Alternate bearing in Californian pears and avocados

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365

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ALTERNATE BEARING IN CALIFORNIAN PEARS AND AVOCADOS1/

There is considerable debate among biologists, farmers, and others as to whether particular crops are alternate bearing: High yield harvests are followed by low yield ones. In this paper, we present a simple methodology for measuring the degree of explained and unexplained alternate bearing in a crop.

Crop yields vary predictably from year to year for a variety of reasons. There are both biological and economic factors which may cause alternate bearing a particular crop. Biological and climatological factors include weather, disease, the age distribution of plants, and the previous year's yield.2/ Economic incentives which influence the activities of farmers may cause fluctuations.3/ For example, if a crop's price is expected to be low in a given year, or the cost of an input (labor, water, fertilizer) high, less inputs may be used. Using statistical techniques, a researcher can determine how these factors individual and collectively affect year to year variations in yield.

There also may be other unmeasured biological or economic factors which contribute to alternate bearing. For example, the number of buds in the previous season may affect the current harvest, yet no record may be kept of this number. The impact of these unmeasured factors is estimated in our methodology.

We use a standard multiple regression approach to estimate yield as a function of measured economic and biological factors. The error term in this equation reflects the missing (primarily biological) factors. If these unobserved factors lead to alternately high and low yields, then this error term should be negatively correlated over time. Thus a test for negative autocorrelation of various orders is a test for unexplained alternate bearing.

We begin our discussion by surveying the literature on alternate bearing. We then specify our model and test it on California pears and avocados. The final section contains conclusions. The paper is followed by an appendix which describes the data.

The Literature

There is an extensive biological literature and a more limited economics literature on alternate bearing. Basically, the biological literature is very crop specific: different issues are relevant for various crops. The economic and econometric literature has completely failed to come to grips with this issue in a useful manner, so far as we can determine.

In this survey, we concentrate on economics articles on deciduous crops; however, so far as we know, the literature on other crops is similar. Typically, most studies have either ignored the alternate bearing problem, or have awkward (and often wrong) means to deal with it.

For example, one recent system model of the U. S. pear market, O'Rourke and Masud, treats supply as predetermined. Another study of deciduous crops, Aritelle and Price, generally attribute yield per acre to a time trend, "thus ignoring the randomness of production due to weather."

A much sounder approach is that in Minami, French, and King. They believe that changes in production in the California cling peach industry are implemented primarily through the planting of new trees or the removal of old trees.[4/] They model yield as a function of a time trend, dummy variables to represent age groups, geographic districts and varietal group. In other words, their yield equation reflects both economic and biological factors. They do not explicitly test for alternate bearing, however.

A study of the Florida Aavocado industry, Degner and Durham, does consider alternate bearing directly. This study models yield as a function of a (positive) time trend and a variable which takes on values of 0 and 1 in alternating time periods: 0, 1, 0, 1,... This latter variable was designed to capture the alternate bearing phenomenon. There are two serious problems with their approach.

First, by ignoring all economic and biological variables save for these two, the model (and in particular the coefficient on the alternate bearing variable) is seriously biased. Second, unless alternate bearing is completely determinate in the manner specified (e.g., there are never two good or two bad years in a row), they have improperly modeled alternate bearing. Our results, discussed below, strongly indicate, at least for California avocados and pears, that alternate bearning is much more complex than their model suggests.

The Model

Given T observations, yield, Y [a (T x 1) vector], is a function of K biological and economic variables, X [a (T x K) matrix]:

$$Y = X\beta + e, \tag{1}$$

where e is a random vector with $E[e] = 0$ and $E[ee'] = \Phi = \sigma^2\Psi$. There is autocorrelation if the disturbance term corresponding to different observations are correlated: Ψ is not diagonal.

Autocorrelation may be due to omitted variables.5/ While in most econometric models, the autocorrelation is assumed to be positive (a positive error in one period implies that a positive error in the next period is very likely), here, negative correlation is predicted to reflect alternate bearing.

