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A MODEL OF SUPPLY RESPONSE IN THE AUSTRALIAN ORANGE GROWING INDUSTRY*

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A model of the Australian orange growing industry to explain changes in plantings, removals, the number and age composition of trees and orange production is developed and estimated. Most of the variation in plantings is explained by the expected profitability of growing oranges, the current stocks of bearing and nonbearing trees, and removals of trees last year. Estimates of the elasticities of response of plantings and production to price changes are low and there are long time lags. An illustrative application of the model projects future developments in the industry for alternative assumptions about the profitability of growing oranges.

Introduction

A model of supply response in the Australian orange growing industry is developed to try to assess, at the aggregate level, the effects of changes in prices for oranges received by growers on tree numbers and production of oranges. This study was precipitated by the IAC Inquiry into the level of protection which should be afforded domestic production of citrus, mainly oranges.

Initially the objective was to estimate the aggregative effects on tree numbers and production of oranges, of price changes arising from alternative levels of tariffs on imports of orange juice concentrate. Disaggregated estimates for each major variety of oranges (navel and valencia) by the major producing regions would certainly be more useful in some policy problems and, in addition to the aggregate estimates, would be valuable to businesses providing inputs to the industry, orange producers, businesses using oranges as an input, and the IAC.

Unfortunately, modelling supply response of perennial crops, especially in developed economies, has been a comparatively neglected field. The little work which has been done in the area – notably French and Bressler (1962), French and Matthews (1971), and Baritelle and Price (1974) in the U.S.A., and Rae and Carman (1975) in New Zealand – has suffered from theoretical difficulties and, invariably, data problems. This study is no exception. Also, in an Australian context, the Bureau of Agricultural Economics (1970) could not identify supply response to changes in profitability (or expected profitability) for any of nine perennial crops including citrus, and had to ignore this variable in formulating supply projections. There are severe limitations on data pertinent to modelling supply response in the Australian orange industry. As a consequence of this and the theoretical problems, only an aggregated model

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was attempted; but if suitable data were available, estimates could be obtained by region and by variety simply by duplicating the estimating procedure.

The principal objective of this study, then, is as a tentative step to quantify a supply response model for an Australian perennial crop. The results are of some, albeit limited, usefulness for appraisal of alternative tariff policies.

Modelling supply response of perennial crops requires careful attention to the time dimension associated with long gestation periods from planting to bearing and the extended life of trees. A general approach to the analysis of supply response for perennial crops was reported by French and Matthews (1971). This framework, with modifications, has been applied by others, including Rae and Carman (1975).

Whilst building on the French and Matthews framework, the model developed here differs in several important respects. Investment in trees is treated in a framework of input demand in which greater attention is paid to the influence of the age composition of orchards on planting decisions. Four alternative hypotheses concerning the process of adjustment are empirically evaluated, and separate plantings and removals equations are estimated. Specification and estimation of a plantings equation are emphasised, with the addition of removals and yield equations and a number of identities to complete the model.

In the paper a stepwise development of a model is presented. The model is estimated for aggregate data for the Australian orange industry[1], and an illustrative application of the estimated model is reported. Development of the model proceeds from a demand function for a desired input of services of trees, an investment model, to a derived function for plantings. The general forms of the empirical models for estimating functions for plantings, removals, and yields of trees are summarised below.

Plantings:

$$PL_t = a_0 + a_1\Pi_t^e + a_2 NB_{t-1} + a_3 B_{t-1} + a_5 R_{t-1} + v_t.$$

Yields:

$$Y_t = g_0 + g_1 K_t + g_2 T_t + h_t.$$

Removals:

$$R_t = dB_t + w_t.$$

In the above equations, PL_t is the number of trees planted in year t (thousands), Π_t^e is expected profitability of growing oranges in year t, measured as revenue per bearing tree, deflated by an index of costs (\$), NB_{t-1} is the number of nonbearing trees in year $t-1$ (thousands), B_{t-1} is the number of bearing trees in year $t-1$ (thousands), R_{t-1} is the number of trees removed during year $t-1$ (thousands), Y_t is the average yield per bearing tree in year t, K_t is the proportion of bearing trees of age less than ten years in year t, T_t is a time trend variable, R_t is the number of trees removed during year t (thousands), B_t is the number of bearing trees in year t (thousands), a_0, a_1, a_2, a_3, a_5, g_0, g_1, g_2, and d, are the parameters of the models, and v_t, h_t, and w_t are random disturbance terms.

[1] In practice the aggregate approach assumes away potentially important inter-regional, inter-state, and inter-varietal differences, and problems of aggregation are ignored.

Annual data for the period 1961/62 to 1975/76 are used to estimate the functions. Projections of plantings, tree numbers and output of oranges for 30 years from 1974/75 are made for a range of farm-gate prices for oranges.

Input Demand Model

Orange trees are durable resources which provide flows of services as inputs to the production of fruit. Trees of different ages provide different time patterns of services. Then, the aggregate annual flow of services of trees of different ages can be represented as:

$$S_t = \Sigma_i s_i N_{i,t}, \tag{1}$$

where S_t is the aggregate flow of services of the orchard in period t,
s_i is the flow of services provided by a tree aged i years, and
$N_{i,t}$ is the number of trees of age i at the start of year t.

Holding technology, weather, and the level of use of all other inputs constant, the yield of any tree is directly proportional to its service flow coefficient (s_i). The coefficients, then, could be estimated from data on the relation between tree ages and their yields. However, the service flow coefficients are for analytical convenience only, and their estimation is not necessary.

It is assumed that producers have a desired level of the aggregate flow of orange tree services. The desired level is that which maximises expected profits given current values of producers' expectations of 'normal prices' of outputs and inputs and of the technical production constraints. For reasons of simplicity and the unavailability of data, it is necessary in a practical context to omit some potential explanatory variables. In this study the opportunity returns from alternative activities are omitted. Over the several orange growing areas there is a diversity of alternative activities and no meaningful variable, applying to the aggregate, seems possible. It is likely that only a small specification bias, if any, will arise from this omission.[2] The desired flow of services is assumed to be influenced primarily by the expected profitability of growing oranges. This compound variable includes expectations of the price of oranges and the cost of inputs, and technology in terms of yields per orange tree. Then, assuming a linear function:

$$S_t^* = b_0 + b_1 \Pi_t^e + u_t, \tag{2}$$

where S_t^* is the desired flow of services of orange trees,
Π_t^e is expected profitability from growing oranges, and
u_t is a random error term for all other explanatory factors, and is assumed $N(0, \sigma^2)$.

