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APMAA Estimates of Supply Elasticities for Australian Wool, Beef and Wheat

John A. Wicks and John L. Dillon*

Based on the University of New England's Aggregative Programming Model of Australian Agriculture (APMAA), estimates of own and cross-price elasticities of supply for wool, beef and wheat under two scenarios are presented by State, B.A.E. zone, farm type and for Australia as a whole. Where possible, these estimates are compared with previous estimates based on econometric analysis of time-series data.

1 Introduction

Estimation of own and cross-price elasticities of supply for agricultural or other commodities depends on prior knowledge, either explicit or implicit, of the relevant supply functions. Such functions can be estimated using either a positive or a conditionally predictive approach. These two approaches differ fundamentally in their methodology. The positive method is based on statistical estimation of a supply function from a sequence of historical time-series observations on producers' actual aggregate behaviour. For the conditionally predictive method, a simulation model of the sector under consideration is usually constructed and supply response data generated via price parametization under the assumption of expected profit or utility maximization. Using the generated data, a supply function may then be fitted by statistical procedures. Linear programming-based models provide the simplest example of this approach. Less frequently, cross-sectional sample data may be used to estimate a production function from which conditionally predictive supply response estimates may be derived (see, e.g., Dillon [6]).

Most previous price elasticity estimates for Australian rural products, and wool, beef and wheat in particular, have been based on the positive approach of using time-series data to derive the appropriate supply functions (see, e.g., Freebairn [8], Gruen *et al.* [9], Malecky [10] and Powell and Gruen [13]). As is the case for studies of other countries, these studies have involved the estimation of equations relating supply of each particular commodity to its own price and, so far as possible given available data, to the prices of competing product alternatives and other relevant variables affecting supply. The actual econometric procedures applied to the available time-series data vary in complexity depending largely on the way in which producer price expectations are modelled. Data problems constitute the greatest limitation to the

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* Department of Agricultural Economics and Business Management, University of New England, Armidale, N.S.W. This research was supported in part by the Wool Research Trust Fund of the Australian Wool Corporation. We are grateful to Kevin Parton and Roy Powell for comments.

estimation of such positive supply functions. Rarely is there a sufficiently long trace of time-series data available to permit inclusion of all of the desired variables; and even if available, such data may often be confounded by externally imposed shocks or structural change.

In contrast, the conditionally predictive approach utilizes a set of synthetic expected prices to generate observations of simulated supply response. Results are summarized via statistically estimated response equations which are then used to estimate elasticities. This approach has the advantage that no relationship needs to be established between actual and expected prices since "expected" prices can be directly specified in the simulation model. As well, data shortages are eliminated since the desired number of sets of observations can always be generated, costs permitting. Moreover, relevant technological and other structural changes can be encompassed in the model before it is run. On the debit side, there are problems in ensuring that the simulation model is sufficiently realistic and that it is internally consistent. The former may appear either as problems of data availability for model construction or as difficulties in the specification of producer objectives.

In this paper we report own-price elasticities and cross elasticities of supply for wool, beef and wheat derived from an Aggregative Programming Model of Australian Agriculture (APMAA) which was used to simulate farmers' responses to various price regimes for wool, beef and wheat.[1] These estimates are compared with elasticities previously derived from positively estimated supply functions.

2 Supply Response Estimation Using APMAA

Since the APMAA model has been described elsewhere (Walker and Dillon [16]), comments here are restricted to aspects of the model specific to the present analysis. The version of the model used comprises 521 representative farms accounting for 90 per cent or more of Australia's extensive crop and livestock production. Each of these representative farms is modelled as a linear programme, is located in one of 63 Statistical Divisions, is one of six farm types (sheep-grain, sheep, grain, beef cattle, dairy cattle or multipurpose), and belongs to one of three size categories (small, medium or large). However, only a very few of the Statistical Divisions do in fact contain all of the possible representative farms.

In order to obtain the number of solutions necessary for estimating the desired supply response surfaces with reasonable confidence, some simplifying assumptions were required. Only the major activities, namely wheat, beef and sheep, were considered in the analysis. Minor grain crops and dairy enterprises were excluded as these would tend to increase the complexity of the model without adding greatly to the quality of the output generated. Beef and sheep activities were modelled on the basis of a self-replacing herd or flock. For example, a Merino activity contains one breeding ewe plus portions of a replacement ewe, a ram, a lamb and a wether. The appropriate proportions were derived from available agricultural statistics for each Statistical Division. Similar aggregations were performed for each of the beef cattle enterprises.

