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Calibrating and Validating an Equilibrium Displacement Model of the Australian Sheep Meat Industry[1]

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Abstract

A new equilibrium displacement model of the Australian sheep meat industry was specified, calibrated and validated to enable the distribution of the total benefits from the adoption of new technology or promotion investments to be estimated across sheep meat value chains. A number of hypothetical simulations were run to test the impact of various 1 per cent displacements from the initial equilibrium. The gross benefits to the various industry sectors from the displacements were found to be broadly consistent with a 1 per cent change in total value in the sector where the displacement occurred. In the base case, sheep meat producers receive between 29 and 52 per cent of the potential gross benefits from the hypothetical investments, overseas consumers receive between 10 and 28 per cent, while domestic consumers receive between 15 and 47 per cent, depending on the particular scenario. Sheep meat processors, exporters and domestic retailers all receive much smaller shares of gross benefits, generally less than 15 per cent but ranging up to 26 per cent in one instance. While the updated model provides a framework that reflects the current industry size and structure, as always the results are conditional on the specified price and quantity values, their underlying assumptions and calculations, and the parameter values used to represent industry responses to price changes.

Key words: sheep meat, equilibrium displacement modelling, simulation experiments, producer benefits

Background

Following recent efforts to update existing equilibrium displacement models (EDMs) of the Australian beef and pig meat industries (Zhang et al., 2018a,b), a new sheep meat industry EDM was specified, calibrated and validated. This model is based on the existing very large and complicated Australian sheep and wool model developed by Mounter et al. (2008a,b, 2009). Several new projects, including the Advanced Livestock Measurement Technology project and a sheep meat dry aging project, have requested estimates of the benefits of adopting the new technologies likely to

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emerge from these sheep meat oriented projects. Thus, this new model focuses only on sheep meat production, processing, exporting and retailing. Wool production is excluded.

Use of the new model will enable estimation of the vertical disaggregation of the total potential benefits from new technologies that are adopted at either the farm level or other sectors of the sheep meat value chains (as well as generic promotion and potentially other policy changes in the different sectors and markets), based on current industry structure and conduct. Importantly, the model will show the extent of trade-offs inherent in such multi-product industries, where investments and subsequent impacts in one part disadvantage participants in other parts.

Methodology

As outlined in detail in Mounter et al. (2018a) and elsewhere, the EDM approach employs comparative static analysis in a partial equilibrium framework. The broad principles are outlined in Alston, Norton and Pardey (1995). Representation of an industry within an EDM consists of a system of demand and supply equations. The equations are expressed in terms of relative changes and elasticities by total differentiation of the general functional form equations and conversion into elasticity form. The impacts of exogenous changes, such as new technologies or promotions, are modelled as shifts in demand or supply in the relevant markets. From the resulting price and quantity changes in all markets, the welfare changes to the various industry participants are estimated as changes in producer and consumer surplus. The framework is partial in the sense that prices in markets not included in the model are assumed constant.

The approach offers a number of advantages over other modelling approaches in that it provides a consistent economic framework for examining various broad types of research and promotion, and is not overly data-intensive. For example, compared with the historical time series requirements of econometric modelling, EDM needs only one set of base equilibrium price and quantity data, and values for market parameters such as Marshallian demand and supply elasticities. Some years ago, considerable effort was put into building standalone econometric models of the Australian grazing livestock industries, including the lamb industry (see, for example, Vere and Griffith, 1995), and explicitly linking together these different industries (Vere et al., 2000; Vere and Griffith, 2004). However, this effort had to be discontinued due to the increasing unavailability of crucial time series data on the key explanatory variables.