A number of alternative models of how expected profits, Π_t^e, might be represented in terms of observable variables, including current and previous levels of profits, $\Pi_t, \Pi_{t-1}, \ldots . \Pi_{t-r}$, have been discussed in the

[2] Thiel (1971, pp. 548–62) discussed the biases which arise where variables are omitted. He concluded that there is zero specification bias where the excluded variable is uncorrelated with any of the included variables. Although this condition is unlikely to be perfectly fulfilled in most real-world circumstances, it may well be approximately so. There is no prior reason to suspect a high degree of correlation between the opportunity costs of alternative products and the other variables which are considered in the model.

literature and tested in other studies.[3] Unfortunately there are no compelling arguments or results favouring one particular model. In this study, experiments were performed varying the period using simple moving average models. That is, expected profit is represented by:

$$\Pi_t^e = (1/n)\sum_{j=1}^{n} \Pi_{t-j}, \qquad n \geq 2 \tag{3}$$

where $\Pi_h = P_h Y_h / W_h$ is actual real profit in period h with P_h being price of oranges ($/t), Y^h being yield of oranges (t/tree), and W^h being the index of input costs (average weekly earnings).

The length of the moving average, n, was varied from two years — long enough to average out the effects of biennial yield fluctuations — to six years. Statistical criteria were used to select the preferred value.

Investment Model

As a corollary to other studies of the demand for durable goods (see, for example, Griliches 1959, 1960)), it is assumed that the decision to invest in orange trees is influenced by the desired flow of services, the expected flow of services from the current stock of trees, and costs of adjustment.

As an approximation, it is assumed that the desired level of investment is given by the discrepancy between the desired level of services as defined in (2) and the expected level of services to be provided by existing trees in a current or near future year of concern to producers. The latter is in part an analytical device, but it does have some intuitive appeal, given the longevity and age-specific productivity of fruit trees. The expected supply of services in a future period as envisaged in the current period is defined in terms of tree numbers and removals by age category. In algebraic terms:

$$S_{t+b}^e = \Sigma_i z_i (N_{i,t-1} - R_{i,t-1}), \tag{4}$$

where S_{t+b}^e is the expected level of services to be provided in year $t+b$ from existing trees,

$N_{i,t-1}$ is the number of trees of age i at the start of year $t-1$,

$R_{i,t-1}$ is the number of trees of age i removed during year $t-1$, and

$z_i (= Pr(i, b) s_{i+b+1})$ is the expected service value of trees age i in year $t-1$ with $Pr(i, b)$ being the probability that a tree of age i will survive to an age $i+b+1$ and s_{i+b+1} is the service value of a tree age $i+b+1$ as defined earlier.

Thus S_{t+b}^e measures the expected aggregate flow of services in $t+b$ as envisaged from the year t, precluding the effects of current or future plantings but taking account of expected removals in the intervening years implicitly through z_i. It is conceivable that producers may also have expected future plantings which they take into account in making current

[3] French and Matthews (1971) experimented with geometrically declining weights on past observations of prices but found that a simple two-year average proved statistically superior in all their models. Other authors who used simple averages include Chan (1962) and Saylor (1974). In studies of perennial crops in developing countries a simple lagged value of the price variable has often been used. For examples see Singh and Rao (1974). Maitha (1969) used a Fisher lag scheme to assign unequal weights to past events and experimented with the form of the lag. Baritelle and Price (1974) used a polynomial lag model.

plantings decisions. However, it is assumed that they attempt to make all of the desired adjustment to the particular disequilibrium of concern in the current period. Like s_i, z_i is for analytical convenience only and is not estimated directly.

In empirical work, because there exist separate data on tree numbers for only a few age classes of trees, it is possible to consider only a few age categories. Considering only three age classes of trees, equation (4) reduced to:

$$S^e_{t+b} = z_n NB_{t-1} + z_y YB_{t-1} + z_m MB_{t-1} - z_r R_{t-1}, \tag{5}$$

where NB_{t-1} is the number of nonbearing trees (defined in ABS statistics as 0–4 years),

YB_{t-1} is the number of young bearing trees (trees 5–9 years and measured as $YB_t = NB_{t-5}$),[4]

MB_{t-1} is the number of mature bearing trees (trees 10 years and older and measured as $B_{t-1} - YB_{t-1}$ with B_{t-1} being total bearing trees),

R_{t-1} is number of trees removed in year $t-1$, and

z_n, z_y, z_m, z_r are defined analogously to z_i above.

Then, the desired gross investment in the provision of orange tree services is given by:

$$I^*_t = S^*_t - S^e_{t+b}, \tag{6}$$

where I^*_t is the desired level of investment,

S^*_t is the desired level of services as defined in (2), and

S^e_{t+b} is the expected level of services to be provided in the target year by existing trees as defined in (5).

Changes in investment could be affected by both changes in tree plantings and tree removals. In principle the two should be treated as a joint optimisation problem. However, for simplicity and as a plausible assumption, it is argued that removals are determined independently of the desired investment and are influenced primarily by the age composition of the trees and by seasonal conditions. This assumption is based on theoretical arguments, 'expert industry sources', and the results of three empirical studies. The supporting arguments are detailed in Alston (1978). In summary, producers are reluctant to pull out healthy trees even in the face of severe falls in profitability[5], and, in view of asset fixity arguments and the high cost of establishing orange trees, it is unlikely that observable fluctuations in returns, at least those over the sample period, would greatly influence removal decisions relative to the influences of age and seasonal conditions. The applied work by Curran

[4] This crude procedure, which was also used by French and Matthews (1971) and the BAE (1977), might be extended to estimate the numbers in additional age classes. However, it is less likely to be valid for older age classes and there is a loss of data and degrees of freedom involved in both the calculation of each additional age class and the inclusion of additional variables in the empirical equation. The three age classes included are the ones most likely, on prior grounds, to exhibit significant differences. Fortunately, in the analysis, this procedure and its underlying assumption became redundant because the coefficients of bearing trees in the different age classes were not significantly different from each other.

