula: $y_{2st} = \sum_{i=1}^{12} (\sum_{j=1}^{10} P_{ijst}/10)/12$ where P_{ijst} is the j^{th} insect infestation percentage in the i^{th} month of t^{th} production period and s^{th} grove. Insects included in y_2 are: citrus red mite, Texas C. mite, six-spotted mite, rust mite, black scale, purple scale, glover scale, chaff scale, yellow scale, and red scale. The simple unweighted aggregation of insect infestation percentages ignores interactions among the effects of insect infestations and differences in the level of harm by individual types of pests. The same kinds of aggregation problems exist in definitions of x_1 and x_5.

[4] Fertilizer ingredients included in x_1 are N, P_2O_5, K_2O, MgO, Zn, and Mn.

x_{5st} = pounds of active ingredients of pesticides[5] applied per tree in the s^{th} grove and t^{th} year,

and $y_{1s,t-1}$, and $y_{2s,t-1}$ are y_{1st} and y_{2st} lagged one period, respectively.

Both equations are over-identified [3, pp. 307-318]. Numbers in parentheses are estimated asymptotic standard errors of the estimated coefficients. These standard errors provide measures of statistical reliability. The results given in equations (3) and (4) show that lagged yield is a significant variable (at the 2 percent significance level with an asymptotic test) in explaining current yield. Pest infestation is significant at the 10 percent significance level. All signs are consistent with theoretical expectations. However, the coefficient of yield in equation (4) indicates that yield has little influence on pest populations. Hence, the empirical results indicate less simultaneity than expected.

The coefficients in both equations can be interpreted as the direct effects on yield and pest infestation, respectively, of changes in the associated variables.

The reduced form equations for the system express each endogenous variable as a function of the predetermined variables in the system. The coefficients of the reduced form equations represent the partial derivative of the conditional expectation of the current endogenous variable with respect to a predetermined variable[6] with all other predetermined variables held constant. Thus, a reduced form coefficient indicates the "total" effect of a change in x_{jst} on (the conditional expectation of) y_{ist} after taking account of the interdependencies among the current endogenous variables. In economic jargon these coefficients are multipliers. One may suspect that some predetermined variables make larger contributions to the statistical explanation of an endogenous variable than do others. The beta coefficients of the predetermined variables [3, pp. 197-200] provide an objective measure of typical changes in the form of the sample standard deviation.[7] The reduced form estimates and the corresponding beta coefficients are presented in Table 1.

The results in Table 1 show in general, that total effects of the predetermined variables are less than their direct effects. One reason for this may be that a favorable environment for tree growth may also be a favorable environment for pests.

The beta coefficient indicates that lagged yield, pesticides, and age of the tree explained more yield variations than other predetermined variables. And planting density, weather, and pesticides appear to be more important in explaining pest infestation variation than do the other predetermined variables.

APPLICATIONS OF THE MODEL

Rates of Technical Substitution

The rate of technical substitution (RTS) at a point equals the ratio of the marginal product of one input to the marginal product of the other at that point. Since the system is in linear form, the RTS's are constants. The estimated RTS's are given in Table 2. The numbers shown in each column indicate the RTS's of inputs given by rows for the input given by the columns, respectively. For instance, the number in the position given by the first column and ninth row gives the RTS of pesticide for fertilizer. A one pound reduction in fertilizer requires a .2990 pound increase in pesticide to maintain a constant level of yield. As indicated by the third column, weather is an important factor in determining the results of the system.

Dynamic Properties

Some of the most interesting applications of estimated structural models are concerned with their dynamic aspects. In both equations, the predetermined variables included lagged yield and lagged pest population–so the model is dynamic. Thus, the model results can be used to estimate how the time path of the exogenous variables generate the time path of the endogenous variables. For example, the data in Table 1 indicate that if pesticides are increased in use by one pound in period t - 1, with other predetermined variables held constant, pest infestation in period t - 1 will decrease by .024 percent. However, a decrease in pest infestation by one percent in period t - 1 will cause an increase in yield in period t of .024 boxes and a decrease in pest infestation in period t of .029 percent. Improvement in the tree's environment by pest control practices in period t will result in an increased pest infestation in period t + 1 by .046 percent per box of fruit increased in period t. This argument can go on to th

[5] Pesticides included in x_5 are chlorbenzilate, guthion, sulfur, zineb, trithion, delnav, Kalthane, oil, tedion, and parathion.

