ASSESSING THE IMPACTS OF PRODUCTION TECHNOLOGY ADOPTION IN THE AUSTRALIAN PRIME LAMB INDUSTRY[1]

D.T. Vere, G.R. Griffith and B.W. Bootle

NSW Agriculture

1. Introduction

Improved technology adoption is an important source of productivity gains in agricultural production. Productivity gains are likely to be sustainable where technology adoption and maintenance results in improved production practices. In livestock production, such technologies include genetically superior breeding stock, pasture improvement and improved farm management. The widespread adoption of animal production technology may also have market effects. Where new technology results in increased output, the nature of the Australian livestock markets suggests that the prices paid by consumers and the prices received by producers will likely be lower than those prior to the technology adoption. The adoption of animal production technology therefore has implications for producers, consumers and other livestock market participants.

Assessing the economic potential of livestock production technology adoption requires the use of a modelling approach which considers both farm and market components. The farm-level models establish the output and revenue changes resulting from the technology, given farm constraints and producer objectives. Industry supply responses can then be estimated by aggregating the farm responses under an assumed level of technology adoption across the industry. When linked to the market models, the relative impacts of the farm technology on all market participants can be determined.

This type of assessment is considered to be useful for several reasons. It provides livestock producers with a comparative assessment of the economic benefits of adopting alternate production technologies under the usual resource constraints. By highlighting the productivity changes and associated profitability implications, producers gain an appreciation of those technology options best suited to their situations. Improved resource allocation is encouraged as a result. Another reason is that it provides objective information on the aggregate market impact of production technology adoption. With assumptions about the nature of the supply and demand curves, the type of supply shift, and the relationship between producer and consumer prices, measures of total benefits and costs can be derived, and the present values of the annual benefits and costs can be calculated. Further, both sets of results can then be used to identify the various options in the livestock research programmes to allow the efficient allocation of the research budget. While some public authorities have large annual budgets for livestock research (e.g., the United States Department of Agriculture allocated about $US550 million to this activity in 1991), the social gains to these expenditures are less well recognised (Norton and Peterson 1991).

[1] The financial support of the Meat Research Corporation in this research is acknowledged. The views expressed herein are not necessarily those of the Corporation.

This paper describes the development of economic modelling procedures for the ex ante assessment of the farm and market level impacts of the adoption of livestock production technology. It is applied to the assessment of the impacts of the introduction of a lamb breeding programme on the Australian lamb market. The assessment focusses on the Elite lamb breeding programme which has been recently introduced in New South Wales, Victoria, South Australia and Tasmania under the sponsorship of the Meat Research Corporation. The programme's main objective is to increase the production and domestic consumption of leaner, heavier (Elite) lamb by 25,000 tonnes per annum by 1994[2]. Because this technology remains in the developmental stage, the preliminary nature of the results presented is stressed.

2. Methods

The relationship between productivity and technological change is fundamental to this analysis. The analysis considers improved technology adoption to be a primary source of productivity gains, either from increasing outputs from the same inputs, or from maintaining outputs from reduced inputs. Productivity can thus be defined in terms of the relationship between outputs and inputs where improved production practices induce either shifts along the production function from resource adjustments or shifts of the production function from increased outputs. This definition enables the impact of production technology to be measured as the productivity changes induced by its adoption.

Four main cost components can be identified from the introduction of new technology in livestock production;

(i) direct production cost comparisons between the improved and the existing production systems; these are often established using farm budgets such as gross margins, partial budgets and cash flows;

(ii) the costs of farm-level adjustment; even if the direct costs of the alternative production systems do not differ greatly, there may be significant costs in adjusting from one system to another in terms of the different resource inputs and management skills required; farm programming models provide a means of estimating these costs;

(iii) the costs of industry adjustment which reflect the extent to all producers can readily adapt to the new technology; some producers may exit production if they cannot adopt the technology and their production practices prove to be inefficient relative to those based on the new technology; others may expand production for the opposite reasons; these costs might be estimated from broader programming models; and,

(iv) the costs of the price and consumption effects resulting from the quantity changes; these are usually assessed using quantitative market models.

---

[2] An Elite lamb is defined as having a 22-plus kg carcase weight with a 2 or 3 fat score.

