A MODEL OF NEW ZEALAND APPLE SUPPLY RESPONSE TO TECHNOLOGICAL CHANGE*

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A supply response model for New Zealand apples is specified and equations for new plantings, removals, yields and adoption of an innovation are estimated. The model expands on perennial crop models previously estimated by incorporating the time pattern of adoption of a planting innovation and formulation of a measure of yield expectations given technological change.

New Zealand apple plantings have increased rapidly since rootstocks producing smaller than usual trees were introduced in the mid-1960s. Semi-intensive planting utilizing these rootstocks offers per acre yields two-to-three times greater than that of present bearing trees.[1] Apple production will certainly expand, perhaps dramatically, as a result of both increased acreages and higher average yields. Planning for the expansion, including provision for storage, processing, and packing facilities, requires projection of probable annual production increases. Projected supply response and its probable impacts will also be important inputs to governmental and industry decisions concerning recently proposed planting and/or supply controls.

This paper discusses an approach to projecting likely changes in the supply of New Zealand-produced apples in response to the technological change. A general supply response model formulated by French and Matthews for U.S. crops provided the foundation for development of a supply response model for New Zealand apples [5]. Application of the New Zealand model demonstrates the usefulness of the French and Matthews model in the setting of another country and expands their results by (1) incorporating empirical results on the time pattern of adoption of an innovation, and (2) formulating an appropriate measure of yield expectations given technological change.

The next section contains the development of the theoretical model. Then hypotheses which relate non-observable expectations to observable variables are formulated. Finally, results of estimating the supply response model are presented.

The Model

The theoretical apple supply projection model has several com-

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[1] Semi-intensive plantings have 220-264 trees per acre as compared with 100-120 trees per acre in standard plantings.

ponents, including expressions for total production, bearing acreage, new plantings, removals, and average yields. Total production is the product of bearing acreage and average per acre yields. Bearing acreage in any year depends on new plantings made several years earlier and removals. It was hypothesized that growers make decisions about the level of new plantings in any year on the basis of expected profits, which are a combination of expected product prices, yields and input costs. The tree removal decision was hypothesized to depend on several factors including expected profit, tree age distribution, disease, and urbanization.

The rate of adoption of the semi-intensive planting innovation entered the model at several points. It was used to construct separate estimates of bearing acreage for regular and semi-intensive plantings, to estimate average per acre yields, and to develop a yield expectations variable.

Desired acreage and new plantings

The total bearing acreage of apples desired by producers at any point in time will depend upon their aggregate long-run profit expectations. Because of the perennial nature of the crop, desired bearing acreage may be written as the sum of total (bearing plus non-bearing) acreage of the previous time period plus some desired adjustment. We began with the expression:

$$BA^d_t = TA_{t-k-1} + a_1 PR^*_{t-k} + u_{1t} \tag{1}$$

where BA^d_t = bearing acreage desired by producers for year t;
TA_{t-k-1} = actual total acreage in year $t—k—1$;
PR^*_{t-k} = expected long-run profitability per acre as formulated in year $t—k$; and
u_{1t} = a disturbance term.

Years are subscripted by t, with each year commencing from winter (when new plantings are made) and ending with harvesting in autumn. There is a lag of k years from the time a grower places an order for trees until they reach bearing age, a lag of j years from the time trees are planted until they reach bearing age, and a lag of i years between ordering and planting trees $(k - j = i)$.

The aggregate desired level of new plantings for year $t—j$ will be the amount necessary to bring actual total acreage as at the end of year $t—k—1$, up to the level desired for year t:

$$N^d_{t-j} = BA^d_t - TA_{t-k-1} + R^*_t \tag{2}$$

where N^d_{t-j} = desired acreage of new plantings to be made in year $t—j$ (and hence ordered in year $t—k$); and
R^*_t = acreage expected to be removed at the beginning of year t.