[1] More detailed results for the analysis reported in this paper as Scenario 1 are provided in [17].

Constraints for each representative farm matrix had to be similarly constructed on a relatively aggregated basis due to lack of detailed data, together with the need to contain matrix size. This resulted in a need to specify as few land types and seasonal feedpool constraints as was possible, consistent with maintaining an adequately formulated model.

Since the solution procedure to be used was linear programming, flexibility constraints were introduced so as to reflect intermediate-run response possibilities. Lower flexibility constraints for the area of wheat, number of ewe breeding units, and number of beef cattle breeding units were derived by applying regression analysis to time time series data for each of the Statistical Divisions.[2] Using the trend line and the standard deviation of observations, a lower bound was estimated for decreases in each of the groups of activities. An upper bound on the most profitable enterprise was thus effectively determined by the amount of resources which could be shifted from production of less profitable enterprises.

Within the simplified structure thus specified, the objective for each representative farm was defined as maximization of individual expected total gross margin. No interdependence was modelled between representative farms for either factors of production, or intermediate products, or final products. Intuitively, ignoring such interdependencies should result in much larger changes in farm plans than would be observed in practice. Supply elasticities would then tend to be over-estimated. In reality, overestimation is not so likely to occur for a variety of reasons. These emanate both from the underlying structure of APMAA, and the concepts inevitably incorporated into the simultaneous solution of all of the representative farms in an aggregative programming model. To deal first with the structural aspects, all of the livestock activities are assumed to be self-replacing. Thus it is implied that any buying and selling of store animals, together with their subsequent fattening, will occur between farms modelled by a single representative farm. The same restriction will be valid for the purchase and sale of feed grains and hay. Consequently a limitation is implied in that trading is not permitted between different farm types or regions, but this is hardly likely to cause significant errors in the final analysis. Second, simultaneous solution of all representative farms leads to determination of a general equilibrium solution. Whilst the general equilibrium solution may be acceptable for long-run analyses, for intermediate-run and short-run analyses it attributes properties to representative farm decision making which cannot be realized in practice. In the intermediate-run it seems more reasonable for decision-makers to acquire the inputs which they require and sell output as desired in order to achieve their own objectives. The most that can ever be expected is for the direction of change in their farm plans to be towards an equilibrium state, and this should be adequately reflected by the effects of the flexibility constraints.

Once the model had been solved (i.e., solutions determined for each of the representative farm linear programmes), it was a relatively simple matter to aggregate results by either region or farm type for estimation of supply response equations.

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[2] Miller [11] provides a detailed explanation of a variety of methods, including the regression approach used here, for estimating the flexibility coefficients required for determining flexibility constraints.

Based on 1970–1 costs and returns, high and low prices for each of wool, beef and wheat were selected subjectively. All other prices were held constant. Within this structure two variants of the model were specified. These will be referred to as Scenario 1 and Scenario 2. In Scenario 1, the numbers of sheep and beef cattle units and the area of cropping land were allowed to increase by up to 10 per cent above the trend values. Scenario 1 thus reflects a short to intermediate-run analysis. Scenario 2 allowed expansion of the same activities up to a maximum of 30 per cent and can thus be regarded as reflecting more of an intermediate-run analysis. Estimated elasticities will therefore be evaluated in this context.

The APMAA model was run for various price combinations of wool, beef and wheat yielding observations on wool, beef and wheat supply for each representative farm. Ideally the analysis should have comprised a complete parametric variation of each of the three sets of prices over the desired range. A full set of basis changes would then have been defined, yielding a complex step function in four dimensions for each of the representative farms. Aggregate supply could be obtained by appropriately summing these functions. The likely problems of such a parametric analysis for just one of the representative farms were considered so great that a compromise had to be established. Accordingly, five equally spaced price levels, including low and high, were specified within the predefined range for each of wool, beef and wheat. Combination of these prices produced a 5^3 complete factorial design encompassing 125 different price regimes. The model was run for each of these price regimes to determine wool, beef and wheat supply. Supply response for each commodity was thus estimated as a set of 125 points in the four-dimensional space of output quantity and wool, beef and wheat price.