Neither biological nor economic theories predict, however, the order of the autocorrelation process. We, therefore, started with a very high order autocorrelation processes and sequentially lowered the order, testing for significance of the last coefficient.6/ We also examined each set of estimates to determine whether the autocorrelation process was stable. To test for the possibility of an infinite-ordered process, we also tried an equivalent first-order moving average process. The results of these tests are reported below.

In the first-order autocorrelation process, AR(1), the error structure may be written as (Judge, et al., pp. 170-1):

$$e_t = \rho_1 e_{t-1} + \nu_t, \tag{2}$$

where the ν_t are random variables with $E[\nu_t] = 0$, $E[\nu_t^2] = \sigma_\nu^2$, and $E[\nu_t \nu_s] = 0$ for $t \neq s$. The process is stationary so long as $|\rho_1| < 1$

In the second-order autocorrelation process, AR(2), the error structure is (Judge, et al., p. 190):

$$e_t = \theta_1 e_{t-1} + \theta_2 e_{t-2} + \nu_t, \tag{3}$$

where $E[\nu_t] = 0$, $E[\nu_t \nu_s] = 0$ for $t \neq s$, and $E[\nu_t^2] = \sigma_\nu^2$. This process is stationary if $\theta_1 + \theta_2 < 1$, $\theta_2 - \theta_1 < 1$, and $-1 < \theta_2 < 1$. The autocorrelation coefficients are:

$$\rho_1 = \frac{\theta_1}{(1 - \theta_2)} \tag{4}$$

$$\rho_2 = \theta_2 + \frac{\theta_1^{\,2}}{(1 - \theta_2)} \tag{5}$$

$$\rho_s = \theta_1\rho_{s-1} + \theta_2\rho_{s-2}, \qquad s > 2. \tag{6}$$

This model is used to estimate yield functions for Californian pears and avocados.

Californian Bartlett Pears

Bartlett Pears are grown on almost three-fourths of the pear acreage of the Western States and are an important commercial variety in Michigan and New York (Science and Education Administration, p. 25). Roughly one-third of Bartlett pears are sold as fresh fruit, two-thirds are canned, and a small amount is dried.

Chief expenses include skilled labor (equipment operators and crew supervisors), unskilled labor (pruners, pickers, irrigators and others), interest payments on capital (trees, tractors, bin trailers, sprayer air carriers, tree squirrel, cover crop and limb shredder, nurse truck for sprayer, weed sprayer, pickup truck, ladders, picking bags, forklift, and duster), fuel and repairs, materials (chemicals), and water (Cooperative Agricultural Extension (1983)). In our model, due to lack of data on many of these factors, we concentrated on the average labor cost (in real terms) of harvesting Bartlett pears and the average price paid by farmers in California for gasoline (which is also a proxy for water costs).

Our model also includes biological factors: the fraction of trees estimated in each bearing age group (6-10 years old, 11-15, 16-20, 21-25, 26-30, and over 30), December and January heating degree days (low temperatures are required during the winter to complete dormant period), and March and April average maximum temperatures (high temperatures for the two months preceding harvest are desirable).7/ A time trend was also included to reflect technological progress.

To capture the effect of previous periods weather and harvest on the current harvest, we included both weather variables lagged and lagged yield. Ordinary least squares [OLS] and first-order autocorrelation [AR(1)] estimates are reported in Table 1 for the period 1952-1983.8/ On the basis of likelihood ratio tests using the AR(1) estimates, we rejected the lagged weather variables.9/ On the basis of a likelihood ratio test, we cannot reject the lagged yield term, however. Since models with lagged endogenous variables with autocorrelation corrections must be viewed with caution, we have also reported the equations without lagged yield.10/

A comparison of the coefficients show that the estimates differ as the assumption about the error structure is changed. The AR(1) process explains 15 percent more of the total variation. The likelihood ratio test that there is no autocorrelation is $\chi^2(1) = 16.82$ ($\chi^2(1) = 3.84$ at the 0.05 level), and the t-statistic on ρ_1 is statistically significant at the 0.05 level (see Table 1). On the basis of a likelihood ratio test, we can reject an AR(2) process.11/

According to our AR(1) estimates, more heating degree days in December and January of the current year may increase yield, however, the coefficient is at best marginally statistically significantly (t-statistic = 1.65). Good (warm) weather in March and April in the current year also raises yield by a statistically significant amount (t-statistic = 2.54).