To recognize that the actual level of plantings in any year might differ from the desired level, a Nerlove-type [16] adjustment relationship was specified:

$$N_{t-j} - N_{t-j-1} = \alpha(N^d_{t-j} - N_{t-j-1}) \tag{3}$$

where N_{t-j} = actual acreage planted in year $t—j$; and
α = coefficient of adjustment, $0 \leqq \alpha \leqq 1$.

The new plantings equation was obtained by substituting equation (1) into (2), and (2) into (3). This gives:[2]

$$(4) \qquad N_{t-j} = \alpha a_1\, PR^*_{t-k} + \alpha R^*_t + (1-\alpha) N_{t-j-1} + \alpha u_{1t}.$$

Aggregate annual new plantings (N_t) were divided into semi-intensive (N^n_t) and standard types (N^o_t) to calculate bearing acreage and production for each technology. The growing literature on the adoption of innovations provided the basis for estimating the annual proportion of total new plantings that are of the semi-intensive type.

The adoption process

Even though yields per acre are significantly higher, the changeover by producers to semi-intensive plantings was not immediate. In fact, after eight years some of the standard-type orchards are still planted. This time lag in the adoption of an innovation is well documented, with a number of studies finding that the percentage adoption of an innovation follows an S-shaped curve through time.[3] The logistic function has been successfully used to empirically summarize this adjustment process for a number of innovations, including hybrid corn [6], soybeans [18], consumer durables [1], and durable inputs [12, 13].[4]

The annual percentage of new apple orchards that are planted on the semi-intensive system has been increasing in New Zealand, and has followed an S-shaped time trend. To summarize the adoption process, we used the logistic growth curve:

$$(8) \qquad 100 r_t = K / \left[1 + e^{-(a_3 + b_3 T)}\right]$$

where r_t = the proportion of new plantings in year t that are semi-intensive, or N^n_t / N_t;

K = the ceiling value, assumed to be 100 per cent; and

T = a time trend variable.

[2] Alternatively, the adjustment coefficient may take on a different value over the period following the introduction of the new-type trees than beforehand because of the higher costs of establishing semi-intensive apple orchards. Letting $\tilde{t}$ be the year in which the new-type trees were first planted:

$$(5) \qquad N_{t-j} - N_{t-j-1} = \alpha_1 (N^d_{t-j} - N_{t-j-1}) \quad \text{if } (t - j) < t$$
$$N_{t-j} - N_{t-j-1} = (\alpha_1 + \alpha_2)(N^d_{t-j} - N_{t-j-1}) \quad \text{if } (t - j) \geqslant \tilde{t}$$

which yields

$$(6) \qquad N_{t-j} = \alpha_1 N^d_{t-j} + (1 - \alpha_1) N_{t-j-1} + [\alpha_2 (N^d_{t-j} - N_{t-j-1})] X_{t-j}$$

where α_1 = coefficient of adjustment for all years prior to year $\tilde{t}$;

$\alpha_1 + \alpha_2$ = coefficient of adjustment for all years $\tilde{t}$ and beyond;

and $X_{t-j} = \begin{cases} 0 \text{ for all } (t - j) < \tilde{t} \\ 1 \text{ for all } (t - j) \geqq \tilde{t}. \end{cases}$

The new plantings equation is now obtained by substituting (1) into (2), and (2) into (6). This gives:

$$(7) \qquad N_{t-j} = (\alpha_1 a_1)\, PR^*_{t-k} + \alpha_2 a_1\, PR^*_{t-k} \,.\, X_{t-j} + \alpha_1 R^*_t + \alpha_2 R^*_t \,.\, X_{t-j} + (1 - \alpha_1) N_{t-j-1} - \alpha_2 N_{t-j-1} \,.\, X_{t-j} + \alpha_1 u_{1t} + \alpha_2 u_{1t} \,.\, X_{t-j}.$$

[3] For summaries of research concerning the adoption and diffusion of innovations see Katz, *et al.* [9], Rogers and Shoemaker [20], and Jones [8]. They discuss the results of many studies including some of those mentioned in this paper.