Quadratic functions were fitted to these points to give an approximation of the response surface. Such a response surface approach, rather than being an approximation, may in fact increase the validity of the analysis. The reason is that when the 521 representative farms are aggregated, the large steps characteristic of a single representative farm analysis will be aggregated to produce far more, relatively smaller steps. However, APMAA is itself a simplification of reality in which some 146 000 agricultural holdings are modelled by 521 representative farms. If supply response had been estimated individually for each of these agricultural holdings, and these results aggregated, the resultant response surface may have been far closer to the curvilinear function derived than the possible stepped function.

Results under each price regime were aggregated by State, by farm type, by zone as defined in the B.A.E.'s *Australian Grazing Industry Survey* (B.A.E. [4]), and for the entire country. At each of these levels of aggregation, data from the analysis can be conceptualized as a four-dimensional supply response surface, the dimensions comprising the prices for the three commodities together with the output of the commodity being studied. To this response data, quadratic supply functions were fitted by least-squares regression.[3] The

[3] Conventional agricultural supply analysis based on time-series data has typically used a linear or logarithmic supply equation in preference to the quadratic, or other polynomial, form. The rationale for fitting a polynomial function is based on the Taylor series approximation of the unknown function generating the response surface (Myers [12], p. 62). In the present study, the quadratic response function proved to fit the data adequately and so no higher order relationships were investigated. Of course, since such response surface analysis makes no attempt to understand the mechanism of the underlying system, results should only be interpreted for points within the data set and caution exercised in any extrapolation beyond this range.

supply equations took the general form:

$$S = f(PWO, PBE, PWH)$$
$$= a_0 + a_1PWO + a_2PBE + a_3PWH + a_{11}(PWO)^2 + a_{22}(PBE)^2 + a_{33}(PWH)^2 + a_{12}(PWO)(PBE) + a_{13}(PWO)(PWH) + a_{23}(PBE)(PWH)$$

where S is the supply of wool, beef or wheat, depending on specification; and PWO, PBE and PWH respectively denote the price of wool, beef and wheat. All of the estimated supply equations explained more than 80 per cent of the variance in the simulated supply observations.

As an example, the estimated supply equations for New South Wales, under Scenario 1, and their related statistics, were:

$$Q_{WH} = \underset{(1.61)}{-41.43} + \underset{(14.65)}{6.12PWH} - \underset{(10.75)}{142.70PBE} - \underset{(6.41)}{10.71PWO} - \underset{(15.15)}{0.05(PWH)^2} + \underset{(8.81)}{1.74(PWH)(PBE)} \qquad \bar{R}^2 = 0.94$$

$$Q_{BE} = \underset{(1.27)}{17.72} + \underset{(5.29)}{881.66PBE} - \underset{(6.00)}{54.78PWO} + \underset{(10.47)}{0.06(PWH)^2} + \underset{(3.06)}{334.61(PBE)^2} - \underset{(15.15)}{16.55(PWH)(PBE)} \qquad \bar{R}^2 = 0.86$$

$$Q_{WO} = \underset{(43.84)}{387.45} - \underset{(11.80)}{338.37PBE} + \underset{(17.83)}{53.44(PWO)^2} + \underset{(9.40)}{4.06(PWH)(PBE)} - \underset{(14.14)}{2.33(PWH)(PWO)} \qquad \bar{R}^2 = 0.83$$

where the values in parenthesis are t statistics and the units for wheat, beef and wool are 10^5 tonnes, 10^3 tonnes and 10^6 kilogrammes respectively.

Elasticity estimates were taken at the mid-range levels of the simulated price regimes, i.e., at prices of $2.32 per kg clean for wool, $0.62 per kg dressed for beef and $55.10 per tonne for wheat in terms of 1970–1 dollars, and derived directly from the estimated supply equations.