[6] $y_{1s,t-1}$ and $y_{2s,t-1}$ are of course considered as predetermined variables.

[7] Goldberger [2, p. 72] used another measure to determine the contribution of predetermined variables to endogenous variables, i.e., $\mu_{ij}=\pi_{ij}\sum_t|Z_{jt}|$ where π_{ij} is the appropriate element of the reduced form matrix, $\sum_t|Z_{jt}|$ is the sum of the absolute values of the annual changes in predetermined variable z_j, and μ_{ij} is the measure of the importance of z_j in explaining endogenous variable y_i.

Table 1. **ESTIMATED REDUCED FORM EQUATION COEFFICIENTS AND THEIR CORRESPONDING BETA COEFFICIENTS.**

endogenous variables / predetermined variables	Yield y_{1st}		Pest Infestation y_{2st}	
	Reduced form coefficients	Beta coefficients	Reduced form coefficients	Beta coefficients
Constant term	4.9803	---	-2.1231	---
Fertilizer x_{1st}	.0058	.0149	.0006	.0015
Age of the tree x_{2st}	.0347	.1137	.0036	.0117
Weather index x_{3st}	.4753	.0563	1.6855	.1978
Planting density x_{4st}	-.0539	.0281	.0652	.3385
Pesticide x_{5st}	.0194	.1219	-.0235	.1461
Lagged Yield $y_{1s,t-1}$	.4426	.4169	.0461	.0430
Lagged pest infestation $y_{2s,t-1}$	-.0237	.0274	.0287	.0329

Table 2. **RATES OF TECHNICAL SUBSTITUTION ESTIMATED FROM ESTIMATED REDUCED FORM COEFFICIENTS.**[a]

		x_{1st}	x_{2st}	x_{3st}	x_{4st}	x_{5st}
x_{1st}	y_{1st}	1.0	5.9828	81.9483	-9.2931	3.3448
	y_{2st}	1.0	6.0000	2809.1667	108.6667	-39.1667
x_{2st}	y_{1st}	.1672	1.0	13.6974	-1.5533	.5591
	y_{2st}	.1667	1.0	468.1944	18.1111	-6.5278
x_{3st}	y_{1st}	.0122	.0730	1.0	-.1134	.0408
	y_{2st}	.0004	.0021	1.0	.0387	-.0139
x_{4st}	y_{1st}	-.1076	-.6438	-8.8182	1.0	-.3599
	y_{2st}	.0092	.0552	25.8512	1.0	-.3604
x_{5st}	y_{1st}	.2990	1.7887	24.5000	-2.7884	1.0
	y_{2st}	-.0255	-.1532	-71.7234	2.7745	1.0

[a]For variable definitions see section in text titled Empirical Results.

distant future. In order to explore this phenomenon the delay-τ multipliers and culmulated multipliers[8] [3, pp. 374-375] for pesticide and fertilizer are computed for the period 1963-64 through 1966-67 and are given in Table 3.

C_τ's in Table 3, give the time path of changes in the endogenous variables, given that an exogenous variable is raised by one unit in a period and then restored to its original level. Estimates indicate increases in yield of .019 boxes on period 0, .004 boxes in period 2, etc. when the use of pesticides is increased by one pound. Similarly, pest infestation decreases .023 percent in period 0, .004 percent in period 2 and so on.

The D_τ's in Table 3 give the current and future values of the change in an endogenous variable

[8]When τ=0, delay-τ multipliers are called impact multipliers. As $\tau \rightarrow \infty$, cumulated multipliers are called equilibrium multipliers.

Table 3. **ESTIMATED DELAY-τ MULTIPLIERS (C_τ) AND CUMULATED MULTIPLIERS (D_τ) FOR PESTICIDE AND FERTILIZER.**

τ	Fertilizer				Pesticide			
	C_τ		D_τ		C_τ		D_τ	
	y_1	y_2	y_1	y_2	y_1	y_2	y_1	y_2
0	.005755	.000599	.005755	.000599	.019385	−.023459	.019385	−.023460
2	.001114	.000125	.009402	.001007	.004038	−.000428	.032558	−.022811
4	.002116	.000024	.010108	.001086	.000782	−.000088	.035119	−.022520
6	.000042	.000005	.010245	.001102	.000151	−.000017	.035610	−.022469
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
15	0.0	0.0	.010278	.001054	0.0	0.0	.035731	−.022456
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
∞	0.0	0.0	.010278	.001054	0.0	0.0	.035731	−.022456