Another approach is that of computable general equilibrium (CGE) as reported in Wittwer et al. (2005) and Borrell et al. (2014). The Borrell et al. study examined the potential payoffs and distributions resulting from demand expansion and productivity improvement across a number of components of the Australian food sector (including sheep meat), while the Wittwer et al. study analysed the economy-wide effects of investments in weed management in Australian cropping industries. The CGE approach is expected to capture a wider range of benefits from the implementation of new technologies in agricultural industries, due to improved resource allocation in the rest of the economy, but benefits to individual value chain participants are typically reduced as well. For example, comparing similar simulation scenarios in improved weed management, the CGE approach (Wittwer et al., 2005) generated benefits approximately 40 per cent greater than the partial equilibrium approach (Vere et al., 1997).

Such large spillovers are not expected in the sheep meat innovations which are the focus of the current modelling effort. In addition, in a practical sense, the EDMs can now be specified and solved in Excel and are readily transferable, whereas the CGE models require specialised software and they are not generally available in the public domain.

The structure of the industry

The structure of this simplified model is shown in Figure 1. The definitions of the price and quantity variables used in Figure 1 are given in Table 1.

Table 1. Definitions of price and quantity variables in the model

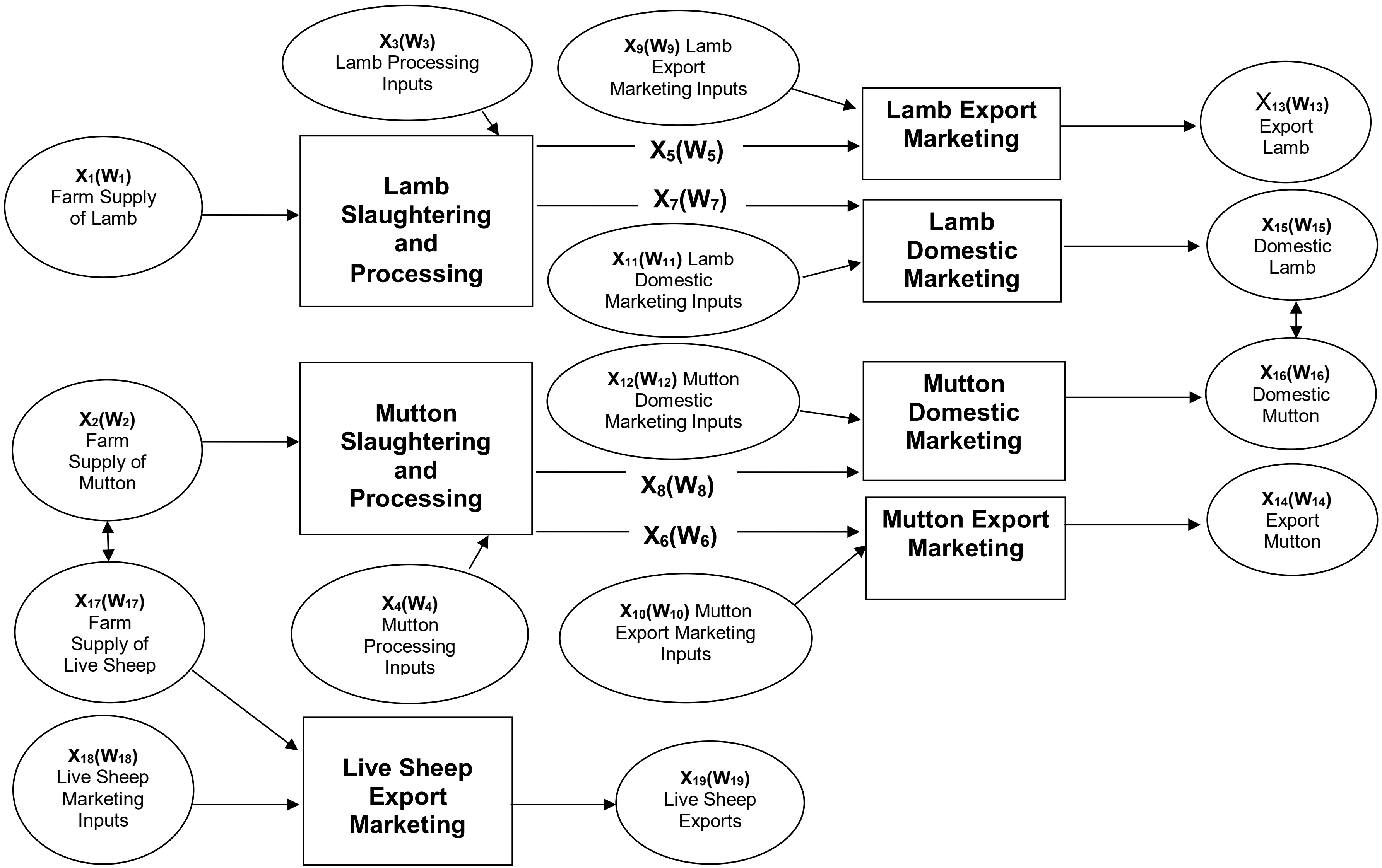
X1 farm quantity of lamb,	W1 farm price of lamb,
X2 farm quantity of mutton,	W2 farm price of mutton,
X3 lamb processing inputs,	W3 price of lamb processing inputs,
X4 mutton processing inputs,	W4 price of mutton processing inputs,
X5 quantity of processed export lamb,	W5 price of processed export lamb,
X6 quantity of processed export mutton,	W6 price of processed export mutton,
X7 quantity of processed domestic lamb,	W7 price of processed domestic lamb,
X8 quantity of processed domestic mutton,	W8 price of processed domestic mutton,
X9 lamb export marketing inputs,	W9 price of lamb export marketing inputs,
X10 mutton export marketing inputs,	W10 price of mutton export marketing inputs,
X11 lamb domestic marketing inputs,	W11 price of lamb domestic marketing inputs,
X12 mutton domestic marketing inputs,	W12 price of mutton domestic marketing inputs,
X13 quantity of export lamb,	W13 price of export lamb,
X14 quantity of export mutton,	W14 price of export mutton,
X15 quantity of domestic lamb,	W15 price of domestic lamb,
X16 quantity of domestic mutton,	W16 price of domestic mutton,
X17 farm quantity of live sheep,	W17 farm price of live sheep,
X18 live sheep marketing inputs,	W18 price of live sheep marketing inputs,
X19 quantity of live sheep exports.	W19 price of live sheep exports.