Evaluation of the supply equations within the simulated price range generates a set of projected outputs. Such an evaluation for the mid-range prices is shown by State and Australia-wide in Table 1 for Scenario 1. Not too much should be made of this comparison since the price structure existing in 1975–6 was not in fact the average of the modelled regimes, even after making allowances for inflation. Prolonged high prices for beef, followed by a severe slump, would both contribute to higher production of beef than estimated and likely lower production of wheat and wool. This is borne out by the figures of Table 1. However, the results do illustrate dramatically the dangers inherent in projecting resource availabilities forward several years on the basis of historical trends. The growth trend in wheat acreage in the years up to 1970 has not continued since, and this has led to a significant overestimate of actual production by the model. So long as the many other economic variables encapsulated in the flexibility constraints do not alter, the mis-specification implies an underestimation of wheat elasticities of supply and an over-estimation of beef elasticities of supply, at the given price levels.

Table 1: Estimated Production at Mid-range of Prices for Wool, Beef and Wheat, and Actual Production 1975–6: *Scenario* 1

	Estimated			Actual[a]		
	Wool (10^6kg)	Beef (10^3t)	Wheat (10^6t)	Wool (10^6kg)	Beef (10^3t)	Wheat (10^6t)
Australia[b]	719.4	999.6	33.6	754.3	1 840.4	11.98
By States—						
New South Wales	307.1	195.8	10.4	240.3	535.5	4.3
Victoria	174.9	236.1	3.2	137.9	492.8	1.6
Queensland	43.6	457.2	5.2	66.3	495.5	0.8
South Australia	123.3	107.1	8.3	105.6	92.0	1.1
Western Australia	91.1	37.6	5.5	183.6	147.2	4.1
Tasmania	16.3	33.1	1.1	20.0	59.2	0 0

[a] *Sources:* [1], [2], [3].

[b] Australia-wide production estimates differ from the sum of State production estimates since each were estimated from different equations.

3 Elasticity Estimates and Comparisons

The APMAA-based estimates of own and cross-elasticities of supply for Australian wool, beef and wheat are shown in Tables 2 and 3 for Scenarios 1 and 2 respectively. Results are presented for the whole of Australia as well as by State, by B.A.E. zone and by farm type on an Australia-wide basis. The signs of all the estimated elasticities are consistent with prior expectations, as is the general pattern of increase in the absolute value of elasticity as we move from Scenario 1 to Scenario 2. The latter expectation is satisfied for all but 4 of the 288 estimates. The exceptions are the elasticities of beef with respect to the price of beef and the price of wool in South Australia, the elasticity of beef with respect to the price of wool in the high rainfall zone, and the elasticity of wheat with respect to the price of wool for sheep-grain farms. For Tasmania and Western Australia under both scenarios, wool production showed no response to variation in wool, beef or wheat prices. This result appears consistent with recent trends in Tasmania and Western Australia. Sheep production has increased at a lower rate than beef and wheat production in Tasmania, and at a higher rate in Western Australia. Furthermore, turning points in the trend of sheep numbers are fewer in Tasmania and Western Australia than in other States, suggesting a less responsive price dependency between wool and other major activities.

Comparison of all of the supply elasticities estimated here with other estimates is not possible since such detailed information is not available for all States, zones or farm types. However, some comparisons are possible for own-price elasticities on a national basis.

For wool, we estimate an own-price elasticity of 0.25 for the shorter run and 0.36 for the longer run scenario. These results are in fair agreement with the estimates of 5-year elasticities of 0.33 by Powell and Gruen [13] and 0.35 by Malecky [7]. Witherell's [18] estimate of between 0.12 and 0.28 for a "long-run"

Table 2: Estimated Own- and Cross-price Elasticities of Supply for Australian Wool, Beef and Wheat: Scenario 1

