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Interactions of Technological Change in Australian Agriculture: An Aggregative Programming Analysis

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In this paper an extension of the work previously undertaken using the Aggregative Programming Model of Australian Agriculture for the analysis of the effects on Australian agriculture of changes in productivity is described. The impact of four specific improvements in technology, two in the sheep sector and one each of the beef and wheat sectors, are analyzed both separately and in combination. The rates of productivity growth resulting from the technological changes are measured both nationally and by State. Results are presented showing net farm income by State and for all Australia, as well as agricultural output for all Australia.

1 Introduction

Two of the principle methods for increasing profitability and productivity. which are often readily available to farmers, are to vary the enterprise mix within the farm plan and to introduce appropriate new technologies. Research into past trends (for example Powell [11], and Young [18]) has indicated that, historically, increases in productivity have made significant contributions to Australian agricultural output. However, the likely benefits from future productivity growth, are a matter for considerable conjecture.

Programming models provide one method whereby the impact of alternative potential technological changes can be investigated. Wicks and Dillon [15], and Wicks, Parton and Beesley [17] have used the Aggregative Programming Model of Australian Agriculture (A.P.M.A.A.)[1] to investigate the influence of increases in labour productivity on Australian farm output. Other analyses by the Bureau of Agricultural Economics (e.g., Bond [4], Easter [7] and Kingma [10]) have involved use of a Regional Programming Model[2] to investigate the effects of a variety of aspects of technological change on output and farm incomes.

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1. A.P.M.A.A. is a highly disaggregated representative farm model. In order to permit ready solution each representative farm must be modelled as simply as possible without losing the important farm planning relationships.
2. The Regional Planning Model used for the analyses has been described by Easter and Kingma [8].

All of these analyses have concentrated on the separate evaluation of individual aspects of technological change. In the real-world economy changes rarely occur in isolation. When more than one change occurs in a single industry, or in more than one industry, the effects are likely to be far more complex than a simple summation of the effects of individual technological changes. Depending on the nature of the technological changes, the overall result may be greater than, equal to, or less than an additive effect.

A greater than additive effect will arise if the technological changes result in a release of resources from the production activities which they affect, and if these resources can be combined to increase production of some other activity. An additive effect will only result if the effects of technological changes on different activities are completely separate, and thus unable to interact. Careful consideration of possible changes suggests this to be a very unlikely situation. Finally, a less than additive effect may arise when the technological change results in competition between two activities for one limiting resource. The resource is then allocated to that activity with the comparative advantage.

Clearly the number of possible combinations of complementary and competing technological changes which could theoretically be investigated is almost limitless. Moreover, it would be extremely difficult to determine prior to analysis the exact effect of any single, or group of technological changes. Thus it is necessary to select a limited number of changes and to examine these individually, and in combination.[3]

In this paper, the individual and combined effects of four technological changes related to the sheep, beef and grain sectors of Australian agriculture, are analyzed. In the following section some brief details of the A.P.M.A.A. model are provided, together with a review of the technological changes to be considered. Results are presented in the third section. In the fourth section of the paper broad conclusions are drawn from the results obtained, and the potential value of such analyses in policy making is briefly considered.

2 Specification of the Model and Technological Changes Analysed

The A.P.M.A.A. model has been described elsewhere by Walker and Dillon [13] and Wicks, Mueller and Crellin [16]. Since this model was based on 1970–71 data, various coefficients had to be updated to reflect the most recent period possible, namely 1975–76. A brief resume of the model, together with details of the update used for our analysis is provided in the Appendix. The updated model was then used as the basis from which five-year projections were made.

Thus, the analysis performed was intended to reflect the intermediate-run effects of technological change. Specifically, there was an over-riding assumption that the introduction of any given change would begin in the base year (i.e., 1975–76) and would take until the fifth year to be completed.

3. At this juncture it is worth noting that explicit sensitivity analysis, although highly desirable, is rarely possible in aggregative programming analyses. This is due solely to the magnitude of the model and the consequent costs in terms of computer resources and actual time required to undertake an adequate sensitivity analysis. However, some implicit sensitivity analysis may be undertaken readily by reference to other results obtained using the model. In the case of A.P.M.A.A. these indicate that the model is sufficiently accurate and robust for the subsequent results to have some meaning.

Therefore the results obtained reflect the equilibrium state after complete, but not instantaneous, adoption of the new technologies. Although the formulation is fairly specific to years, there is no intention that results should be interpreted as forecasts of what will happen. They are, in fact, projections of what should happen, subject to a given set of prices, as a consequence of particular technological changes.