For both the lamb and mutton sectors, live animals are slaughtered and processed into carcases and cuts, and these are then distributed through domestic and export marketing sectors to local and overseas consumers. A separate live sheep trade sector takes live animals and distributes them through an export marketing sector to overseas purchasers of live sheep. In each of the slaughtering and distribution production functions, other inputs are combined with the sheep meat input to produce the transformed product.

There are 38 endogenous variables in the model (19 sets of prices and quantities) (Table 2), plus another 4 aggregate input and output indexes for the lamb and mutton slaughtering and processing sectors. This gives a total of 42 endogenous variables which requires 42 equations for a properly identified solution. The 42 equations of the new sheep meat model are outlined in the Appendix. They are presented in implicit displacement form, exactly as solved by the software, where the notation e(.) means proportional change in variable (.). Thus in equation 1, ex1 means proportional change in X_1. Also included in the model are 14 cost shares (for example kx3 in equation 5), 4 revenue shares (for example rx7 in equation 3), 10 possible supply shifters (for example tx1 in equation 1), 5 possible demand shifters (for example nx13 in equation 13), and the relevant elasticity parameters for the various equations as shown in Table 3. The full justification for the derivation of the model in this form is as reported in Mounter et al. (2008a).

The supply and demand shifters referred to above are defined as parallel shifts in the price direction. It is worth noting that there has been much discussion in the literature about the effects of different types of research-induced supply shifts on the size and distribution of research benefits. Typically, assumptions need to be made about the nature of shifts as specific information is absent.