[4] Recent articles have used a form of the logistic function in developing the process of an innovation cycle [10] and a threshold model of a purchasing decision [7].

A simple log transformation, as described by Griliches [6, p. 504], results in an equation linear in a_3 and b_3 that can be estimated by use of ordinary least squares. The equation estimated is:

$$(9) \qquad \log_e (r_t/(1 - r_t)) = a_3 + b_3T + u_{3t}$$

where b_3 = the 'rate of acceptance' coefficient; and
u_{3t} = a disturbance term.

Equation (9) was used to calculate new semi-intensive plantings:

$$(10) \qquad N^n{}_t = r_tN_t$$

and therefore new plantings of old-type trees:

$$(11) \qquad N^o{}_t = N_t - N^n{}_t.$$

It also enters into the calculation of expected yields.

Acreage removed

Actual tree removals must be estimated in order to estimate bearing acreage. Actual and expected removals may differ because of unexpected tree damage or death due to disease or climate factors. The estimated relationship refers only to removals of old-type trees. Semi-intensive plantings were in production only during the last three years of the 15-year period spanned by our removals data and amounted to about four per cent of 1973 bearing acreage. Thus, removals of new-type trees over this period would have been negligible.

Apple trees are removed in response to both short- and long-run profit expectations. In the short-run (year-to-year), removals may be deferred in response to high, or accelerated in response to low, profit expectations. An important aspect of the longer-run situation is the impact of technological change on the optimal replacement time for the *old* technology. As is well known [17], the old-type trees would be replaced at an earlier age if replaced with a more profitable tree-type than if they were replaced with identical old-type trees.

Although a small proportion of young trees would die before they reached bearing age, such removals may realistically be assumed negligible, and total removals due to disease are assumed proportional to the aggregate bearing acreage.

The removals relationship (old technology) was therefore estimated as:

$$(12) \qquad R^o{}_t = a_4 + b_4BA^o{}_{t-1} + c_4Q^*{}_{t-i} + d_4C_t + e_4P^*{}_{st} + u_4t$$

where $R^o{}_t$ = total acres of old-type trees removed in year t;
$BA^o{}_{t-1}$ = bearing acreage of old-type trees in year t—1;
$Q^*{}_{t-i}$ = a replacement-profitability expectations variable;
C_t = an index of climatic factors that may influence tree death;
$P^*{}_{st}$ = short-run expected price per unit of product, formulated in year t; and
u_{4t} = a disturbance term.

The variable $Q^*{}_{t-i}$ was measured as a ratio of the long-run profit expectation for new plantings of trees to the short-run profit expectation of existing trees, and takes into account that proportion of bearing acreage of (old-type) trees whose age is beyond that at which productivity typically begins to fall. These expectations were made i years prior to the actual removal of trees to be replaced, since i years elapsed between ordering and receiving trees, and otherwise healthy trees to be replaced because of falling yields would not ordinarily be removed until their replacements were on hand.

To allow changes in total bearing acreage to be predicted for future years, removals of new-type trees ($R^n{}_t$) must somehow be estimated. Initially, removal of new-type trees would result from death or damage due to disease, insect or climatic factors, and not due to declining productivity. One way to proceed would involve the specification of annual removals of new-type trees as some fixed proportion of bearing acreage of such trees in the previous year, where the estimated proportion would take into account commercial experience thus far, and the likely age-distribution of new-type trees over the projection period. Thus,

$$R^n{}_t = \gamma BA^n{}_{t-1} \tag{13}$$

where $\gamma =$ a constant; and
$BA^n{}_{t-1} =$ bearing acreage of new-type trees in year $t-1$.