Grouping	Wool w.r.t.[a] price of			Beef w.r.t. price of			Wheat w.r.t. price of		
	Wool	Beef	Wheat	Wool	Beef	Wheat	Wool	Beef	Wheat
Australia	0.25	−0.18	−0.20	−0.38	0.69	−0.44	−0.21	−0.21	1.10
By States—									
New South Wales . .	0.61	−0.16	−0.35	−0.52	0.94	−0.66	−0.20	−0.26	1.06
Victoria	0.56	−0.62	−0.10	−0.78	1.13	0.00	−0.66	0.00	0.65
Queensland	0.30	−0.17	0.00	−0.06	0.23	−0.37	0.00	−0.57	1.12
South Australia . .	0.20	−0.12	−0.13	−0.80	1.01	−0.11	−0.24	0.00	1.68
Western Australia . .	0.00	0.00	0.00	−2.20	3.61	−3.51	−0.24	−0.17	1.01
Tasmania	0.00	0.00	0.00	−0.47	0.39	−0.18	0.00	−0.09	0.15
By B.A.E. Zone—									
High Rainfall	0.32	−0.37	−0.02	−0.50	0.56	−0.10	−0.06	−0.21	0.89
Wheat-Sheep	0.17	−0.04	−0.27	−0.23	0.46	−0.62	−0.17	−0.13	1.31
Pastoral	0.49	−0.34	−0.25	−0.37	0.49	−0.22	−0.05	−0.16	0.29
By Farm Type—									
Sheep-Grain	0.61	−0.05	−0.40	−1.20	2.63	−3.18	−0.30	−0.06	1.34
Sheep	0.29	−0.21	−0.10	−0.82	1.20	−0.38	−0.13	−0.22	0.76
Grain	0.28	−0.10	−1.24	0.00	0.89	−1.39	−0.13	−0.23	0.92
Beef Cattle	0.95	−1.32	−0.08	−0.13	0.26	−0.15	0.00	−0.58	1.19
Dairy Cattle	0.17	−0.17	−0.19	−0.78	0.52	−0.11	−0.12	−0.23	1.25
Multipurpose	0.24	−0.11	−0.33	0.00	0.55	−0.70	−0.13	−0.25	1.05

[a] w.r.t.—with respect to.

Table 3: Estimated Own- and Cross-price Elasticities of Supply for Australian Wool, Beef and Wheat: Scenario 2

Grouping	Wool w.r.t.[a] price of			Beef w.r.t. price of			Wheat w.r.t. price of		
	Wool	Beef	Wheat	Wool	Beef	Wheat	Wool	Beef	Wheat
Australia	0.36	−0.25	−0.29	−0.51	0.90	−0.65	−0.24	−0.24	1.26
By States—									
New South Wales . .	0.91	−0.24	−0.51	−0.65	1.21	−0.87	−0.24	−0.28	1.15
Victoria	0.74	−0.82	−0.12	−1.06	1.52	0.00	−0.72	0.00	0.70
Queensland	0.64	−0.39	0.00	−0.07	0.32	−0.51	0.00	−0.62	1.20
South Australia . .	0.28	−0.18	−0.18	−0.22	0.91	−0.11	−0.26	0.00	1.70
Western Australia . .	0.00	0.00	0.00	−2.20	4.12	−4.55	−0.33	−0.24	1.40
Tasmania	0.00	0.00	0.00	−0.51	0.48	−0.28	0.00	−0.09	0.14
By B.A.E. Zone—									
High Rainfall	0.45	−0.52	−0.04	−0.37	0.89	−0.15	−0.08	−0.23	0.76
Wheat-Sheep	0.28	−0.07	−0.40	−0.32	1.01	−1.29	−0.33	−0.21	1.55
Pastoral	0.51	−0.34	−0.32	−0.92	0.64	−0.29	−0.06	−0.18	0.48
By Farm Type—									
Sheep-Grain	0.87	−0.08	−0.57	−1.71	3.81	−4.70	−0.24	−0.10	1.57
Sheep	0.43	−0.30	−0.16	−1.07	1.60	−1.56	−0.14	−0.23	0.78
Grain	0.36	−0.13	−1.54	0.00	1.06	−1.64	−0.17	−0.29	1.16
Beef Cattle	1.13	−1.54	−0.11	−0.16	0.35	−0.23	0.00	−0.60	1.20
Dairy Cattle	0.27	−0.25	−0.19	−0.88	0.62	−0.16	−0.13	−0.25	1.31
Multipurpose	0.37	−0.18	−0.44	0.00	0.72	−0.95	−0.14	−0.27	1.10

[a] w.r.t.—with respect to.

elasticity is somewhat lower. For beef, it is more difficult to draw any conclusions due to the relative paucity of comparable estimates. Our results show an own-price elasticity of 0.69 for Scenario 1 and 0.90 for Scenario 2. Powell and Gruen [13] have estimated a 1-year elasticity of 0.16, but did not estimate a value for a longer run. More recently Vincent, Dixon and Powell [15] have presented results for the three B.A.E. zones estimated by a CRETH (constant rate of elasticity of transformation homothetic) system. Their 1-year own-price elasticity estimates for beef were 1.01 in the pastoral zone, 0.48 in the wheat-sheep zone and 0.34 in the high rainfall zone. They also found significant cross-elasticity effects. Overall, the relative magnitudes of their estimates tend to support the values derived from the APMAA model. Own-price elasticity estimates for wheat are also relatively sparse. Powell and Gruen [13] estimated a 1-year elasticity of 0.18 and a 5-year elasticity of 0.85. Our estimates are 1.10 for Scenario 1 and 1.26 for Scenario 2.