Four different sources of technological change, one for each of the beef and grain sectors and two for the sheep sector, were then specified within the modified model. Since the method by which these technological changes were incorporated into the model might influence the results obtained, the possible approaches are now briefly discussed in order of complexity. First, the coefficients of the old activity might be changed to reflect increased productivity. For very simple cases, where an increase in gross margin and no other change is ensured, this is adequate. Second, the coefficients for the new activity may be computed, and the new and old activities compared exogenously to the model. The more profitable can then be used in the analysis. This approach is suitable for changes of intermediate complexity, such as one involving changes in yields and variable costs. Third, the new activity may be defined and incorporated as an additional activity in the model. In our analysis we restricted methods for inclusion of improved technologies to the first two listed above. The reasons for so doing were both that we believed the types of changes included could be adequately modelled by the simpler approaches and also that the additional matrix size which would result from duplication of several activities might well tax our available computing resources.

The technological changes included for the sheep sector were the introduction of jumbo bales for the marketing of wool, and a 10 per cent increase in the number of sheep handled per man. Jumbo bales have been popularized in recent years as an innovation through which producers can receive an improved return for their wool. At the present time this technology merely requires sale of traditionally baled wool through a specific outlet, the agent undertaking the necessary rebaling. The benefits to the grower are in terms of reduced costs of storage and transport. Once the technique is sufficiently widely adopted it is possible that production of jumbo bales will be extended to the farm level. Indications are that adoption of the technique, as currently practised, will increase dramatically in the next few years, and the benefit to the producer is an increased return of approximately 2 per cent.[4] For each of the runs involving the introduction of jumbo bales, complete adoption within the period modelled was specified, and 2 per cent increase in returns was credited to the producer. For the case of improvement in sheep handling efficiency, Fels and Hogstrom [9] have shown, for Western Australia, that, between 1965 and 1970, the average number of sheep handled per man increased at an average of approximately 7 per cent per annum. Furthermore, in 1970, they located a significant number of producers who were handling over twice as many sheep per man as the Western Australian average without apparent reduction in quality or quantity of product. This led us to believe that a 10 per cent increase in efficiency in sheep handling would be achievable in the intermediate-run.

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4. Personal communication. Mr G. George, Australian Wool Corporation. Mr George indicated that the adoption of jumbo bale technology would result in a total increase in returns of 6 per cent. Of this one third would actually accrue to the producer and the remainder to the agent.

The improvement in the beef sector involved an average increase in feed conversion efficiency of beef cattle of 2.5 per cent.[5] Obviously some beef cattle herds have greater potential for improvement than others but there were insufficient data available to permit such variation in model specification. Thus a sector wide average was used.

There were greater problems in specifying a change in the grain sector due to the absence of any obvious major technological change on the immediate horizon. However, it is apparent that a significant amount of grain is commonly lost through inefficiencies in the harvesting system. We therefore hypothesized an improvement in grain harvesting, which we believed could achieve considerable benefits at a reasonable cost. The values used were a 10 per cent increase in harvesting costs, and a 5 per cent increase in the recovery rate of harvested grain. The technology was permitted only for those farms with potential to grow more than 100 hectares of grain per annum. The technological change is therefore only of limited applicability and is both cost and output increasing.

With the technological changes quantified, eleven runs of A.P.M.A.A. were implement ed These were a base run with no technological change, four runs each incorporating one technological change, four runs each incorporating two technological changes, one run incorporating three technological changes (one from each sector), and a final run incorporating all four technological changes. The results obtained from each of the runs are reported in the following section.

3 Results

Since all of the results reported in this paper were obtained from a profit maximizing, linear programming based model, they must be subject to the limitations of that method. However, since we consider them in terms of differences between two runs of the model, it is anticipated that errors are fairly minimal.

In the first column of Table 1 Australia-wide estimates of growth in total factor productivity arising from each of the individual, and groups of, technological changes are reported. These estimates were computed as follows. The fixed cost component of input costs was derived from the BAE's 1973–74 Australian Grazing Industry Survey [5] indexed to 1975–76 costs using the *BAE's Index of Prices Paid.* Variable cost items were derived directly from the optimal plan estimated by the model. The unimproved capital value (U.C.V.) of land was obtained from Powell [11] and indexed to 1975–76.[6] These three items constituted the total value of inputs. The value of output was estimated from the solutions to the A.P.M.A.A. representative farms, and

5. Dr K. Hammond of the Animal Genetics and Breeding Unit, U.N.E. in a personal communication, indicated that conversion efficiency in individual herds could currently be increased by between 2 and 4 per cent per annum. Thus an overall average increase of 2.5 per cent in the intermediate-run (i.e., over approximately 5 years) would appear to be a quite reasonable objective.