Figure 1. Structure of the Australian sheep meat equilibrium displacement model



Alston, Norton and Pardey (1995, p.64) summarise these difficulties and argue in favour of assuming parallel rather than pivotal shifts:

> "The industry curve is based on the aggregation of supply curves for individual firms. Shifts in the industry curve depend on the effects of new technologies on the marginal costs of existing firms and on entry and exit of firms. One would need to examine the characteristics of individual firms that affect marginal costs and technology adoption in order to predict which types of firms would benefit from a particular new technology. In addition, with current techniques and typically available data, it is not possible to settle these questions econometrically. We might hope to obtain plausible estimates of elasticities at the data means, but definitive results concerning functional forms are unlikely and it is impossible to get statistical results that can be extrapolated to the price or quantity axes (i.e., the full length of the function) with any confidence. Thus, assumptions about the nature of the research-induced supply shift are unavoidable. Our conclusion is that it is important to be aware of the consequences of different assumptions. Our preference - in the absence of the information required to choose a particular type of shift - is to follow Rose's (1980) suggestion and employ a parallel shift. Rose (1980, p. 837) argued that "For most innovations, the best information available may be a cost-reduction estimate for a single point on the supply curve .... [It] is unlikely that any knowledge of the shape of the supply curve, or the position at which the single estimate applies, will be available. The only realistic strategy is to assume that the supply shift is parallel." We find the arguments of Rose persuasive, and therefore we are inclined to assume vertically parallel research-induced supply shifts. Under this assumption, the functional forms of supply and demand are unimportant and it is convenient to use a local linear approximation as suggested by Alston and Wohlgenant (1990)."

The base price and quantity data

Average price and quantity data over the five-year period 2012-2016 were used as the base equilibrium values. Input cost shares and output revenue shares were derived accordingly. The price and quantity data, and the associated sector total values, cost shares and/or revenue shares, are reported in Table 2. Details of the sources and the assumptions made for the specification of a set of base equilibrium prices and quantities for all inputs and outputs of all sectors for each year of 2012-2016 are described below.

Quantities

X_1, X_2, X_5, $X_6 \Rightarrow X_7$, X_8, X_{15}, X_{16}

The volume of total Australian lamb (X_1) and mutton (X_2) production in carcass weight were sourced from ABARES (2017). The quantities of exported lamb (X_5) and mutton (X_6) were also taken from this report. MLA (2017a) reports total lamb and mutton consumption (X_7 and X_8) but the quantities of domestic mutton consumption (X_8) are only available for 2012-2014. The quantity of domestic mutton consumption (X_8), was derived by the quantity of total mutton production (X_2) less the quantity of that which is exported, $X_8=X_2-X_6$. This resulted in a positive average 2012-2016 value of 3,200 tonnes cwt (2,176 tonnes in terms of retail cuts) but some implied negative domestic disappearance in a couple of years (we assume due to exports being sourced out of unreported changes in frozen stocks). As an alternative, MLA (2016) and MLA (2017b) estimate that the domestic consumption of mutton accounts for 9 per cent and 8 per cent of total Australian mutton production for 2015 and 2016 respectively. It was decided to rely on the published export data.

Since the retail price used is for the cuts of meat actually sold at retail, the relevant quantity should be the weight of retail cuts rather than carcase weight. The ratio of 68 per cent was previously used in Mounter et al. (2008a) to convert carcass weight to equivalent weight of saleable retail cuts. The same percentage was used here to calculate the quantity of domestic lamb and mutton consumption, that are $X_{15}=0.68*X_7$ and $X_{16}=0.68*X_8$ respectively.