Comparison of cross-elasticities, even on a national scale, is restricted by the limited availability of estimates. The more comprehensive studies of Australian agriculture reported by Powell and Gruen [13], Gruen *et al.* [9] and Vincent, Dixon and Powell [15] provide cross-elasticity information only for 1-year estimates.

On a State basis, lack of relevant studies restricts comparison to New South Wales and South Australia, and then for a limited number of products. Duloy and Watson [7] present results for New South Wales wheat supply by region. Their dynamic model for old-established wheat growing areas yields short-run own-price elasticities between 0.33 and 0.51 and long-run elasticities between 0.59 and 1.0. For wheat supply from the newer regions, their short-run estimates are 0.13 and 0.16, whereas long-run elasticities are between −0.01 and 7.95. Using APMAA, we estimate a short to intermediate-run elasticity of 1.06 and an intermediate to longer run elasticity of 1.15. Freebairn [8] estimated an econometric model of the New South Wales livestock sector which yielded 4-year own-price elasticities of supply for wool of 0.37 and for beef of 0.11, as compared to our estimates of 0.61 and 0.94 respectively. His estimate of the cross-elasticity of wool supply with respect to the price of beef was −0.14 (*v.* our −0.16), and for beef with respect to the price of wool it was −0.19 (*v.* our −0.52). For South Australia, Dahlberg [5] has estimated a 2-year own-price elasticity of wool of 0.08 and a short-run cross-elasticity of wool with respect to the price of wheat of −0.42. These values relate solely to the wheat-sheep zone, no results having been obtained for the high rainfall or pastoral zones. Intuitively, one would anticipate that aggregation of these three regions to derive State elasticity estimates for South Australian wool would lead to values more like those estimated by our model, i.e., own and wheat cross elasticities of 0.20 and −0.13 respectively.

Comparison of our estimates by B.A.E. zone and farm type with other studies is not possible. To our knowledge only one other study gives elasticity estimates for all Australia on the basis of B.A.E. zones (Vincent, Dixon and Powell [15]), and these are 1-year elasticities. For response by farm type, we know of no comparable studies.

4 Policy Considerations

The results presented in this paper represent one of the most comprehensive sets of elasticity estimates available to date. Of direct importance to the policymaker are the indications that the elasticities provide on the difference in response to changes in prices observed between States and between different farm types. Such information can be of considerable value in the formulation of policies aimed at particular sectors of the agricultural industry.

A second aspect of direct interest to policy-makers is the estimated cross-elasticities. These highlight the significance of policy-related price changes in the eventual production of other commodities. For example, if the price of wheat is increased as a policy measure aimed at increasing wheat production, there will inevitably be an effect on the total and regional distribution of beef and wool production. The current study provides some indication of these effects.

5 Concluding Comments

From the results presented in this paper, it is suggested that a multilevel aggregative programming model—such as APMAA—can perform a significant role in the estimation of supply elasticities. Moreover, because of the highly disaggregated nature of the model, one set of analyses can be used for generating own and cross-elasticities of supply for many different subsectors of the agricultural sector. In this study of wool, beef and wheat, we have restricted our analysis to the entire sector, individual States, B.A.E. zones and major farm types—all at a single price regime—so that the volume of results would not be too great. Such a disaggregated structure is generally infeasible for the more orthodox positive approach using time-series data because of consequent data and estimation problems.

While following the approach of Shumway and Chang [14] in comparing the results from these different types of models, albeit in our case more subjectively, it is obvious that caution must be exercised in making comparisons. For adaptive expectations-type econometric models, definitive procedures exist for estimation of 1-year, multi-year and long-run elasticities. By contrast, aggregative programming models depend on the inherent structure of the model for the length of run to be considered and generate—not historical reflections of aggregate farmer behaviour—but conditionally predictive estimates reflecting chosen model specification and assumptions.

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