6. Although the U.C.V. of land is not independent of the state of adoption of new technologies, sensitivity analysis of the results indicate that changes in U.C.V. of land, of the order likely to be generated by these technological changes, would not have a significant effect on the estimated rate of productivity growth. A similar situation occurs when we attempt to estimate productivity growth for individual States. In this latter case we validated the results by estimating productivity growth under a wide range of assumptions concerning the relative U.C.V.'s of improved and unimproved land. In no case were our results sufficiently variable to warrant further investigations of the importance of U.C.V.

Table 1: Total Factor Productivity Growth Derived from Selected Technological Changes by State and for all Australia

Sector(s) in which technological change occurs	Australia	States					
		New South Wales	Victoria	Queensland	South Australia	Western Australia*	Tasmania
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Sheep (JB)†	0.56	0.43	0.43	0.15	1.11	1.32	0.34
Sheep (LP)‡	0.86	0.99	0.00	0.53	3.80	0.00	1.20
Beef	0.28	0.59	0.15	0.26	0.13	0.13	0.35
Grain	1.34	0.97	0.65	1.69	0.90	3.00	0.00
Sheep (JB), Beef	0.88	1.13	0.59	0.41	1.25	1.47	0.70
Beef, Grain	1.60	1.58	0.80	1.94	1.00	3.13	0.35
Grain, Sheep (JB)	1.90	1.64	1.08	1.83	2.01	3.77	0.34
Sheep (JB), Sheep (LP)	1.50	1.62	0.43	0.74	4.99	1.32	1.55
Sheep (JB), Beef, Grain	2.14	2.12	1.23	2.09	2.14	3.90	0.70
Sheep (JB), Sheep (LP), Beef, Grain	3.06	3.19	1.23	2.67	6.33	3.91	1.92

* Including Northern Territory.
† Denotes jumbo bale technology in the sheep sector.
‡ Denotes a 10 per cent increase in labour productivity in the sheep sector.

ranged from $3 600 m to $3 730 m. The rate of total factor productivity growth was then calculated as the percentage increase in output per unit of input after adoption of the technological change as compared to output per unit of input before. Points of interest from the Australia-wide results are first that, at the national level, complementary and competitive effects do not appear to be at all important. The sum of the four individual changes is 3.04 per cent as compared to 3.06 per cent for the combined changes. For the three changes—wool (JB), beef and wheat—it is 2.18 per cent as compared to 2.14 per cent. However, this result does not negate the hypothesis of non-additive effects, since agriculture in different States may respond in different ways. Thus it is conceivable that losses in one region may be masked by gains in another, and the high level of aggregation will therefore tend to cause a misleading result.

Second, the rate of total factor productivity growth arising even from the complete package of technological changes is relatively low, when compared to the rates achieved during the 1960's. Indeed given that such changes would require approximately five years for relatively complete adoption, the complete package would account for approximately 0.5 per cent increase per annum in total factor productivity. This would suggest that a considerably larger package of technological changes would be required to induce productivity growth at levels similar to those previously obtained.

In the remainder of Table 1 total factor productivity growth by State, for each of the individual and groups of technological changes, is shown. Although in Australia productivity growth has usually been measured for the country as a whole [11, 17], it should be possible to derive additional useful conclusions if productivity growth can be broken down to the level of individual States. Use of an aggregative programming model facilitates such breakdown since the majority of inputs and outputs can be estimated directly from the model. Time consuming construction of adequate data series is therefore not required. In order to facilitate initial estimation of appropriate values, the U.C.V. per unit of land was assumed to be constant, on average, for all Australia. Consequently, the U.C.V. per unit of land was assumed proportional to the area of agricultural land in that State.

The State results provide much stronger support of the hypothesis of non-additivity of the effects of productivity change than do the Australia-wide results. For example, in New South Wales the sum of the effects of the four changes individually is 2.98 per cent whereas for the four changes combined it is 3.19 per cent. In Western Australia the comparable values are 4.45 per cent and 3.91 per cent respectively. For the situation of two productivity changes in the sheep sector, the individual values for New South Wales are 0.43 per cent for the jumbo bale technology and 0.99 per cent for labour productivity. When combined the increase is 1.62 per cent, giving an additional gain of 0.20 percentage points. For the other States the effect is not so marked. However, these results suggest that presentation of results on a national basis has tended to mask many countervailing forces.