The different cost components indicate that there are implications for producers and consumers from livestock production technology adoption, and the need for farm and market-level models to accurately assess technology adoption impacts.[3]

2.1 Measuring farm-level impacts

Farm-level assessment of production technology adoption has two dimensions. The first is the relative cost comparison of the range of options for effecting livestock productivity gains. This is usually done by calculating gross margin budgets in which the non-fixed costs and output differentials for each technology alternative can be compared. The approach is limited in that differences in production costs or gross margins do not always constitute an economic gain for producers because of differences in their preferences for risk and debt and in their ability as managers, and because it is enterprise specific, it takes no account of the whole farm situation and it ignores market effects.

A more rigorous method for production technology assessment is to construct a representative farm model. This approach utilises a whole farm programming model containing gross margin budgets for the appropriate production activities. It enables the calculation of optimal enterprise combinations which maximise an objective function such as net farm income, subject to various constraints (including technologies) and given input and product prices. The solutions indicate the stability of the production activities under changing costs and prices, the shadow prices or marginal value products of the limiting resources, and the opportunity costs of excluded activities or of requiring the inclusion of specific activity levels. These marginalities conform more closely to conventional economic theory than do the average measures given by other farm budgeting methods such as gross margins. The representative farm model improves on gross margin analysis since differences in current and new technologies may be readily incorporated, the analysis relates to the whole-farm context, and output response is measurable. A particular advantage of using LP in livestock modelling is the logical reconciliation of animal requirements and pasture production, which with the inclusion of seasonal transfers, enables animal numbers to be accurately matched with the available feed supply. The main limitation of LP in this modelling context is that the longer term responses in the market place are ignored. Being farm based, LP assumes that farm prices are unaffected by the new technology or by the new enterprise combination.

One procedure adopted for examining farm-level technology impacts using an LP model is to generate a base or control solution and simulate the impacts of changes in the levels of the technical coefficients holding prices and costs constant. The

---

[3] These considerations indicate differences in the potential impacts of technology adoption on a particular farm (categories i and ii) and on the aggregate industry (categories iii and iv). They reflect not only the peculiarities of individual livestock production systems and management objectives, but also the extent of timing of the adoption of the technology at the industry level.

differences between the base and simulation solutions are expressed as percentage changes or as elasticities, i.e., the percentage change in a productivity coefficient (e.g. labour, fertilizer) necessary to generate a given change in the objective function (e.g. net income), **ceteris paribus**. The coefficients can then be ranked in terms of their importance as productivity influences. This programming approach has been applied elsewhere in assessing the impact of production technology productivity change in the Australian sheep and grazing industries. For example, using ABARE's Regional Programming Model, Easter (1977) and Love **et al.** (1982) found that the productivity gains associated with feed availability most influenced sheep and grazing outputs, returns and industry incomes.

Both these types of farm models were components in the broader model which was used to assess the impact of new technology adoption in Australian prime lamb production. Gross margin budgets are a standard means of comparing alternate livestock enterprises or production technology options within a specific enterprise. Traditionally, this budgeting method has expressed economic returns on a per unit basis, usually either gross return per unit area, per livestock unit (head or dry sheep equivalent) or per unit of capital invested. However, the economic efficiency of feed conversion is now considered to be a more appropriate comparative basis for livestock production, as feed availability and the timing of feed usage is regarded as being the most limiting economic resource in Australia's extensive livestock production systems (Bootle 1991), i.e., whether the enterprise is an efficient converter of pasture to profit.

The gross margins provide the basis for estimating the supply shift parameter for the market-level assessment of the Elite lamb technology (Section 2.2). Two estimates of this parameter were considered, both of which were expressed in terms of the percentage production cost reductions resulting from the adoption of the technology. As a simplifying assumption, the farm level models related to New South Wales lamb production systems. These systems were considered to be reasonably representative of lamb production throughout the other states since New South Wales is the main lamb producing state, contributing about 45 per cent of annual national matings for prime lamb production.