[5] Discussions with some growers and officers of the Victorian Department of Agriculture support this argument, but the sample of opinion could not be said to constitute a random or even a representative sample.

and Nichols (1972) on clingstone peaches, by Etherington (1977) on rubber trees, and by French and Bressler (1962) on lemons, lends empirical support to this assumption. Then, the investment decision is reflected in the plantings decision.

Plantings Model

The demand for desired plantings is a discontinuous function: it equals the desired gross investment if it is positive and is zero if the desired gross investment is zero or negative. That is (with a unit of plantings defined so that it contributes a unit to expected services), the demand for desired plantings is expressed as:

$$PL_t^* = I_t^* = S_t^* - S_{t+b}^e \qquad \text{if } S_t^* > S_{t+b}^e, \tag{7}$$

where PL_t^* is desired plantings in t.

Where desired gross investment in aggregate is zero or negative, equation (7) is inappropriate. The assumption of a positive value for the aggregate desired planting is carried through the remainder of the algebra for the development of the plantings model.[6]

In discussing the adjustment process it is helpful to decompose (7) as:

$$PL_t^* = (S_t^* - S_{t-1}) + (S_{t-1} - S_{t+b}^e - z_r R_{t-1}) + z_r R_{t-1}, \tag{8}$$

where $S_t^* - S_{t-1}$ is the demand for plantings for net investment,
$S_{t-1} - S_{t+b}^e - z_r R_{t-1}$ is the demand for plantings for replacement of expected changes in the services of trees between t and $t+b$ (due to changes in the number and age composition of trees), and
$z_r R_{t-1}$ is the demand for replanting to replace trees removed in the previous year.

The next step requires moving from a desired to an actual plantings model and consideration of adjustment costs. In the absence of strong *a priori* knowledge, four types of models will be evaluated. The first assumes complete adjustment, i.e. actual plantings equal desired plantings. The other models assume that adjustment costs are important factors and that in any one period there is partial adjustment only.[7]

Complete adjustment

If complete adjustment is assumed, the empirical form for the plantings model is derived by substituting into equation (8) for S_t^* from equation (2) and for S_{t+b}^e from equation (5), and consolidating terms as:

$$PL_t = b_0 + b_1 \Pi_t^e - z_n NB_{t-1} - z_y YB_{t-1} - z_m MB_{t-1} + z_r R_{t-1} + u_t, \tag{9}$$

where Π_t^e is expected profitability of growing oranges as envisaged from the year t,
NB_{t-1}, YB_{t-1}, MB_{t-1} and R_{t-1} are, respectively, the numbers of trees in the age classes non-bearing, young bearing, and mature

[6] Given that our model is estimated with aggregate data, it is unlikely that $\hat{PL}_t$ would be zero because this would require a zero level of plantings for all farmers that make up the aggregate. Even so, as discussed in footnote 8 below, our assumption means, at least at the strictly theoretical level, that the error term of the estimated model will not be normally distributed but rather as a truncated normal. While this problem is ignored, it does mean that the statistical tests are approximate only.

[7] At a theoretical level and following Griliches (1959), it is assumed that the investment cost function is a quadratic function and that the loss of profits due to incomplete adjustment also is a quadratic function.

bearing, and the number of trees removed, during the year $t-1$, as defined above,
b_0 and b_1 are the parameters of the demand for desired stocks, z_n, z_y, and z_m are the coefficients for contributions to expected future services for trees in the different age classes,
z_r is defined analogously for trees removed during $t-1$, and
u_t is the random disturbance term in the equation for the demand for desired stocks.

Three alternative plantings models are derived by applying a partial adjustment process of the form $\gamma(x_t^*-x_{t-1})$ — where γ is the partial adjustment coefficient, x_t^* is the desired level and x_{t-1} is the actual level of the previous period — to different subsets of the components in the right-hand side of equation (8).

Partial adjustment on net investment

Following the investment studies by Chow (1960) and Griliches (1960) for U.S. automobiles and tractors, respectively, the second model assumes there are adjustment costs on net investment only, i.e. partial adjustment of $S_t^*-S_{t-1}$ and complete adjustment for the second and third right-hand terms of equation (8).

After substituting in equation (8) for S_t^* and S_{t+b}^e with equations (2) and (5), applying partial adjustment to $S_t^*-S_{t-1}$ and consolidating terms, the plantings model is:

$$(10)\quad PL_t = \gamma b_0+\gamma b_1\Pi_t^e+\{(1-\gamma)s_n-z_n\}NB_{t-1} +\{(1-\gamma)s_y-z_y\}YB_{t-1}+\{(1-\gamma)s_m-z_m\}MB_{t-1} +z_rR_{t-1}+\gamma u_t,$$

where γ is the coefficient of adjustment, $0<\gamma\leq 1$,
s_n, s_y, and s_m are, respectively, the average service flow coefficients applying to nonbearing, young bearing, and mature bearing trees, defined analogously to s_t, and all other terms are as defined above.

Partial adjustment on net and replacement investment

The third model assumes partial adjustment for both net investment and the replacement of expected losses in services of trees between now and the target period, i.e. partial adjustment of $S_t^*-S_{t+b}^e-z_rR_{t-1}$. Applying this partial adjustment model to equation (8) after substitution for S_t^* and S_{t+b}^e with equations (2) and (5), and consolidating terms, gives:

$$(11)\quad PL_t = \phi b_0+\phi b_1\Pi_t^e-\phi z_nNB_{t-1}-\phi z_yYB_{t-1}-\phi z_mMB_{t-1}+z_rR_{t-1}+\phi u_t,$$

where ϕ is the coefficient of adjustment, $0<\phi\leq 1$, and all other terms are as previously defined.