In Table 2 the national output of major commodities is shown, together with the estimated changes in sheep and beef cattle breeding units for each of the situations examined. A more detailed regional analysis is computationally possible but is prevented by the volume of results which would need to be presented.

Table 2: Total Australian Production of Major Commodities and Changes in Livestock Breeding Units for Selected Technological Changes

Commodity (unit)	Sector(s) in which technological change occurs									
	Nil	Sheep (JB)	Sheep (LP)	Beef	Grain	Sheep (JB) Beef	Beef Grain	Grain Sheep (JB)	Sheep (JB) Sheep (LP)	Sheep (JB) Beef Grain	Sheep (JB) Sheep (LP) Beef Grain
Wheat (10^5t)	132	133	133	133	141	132	139	141	133	140	140
Coarse Grains (10^5t)	10	10	10	10	10	10	10	10	10	10	10
Total Grains (10^5t)	142	143	143	143	151	142	149	151	143	150	150
Lamb (10^3t)	255	261	252	252	264	253	254	263	252	256	251
Hogget (10^3t)	228	223	237	228	227	224	228	226	233	227	236
Mutton (10^3t)	307	312	315	307	308	311	306	308	318	307	317
Total Sheepmeats (10^3t)	790	796	804	787	799	788	788	798	803	790	804
Veal (10^3t)	380	380	379	381	376	380	380	376	379	380	379
Fat Beef (10^3t)	694	681	689	704	676	700	704	676	689	699	694
Manufacturing Beef (10^3t)	392	390	399	396	388	395	396	388	390	395	393
Total Beef (10^3t)	1 466	1 451	1 459	1 481	1 440	1 475	1 480	1 440	1 458	1 474	1 466
Wool (10^3t clean)	351	355	365	350	351	354	349	352	368	351	366
Fresh Milk (10^6 litres)	6 185	6 185	6 184	6 184	6 186	6 184	6 184	6 186	6 184	6 184	6 185
Change in number of sheep breeding units (per cent)	0	1.0	2.8	—0.3	1.1	0.0	—0.3	1.0	2.8	0.0	2.9
Change in number of cattle breeding units (per cent)	0	—1.0	—0.7	1.2	—1.7	0.8	1.1	—1.7	—0.7	0.8	0.0

In the case of jumbo bales, the new technology results in a 1.3 per cent increase in wool production and a 2.1 per cent decrease in hogget meat production. This is due to the increased profitability of retaining hoggets in the wool producing flock. Lamb and sheepmeat production are marginally increased, wheat production increases by approximately 1 per cent and beef production decreases by approximately 1 per cent.

With an increase in labour productivity in the wool sector there is an increase of 2.8 per cent in the number of breeding ewes retained, as compared to the base results. The additional ewes are utilized in merino enterprises for the production of additional hoggets and wethers. This results in a 4 per cent increase in hogget output, a 2.5 per cent increase in mutton output and a 4 per cent increase in wool output. At the same time production of wheat is marginally increased.

Beef production responds positively, as would be expected, to an improvement in beef technology and there is a simultaneous decrease in sheepmeat production and increase in wheat production. Finally, wheat production appears to increase significantly in response to the new grain technology. However, approximately 50 per cent of this change is doubtless accounted for by the increase in harvested yield rather than by changes in planned production. The grain technology also has a positive effect on sheepmeat and wool production and a negative effect on beef production.

Except in the case of the two sheep technologies, the levels of output consequent upon the introduction of two new technologies are intermediate to the levels of the two technologies considered individually. Thus combination of technologies has resulted in a trade-off, due to the comparative advantages conferred by the new technologies. For the case of the two sheep technologies combined, there is a mutually beneficial effect with wool and mutton output at the highest level for any of the scenarios. As a result of the increased competitiveness of wool, both lamb and hogget production decline.

In the three-technology scenario, there is a tendency for each to counteract the other. Thus the sheep enterprise changes little from the base situation, grain production is increased but mainly through increased efficiency of grain recovery at harvest and the additional feed availability results in a marginal increase in beef production. These impacts are reflected by the changes in livestock breeding numbers. For the final scenario, where all four technologies are included, wool has a comparative advantage such that breeding ewes rather than breeding cattle are retained, hogget, mutton and wool production are increased and lamb production decreased. There is also a marginal increase, approximately 1 per cent, in the area of wheat, and again the greatest gain comes from the increase in grain recovery per hectare.