The first supply shift estimate was calculated from the gross margin differences between the standard and Elite lamb systems based on the "Sheep Cents" budgeting programme developed by Bootle (1991). Gross margin budgets were calculated for four New South Wales lamb production regions, the northern tablelands, the central and southern slopes and the southern irrigation areas[4]. Because the Elite lamb technology is still in the development stage, the budget assumptions for the technology were elicited from the programme's lamb production specialists. A risk sensitivity analysis on the main gross margin parameters was undertaken to produce a range and probability estimate for the likely outcomes (in lieu of the gross margin's typical average estimate) using the @ Risk package. Risk analysis on three parameters was

---

[4] The gross margins for the southern irrigation area were not considered further as the relative profitability of Elite lamb in this area was less than that of the standard system because of the high costs of supplementary feeding over Summer.

simultaneously considered; lamb price with a 30 per cent variation, supplementary feed with a 50 per cent variation and wool and mutton (culled ewe) prices with a 20 per cent variation (Table 1). A triangular distribution (giving minimum, mean and maximum values for each distribution) was chosen because there were insufficient data to determine the actual probability distribution.

Table 1. New South Wales Lamb production gross margins ($ per DSE)

New South Wales region	Standard system with risk	Elite system with risk
Northern tablelands	7.83	7.84
Central slopes	7.34	7.54
Southern slopes	6.84	7.22

From the budgets in Table 1, the first supply shift parameter from the introduction of the Elite lamb technology was estimated to be equivalent to a 2.6 per cent reduction in the average lamb production costs across the three regions (Table 2).

The second supply shift parameter was estimated using a whole-farm LP model which was constructed to be representative of the mixed farming systems in which the Elite lamb technology is considered to be applicable. Here, the LP model related to the New South Wales central slopes and incorporated the lamb production gross margins (and those for other activities) from Table 1[5]. This approach was considered to provide a more rigorous estimate of the supply shift parameter because it was a measure of the net effect of the technology adoption over all the farm activities, after allowing for the substitutability between these activities and the resulting resource adjustments. Accordingly, this second supply shift parameter estimate was expected to less than the first and was calculated to be equivalent to a 1.3 per cent reduction in the costs of lamb production (Table 2).

2.2 Measuring market-level impacts

Programming models of farm production rely on the assumption that output prices are not affected by the changes in resource allocation or product mix. This may be realistic when one farm is considered since changes in its output will rarely affect market price. However, when new production technology is expected to be widely adopted in an industry, the sum of all individual farm changes will very likely lead to a change in the price of the output (particularly in the lamb industry where prices

---

[5] To further this analysis, separate LP models will be necessary because the economic implications of the adoption of a new production technology of this nature was expected to differ across regions. They also enable the benefits of the ME-based gross margins to be fully realised because of differences in joining and pasture growth patterns throughout the regions.

are highly seasonal and sensitive to supply changes). Thus it is not sufficient to establish the relative on-farm feasibility of livestock production technology without considering the potential industry and market effects.

There are two main approaches to estimating the **ex ante** market impacts of livestock production technology adoption. The first is to determine the economic surplus changes and distributions from the introduction of new technology. This approach is similar to that which has been widely used to estimate the benefits of agricultural research (e.g., Lindner and Jarrett 1978; Edwards and Freebairn 1984; Davis, Oram and Ryan 1987). Here, technology adoption is assumed to result in an outward shift the product's supply curve, with the demand curve remaining stationary. With assumptions about the slope of the supply and demand curves, the nature of the supply shift, and the relationship between producer and consumer prices, the effect of the shift in supply on producers and consumers can be evaluated. The benefits of this approach are that it allows the different impacts on producers and consumers to be identified and the sensitivity of the results to alternative assumptions to be readily examined. Its major limitations are that the economic surplus calculations rely on the availability of market parameter estimates, and that the model's static nature makes it difficult to take account of the time path of responses to technology adoption before a final equilibrium is achieved.

The second method is to simulate the impacts of the new technology on the relevant market variables. This market simulation approach is based on the use of a quantitative market model; two popular forms of which are the structural econometric model and the linear elasticity model. A structural livestock market model is usually specified as a system of equations (representing the breeding, production, consumption, and price variables) which solves simultaneously and generates equilibrium values for the set of endogenous variables. The linear elasticity model is specified in equilibrium with assumed parameters and elasticities (an example of this approach is in Lemieux and Wohlgenant 1989). In simulating the market impacts of new technology adoption using either type of model, the values of the market variables or parameters are altered, the model re-solved, and the results compared with the base model solution. Any changes in the results are assumed to be attributable to the imposed changes resulting from technology adoption. With some standard formulae (given below), these price-quantity changes can be translated into measures of economic surplus change which are allocated to producers and consumers according to the supply and demand elasticities. The main advantage of econometric simulation is that the dynamic responses to technology adoption can be traced out over time as the model solves period by period.