The coefficient on the time trend is positive, and statistically significant, which may indicate technological progress. The statistical insignificance of the harvest wage may imply that it pays to harvest everything given harvest wages in the observed range. The statistical insignificance of the gasoline price is more difficult to explain (though it is probably a weak proxy for water costs).

The results for the age distribution of the trees are surprising. To prevent perfect multicollinearity, the share of bearing trees in the prime range of 16-20 years was dropped. The coefficients on the older age groups are statistically significantly positive. That is, trees older than 16-20 years appear to produce more. Pear farmers report, however, that older trees are less productive. We are unable to explain the reason for these results.

The results for the AR(1) equation without lagged yield is similar in the sign of the coefficients and the statistical significance of the variables. There appears to be less remaining autocorrelation in the equation with the lagged yield, but that may be misleading as the Durbin-Watson statistic is biased towards 2.00 when a lagged dependent variables is included.

Californian Avocados

We concentrated on two of the six major varieties: Haas and Fuerte.12/ Most trees have a proclivity to set a heavy crop one year followed by a light crop the next (or no fruit at all). The Fuerte is notorious for the entire grove to skip a year or two of production. The Haas groves have less severe fluctuations since an entire grove may not be affected: some trees skip the first year while others produce that year and skip the next.

Which weather variables are most important is a subject of debate. Wind is a common winter hazard. In the winter of 1982, violent winds caused massive crop loss; while lesser losses have been suffered in other years. Northern counties are more vulnerable to normal wind loss. Severe freezing weather causes losses; but except for 1978, recent winters have been relatively mild.

Approximately 60 percent of bearing acreage is located in and around Fallbrook, Escondido, and Rancho. Another 30 percent is in the area around Oxnard, Ventura, and Santa Barbara (stretching north along the coast to Monterey). Ten percent is in and around the Orange County foothills. A final 1 percent is in the Tulare County foothills. Thus, macro weather variables must be viewed with some suspicion.

Yields are also affected by poor cultural attention, crop blights from insects and pests, diseases, and so forth.13/ Unfortunately, measures of these factors are not available.

Table 2 reports the results for the Haas regressions. It should be noted that there are very few degrees of freedom -- in some cases, only six degrees of freedom.14/ Again, the AR(2) specification dominates the others using the tests described above. While the adjusted R^2 for the OLS regression is 0.31 and only one variable is statistically significant at the 0.05 level; in the

AR(2) equation, the adjusted R2 is 0.81 and three variables are statistically significant. In addition the t-statistics on ρ_1 and ρ_2 are -9.28 and -4.72, respectively. The Durbin-Watson statistic in the AR(2) equation is 1.92 indicating that there is little residual autocorrelation.15/

Neither the wage nor gasoline price variable are statistically significant in the AR(2) equation. Time has a negative sign and a t-statistic of -1.61. The negative sign may reflect adverse moves in disease and other unmeasured variables. The heat and wind variables are statistically significant and negative; but the freeze variable is insignificant. There is no statistically significant difference in the first three age groups, but the last age group seems to have significantly higher yields.16/

Table 3 reports the results for the Fuerte regressions. Again, limited degrees of freedom severely hamper the results. The AR(2) specification dominates the others; however, the Durbin-Watson after adjustment is 2.698 which indicates that all the autocorrelation has not been removed.17/ The only statistically significant effects are the negative impact of wind and the age distribution. Apparently younger and older trees have lower yields than those 15-19.