Partial adjustment on all investment

A fourth model, and this is the one used by French and Matthews (1971), assumes that adjustment costs affect all new plantings in such a way that actual plantings are a fixed fraction of desired plantings, i.e. partial adjustment of all right-hand terms of (8). After substituting equations (2) and (5) for S_t^* and S_{t+b}^e, and multiplying through the right-hand side by the partial adjustment coefficient (ψ), equation (8) becomes:

$$(12)\quad PL_t = \psi b_0+\psi b_1\Pi_t^e-\psi z_nNB_{t-1}-\psi z_yYB_{t-1}-\psi z_mMB_{t-1}+\psi z_rR_{t-1}+\psi u_t,$$

where ψ is the coefficient of adjustment, $0 < \psi \leq 1$ and all other terms are as previously defined.

All of the models represented in equations (9), (10), (11) and (12) result in precisely the same reduced form equation for estimation:

$$(13) \qquad PL_t = a_0 + a_1\Pi_t^e + a_2 NB_{t-1} + a_3 YB_{t-1} + a_4 MB_{t-1} + a_5 R_{t-1} + v_t,$$

where the variables are as defined above, and v_t is a disturbance term which is interpreted as u_t, γu_t, ϕu_t, and ψu_t for the different models. Given that u_t is defined as $N(0, \sigma^2)$, then the reduced form disturbance will be a normal random variate.[8] The structural coefficients of the reduced form equation can be interpreted in four ways according to the four models of the process of adjustment, as shown in Table 1.

TABLE 1

Implied Structural Coefficients for Four Adjustment Models from Estimated Coefficients of Reduced Form Plantings Function

Reduced form coefficient	Implied structural coefficients			
	Complete adjustment	Incomplete adjustment of net investment[a]	Incomplete adjustment on all but last year's removals	Incomplete adjustment on all plantings
a_0	b_0	γb_0	ϕb_0	ψb_0
a_1	b_1	γb_1	ϕb_1	ψb_1
a_2	$-z_n$	$(1-\gamma)s_n - z_n$	$-\phi z_n$	$-\psi z_n$
a_3	$-z_y$	$(1-\gamma)s_y - z_y$	$-\phi z_y$	$-\psi z_y$
a_4	$-z_b$	$(1-\gamma)s_m - z_m$	$-\phi z_m$	$-\psi z_m$
a_5	z_r	z_r	z_r	ψz_r
v_t	u_t	γu_t	ϕu_t	ψu_t

[a] Assumes $S_{t-1} = s_n NB_{t-1} + s_y YB_{t-1} + s_m MB_{t-1}$

Empirical Plantings Function

Data on plantings and removals used in estimating the parameters of the plantings function (13) had to be generated. Details of the procedure and data sources are given in the Appendix. In effect, the variables *PL* and *R* are measured with error so that we have an errors in variables model. This means that the estimated parameters using the OLS procedure will be biased. However, on the basis of theoretical considerations

[8] For simplicity we ignore the constraint that plantings must be non-negative. Where plantings are measured with error, this constraint has implications for the error terms in the statistical equation. An estimate of plantings is defined as: $\hat{PL}_t = PL_t + e_t$, where $\hat{PL}_t$ is the estimate of plantings and e_t is a random normal deviate. In the empirical model the constraint is applied as $\hat{PL} > 0$ and when this constraint is applied there is a constraint on the error distribution such that $e_t < \hat{PL}_t$. The assumption of normality is necessary to justify only certain tests and for the construction of confidence intervals. Malinvaud (1970, pp. 93–100) discussed the role of the assumption of normality. He concluded that, when the assumption is violated, the parameter estimates still have BLUE properties, and that, if the errors are not normally distributed but have a variance, it is generally true that only trivial errors are made in the powers or levels of significance if we retain the formulae which are strictly applicable in the case where the errors are normal.

and experimentation with different ways of generating the data, it seems likely that the biases will not be of much importance.[9]

In the Appendix the potential biases are examined and it is shown that the coefficient of removals (a_5) will be biased towards unity, but the bias approaches zero as the true value of a_5 approaches unity and as the measurement error variance approaches zero. The direction of bias of the other coefficients will depend on the correlation between the variable for removals and the other variables, with there being no bias if the two sets of variables are orthogonal.

Equation (13) was estimated by OLS using annual data for the period 1961/62 to 1975/76.[10] In the preferred model, expected profitability was represented by the five-year moving average of past profitability levels. It was found that the estimated coefficients on young bearing trees and mature bearing trees were not significantly different from each other. Thus a simpler model aggregating these variables into a variable for all bearing trees was estimated.

The preferred estimated function is:

$$(14)\quad PL_t = \underset{(266)}{1677} + \underset{(2122)}{8277}\Pi_t^e - \underset{(0.05)}{0.29}NB_{t-1} - \underset{(0.05)}{0.43}B_{t-1} + \underset{(0.06)}{1.00}R_{t-1}$$

$$\bar{R}^2 = 0.97, \qquad \text{D.W.} = 2.39$$

where PL_t is number of trees planted (10^3),

$$\Pi_t^e = 0.2(\Pi_{t-1} + \Pi_{t-2} + \Pi_{t-3} + \Pi_{t-4} + \Pi_{t-5})$$

is expected profitability in dollars per tree,

Π_{t-i} = actual profitability, given by revenue per bearing tree deflated by average weekly earnings in the year $t-i$, \$/tree,
NB_{t-1} is the number of nonbearing trees (10^3),
B_{t-1} is the number of bearing trees (10^3), and
R_{t-1} is the number of trees removed (10^3).
The terms in brackets are estimated standard errors.

The empirical model in equation (14) has quite satisfactory statistical properties. The model explains a high proportion of the variation in the plantings data, the hypothesis of positive first-order autocorrelation is rejected at the 5 per cent confidence level and the test for first-order autocorrelation is inconclusive. Importantly, the estimated coefficients are all estimated as significantly different from zero at the 1 per cent level at least. The signs on the estimated coefficients are all consistent with prior expectations from theory. The coefficients of bearing and nonbearing trees show that bearing trees make a greater contribution to expected service flows than younger, nonbearing, trees and therefore have a greater depressing effect on plantings. On the basis of the relative sizes of the estimated coefficients on numbers of bearing trees and numbers of trees removed, and using the structural interpretations in Table 1, both the complete adjustment model and the model with partial adjustment of all plantings can be rejected. They would imply that $z_r > z_b$, i.e. that the

[9] Specifically, the explanatory variable 'estimated removals', $\hat{R}_{t-1} = R_{t-1} + e_t$, will be correlated with the error term, $v_t = (1-a_5)e_t + a_6 u_t$, where e_t is the unknown error in estimating plantings and removals. The estimated coefficient on R_{t-1} will be smaller the smaller the variance of the measurement error e_t and the closer to unity is the true parameter on the removals variable.