If realised, the production increase objectives of the Elite lamb programme will represent an 8.4 per cent increase over Australia's annual lamb output which has averaged 296,000 tonnes since 1980. Lamb's national market conditions – an inelastic supply and an elastic demand – suggest that a permanent production increase of this magnitude might be expected to have significant market effects. Specifically, the nature of the elasticities suggests that lamb producers would capture the major share of the benefits from the adoption of the Elite lamb technology.

The methods adopted for assessing the potential market impacts of this technology contains elements of both the economic surplus and the econometric market simulation approaches. The formulae for the economic surplus model provide estimates of the likely benefit levels from lamb technology adoption and their distribution. Both are important considerations in planning and managing the technology-generating research process. The overall benefits from technology adoption indicate the relative economic merits of technology options. When the programme costs are also considered, these benefit estimates can be projected over time and discounted to present day values to yield the social investment criteria, net present value, benefit-cost ratio and internal rate of return. Similarly, the relative benefit shares provide guidelines for determining the appropriate equities in the sponsorship of the technology-generation process, whether by producers through their contributions to industry research funds, or by consumers through publicly-funded research.

Figure 1 illustrates the Australian lamb market in a closed economy equilibrium situation (lamb exports are considered to be insignificant at less than 15 per cent of output)[6]. Lamb production is Q_0 for which consumers pay a price of P_0. Producers have an economic surplus equivalent to BP_0C while consumer surplus is the area P_0AC. The adoption of the Elite lamb technology reduces per unit production costs and shifts the lamb supply curve outwards to S_1, resulting in greater output at a lower price. Here, the lamb demand curve D_0 remains stationary since the additional lamb output is assumed to face the same demand as all other lamb. The area of economic surplus is now **FAD** comprising increased consumers' and producers' surpluses of P_1AD and FP_1D, respectively, which represent the impact of the technology adoption on both consumers and producers. The net change in economic surplus is equivalent to the benefits of production technology adoption. It is given by the area **FBCD**, the difference between the areas **FAD** and **BAC**. The incremental benefit area **FBCD** incorporates the production cost reductions for the initial output Q_0 (the area **FBCE**), and the value to consumers of the extra production at S_1, net of production costs (the area **ECD**). Where the supply curve shift is parallel so that the vertical distance between the two supply curves is constant, the changes in the economic surplus areas from the adoption of the Elite lamb technology can be estimated as;

Change in consumers' surplus;

$$(1)\quad \Delta CS = P_0Q_0Z(1 + 0.5Z\eta)$$

Change in producers' surplus;

$$(2)\quad \Delta PS = P_0Q_0(K - Z)(1 + 0.5Z\eta)$$

Change in total surplus ($\Delta CS + \Delta PS$);

---

[6] This simple representation of the lamb market assumes a perfectly elastic supply of marketing services. This results in a constant marketing margin over all levels of output which has a neutral effect on the distribution of benefits between producers and consumers.

(3) $\Delta TS = P_0Q_0K(1 + 0.5Z\eta)$

where, P_0 and Q_0 are the initial equilibrium market–clearing price and quantity for lambs, Z is the percentage reduction in price from the supply shift defined as $Z = K\varepsilon/(\varepsilon+\eta)$, K is the vertical supply shift expressed as the percentage reduction in lamb production costs from the adoption of the new technology, and ε and η are respectively, the price elasticities of supply and demand for lamb. The derivation of these formulae assume that the supply and demand functions are linear for small changes from the initial equilibrium. With quantified market parameters, the economic surplus equations can be solved for the changes in the quantities and prices induced by the adoption of the production technology on the farm.