Alternate Bearing with Missing Variables

Our procedure estimates the degree of autocorrelation. That is, we attempt to explain how much of the alternate bearing fluctuation is due to missing variables. If other important biological or economic variables are left out, the estimated autocorrelation process will change.

For example, with the Hass avocados, the AR(2) specification we use gives a ρ_1 of -1.46 and a ρ_2 of -0.74. The comparable values if the weather variables are left out are -0.364 and 0.037. Leaving out the economic variables (which were statistically insignificant) made no difference.

In the pears regression (without lagged yield), ρ_1 was -0.76. If all the biological and weather variables are left out, the estimated ρ_1 is -0.5578. If the economic variables (wage and gas prices) are left out, $\rho_1 = -0.6825$, which is not statistically significantly different from -0.7295 (which is not surprising since neither economic variable is statistically significant at the 0.05 level). If all variables except the constant and the time trend are left out, $\rho_1 = -0.1818$ (with a t-statistic of -1.01).

Thus, in the case of pears, leaving out relevant variables may lead one to infer that there is less unexplained alternate bearing, rather than more. Possibly the observed weather, biological, and economic effects counterbalance the fluctuations which are due to unobserved variables.

Forecasting

The chief purpose of obtaining better estimating equations is to be able to forecast future yield more accurately. When error terms are autocorrelated, forecasts depend on earlier periods' error terms. We reestimated our Bartlett pears OLS and AR(1) processes over the period 1953–1977 and then simulated the remaining periods.18/

In Table 4, the simulations based on the equations with lagged yield and without are reported.19/ Using any reasonable criterion, such as mean error, root mean square error, or Theil's inequality coefficient, the AR(1) forecasts dominate the OLS forecasts over the entire forecast period, as shown in the table.20/ The OLS forecasts are superior for the first period, but degenerate rapidly in future time periods. Indeed, the OLS yield forecast based on the regression without lagged yield is negative five years in the future.

Conclusions

This paper illustrates that it is possible to calculate how much alternate bearing in a crop is due to unexplained factors, and how much yearly variation is due to known biological and economic factors. The technique is easy to use, and is available on many commonly available statistical packages (e.g., SHAZAM).

The paper also shows that failure to account for obviously relevant economic and biological factors can lead one to either underestimate or overestimate the amount of unemplained alternate bearing behavior. From our survey of some of the economics literature, we believe that the degree of alternate bearing has been either ignored or seriously misestimated in most studies. Use of our proposed method generally leads to more accurate forecasts of future yields.

Appendix

Variable Definitions and Data Sources

Bartlett Pears

Yield: California Bartlett production per bearing acre (California Crop and Livestock Reporting Service, Fruit and Nut Statistics, 1952-1983).

Decline: Percent of Californian trees affected by pear decline (Estimated made by the Bureau of Plant Pathology, California Department of Agriculture and the U. C. Davis Agricultural Extension Service). Note: Pear decline is the major disease (biological factor) that has affected Bartlett yields in California. It is a plant virus that is transmitted by an insect (the pear psyllid). The disease hit 10,000 California trees in 1959, a maximum of 1,110,000 trees were affected in 1962, and the number has fallen since then, with perhaps only 300,000 tree affected in the late 1970s.

Age Groups of Trees: Percent of Bartlett acreage in Caliafornia that is in each (bearing) age group category (California Crop and Livestock Reporting Service, California Fruit and Nut Acreage, 1936-1982). Age Group 1: the first five years of bearing (ages 6-10). Age Group 2: 11-15. Age Group 3: 16-20. Age Group 4: 21-25 (This percentage is calculated assuming that 2 percent of planted acreage is removed every 5 years of aging. This 2 percent was calculated as the average decline rate for acreage between 6 and 20). Age Group 5: 26-30 (assuming a 2 percent decline rate). Group 6: over 30 (assuming a 2 percent decline rate).