Table 2. Base equilibrium prices, quantities and revenue and cost shares (average of 2012-2016)

	Quantity and Price	**Cost and Revenue Shares**
Final Sheep Products	Export Sheep Meat (in tonnes and *$/kg*, shipped weight, TV=$m): X_{13}=223,105 W_{13}=6.81 TV_{13}=1,519 X_{14}=149,571 W_{14}=4.41 TV_{14}=660 TV_{13+14}=2,179 Export Live Sheep (in tonnes and *$/kg*, carcass weight, TV=$m): X_{19}=48,714 W_{19}=4.70 TV_{19}=229 Domestic Sheep Meat (in tonnes and *$/kg*, retail cuts, TV=$m): X_{15}=141,799 W_{15}=13.5 TV_{15}=1,914 X_{16}= 2,176 W_{16}=9.33 TV_{16}=20 TV_{15+16}=1,934	Export Marketing Revenue Shares: γ_{X13}=0.63 γ_{X14}=0.27 γ_{X19}=0.10 Domestic Marketing Revenue Shares: γ_{X15}=0.99 γ_{X16}=0.01
Wholesale Carcass	Export Sheep Carcass (in tonnes and *$/kg*, carcass weight): X_5 =276,345 W_5=5.00 TV_5=1,382 X_6 =189,200 W_6=3.22 TV_6=609 TV_{5+6} =1,991 Domestic Sheep Carcass (in tonnes and *$/kg*, carcass weight): X_7=208,529 W_7 =5.00 TV_7=1,043 X_8=3,200 W_8 =3.22 TV_8=10 TV_{7+8}=1,053	Export Marketing Cost Shares: k_{X5}=0.91 k_{X9}=0.09 k_{X6}=0.92 k_{X10}=0.08 k_{X17}=0.62 k_{X18}=0.38 Domestic Marketing Cost Shares: k_{X7}=0.54 k_{X11}=0.46 k_{X8}=0.51 k_{X12}=0.49 Processing Revenue Shares γ_{X5}=0.56 γ_{x6}=0.98 γ_{X7}=0.43 γ_{x8}=0.02
Live Sheep	Export Live Sheep (in tonnes and *$/kg*, carcass weight, TV=$m): X_{17}=48,714 W_{17}=2.90 TV_{17}=141 Domestic Live Sheep (in tonnes and *$/kg*, carcass weight, TV=$m): X_1=484,874 W_1=4.69 TV_1=2,274 X_2=192,400 W_2= 2.90 TV_2=558 TV_{1+2} =2,832	Processing Cost Shares k_{X1}=0.94 k_{X2}=0.90 k_{X3}=0.06 k_{X4}=0.10

X_{13}, X_{14}
The quantities of exported lamb (X_{13}) and mutton (X_{14}) were obtained from MLA (2017a) in terms of shipped weight. Compared with the carcase weight quantities coming out of the processing sector, they are about 80 per cent, thus for example $X_{14}=0.80*X_6$.

X_{17}, X_{19}
The quantity of live sheep exports ($X_{17} = X_{19}$) was calculated by multiplying the recorded number of head by the average carcass weight sourced from MLA (2017a).

Prices

W_1, W_2, $W_{17} \Rightarrow W_5$, W_6, W_7, W_8
MLA (2017a) reports saleyard prices for lamb and mutton in carcass weight. The data on mutton for 18-24 kg was used as the price for mutton (W_2) and live sheep for exports (W_{17}). The Australia Saleyard Lamb Indicators reports lamb prices for five grades (light lamb 12-18 kg, trade lamb 18-22 kg, heavy lamb 22+ kg, Merino lamb 16-22 kg, and restocker/feeder lamb 0-18 kg). The price of lamb at the farm level (W_1) was specified by taking the average of all the prices of these categories.

Data on wholesale prices are not reported. The only information about the wholesale market is the total value of sheep and lamb production reported by ABS (2017), i.e. $TV_{(5+6+7+8)}$. In the absence of other useful data, the costs for slaughtering mutton, and lamb for domestic and export markets are considered to be the same. The aggregated price for wholesale carcasses are calculated by dividing the total value of production by the total quantity of production, i.e. $W_{(5+6+7+8)} = TV_{(5+6+7+8)}/(X_5+X_6+X_7+X_8)$, Using the same method, the aggregated price for the farm level was calculated, i.e. $W_{(1+2)}=TV_{(1+2)}/(X_1+X_2)$.