Market simulation with a validated quantitative model provides estimates of the parameter values required by the economic surplus formulae; these are the initial lamb market equilibrium quantity (Q_0) and price (P_0), which together define point A (Figure 1), the changed quantities and prices Q_1 and P_1, which together with the elasticities of demand (η) and supply (ε) for lamb, and K, the vertical shift in the lamb supply function, define point B. Most of these parameters were estimated using the structural econometric model of the Australian lamb market described in Vere, Griffith and Bootle (1992)[7], with prices expressed in real terms. The own–price demand elasticity was derived from this model's lamb consumption equation, while the supply elasticity was from ABARE's EMABA model as reported in Hall, Fraser and Purtill (1988, Table 3). The supply shift parameters (previously defined) were assumed to be equivalent to the change in the marginal cost of producing lamb at the initial equilibrium prices and quantities. Equilibrium quantities and prices were (arbitrarily chosen as) the quarterly aggregates for 1985. These parameter values are given in Table 2.

The adoption rate for a new livestock production technology has been shown to have a major effect on market prices and quantities following its introduction (Griffith et al. 1991). In ex ante analyses, adoption rates are often expressed as percentages of likely producer uptake with sensitivities between high and low adoption expectations. They are recognised as being difficult to estimate since adoption is itself endogenous, depending on the technology's profit time path and the profit expectations of producers (US Congress 1986, in Lemieux and Wohlgenant 1989). Attempting to hypothesise producer percentage adoption rates for Elite lamb was more complicated because the technology has yet to be developed to the point where it can be released to the lamb industry. In lieu, the potential adoption of the technology adoption was expressed as the increase in average carcase weight that results from a percentage of the number

[7]In summary, this model is a system of 13 equations which represent the main economic variables in the Australian lamb market in four blocks containing the breeding, production, consumption and price components. The model's supply and demand sides are linked by an equilibrium condition, the supply side is recursive, while current prices influence the demand block. The model was estimated from quarterly data between 1969(1) to 1990(4) and validated under a dynamic simulation routine over the estimation period.

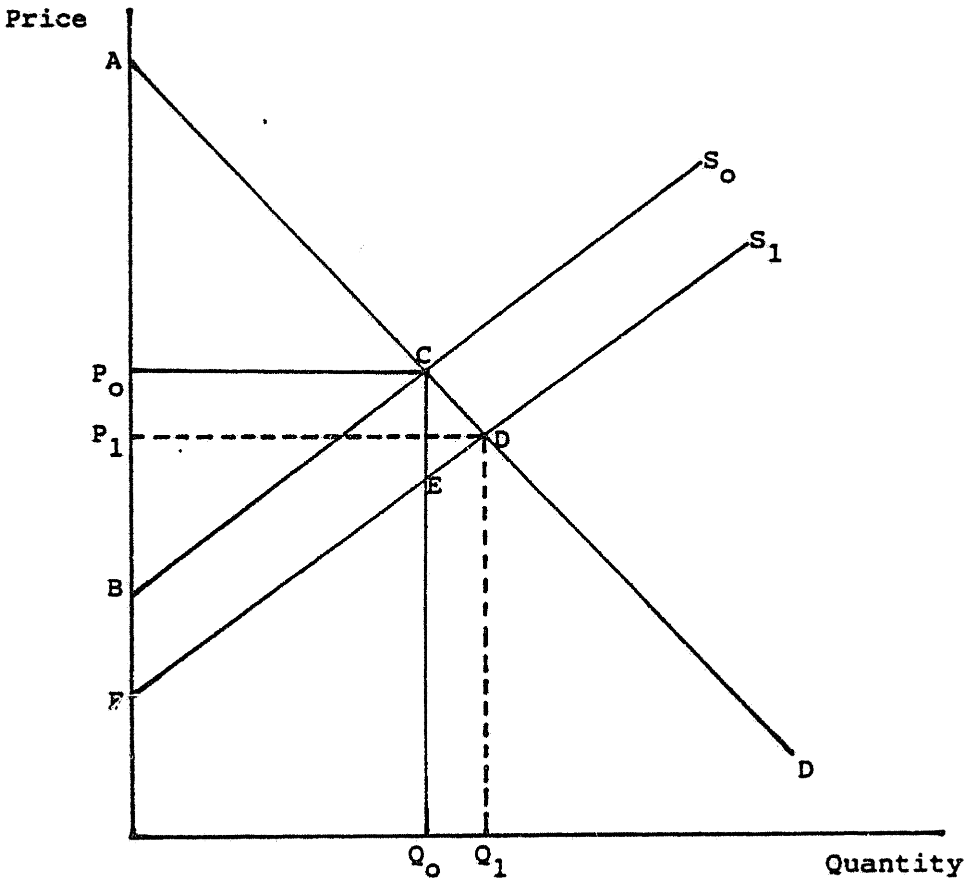

Figure 1: Economic Surplus Changes from the Adoption of New Technology in Prime Lamb Production