December-January Heating Degree Days: Measured in Lakeport, Lake County and Sacramento, Sacramento County as the sum of total degree days for each city (U. S. National Oceanic and Atmospheric Administration, Climatological

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Data, California, 1963-1982). Note: Commercial pear varieties on the Pacific Coast require a period of low temperatures (about 1200 hours below 45° F) during the winter to complete their dormant period.

March-April Average Maximum Temperatures: Measured in Lakeport and Sacramento as the average of the March and April averages for each city (ibid.) Note: Bartletts reach their biggest dessert and best shipping and storage qualities when there are particularly high temperatures for the two months preceding harvest.

Pear Harvest Labor Wage: Deflated (by U. S. GNP deflator) production weighted average labor cost in dollars per hour paid to those harvesting Bartlett pears in Sacramento, Lake, and Mendocino Counties (California Department of Human Resources Development, Farm Labor Report, 1952-1983). Note: In 1982, Sacramento County had 23 percent of bearing acreage, Lake County had 19 percent, and Mendocino County had 13 percent.

GNP Deflator: Set equal 100 in 1972 (Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts of the U. S.).

Gasoline Price: Deflated (by U. S. GNP deflator) average price paid by farmers in California for gasoline, regular, service station in cents per gallon (U. S. D. A., Statistical Reporting Service Agricultural Prices, 1952-1982). Note: this variable serves as a proxy for (pumped) water as well.

Hass Avocados

Yield: Yield per bearing acre of Hass acreage in California (1963-1979: University of California, Division of Agricultural Sciences Leaflet 2356, "Economic Trends in the California Avocado Industry," October 1980; 1980-1982: California Avocado Commission, Annual Reports, 1981-1983).

Age Groups: Percent of Hass acreage in each bearing group (California Fruit and Nut Acreage, op. cit.). Age Group 1: The first five years of bearing (3-7 years). Since the Haas is a relatively new crop in California (since 1960), 65 percent of the Haas average was in this age group. Age Group 2: 8-12. Age Group 3: 13-18. Age Group 4: over 18 (This percentage was calculated assuming that the planted acreage declined 6 percent every 5 years as it ages. This 6 percent figure reflects the average decline rate for trees 3 to 12 years old.)

Freeze: Number of days during the year that the minimum temperature was 32° F or below in Escondido or Santa Paula (Climatological Data, op. cit.). Note: Ventura County, where Santa Paula is located, had 20 percent of California's total avocado bearing acreage in 1982 (Riverside County had 12 percent and Santa Barabara had 9 percent).

Heat: Number of days during the year that the maximum temperature was 100° F or more in Escondido or Santa Paula (ibid.). Note: heat waves (over 100°) cause enough stress to the trees that the fruit will drop.

Wind: Number of days during the year that the wind traveled more than 150 miles, Chula Vista, San Diego County (ibid.). Note: fruit (and sometimes trees) will drop in high winds.

Avocado Harvest Labor Wage: Deflated (by U. S. GNP deflator) average labor cost in dollars per hour paid for harvesting avocados in San Diego County (California Department of Human Resources Development, Farm Labor Report, 1952-82)

Fuerte Avocados

Yield: Yield per bearing acre of Fuerte acreage in California (same source as for Hass).

Age Groups: Percent of California Fuerte acreage in each bearing age group (California Fruit and Nut Acreage, op. cit.). Age Group 1: the first five years of bearing age (5-9). Age Group 2: 10-14. Age Group 3: 15-19. Age Group 4: 20-24 (This percentage was calculated assuming that planted acreage declines 9 percent every five years as its ages, where 9 percent is the average decline rate for trees 5 to 19 years old). Age Group 5: Over 24 years old (assuming a 9 percent decline rate).

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Footnotes

[1]Roy E. Allen is an Assistant Professor of Economics at St. Mary's College and Jeffrey M. Perloff is an Associate Professor Of Agricultural and Resource Economics at the University of California, Berkeley. This research was funded by the Giannini Foundation. Roy Allen was at Berkeley at the time this paper was written. We wish to thank David Zilberman who helped formulate this research project. Giannini Foundation Paper No. .