The yield relationships

Two yield equations were required, one to estimate yields per bearing acre of old-type trees and the other, yield per bearing acre of the new technology. Since production of apples from new-type trees was negligible over the period covered by our data, historical production data were used to estimate the per acre yield relationship for the old technology. Annual yields have typically shown alternate bearing tendencies and will also depend on the age-distribution of the trees. French and Matthews [5, p. 485] included independent variables that measured the acreage in various age classes, but these data were not available for New Zealand apples. In our model, we express yield as a function of a time trend variable to account for technological improvements to the old-type production method, the proportion of bearing acreage that is above the age at which production may be expected to decline, and a dummy variable to account for alternate bearing:

$$Y^o{}_t = a_5 + b_5 T + c_5(A^o{}_o/BA^o)_t + d_5 D_t + u_{5t} \tag{14}$$

where $Y^o{}_t =$ yield per bearing acre of old-type trees in year t;
$T =$ a time trend variable;
$A^o{}_{ot} =$ acreage (of old-type trees) over 30 years of age in year t;
$D_t =$ a $(+1, -1)$ dummy variable; and
$u_{5t} =$ a disturbance term.

Experimental evidence was relied upon to allow the yield-superiority per bearing acre of the new-type tree over the old type to be predicted. Since such yields will depend (*inter alia*) upon the age-distribution of the trees, the period over which predictions are to be made must be borne in mind when calculating the likely yield-superiority of the new technology. Then,

$$Y^n{}_t = \delta Y^o{}_t + u_{6t} \tag{15}$$

where $Y^n{}_t =$ yield per bearing acre of new-type trees in year t;
$\delta =$ a constant, computed from experimental evidence; and
$u_{6t} =$ a disturbance term.

Change in acreage and total production

The total change in bearing acreage of each tree type, from one year to the next, may be defined as:

$$(16) \qquad BA^n{}_t = BA^n{}_{t-1} + N^n{}_{t-j} - R^n{}_t$$

$$(17) \qquad BA^o{}_t = BA^o{}_{t-1} + N^o{}_{t-j} - R^o{}_t.$$

Thus, the bearing acreage of either technology at the end of year t will be equal to the bearing acreage of the previous year *plus* new plantings made j years earlier *less* removals of the current year. Since actual new plantings and removals are estimated, total production may be estimated as:

$$(18) \qquad Q_t = BA^o{}_tY^o{}_t + BA^n{}_tY^n{}_t$$

where Q_t = estimated total crop production in year t.

Producer Expectations

Before making projections of production with (18), equations (4), (9), (12), (13), (14) and (15) must be estimated. These equations contain several expectation variables that have non-observable values. Thus, hypotheses must be formed to relate these expectations to observable variables.

Profit expectations

Long-run profit expectations were hypothesized to be a linear function of producers' long-run price and yield expectations:

$$(19) \qquad PR^*{}_t = a_6 + b_6P^*{}_t \cdot Y^*{}_t + u_{7t}$$

where $P^*{}_t$ = producers' expectation of deflated price per unit of output, formulated in year t;

$Y^*{}_t$ = producers' expectation of yields per acre, formulated in year t; and

u_{7t} = a disturbance term.

While an expected yield variable enters French and Matthews' model explicitly as a factor influencing the amount of acreage required to produce a given quantity of output [5, p. 480], this effect is only implicit in our formulation. It is possible that a grower aiming at a target level of production might reduce his total acreage after adopting the new technology, but new plantings (of the new technology) must still be made if the higher yields are to be realized. As a result, his total acreage might be reduced through removing more acreage than is newly planted. Hence we would expect yield expectations to exert a positive influence on new plantings (and on removals).

The deflated price expectations variable was quantified as a four-year moving average of average deflated prices received by growers from the Marketing Board.[5]

$$(20) \qquad P^*{}_t = \sum_{i=1}^{4} (P/W)_{t-i}/4 = \overline{(P/W)}_t$$

[5] Averages from two to six years were tested as was a weighted average which emphasized the most recent prices. The simple four-year average gave the best statistical results.

where P_t = average grower price in year t; and
W_t = farm labour cost index in year t.

Changes in the cost index W can be thought of as measuring changes in costs per unit of output for a given technology, while the yield expectations variable will influence profit expectations through its effect in lowering expected costs per unit of output and raising expected revenue per acre as a result of the technological change.