[10] Complete details on the different models estimated are given in Alston (1978).

service value of trees being removed is double that of bearing trees, and that producers would remove their better trees whilst retaining less productive trees. In the case of the other two models, the estimated coefficients are not inconsistent with prior knowledge. However, it is not possible to choose one in preference to the other. They both suggest some degree of partial adjustment of actual towards desired plantings, particularly with respect to net investment, and that most of the trees removed are replaced in the next year.

It is not possible, nor necessary, to identify either s_i, z_i, or the coefficient of adjustment for either the second or the third adjustment model from the empirical model. However, both s_i and z_i are expected to have positive signs and the empirical estimates are consistent with this for both models under a range of values of s_i, z_i, and γ for the second model and for z_i and ϕ for the third model.

In summary, most of the variation in plantings of orange trees over the sample period is explainable in terms of shifts in the expected profitability of growing oranges, the numbers of nonbearing and bearing trees, and trees removed in the previous period.

Removals Function

It is assumed that tree removals are determined primarily by the number and age distribution of trees in interaction with seasonal conditions. Useful measures of seasonal variables and data on the age distribution of trees, particularly in the older age classes which are expected to have highest removal rates, are not readily available.

A number of procedures for estimating data on the age distribution of trees were considered.[11] None of these were appropriate and it was decided to use a crude procedure for the removals relationship to complete a model for predictive purposes and to test the sensitivity of the predictive model to this procedure.

A simplistic function is:

$$R_t = dB_t + w_t, \tag{15}$$

where R_t is the number of trees removed,
B_t is the number of bearing trees, and
w_t is a random disturbance term assumed to be normally distributed with mean zero and constant variance.

The normal or average removal rate d in (15) can be calculated as the sum of removals occurring over a number of years divided by the sum of numbers of bearing trees in those years. Using this procedure over 1934/35 to 1974/75, the removals equation is estimated as:

$$R_t = 0.0415B_t + w_t. \tag{16}$$

[11] One possible approach is to impute data on tree numbers in the older age classes from data on plantings and tree numbers in the distant past. This would require either a quite unrealistic assumption of constant or zero removal rates for trees in different age classes over quite long periods of time, or the artificial construction of some type of population 'decay curve' for which information is not available. More importantly, there is a loss of data and degrees of freedom in the calculation of such data. For example, to calculate the number of trees of age 60 years in one year, and orange trees often survive in excess of 60 years, requires at least 60 years of previous data. Such data were not available. Also, the data of annual removals were measured with errors which could not be eliminated as was possible with the plantings data.

On average, just over 4 per cent of bearing trees are removed each year, similar to French and Bressler's (1962) estimate of an annual removal rate of 4.5 per cent in the California lemon industry.

Yield Function

Average yield per bearing tree might vary with the age composition of trees, with seasonal conditions, with technology, and in response to changes in expectations of profits. According to industry sources (see footnote 5), the most critical variables influencing yields over time are improvements in genetic quality of trees and planting densities, weather conditions, alternate bearing and tree ages.

Although in theory short-run movements in expectations of profits or prices would be expected to influence yields (through, say, changes in intensity of fertiliser use) this variable is excluded from the model for two reasons. Firstly, growers tend to standardise cultural practices. Secondly, and as a practical issue, prices in any year are a function of yields in that year through the demand; and through alternate bearing relationships there is thus a high positive correlation between prices in the previous year and yield in the current year which is not due to a supply response to short-run price movements. Because of substantial climatic variability between different growing areas, it is difficult to construct a meaningful index of seasonal conditions at the aggregate level. For similar reasons it is not easy to include explicit allowance for biennial yield fluctuations.

Although, for the reasons above, the effects of producers' expectations, weather, and alternate bearing were not explicitly accounted for, the yield model includes variables to represent technology and age distribution effects. A linear time trend was included to capture secular variation in yields due to improvements in technology and the quality of inputs although, because there is only scanty evidence on the extent of denser plantings, there was no other explicit allowance for the effect of changes in planting densities.[12] Because of data limitations, only two age categories of trees are considered; trees from 5 to 10 years old and trees older than 10 years. Then, the simplified yield function is:

$$Y_t = g_0 + g_1 K_t + g_2 T_t + h_t, \tag{17}$$

where Y_t is the average yield of oranges per bearing tree (t/tree),
$K_t = (YB_t/B_t)$ is the proportion of bearing trees less than 10 years old,
T_t is a linear time trend (1938/39 = 1) and,
h_t is a random term reflecting the effects of seasonal conditions and other omitted variables.

Using OLS and data for 1938/39 to 1975/76, the average yield equation is estimated as:

[12] A more complete model might include variables to account for the effects of changes in planting densities on yields. Recently the trend has been to 'double plant' orange trees at the higher density of 376 trees per hectare instead of the traditional 188 trees per hectare. Although maximum yields per hectare are not greatly altered, the denser plantings produce up to 50 per cent more fruit in the first 10 years after planting, due to achieving commercial and maximum yields at earlier ages. Data are not available on the extent of double plantings in recent years. Rae and Carman (1975) have developed a method for accounting for such technological changes within a French-Matthews supply model for perennial crops.

$$Y_t = 0.0383 - 0.082K_t + 0.0015T_t \quad (18)$$
$$(0.0043)\ (0.021)\ (0.0001)$$
$$\bar{R}^2 = 0.83, \quad \text{D.W.} = 1.73$$

The estimated equation indicates the important role of technological change in raising average yields over time and it gives the desired result that mature-age bearing trees give a higher yield than young-age bearing trees. (That is, the higher is K_t, the proportion of young bearing trees, the lower is average yield.)