[2]For example, the Cooperate Extension of the University of California (1975, p. 13) notes, "The yield and quality of fruit (avocados) in any specific orchard are largely influenced by a number of factors, many of which are predetermined when the orchard is planted. These include location and exposure, topography, soil type and depth, water quantity and quality, variety suitability to climate, disease hazard, and climatic conditions of frost, freeze, extreme heat, wind and air pollution."

[3]For example, ibid., goes on to say, "Some of these predetermined factors can be modified or changed to enhance yields, but it is often difficult and costly to do this. Careful and intelligent management can sometimes minimize predetermined problems, and good cultural practices of irrigation, nutrition, disease and pest control are necessary in any orchard to attain high yields."

[4]They note, however, that "Conceptually, production could also be altered by intensification of cultural practices associated with fertilizing, spraying, irrigating and pruning. As a practical matter, these practices seem highly standardaized and not likely to respond to changes in economic conditions." Particularly since there were supply controls in that industry during their period of study, this conclusion seems well-taken.

[5]Maddala (p. 291), warns that such an interpretation of autocorrelation is problematic. If there is a misspecification of X (due to omitted variables), other assumptions, are likely to be violated: $E[e] = 0$, X and e are uncorrelated, and e_t are homoscedastic. We suspect that omitted variables have biased our results below, but until these variables become available, little can be done to calculate the size of the bias.

[6]See Judge, Griffiths, Hill, and Lee (pp. 213-215). A log-likelihood test is used of the hypothesis that the highest-order autocorrelation coefficient is zero. The higher-order processes were estimated using K. White's SHAZAM which employes the maximum-likelihood approach of Pagan (pp. 267-280). Test statistics cited below, therefore, should be viewed as asymptotic.

[7]We also experimented with a measure of the damage caused by pear decline (a virus transmitted by insects). We concluded that the estimates of the number of trees affected during the 1960s and early 1970s were not reliable. Indeed, for the better part of the last decade, a constant number of acres damaged has

been reported in each year. We finally dropped this variable as being too suspect.

[8]We experimented with a Box-Cox specification, which is questionable in the presence of autocorrelation; see Judge, et al. We assumed a first-order autocorrelation specification and estimated that the Box-Cox coefficient was 2.3 while the autocorrelation coefficient -0.78. This estimate is closer to a linear specification for yield (such as reported in Table 1) than a log-linear one. The forecasts based on the Box-Cox model are close to those based on the linear specification. Due to our lack of confidence in the Box-Cox specification with unknown degree of autocorrelation we used the linear specification below.

[9]The likelihood ratio test statistic with both weather variables lagged one period is $\chi^2(2) = 4.09$ ($\chi^2(2) = 5.99$ at the 0.05 level). Neither t-statistic was greater than 1.00.

[10]See Theil about the problems of estimation and forecast when there is a lagged dependent variable and autocorrelation.

[11]The likelihood ratio test statistic is $\chi^2(1) = 1.33$ and the t-statistic on ρ_2 is -1.33.

[12]The other major varieties are the Zutano, Bacon, Pinkerton, and Reed. The Hass accounts for nearly three-quarters of the entire Californian production and brings a premium price.

[13]Good groves with good care will produce up to 20,000 pounds of fruit an acre. In contrast, poor groves may produce 3,000-4,000 pounds of fruit or even none at all. The recent average has been between 4,000-8,000 depending on whether it is a good or bad year.

[14]Data by varieties is only available for the short time period we used. Experiments indicated that we could not properly estimate a yield equation across varieties which would have allowed us to use a longer time period. Because of the limited number of degrees of freedom, we did not experiment with lagged weather and yield values as we did in the pear regressions.