Short-run expected price, P^*_{st}, was measured as the deflated average grower price received by growers in the previous year:

$$P^*_{st} = (P/W)_{t-1}. \tag{21}$$

Yield expectations

The formulation of an appropriate yield expectations model becomes difficult when technological advance has caused a considerable shift (upwards) of farmers' notions of their perennial crop production functions. Under annual cropping, if a technically-superior type or variety was planted, farmers would have observed yields from the new type on their farms after one year, and could thus update the expectations of yield under the new technology. The problem is more difficult under perennial cropping since a time lag of perhaps five to ten years could elapse between a farmer's formulation of an expected yield from a technologically-improved type of crop and his observation of actual yields. In this case, some expectation models used by other researchers (see [2, 11] for example) are inappropriate for the formulation of farmers' notions of yields from technically-superior crop types during the period immediately following introduction of the new technology, and before commercial yields are observed.

French and Matthews say little about this problem except that 'for discrete jumps in technical knowledge, a 0–1 variable might be used to shift the level of expectations' [5, p. 483]. Such an approach would seem appropriate only if all farmers making planting decisions adopted the new crop type at the same point in time and each such individual grower adapted his expectations instantaneously. Neither of these conditions are likely to hold in practice. First, it has already been argued that individual farmers, for a number of reasons, are likely to adopt a new technology gradually over time. Second, a farmer who does adopt a new technique might have only hazy knowledge about expected yields, which may become 'firmed' or adapted over time as he receives further information from research scientists, extension workers and other farmers. Thus, we would expect farmers' notions of yields, in the aggregate, to exhibit a gradual (and probably non-linear) adaptation as a result of the introduction of new technology. That is, they would be dependent in part on past trends in yields but would also be adjusted in response to research related to semi-intensive production methods and commercial experience with the system.

The yield expectations model to be developed makes the assumption (acceptable to our empirical application) that when the first plantings of the new perennial crop type were made, some scientific evidence (say from crop trials) on the performance of the new crop in relation to existing crop types was available to growers. Further, we assume that from this information scientists, extension workers, or farmers could compute an expected 'break-even' yield that, if attained by the new crop type, would return the same level of profitability to be expected from further plantings of the old type of crop. We now assert the following:

(22) $$Y^o{}_t{}^* = f(Y^o{}_{t-1}, Y^o{}_{t-2}, ...),$$

(23) $$\max Y^*{}_t = r_t Y^s{}_t + (1 - r_t) Y^o{}_t{}^*, \text{ and}$$

(24) $$\min Y^*{}_t = r_t Y^b{}_t + (1 - r_t) Y^o{}_t{}^*,$$

where $Y^*{}_t$ = aggregate yield expectation (for all bearing trees) held by farmers in year t;

$Y^s{}_t$ = farmers' notions of the bearing-tree yields demonstrated by scientists from the new technology, up to year t;

$Y^b{}_t$ = farmers' notions of the 'break-even' yield, as computed in year t;

$Y^o{}_t{}^*$ = aggregate yield expectation (for bearing trees) of the old technology, held by farmers in year t; and

$Y^o{}_t$ = actual yield of bearing trees of the old technology in year t.

Farmers who decide in year t to plant the new crop type, could be assumed to hold expectations of yield somewhere between the 'break-even' yield and the scientists' yields; those who decide not to plant the new type could be assumed to hold yield expectations for the *new* crop type of something less than the 'break-even' yield. Thus for each year we may express a maximum and minimum value of the aggregate yield expectation.

The next step is to formulate a model to allow a time-series of aggregate yield expectations to be traced out somewhere between the maximum and minimum values already computed. It was decided to use a model that recognized that farmers making planting decisions in the current year might have higher expectations of future yields from bearing crops than did farmers who made planting decisions in the previous year, with the increase proportional to the discrepancy between the new-technology yields demonstrated by scientists at the present time and the aggregate yield expectation held by farmers in the preceding time period. That is:

(25) $$Y^*{}_t - Y^*{}_{t-1} = \beta(Y^s{}_t - Y^*{}_{t-1});\ 0 \leqq \beta \leqq 1$$

where β is the familiar coefficient of expectation.