given an exogenous variable is raised by one unit in a period and then sustained at its new level. If an increase in the use of pesticide of one pound in period 0 is sustained at this new level, other things held constant, the cumulated multipliers (D_τ's), tell that yield will increase by a total of .019 boxes in period 0, by a total of .033 boxes in period 2, and so on, and finally reach a new equilibrium which is .036 boxes higher than the original level. The same interpretation can be applied to pest infestation which indicate that pest infestation will be .023 percent less than the original level.

If the effects for pesticide and fertilizer have not been underestimated, or they have been underestimated but not seriously, pesticide and fertilizer seem to have been used beyond their economic optimum–particularly if evaluated within the framework of a naive expectation model.[9] An increase in fertilizer use by one pound, has on the average increased the value of the product by 2.4 cents. Whereas, a pound increase of pesticide increased value of output by 8.2 cents.[10] One would not expect these values of the added product to off-set the added costs of a pound of fertilizer or pesticide.

The citrus produced is of positive benefit to society. However, the residuals produced may have negative costs and/or benefits to society. The lack of knowledge about these external effects of residuals precluded their consideration in this study.

CONCLUDING REMARKS

The study demonstrates the use of a structural econometric model in the study of an economic-ecologic system. Such a model has been used quite widely in the study of economic systems. In the model, citrus pest infestation and yield were included as endogenous variables. Predetermined variables consisted of lagged yield, lagged pest population, amount of productive inputs, weather factors, and certain physical attributes of the tree's site. The system which determines fruit production and pest infestation in a citrus grove is a very complicated natural process and the model is a gross abstraction of this system. Indeed, it must be if the model is to be useful in clarifying the complexities of the real world.

The estimated yield function and pest infestation function were compatible with physical and biological processes in the citrus groves in that the signs were consistent with expectations. Pesticides increase citrus production and decrease pest infestation. Fertilizers increase both citrus production and pest infestation.

Reduced form equations help explain this ecosystem in operation, and the relationships among trees, pests, and their habitat. Delay multipliers and cumulated multipliers show how yield and pest infestation respond to changes in the amount of fertilizers and pesticides used over time. The aggregated data used did not take into account seasonal aspects of pest infestation.

[9] If the use of fertilizer and pesticides reduces variability in expected returns and if the decision maker is risk adverse, the observed levels of use would be closer to the optimal for the decision maker than a naive expectation model would indicate.

[10] Values of the marginal products were obtained by multiplying 2.304 dollars, the average price of oranges in Florida during the 1963-64 through 1967-68 season [10], by the respective cumulative multipliers for fertilizer (.0103) and pesticides (.0357).

REFERENCES

[1] Clarke, George L., *Elements of Ecology,* New York, John Wiley & Sons, Inc., 1954.

[2] Goldberger, A. S., *Impact Multipliers and Dynamic Properties of the Klein-Goldberger Model,* Amsterdam, North-Holland Publishing Company, 1959.

[3] ______, *Econometric Theory,* New York, John Wiley & Sons, Inc., 1964.

[4] Lee, J., "A Simultaneous Equation Model of the Economic-Ecologic System in Citrus Groves," unpublished M.S. thesis, University of Florida, 1972.

[5] Parvin, D. W., Jr., "Effect of Weather on Orange Supplies," unpublished Ph.D. dissertation, University of Florida, 1970.

[6] Simanton, W. A., "Operation of an Ecological Survey for Florida Citrus Pest," *Journal of Economic Entomology,* Vol. 55, pp. 105-112, Feb. 1962.

[7] ______, "Use and Value of a Continuous Field Survey in the Control of Citrus Pest," *Proceedings First International Citrus Symposium,* Vol. 2, pp. 889-896, 1969.

[8] Smith, R. L., *Ecology and Field Biology,* New York, Harper and Row Publishers, 1966.

[9] U.S. Department of Agriculture, Economic Research Service, "Farmers' Pesticides Expenditures in 1966," *Agricultural Economic Report,* No. 192, Sept. 1970.

[10] U.S. Department of Agriculture, Statistical Reporting Service, *Agricultural Prices* -- Annual Summary, 1964 through 1968.