[15]Using the tests described above, we rejected an AR(3) process. We also considered an infinite-order autocorrelation process, which is equivalent to a first-order moving average process, MA(1). Pagan (pp. 267-280) suggests comparing the sum of squared errors not explained by the two models. On this basis, we chose the AR(2) process over the MA(1) process.

[16]Since this crop is relatively new, the older acreages may belong to relatively more sophisticated farmers.

[17]Because of limited degrees of freedom, higher-order autocorrelation processes were difficult to estimate and proved to be unstable.

[18]To save degrees of freedom, the statistically insignificant wage variable was dropped. We did not have enough observations on avocados to estimate over

subperiods.

[19]Where lagged yield is used, the simulations are dynamic: The yield estimated from the previous period is used in each period's forecast. The simulations use the actual values of the other variables.

[20]The Theil inequality coefficient is the ratio of the estimated root mean square error to the root mean square error of a forecast based on the assumption of no change from the previous period.

TABLE 1

California Bartlett Pears, 1952-1983

	OLS		AR(1)[a]		OLS		AR(1)[a]	
	Coefficient	t statistic[b]	Coefficient	t statistic[b]	Coefficient	t statistic[b]	Coefficient	t statistic[b]
Constant	-37.896	-1.82	-36.897	-2.81	-44.150	-2.64	-47.107	-3.42
Time	0.399	1.87	0.505	3.60	0.621	3.41	0.694	4.19
Harvest wage	- 0.776	-0.14	2.097	0.53	1.600	0.37	4.218	1.04
Gas price	- 1.439	-0.43	- 2.343	-1.13	- 0.160	-0.06	-2.239	-1.09
December-January								
Heating degree days	0.0103	2.21	0.007	1.94	0.007	1.91	0.006	1.65
March-April								
Average maximum temperature	0.383	3.91	0.209	2.65	0.271	3.21	0.196	2.54
Share (years)								
6-10	0.033	0.27	0.089	1.39	0.084	0.86	0.127	1.89
11-15	0.028	0.24	0.065	1.11	0.139	1.42	0.123	1.89
21-25	0.107	0.93	0.191	2.97	0.233	2.36	0.270	3.56
26-30	0.281	1.31	0.389	3.06	0.470	2.61	0.540	3.69
30 plus	0.161	1.34	0.238	3.18	- 0.318	2.99	0.351	3.78
Yield lagged					- 0.488	-3.44	- 0.348	-2.17
$\bar{R}^2$	0.57		0.76		0.73		0.88	
Durbin-Watson	3.02		2.21		2.66		2.02	
von Neuman ratio	3.12		2.28		2.76		2.09	
Log likelihood ratio	-44.62		-36.21		-37.04		-33.22	
Standard error of estimate	1.35		1.00		1.07		0.94	
ρ_1			- 0.73	-5.84			- 0.61	-3.41

[a]Maximum likelihood estimation.

[b]t statistic is a two-sided test against the null hypothesis that the coefficient is zero.

TABLE 2

California Haas Regressions, 1965-1982

	OLS		AR(1)		AR(2)	
	Coefficient	t statistic[a]	Coefficient	t statistic[a]	Coefficient	t statistic[a]
Constant	-22,327.0	-1.11	3,585.9	0.18	16,796.0	1.17
Time	- 387.3	-0.93	- 447.88	-1.14	- 512.98	-1.61
Harvest wage	13,282.0	1.51	3,438.8	0.39	- 2,408.6	-0.35
Gas price	- 2,653.7	-0.43	708.37	0.39	738.27	-0.16
Heat	- 5.78	-0.04	- 152.08	-1.58	- 220.91	-4.42
Wind	- 31.17	-0.18	- 164.44	-1.24	- 173.93	-2.31
Freeze	- 19.52	-0.24	- 4.59	-0.10	- 0.65	-0.02
Share (years)						
3- 7	80.28	0.53	64.28	0.49	88.83	0.93
13-18	230.84	1.41	73.96	0.59	16.72	0.22
18 plus	490.29	2.87	373.08	2.70	371.92	4.23
R^2	0.31		0.61		0.81	
Durbin-Watson	2.59		2.33		1.92	
von Neuman ratio	2.74		2.46		2.03	
Log likelihood ratio	- 158.75		- 154.04		- 148.48	
Standard error of estimate	2,454.8		.1,850.0		1,283.3	
ρ_1			- 0.735	-4.59	- 1.462	-9.28
ρ_2					- 0.744	-4.72
Covariance					0.021	
θ_1					- 0.839	
θ_2					0.482	