Various series of values of $Y^*{}_t$ can be constructed by varying the value of β, ensuring that all members of each series fall within the allowable range.[6]. Thus, a range of values of β can be determined. Note that if $\beta = 1$, farmers' notions of future yields from new plantings would, at the first opportunity to make planting decisions in relation to the new technology, be instantaneously and completely adjusted to those yields demonstrated by the scientists from the new technology.

Research work on semi-intensive apple production in New Zealand [14, 15] has shown that, over the first 20 years of the crop's life, the

[6] In some applications it may be possible to estimate β from the data, subject to the constraint that its value falls within the allowable range.

average yield per acre per year from semi-intensive production was 2·36 times as high as that from standard-type plantings. The value of Y^s_t should, strictly speaking, be estimated only from data revealed up to year t. However, these values may be approximated as:

(26) $$Y^s_t = 2{\cdot}36 Y^o_t{}^*, \text{ and}$$

(27) $$Y^o_t{}^* = \sum_{i=1}^{4} Y^o_{t-i}/4.$$

That is, farmers' notions of scientists' yields in year t were computed as a function of farmers' expected yields from standard plantings, where the latter were given by the average of the four preceding years' yields. One 'advantage' of this approximation, in fact, is that the research yields have been *deflated* through their estimation from average commercial yields, a step that farmers most likely take when interpreting crop yields achieved from small, trial plots [3].

The same research data indicated that multiplication of each annual yield per acre from the semi-intensive trial yields by the factor 0·52 reduced the present value of net income per acre (computed over a 20-year period) from the semi-intensive method to that of the traditional method of production. Therefore the 'break-even' yield series was computed as:

(28) $$Y^b_t = 0{\cdot}52 Y^s_t.$$

Having calculated a historical time series of values of $Y^o_t{}^*$, Y^s_t and Y^b_t, the time series of maximum and minimum values of Y^*_t were calculated from equations (23) and (24). Historical values of r_t were used, but when predicting acreage response beyond the period covered by the data, values of r_t predicted by equation (9) were employed. Finally, by tracing out time series of Y^*_t from equation (25) for various values of β, we found that the coefficient of expectation could take on values between 0·05 and 0·20 for the resulting time series of aggregate yield expectations to lie within the minimum and maximum values. We will write the observable form of Y^*_t as $\overline{Y}_t$.

Expectations of replacement profitability

The replacement-profitability expectations variable was defined as the ratio of the long-run income expectation[7] for new plantings of trees to the short-run income expectation of existing (old-type) trees, measured as:

(29) $$Q^*_t = P^*_t Y^*_t / P^*_{st} Y^*_{st}$$

where Y^*_{st} = short-run expected yield per acre from existing trees.

The emergence of a superior crop type would have the effect of increasing the value of Y^*_t and hence the value of Q^*_t. We would thus expect movements in expected removals, actual removals, new plantings and Q^*_t to be positively correlated. The measurement of Y^*_{st} is difficult since it requires the measurement of yields expected in the coming year

[7] Alternatively, Q^*_t could be split into its two components—an expected price ratio and a ratio of expected yields.

from those trees that the farmer is considering replacing, and will *not* be equal to the value of $Y^{o}{}_{t}{}^{*}$, the long-run expected yields from old-type trees. Because it is a short-run yield expectation, we used a two-year moving average to remove the alternate bearing pattern of historical yields, but it seemed reasonable to expect the value of $Y^{*}{}_{st}$ to be lower, the higher the proportion of orchard acreage occupied by trees beyond the age at which productivity begins to decline. That is (*ceteris paribus*) replacement of trees is likely to be greater, the greater is this proportion. Thus, the two-year moving average ($\bar{y}t$) was weighted to produce the effect:

$$(30) \qquad \bar{y}_t = \sum_{i=1}^{2} Y^{o}{}_{t-i}/2$$

$$(31) \qquad Y^{*}{}_{st} = \bar{y}_t BA^{o}{}_{t-1}/A^{o}{}_{o,\, t-1} = \bar{Y}_{st}.$$