of lamb carcases being able to satisfy the Elite lamb specifications (23 kg dressed weight). To illustrate, Australia's average annual lamb production over the 1980's of 296,000 tonnes was equivalent to 17.5 million carcases at an average carcase weight of 17 kg. If the introduction of the technology results in five per cent of lamb carcases being classified as Elite (0.872 million), this results in an annual production increase from the (six kg) heavier lambs of about 5,250 tonnes and an increase in average carcase weight over all lambs from 17 to 17.3 kg. Similarly, the programme's targetted production increase of 25,000 tonnes represents a 24 per cent adoption rate for the technology, i.e., this target weight requires 4.2 million carcases to satisfy the Elite lamb specifications, with an annual average carcase weight over all lambs of 18.4 kg. With the inclusion of a mid-point adoption rate of 15 per cent, these production increase estimates were simulated in the market model to determine the changes in lamb prices and quantities. As an additional sensitivity test, the impact was simulated at 1985 to represent the full impact of immediate adoption, and at 1990 to represent a lagged adoption process which is consistent with the structural model's dynamics. The equilibrium lamb quantities (Q_0's) and prices (P_0's) for the immediate and lagged impact of the technology's adoption are given as the simulation results for 1985 and 1990, respectively (all parameters are in Table 2).

Table 2. Summary of Australian lamb market parameter values

Parameter	Adoption rate (%)			
	Base	5	15	24
Own price supply elasticity (ε)	0.5			
Own price demand elasticity (η)	-1.5			
Pre technology quantity (Q_0):				
immediate impact (kt)	303.9			
lagged impact (kt)	303.1			
Pre technology price (P_0):				
immediate impact (cents)	24.59			
lagged impact (cents)	17.84			
First supply shift parameter (K)	2.6%			
Second supply shift parameter (K)	1.3%			
Average annual production (kt)	296.0	301.3	311.7	321.2
Number of carcases requires (m)		0.875	2.625	4.202
Average carcase weight (kg)		17.3	17.9	18.4
Increase in average carcase weight (%)		1.8	5.3	8.5

3. Results

Estimates of the economic surplus changes resulting from the adoption of the Elite lamb technology are given in Table 3.

Table 3. Estimates of economic surplus change from Elite lamb adoption ($m.)

Adoption Rate (%) by supply shift parameter (%)	Consumers' surplus change	Producers' surplus change	Total surplus change
Immediate impact in first year			
5: K = 2.6	0.874	2.623	3.497
5: K = 1.3	0.441	1.305	1.745
15: K = 2.6	2.579	7.736	10.315
15: K = 1.3	1.271	3.886	5.157
24: K = 2.6	4.321	12.899	17.220
24: K = 1.3	2.097	6.292	8.389
Lagged impact after five years			
5: K = 2.6	0.638	1.195	2.297
5: K = 1.3	0.320	0.962	1.282
15: K = 2.6	1.194	5.741	6.935
15: K = 1.3	0.931	2.848	3.779
24: K = 2.6	3.111	9.334	12.445
24: K = 1.3	1.518	4.553	6.071

The largest total surplus change ($17.2 million) was under the combination of the highest rate of adoption of 24 per cent (equivalent to an 8.5 per cent increase in total lamb production over the average output level), the largest lamb supply curve shift as measured by the percentage reduction in the unit costs of production, and the assumption of an immediate impact of the technology in the market. Lower technology adoption levels, longer adoption periods, and smaller supply shifts resulted in very much reduced benefit estimates (down to $0.32 million). These estimates can be regarded as the potential annual gross benefits from the technology. They are net of the input costs of lamb production which are incorporated in the industry supply curve, but do not include the costs of the technology's development and adoption. The preliminary nature of these results due to the developmental status of the technology should be recognised.