[a]t statistic is a two-sided test against the null hypothesis that the coefficient is zero.

TABLE 3

California Fuerte Avocados, 1964-1982

	OLS		AR(1)		AR(2)	
	Coefficient	t statistic[a]	Coefficient	t statistic[a]	Coefficient	t statistic[a]
Constant	18,875.0	0.42	12,909.0	0.53	27,724.0	1.93
Time	- 1,136.4	-0.82	- 99.54	-0.11	95.06	- 0.19
Harvest wage	8,478.9	1.00	511.48	0.08	- 2,748.3	- 0.65
Gas price	3,545.0	0.43	3,724.4	0.71	- 848.17	- 0.23
Heat	60.49	0.33	- 19.25	-0.20	- 19.42	- 0.41
Wind	96.80	0.46	- 175.93	-1.36	- 273.10	- 3.88
Freeze	- 58.66	-0.57	- 19.25	-0.72	- 37.17	- 1.04
Share (years)						
5- 9	38.04	0.11	- 247.76	-1.30	- 367.79	- 3.39
10-14	- 329.46	-0.47	- 96.23	-0.25	- 320.57	- 1.38
20-24	- 126.77	-0.47	- 103.58	-0.65	- 246.00	- 2.13
24 plus	77.48	0.54	- 12.67	-0.13	- 116.05	- 1.50
$\bar{R}^2$	- 0.414		0.43		0.77	
Durbin-Watson	3.06		2.77		2.70	
von Neuman ratio	3.23		2.93		2.85	
Log likelihood ratio	- 169.65		- 161.69		- 154.25	
Standard error of estimate	2,815.0		1,793.9		1,144.5	
ρ_1			- 0.836	-6.64	- 1.582	-10.70
ρ_2					- 0.765	- 5.18
Covariance					0.020	
θ_1					- 0.896	
θ_2					0.653	

[a]t statistic is a two-sided test against the null hypothesis that the coefficient is zero.

TABLE 4

California Pear Forecasts, 1978-1982

Year	Observed yield	Predicted value OLS	Predicted value AR(1)	Mean error (actual minus predicted) OLS	Mean error (actual minus predicted) AR(1)	Root mean square error OLS	Root mean square error AR(1)	Theil inequality coefficient OLS	Theil inequality coefficient (AR(1)
		Dynamic simulation of regressions with lagged yield							
1978	7.7	8.38	9.84	-0.68	-2.14	0.46	2.14	0.36	1.65
1979	10.9	9.70	11.72	0.26	-1.48	0.97	1.62	0.60	0.99
1980	11.2	7.71	11.17	1.34	-0.98	2.17	1.32	1.17	0.72
1981	12.3	7.91	11.16	2.10	-0.45	2.89	1.28	1.26	0.56
1982	10.8	6.15	10.34	2.61	-0.27	3.32	1.16	1.51	0.53
		Static simulation of regressions without lagged yield							
1978	7.7	7.88	9.59	-0.18	-1.89	0.18	1.89	0.14	1.46
1979	10.9	6.80	11.35	1.96	-1.17	2.90	1.37	1.78	0.84
1980	11.2	0.85	12.29	4.76	-1.14	6.43	1.29	3.50	0.70
1981	12.3	0.36	12.42	6.55	-0.89	8.16	1.12	3.55	0.49
1982	10.8	-3.33	12.79	8.07	-1.11	9.66	1.34	4.38	0.61