Complete Model

Sufficient information is available to complete the model for use for projection purposes and for policy analyses. The estimated equations for numbers of tree plantings, tree removals, bearing trees, nonbearing trees, and total trees are, respectively:

$$PL_t = 1677 + 8277\Pi_t^e - 0.29NB_{t-1} - 0.43B_{t-1} + R_{t-1} + v_t, \quad (19)$$
$$R_t = 0.0415B_t + w_t, \quad (20)$$
$$B_t = B_{t-1} + PL_{t-5} - R_{t-1}, \text{ and} \quad (21)$$
$$NB_t = NB_{t-1} + PL_t - PL_{t-5}. \quad (22)$$

Producers' expected profits are given by:

$$\Pi_t^e = 0.2\sum_{j=1}^{5} \Pi_{t-j}, \quad (23)$$

with actual profit given by

$$\Pi_t = P_t Y_t / W_t. \quad (24)$$

Average yields per bearing tree are given by

$$Y_t = 0.0383 - 0.082K_t + 0.0015T_t + h_t. \quad (25)$$

Finally, total production is given by

$$Q_t = Y_t B_t. \quad (26)$$

Given initial data for plantings, nonbearing trees and bearing trees and exogenous figures for prices[13] and costs, the model can be solved recursively for plantings, numbers of trees and production.

The model may be applied in a stochastic or nonstochastic version. The former would require generation of values for the error terms v_t, w_t, and h_t. For the nonstochastic version, the error terms would be held constant at their expected value of zero. This procedure is adopted below. Projections in this context refer to normal conditions and, in particular,

[13] A more sophisticated model might include equations to predict prices as functions of supply of oranges and demand for oranges for processing and fresh consumption. French and Bressler (1962) included an equation to predict prices in their model of the California lemon industry. However, there have been large shifts in demand for oranges in recent years and it was considered unlikely that a satisfactory model for prediction of prices received by growers could be achieved by statistical analysis of past data. The BAE (1977) has attempted to explain variations in prices received by growers, using a model which includes, as explanatory variables, (a) total production of oranges, (b) the FISCC minimum price for oranges, (c) a dummy variable for alternate bearing, (d) population, and (e) a time trend. Although the model had satisfactory statistical properties, it was fitted to data prior to 1973/74, before important structural changes in demand occurred and before world prices began to have important influences on Australian prices. Therefore this model is considered unsatisfactory for purposes of prediction beyond 1974/75.

abstract from the effects of seasonal fluctuations on yields and the effects of a number of variables on removals.

Validation of the Model

To validate the model, a recursive simulation of supply response was carried out over the sample period. Two sets of simulation were followed; firstly, using the actual removals data and secondly, using the removals data predicted according to (20).

Using actual data for the years 1957/58 to 1961/62 for starting values of lagged endogenous variables, and setting prices and costs at their actual values in all years, the model was used to predict plantings, numbers of bearing trees and total trees, production of oranges, and, in the second case, removals for the years 1962/63 to 1975/76 inclusive. Alston (1978) provides a detailed comparison of the actual values and the values predicted by the simulations and analyses the outcome from this experiment.

In summary, the model provided reasonably accurate predictions over the sample period of numbers of bearing and total trees, and output of oranges. In the simulation using predicted removals data, there were quite large errors in the predictions of plantings and removals in any year due, almost entirely, to the poorly specified removals model with the large component of unexplained variation, w_t. The large error in predicting removals added directly into (19) for predicting plantings causing large errors in predicting plantings in any year – errors which virtually disappeared when actual removals data were used.

More accurate means of predicting annual removals are necessary if useful predictions of plantings in particular years are to be obtained. Because such a means is not available, the model is considered unsatisfactory for prediction of annual plantings. However, the model could be used to predict average removals and plantings over a number of years with reasonable accuracy. Over the 14 years of predictions, the average actual planting was 204 200 trees per year. The average predicted planting over those 14 years was 191 800 trees per year.

Projections Using the Model

The complete model was used to project five-year average plantings, bearing and total tree numbers, and production of oranges for the remainder of this century for different assumptions about the path of orange prices. Part of the exercise gives estimates of the elasticity of response of these variables to changes in prices.

The initial data of plantings, numbers of trees, and profitability levels were the actual values of those variables in the years 1970/71 to 1974/75. Costs in all years beyond 1974/75 were set at the actual value in 1975/76. Prices received by growers over the projection period were set at constant levels with five alternative price settings. These prices are the imputed returns to growers calculated by the IAC (1977) as would occur under *ad valorem* tariffs on imported orange juice of 0, 32, 45, 66 and 124 per cent. Assuming a landed duty free price of 16 cents per litre and Australian processing costs of 6 cents per litre, the imputed returns to growers are 46, 64, 72, 85 and 119 dollars per tonne.

Projections of plantings and of the production of oranges at five-year intervals at the five different price levels are recorded in Tables 2 and 3. Both tables indicate that price changes have a relatively small effect on plantings and on production. Comparison of the tables gives some idea of the time dynamics in the industry and in particular the very long lag between changes in price and changes in production.

A useful summary picture is given by the elasticity estimates reported in Table 4. While the initial response of plantings is quite high (about unity) the elasticity of orange output is negligible for up to 10 years and even after 30 years it is less than 0.18.

Some Implications of the Model

The low elasticity of response of orange production to changes in price received has implications for the social costs of alternative policy deci-

TABLE 2

Projected Plantings as Averages over Five Years at Different Prices Received by Growers (10^3 trees)

Year[a]	Assumed price received by growers after 1974/75 ($/t)				
	46	64	72	85	119
1979/80	75	97	107	122	164
1984/85	144	168	179	197	242
1989/90	186	188	188	188	190
1994/95	158	186	170	177	197
1999/00	165	179	185	197	230
2004/05	175	186	190	197	209

[a] Plantings are averages over five years up to and including the years shown in this column.