As suggested by lamb's market conditions of an inelastic supply and an elastic demand, producers are the major beneficiaries of the Elite lamb technology. The benefit share gained by producers is approximately three times greater than that of consumers over the full range of market situations considered. However, in general these benefit estimates are modest relative to those reported in similar studies of technology adoption in livestock production (such as in Lemieux and Wohlgenant 1989, and Griffith **et al.** 1991). This mainly appears to be the result of the very small production cost reductions–lamb supply curve shifts that can be attributable to the adoption of the technology. At present, the gross margin budgets indicate that the benefits of producing heavier, leaner lambs are diminished by the additional feed requirements and the lack of a price premium for these animals (in New South Wales). Larger benefit levels are likely to result if further development of the technology can demonstrate significant cost advantages in producing Elite compared to standard prime lambs.

4. Discussion

The main purpose of this paper has been to present an economic model for the **ex ante** industry impact assessment of new technology adoption in livestock production. It has been applied to a developing technology for the production of a heavier, leaner prime lamb throughout south-eastern Australia. This type of model was considered to be necessary because the nature of the supply and demand relationships in the Australian lamb market requires the consideration of the effects on both the producers and consumers of lamb to gain a more rigorous assessment of the full potential of the technology. The model comprises well established farm and market level modelling procedures which are considered to be applicable to the investigation of the economic impacts of most livestock and perhaps, other agricultural production technologies.

Several aspects of this analysis will require further investigation, two of which relate to the lamb market's supply and demand sides. The farm models will require some revision as the Elite lamb technology is further refined. Under the presently defined production systems, the lamb production cost reductions are minimal, which results in a very small supply shift (defined in these terms) and low levels of estimated benefits. Larger benefits should result if greater relative cost differences can be demonstrated under the refinement and field validation of the technology. Demand side refinements will also be required if it can be established that there is a measurable consumer preference for lean lamb. This would suggest the need to consider a disaggregated market demand to represent the disposal of the leaner lamb product.

References

Bootle, B.W. (1991), Sheep Cents – An Integrated Program for the Economic Analysis of Wool and Meat Sheep Enterprises, NSW Agriculture, Trangie Agricultural Research Centre.

Davis, J.S., Oram, P.A. and J.G. Ryan (1987), **Assessment of Agricultural Research Priorities: an International Perspective,** Australian Centre for International Agricultural Research, Canberra.

Easter, C.D. (1977), Productivity in the Australian Sheep Industry, paper prepared for Workshop on Productivity Analysis, New South Wales Department of Agriculture, Sydney.

Edwards, G.W. and J.W. Freebairn (1984), "The gains from research into tradable commodities", **American Journal of Agricultural Economics** 66(1), 41–49.

Griffith, G.R., Morris, K.G., Wohlgenant, M.K. and J.D. Mullen (1991), **An Ex Ante Assessment of the Economic Impact of PST on the Australian Pig Industry: Preliminary Results,** NSW Agriculture, Division of Rural and Resource Economics, Research Workpaper (in press).

Hall, J., Fraser, L. and A. Purtill (1988), "Supply response in broadacre agriculture", **Review of Marketing and Agricultural Economics** 56(3), 361–374.

Lemieux, C.M. and M.K. Wohlgenant (1989), "Ex ante evaluation of the economic impact of agricultural biotechnology: the case of porcine somatotropin", **American Journal of Agricultural Economics** 71(4), 903–14.

Lindner, R.K. and F.G. Jarrett (1978), "Supply shifts and the size of research benefits", **American Journal of Agricultural Economics** 60(3), 48–58.

Love, G., Blanks, R., Buik, C. and K. Williams (1982), **Some Potential Economic Effects of Technology and Productivity Change in Australia's Beef Cattle and Sheep Industries,** Bureau of Agricultural Economics, Occasional Paper No. 73, AGPS, Canberra.

Norton, G.W. and W.L. Peterson (1991), **Economic Impact of Research on Livestock Production,** IR–6 Information Report No. 91–1.

Vere, D.T., Griffith, G.R. and B.W. Bootle (1992), **The Development and Application of a Quarterly Econometric Model of the Australian Prime Lamb Industry,** NSW Agriculture, Division of Rural and Resource Economics, Research Workpaper (in press).