Now, $Q^{*}{}_{t}$ may be measured as:

$$(32) \qquad Q^{*}{}_{t} = (\overline{P/W})_t \bar{Y}_t / (P/W)_{t-1} \bar{Y}_{st} = \bar{Q}_t.$$

Expected removals

In equation (2) producers were assumed to take into account their expectations of the acreage of trees likely to be removed over some period of time, so that they could plan compensating new plantings. For a tree to reach bearing age by year t, it must be planted in year $t—j$ and therefore ordered in year $t—k$. Hence removal expectations would be formed in year $t—k$. We hypothesize that growers expect trees to be removed for two reasons—tree death due to disease or insect damage, and declining productivity. Because of the time dimensions involved, expected removals due to the first reason are likely to be proportional to total (rather than bearing) acreage. The replacement-profitability variable is employed to explain expected removals due to declining productivity. Therefore:

$$(33) \qquad R^{*}{}_{t} = a_7 + b_7 TA_{t-k-1} + c_7 \bar{Q}_{t-k} + u_{8t}$$

where the variables are as previously defined and u_{8t} is the disturbance term.

The Estimated Model

Having replaced the unobservable variables by their observable forms, the acreage response model was estimated using ordinary least squares. A five-year gestation period (between planting a tree and that tree being classified as 'bearing') was appropriate, and the average lag experienced between the time a grower placed an order for trees and when he received the trees was four years.[8] Thus $j = 5$, $i = 4$, and $k = 9$.

As is often the case with time series data, multicollinearity was a problem. Over the period studied (1958/59-1972/73), total and bearing acreage demonstrated a gradual upward trend, as did yield and replacement-profitability expectations. Estimation of the specified model equation for new plantings, removals, and average yields resulted in a number

[8] Four years is an unusually long delay between ordering and receiving apple trees. The nursery trade was building up stocks of propagating material for the new-type trees and most were producing the new-type trees only on order. As the new-type trees become 'standard' the lag should be reduced.

of variables with unacceptably large standard errors. These equations were then re-estimated with variables deleted. Equations selected for the projection model were those with the highest $\bar{R}^2$ (coefficient of determination adjusted for degrees of freedom) and the lowest root mean square of the residuals.

New plantings

The estimated new plantings relationship was:

$$N_t = \underset{(35{\cdot}13)}{139{\cdot}41} + \underset{(0{\cdot}03)}{0{\cdot}29}\,(\overline{PY}/\overline{W})_{t-4}$$

$$\bar{R}^2 = 0{\cdot}90 \qquad d = 1{\cdot}63$$

where the figures in parentheses are standard errors and d is the Durbin-Watson statistic. The simple correlation between $\bar{Y}_{t-4}$, TA_{t-5}, $\bar{Q}_{t-4}$ and the lagged dependent variable was high, in the range of 0·93 to 0·99. Deletion of the lagged dependent variable, TA_{t-5}, and $\bar{Q}_{t-4}$ resulted in the equation meeting our selection criteria. The new plantings relationship that included expected yields computed with $\beta = 0{\cdot}20$, gave more acceptable test statistics than did those for other values of β between 0·05 and 0·20.

Rate of adoption

The logistic rate of adoption relationship for the period 1965/66-1972/73 was estimated as:

$$\log_e(r_t/(1-r_t)) = \underset{(0{\cdot}19)}{-1{\cdot}85} + \underset{(0{\cdot}04)}{0{\cdot}29}T;$$

$$\bar{R}^2 = 0{\cdot}91 \qquad d = 1{\cdot}19$$

The value of the 'rate of acceptance' coefficient (0·29) is rather low in comparison with the findings of Griliches, who suggested that for hybrid corn the very elastic long-run supply of hybrid seed meant that the rate of acceptance was explained by variables operating on the demand side [6, p. 515]. In the present study, it was believed that growers might readily have formed higher profit expectations for the new production system but were prevented from making the change-over due to the shortage of nursery stock material.[9] Hence as nurserymen build up their stocks of the new type of tree the rate of acceptance could well increase, and predictions based on the estimated equation should not be made too far into the future.