TABLE 3

Projected Output of Oranges at Different Prices Received by Growers (kt)

Year	Assumed price received by growers after 1974/75 ($/t)				
	47	64	72	85	119
1979/80	379.9	379.9	379.9	379.9	379.9
1984/85	387.3	389.7	390.8	392.5	397.1
1989/90	380.6	393.2	398.7	407.8	431.4
1994/95	408.1	427.8	436.4	450.3	485.8
1999/00	446.2	465.4	473.6	486.8	519.5
2004/05	474.9	497.3	507.2	523.4	565.9

TABLE 4

Elasticities of Average Plantings, Tree Numbers and Output to Small Changes in Prices over Various Lengths of Run[a]

No. of years from 1974/75	Plantings	Bearing trees	Total trees	Output
5	1.0	0.00	0.09	0.00
10	0.6	0.09	0.18	0.02
15	0.0	0.19	0.15	0.17
30	0.2	0.20	0.20	0.18

[a] Elasticity figures were calculated as the average of the elasticities to upwards and downwards movements in prices of $1/t from $72/t.

sions. Orange growers adjust resource allocation and production relatively little and slowly to changes in prices and profits. Consequently, any policy directed at prices, such as tariff policy, has relatively small effects on resource allocation in production and output of oranges.

There are other applications of the model and implications other than those related to low supply response elasticities. The model results demonstrate the time dynamics in supply response, the long lags, the slow adjustments, all of which, along with low own-price supply elasticities, have implications for policy.

The major effects of government-induced price changes for oranges are on the transfer costs between producers and consumers, and to some extent on the allocation of resources in consumption. These effects influence the economic merit of alternative policies of protection for the orange industry. The tariff on imports of orange juice, which has been reviewed recently by the IAC, was revised by the Government in May 1979, and replaced with a new sliding scale tariff. There is some consolation in the knowledge that this will cause only comparatively small additional social costs on the supply side.

APPENDIX
Plantings and Removals Data

The only data of tree numbers which are available are annual data on numbers of bearing and nonbearing trees as recorded by ABS. After making some assumptions and using demographic identities, it is possible to generate series for plantings and removals, although these series will have measurement errors. The method used to generate the series and the implications of the measurement errors for the estimates of the plantings model are discussed below.

Data generation procedure

It is assumed, on the basis of discussions with 'industry experts' and officers of ABS, that the gestation period between planting of a tree and

its achievement of bearing status (as measured by ABS) is five years. It is assumed also that there are no tree removals from nonbearing trees. Then, the following identities hold:

$$\text{(A1)} \quad NB_t = PL_t + PL_{t-1} + PL_{t-2} + PL_{t-3} + PL_{t-4} = NB_{t-1} + PL_t - PL_{t-5},$$

where NB is number of nonbearing trees and PL is plantings of trees. By transformation of (A1), plantings can be represented as:

$$\text{(A2)} \quad PL_t = NB_t - NB_{t-1} + PL_{t-5}.$$

The equation for annual removals is given by transformation of the equation for annual changes in total tree numbers,

$$\text{(A3)} \quad NB_t + B_t = NB_{t-1} + B_{t-1} + PL_t - R_{t-1},$$

where B is number of bearing trees and R is number of trees removed, to give:

$$\text{(A4)} \quad R_{t-1} = NB_{t-1} + B_{5-1} - NB_t + PL_t.$$

Given initial figures on plantings for four years, the series for plantings and removals can be calculated from (A2) and (A4).

Within feasibility constraints, an arbitrary procedure had to be used to calculate starting values for plantings. The constraints are that PL and R be non-negative for all years and that (A1) and (A3) be satisfied for all years. For the base years 1929/30 to 1933/34, the feasible minimum and maximum values for plantings were:

$$\begin{aligned} 66\,500 &\le PL_{1933/34} \le 229\,600; \\ 109\,900 &\le PL_{1932/33} \le 273\,000; \\ 46\,600 &\le PL_{1931/32} \le 209\,700; \\ 78\,100 &\le PL_{1930/31} \le 241\,200; \\ 124\,700 &\le PL_{1929/30} \le 287\,800. \end{aligned}$$

If each is given its minimum, then 425 800 of the 588 900 nonbearing trees in 1933/34 would be allocated. The residual 163 100 trees were allocated according to six alternative, and essentially arbitrary, patterns. In five of these patterns the total residual 163 100 trees were allocated to each of the five years in turn such that in each pattern, tree numbers in one year were set at the feasible maximum and in the other years were all at the feasible minima. These data sets were the boundary points of the feasible range. A sixth pattern was obtained by allocating the residual trees equally between the five initial years.

Given these starting values and ABS figures on numbers of NB and B trees, equations (A2) and (A4) were used to generate the six data series for PL and R. The preferred models using each of these six series are reported in Table A1. With each data series the five-year average profitability variable was best. Other specifications are reported in Alston (1978).

Nature of the measurement errors

The errors in measurement of plantings can be represented as

$$\text{(A5)} \quad PL_t = PL_t^* + v_t$$

where PL is the measured value, PL^* is the 'true' value and v_t is the measurement error. From (A4), R will also be measured with error, and importantly, with the same error as for PL, i.e.

TABLE A1

Regression Results for Plantings Model for Different Data Series on Plantings and Removals[a]

Data series	Initial plantings data for series 1929/30	1930/31	1931/32	1932/33	1933/34	Constant	Expected profits	Regression coefficient[b] Nonbearing	Bearing	Removals	$\bar{R}^2$	d
1	124 700	78 100	46 600	109 900	229 600	1655.89 (6.24)	8108.36 (3.80)	−0.29 (−5.36)	−0.42 (−9.06)	0.95 (9.54)	0.94	2.48
2[c]	124 700	78 100	46 600	273 000	66 500	1677.17 (6.31)	8277.05 (3.87)	−0.29 (−5.63)	−0.43 (−9.49)	1.00 (15.35)	0.97	2.39
3	124 700	78 100	209 700	109 900	66 500	1680.09 (6.10)	8289.68 (3.85)	−0.29 (−5.34)	−0.43 (−8.82)	1.00 (12.48)	0.95	2.39
4	124 700	241 200	46 600	109 900	66 500	1705.84 (6.49)	8615.20 (4.01)	−0.30 (−5.67)	−0.44 (−9.43)	1.07 (10.06)	0.94	2.40
5	287 800	78 100	46 600	109 900	66 500	1636.84 (6.24)	8108.77 (3.90)	−0.28 (−5.49)	−0.42 (−9.04)	0.93 (10.70)	0.94	2.45
6	157 320	110 720	79 120	142 520	99 120	1669.30 (6.17)	8228.55 (3.82)	−0.29 (−5.37)	−0.43 (−8.91)	0.98 (9.60)	0.94	2.40

[a] For more detail see Alston (1978).
[b] t-values in parentheses.
[c] This is the data series used in the model reported in the text.