In Table 3 the increase in total net farm income[7] resulting from adoption of the technological changes is shown. When each of the four changes is considered separately the sum of the increases in net farm income is $88m., that is $4.3m. less than when they are considered in conjunction. The significance of this deviation from the additive effect is a subjective matter. However, we do consider that these results illustrate a need for care when

7. Throughout the analysis, the term net farm income is used to refer to return to capital plus the operator and his family's labour. Operator equity is assumed to be 100 per cent so that no deductions are made for interest payments. Net farm income estimated from the model will therefore be different to that under actual farm equity conditions, and both of these will differ from actual cash incomes which the farms will generate in the short run.

evaluating the impact of various improvements. In the context of policymaking, the results have potential as a guide to the total annual gains in income which might be anticipated from introduction of, or assistance to evolve, specific technological changes. A more detailed analysis of these results, in which benefits are allocated to specific regions and types of farm is provided in Wicks [14].

Table 3: Gains in Total Australian Net Farm Income Resulting from Selected Technological Changes

Sector(s) in which Technological Change occurs	Increase in total net farm income ($10m)
Sheep (JB)	17.3
Sheep (LP)	20.2
Beef	10.5
Grain	40.0
Sheep (JB), Beef	29.2
Beef, Grain	52.0
Grain, Sheep (JB)	59.5
Sheep (JB), Sheep (LP)	40.4
Sheep (JB), Beef, Grain	70.3
Sheep (JB), Sheep (LP), Beef, Grain	92.3

4 Conclusions

The results reported in this paper have illustrated some of the features associated with technological change in Australian agriculture. Although not as evident as initially anticipated, there were clear indications of the competitive and complementary nature of certain combinations of technological changes. In situations where competition exists the agricultural industry, as a whole, does not receive the maximum potential benefits from the technological changes. Thus, unless analyses of technological change are undertaken within the complete framework of other likely changes, results will tend to overestimate the impact of any technological change. Conversely failure to recognize complementarity between technological changes will result in underestimation of the impact.

Evidence is also presented as to how growth in total factor productivity, in response to the same technological change, will vary significantly between States. Such results are of value when policy makers are concerned with regional aspects of policy decisions.

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Appendix

The set of data for the A.P.M.A.A. model comprises some 521 representative farm linear programming matrices which are regionally classified between 63 Statistical Divisions covering non-metropolitan Australia. Each Statistical Division may contain up to eighteen representative farms, these being cross-classified by farm-type and size. The types identified are sheep-cereal grain, sheep, cereal grain, beef cattle, dairy cattle and multipurpose, and the sizes are small, medium and large. The representative farms thus identified model a total of 146 518 actual agricultural holdings. These holdings accounted for at least 95 per cent of Australian production of wool, beef, wheat, coarse grains, milk and sheepmeats in 1970–71, and hence those not included constitute mainly the non-grazing, non-cereal sections of Australian agriculture.

Each of the linear programming models is solved independently, via a profit maximizing, linear programming subroutine. Results may then be aggregated to the desired level.

For our analysis of changes in technologies, resource availabilities were updated to the latest available data period—1975–76 and 1976–77—following the approach described by Wicks and Dillon [15]. The updating procedure was slightly refined as compared to the one previously used in that livestock numbers were updated on a Statistical Division, rather than State, basis. For those coefficients where changes might be expected in the intermediate-run, for example labour and different land types, appropriate changes were made in accordance with current expectations, these being formed in consultation with our colleagues at U.N.E.

Input costs were updated to 1975–76 for each item as reflected in the Bureau of Agricultural Economics' (B.A.E.) *Index of Prices Paid by Farmers*. Then, farmers' terms of trade were projected to continue declining in line with the general trend of the past ten years [6].

Output prices for all commodities except beef were drived as five-year averages up to and including 1975–76. Prices were estimated from the Australian Wool Corporation's *Wool Marketing News* [3], Richmond [12], and the *Annual Report* of the Australian Barley Board [1]. Where applicable, regional differentials were also included. For beef the five-year average, estimated by reference to Richmond [12] and the *Statistical Review of the Meat and Livestock Industry* [2], resulted in a very low price. As it was believed that this represented an unusual situation, beef prices were increased to reflect a moderate recovery in the market. (The extent of the recovery in the price of beef subsequent to our analysis suggests that these values may still be low.) The dressed prices used for the analysis were an all-Australian average of $0.83 per kg for fat beef, $0.89 per kg for veal and $0.71 per kg for manufacturing beef. They maintain the relativities observed in earlier prices [2].