Removals

The estimated equation for removals was:

$$R^o_t = \underset{(372{\cdot}56)}{363{\cdot}50} + \underset{(0{\cdot}03)}{0{\cdot}03}\,BA^o_{t-1} - \underset{(145{\cdot}54)}{289{\cdot}90}\,(P/W)_{t-1}$$

$$\bar{R}^2 = 0{\cdot}61 \qquad d = 1{\cdot}96$$

The rainfall index, C_t, was deleted since its estimated coefficient did not have the expected sign (and always had a high standard error) in

[9] Note in the model that desired new plantings are a function of expected yields, which in turn depend on the actual proportion of new plantings in any year that involved the new technology. Thus, N^d_t is the desired level of new plantings given the existing supply situation with respect to nursery stock, and not the desired level of new plantings had supply problems not existed.

several estimated equations. Very high correlation ($r = 0{\cdot}96$) between BA^o_{t-1} *and* $\bar{Q}_{t-4}$ resulted in high standard errors, especially for the coefficient of the latter variable. Omitting it resulted in the expected improvement in the standard error of BA^o_{t-1}, and $\bar{R}^2$.

Average yields

Average yields per acre for the old-type trees were estimated as:

$$\begin{aligned} Y^o_t &= \underset{(18{\cdot}24)}{584{\cdot}37} + \underset{(2{\cdot}15)}{20{\cdot}48T} + \underset{(8{\cdot}65)}{49{\cdot}69D_t} \\ \bar{R}^2 &= 0{\cdot}92 \quad d = 2{\cdot}67. \end{aligned}$$

Estimation of the yield relationship was hindered by almost perfect correlation ($r = -0{\cdot}99$) between the $(A^o_o/BA^o)_t$ and time trend variables. Hence it was impossible to say whether the gradual improvement in yields per acre over time was due to improvements in husbandry or the changing age-distribution of bearing orchards (or, more likely, both). Data considerations prompted us to delete the $(A^o_o/BA^o)_t$ variable from the final equation. The 'alternate bearing' variable D_t was highly significant in all equations, showing yields per acre alternating almost 50 bushels per acre above and below the trend yield.

Conclusions

This paper has attempted to incorporate a technological change in apple production in the acreage response model. We did this primarily through the impact of the technological change on producers' yield expectations, which influenced their decisions concerning new plantings and replacement of the old technology by the new. The construction of a suitable yield expectations model under such conditions in perennial cropping was difficult, but our approach allowed the use of a logistic equation to estimate the proportion of new plantings that would involve the new technology. Our estimates of total new plantings could be broken down into those of each tree-type, and this allowed the estimation of bearing acreage and total production for each tree-type. An alternative, but seemingly more difficult, approach would involve the design and estimation of equations for new plantings of each tree-type directly.

Estimation of removals of the new-type trees was difficult since such removals would have been negligible over the period covered by our data, and information on such removals was not available. This was not expected to be a problem however, since the removal of new-type trees would continue to be a very low proportion of total removals for at least the next ten years.

Estimation of the model was hindered by multicollinearity and thus we were unable to obtain reliable estimates of the structural parameters. We believe that multicollinearity, often a problem when working with perennial crop data, may be inevitable under conditions of technological change such as described in this article. Since the incentive to adopt the innovation is higher yields (and higher expected profits), one observes increased yields, increased plantings and removals, increased bearing and total acreages, and increased production.

Despite these problems, we feel that the model is operational from the point of view of making projections. Data correlations observed in estimating the model can reasonably be expected to continue into the near future. Given this assumption, the model has been used to project bearing acreage and production of New Zealand apples through 1984-85 [19].

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