(A6) $$R_t = R_t^* + v_t$$

where PL is the measured value, R^* is the 'true' value and v_t is the measurement error as defined above.

From (A1), since NB is measured without error, $\Sigma_{i=0}^{4} v_{t-i} = 0$ for all t. Thus the error term has zero expectation.

Effect of measurement errors

Given that the plantings and removals series are measured with error, what are the implications for the properties of the parameter estimates? We approach this question from a theoretical direction and from experimentation with different data series.

Consider the model

(A7) $$y^* = x_1^*\beta_1 + x_2^*\beta_2 + u$$

where y^* is 'true' plantings, 'true' meaning measured without error, x_1^* is profitability of growing oranges (or a vector of other explanatory variables), x_2^* is 'true' removals, and u is an error term with $Eu = 0$ and $Eu^2 = \sigma_u^2$. This model is a stylised version of the plantings model of the text of the paper.

In this paper, y^* and x_2^* are measured with error but, for the reasons discussed above, the measurement error is the same for both variables. That is,

(A8) $$y = y^* + v, \qquad x_1 = x_1^*, \qquad x_2 = x_2^* + v,$$

where y, x_1 and x_2 are measured variables, y^*, x_1^* and x_2^* are the 'true' variables, and v is an error term with $Ev = 0$, $Ev^2 = \sigma_v^2$ and $Euv = 0$.

The model to be estimated is:

(A9) $$y - v = x_1^*\beta_1 + (x_2 - v)\beta_2 + u$$

or

(A10) $$\begin{aligned} y &= x_1^*\beta_1 + x_2\beta_2 + u + (1-\beta)v \\ &= x\beta + \epsilon. \end{aligned}$$

The OLS estimate of β in (A10) is

(A11) $$\begin{aligned} \hat{\beta} &= (x'x)^{-1}x'y \\ &= \beta + (x'x)^{-1}x'\epsilon \end{aligned}$$

In general, the second right-hand term of (A11) will not have zero expectation because x and ϵ are not independent. The extent of any bias will be smaller the closer β_2 is to unity and the closer σ_v^2 is to zero, that is, when the true parameter on removals is unity and when there is no measurement error.

Some idea of the direction and extent of the biases can be ascertained, following Goldberger (1964), by looking at the asymptotic bias. Expanding (A11), the plim of $\hat{\beta}$ can be derived as

(A12) $$\operatorname{plim}\begin{bmatrix}\hat{\beta}_1 \\ \hat{\beta}_2\end{bmatrix} = \begin{bmatrix}\beta_1 \\ \beta_2\end{bmatrix} + \operatorname{plim}|x'x|\begin{bmatrix} -\operatorname{plim} x_2'x_1(\beta_2 - 1)\sigma_v^2 \\ \operatorname{plim} x_1'x_1(\beta_2 - 1)\sigma_v^2\end{bmatrix}$$

Now, in (A12) $|x'x|$ is positive and so is $x_1'x_1$. The expression illustrates that the bias approaches zero as β_2 approaches unity and σ_v^2 approaches zero.

Consider the asymptotic bias of $\widehat{\beta}_2$. When $\beta_2 > 1$, the estimate $\widehat{\beta}_2$ will be biased downwards and when $\beta_2 < 1$, the estimate $\widehat{\beta}_2$ will be biased upwards. That is, the estimate will be biased towards unity.

The direction of bias of the estimate $\widehat{\beta}_1$ will depend on the correlation between x_1 and x_2, with there being no bias problem if they are orthogonal.

Alston (1978) reported estimates of the plantings model using six sets of data with different patterns of measurement errors. The results of these estimates are shown in Table A1. The table indicates that the estimated parameters are not sensitive to the particular data series used. This result is consistent with the population value of β_2 being close to unity. This means that, in the context of the data and model used, the measurement errors have little effect on the estimates of the model parameters.

Data on returns to growers from the sale of oranges were obtained from the Murrabitt Packing Co. Pty Ltd for the fiscal years 1957/58 to 1975/76 as recorded in the company's annual report. While the company is relatively small in terms of total Australian production of oranges, it is assumed that competition throughout the industry is sufficient to ensure that the data are representative of returns across the industry.

The data used in the preferred model are reported in Table A2.

TABLE A2

Data Used in the Preferred Models[a]

Year	*P*	*W*	*Q*	*B*	*NB*	*PL*	R
	$/t	$	kt	10^3	10^3	10^3	10^3
1961/62	61.09	47.7	177.8	3578	1282	358.2	270.8
1962/63	61.09	49.0	202.6	3693	1520	623.8	70.0
1963/64	80.38	51.6	190.2	3816	1640	313.0	0.0
1964/65	43.17	55.5	235.9	3928	1675	147.0	132.0
1965/66	72.57	58.0	198.9	4029	1721	279.0	254.2
1966/67	76.24	61.9	232.5	4133	1585	222.2	522.8
1967/68	95.99	65.5	214.4	4234	1428	466.8	43.0
1968/69	58.79	70.4	264.3	4504	1134	19.0	154.0
1969/70	92.31	76.3	234.8	4497	1065	78.0	90.0
1970/71	43.63	84.8	322.4	4686	805	19.0	231.2
1971/72	64.30	93.0	291.0	4677	743	160.2	467.8
1972/73	57.87	101.5	351.7	4676	675	398.8	158.0
1973/74	90.02	118.0	309.9	4537	656	0.0	241.0
1974/75	82.21	148.2	340.8	4374	702		

[a] For more data, see Alston (1978).

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