Then the price of wholesale lamb carcasses in the domestic and export industries, and wholesale mutton carcasses are derived respectively by adding the associated saleyard price (W_1,W_2) to the price difference between the two sectors ($\Delta W= W_{(5+6+7+8)} - W_{(1+2)}$), that are $W_5= W_7= W_1+\Delta W$, $W_6= W_8+\Delta W$. A negative value of ΔW for year 2015 was obtained in this calculation process, and was replaced by the average value of other years'. Then 0.31 was specified for ΔW.

W_{13}, W_{14},
The prices of mutton and lamb for exports were derived by dividing the total value of exports by the export quantity. The data of total value of lamb (TV_{13}) and mutton (TV_{14}) exports are available on MLA (2017a). Hence the price of exports of lamb and mutton are specified respectively, i.e. $W_{13}=TV_{13}/X_{13}$, $P_{14}=TV_{14}/X_{14}$.

W_{15}
The retail price for domestic lamb markets is sourced from the report of Australia Retail Meat Prices (MLA, 2017a).

W_{16}
There are no data available on the domestic mutton retail price (W_{16}). Domestic expenditure on mutton (TV_{16}) for 2015, 2016, and 2017 is available (MLA, 2015; MLA, 2016; MLA, 2017b). The average retail price of mutton from 2015-2017 was calculated by dividing the total value of mutton in the domestic market (TV_{16}) by the related quantity (X_{16}), and used as the value for W_{16}, i.e. $W_{16}=TV_{16}/X_{16}$.

W_{19}

The price for live sheep exports (W_{19}) was derived by diving the total value of exported live sheep by the associated quantity (X_{19}). The FOB value for live sheep exports is available from ABS (2017).

Parameter values

The final consideration is to estimate industry responses to price changes. The EDM has seven demand elasticities, nine supply elasticities, a price transmission elasticity, seven input substitution elasticities and two product transformation elasticities. These are shown in Table 3.

Table 3. Base elasticity values in the model

```
own-price elasticity of supply for lamb.
ipx1=1.5;
ipx3=2.0;
ipx9=5.0;
ipx11=5.0;
own-price elasticity of supply for mutton.
ipx2=1.0;
ipx4=2.0;
ipx10=5.0;
ipx12=5.0;
ipx18=2.0;
price transmission elasticity (mutton/live sheep).
ipx=0.74;
elasticity of substitutability of inputs in lamb processing and distribution
sigx1x3=0.1;
sigx5x9=0.1;
sigx7x11=0.1;
elasticity of substitutability of inputs in mutton processing and distribution
sigx2x4=0.1;
sigx6x10=0.1;
sigx8x12=0.1;
sigx17x18=0.1;
elasticity of transformation of lamb outputs
taux5x7=-0.1;
elasticity of transformation of mutton outputs
taux6x8=-0.1;
own-price elasticity of demand for lamb and mutton
itx13=-2.5;
itx15=-1.0;
itx14=-5.00;
itx16=-0.90;
itx19=-2.00;
cross-price elasticities of demand between lamb and mutton
itx15x16=0.13;
itx16x15=0.50;
```

Initially all of these elasticity values were taken directly from the original Mounter et al. (2008a) model, and then various industry reports and other publications were examined to ascertain if the specified relationships in the original model may have changed. For example, more recent empirical estimates of the own-price elasticity of domestic demand for lamb were found to be consistently lower in magnitude than the values specified in the original EDM (Mounter et al., 2012). This parameter value was reduced from -1.5 in the original model to -1.0. Similarly, the own-price elasticity of domestic demand for mutton was reduced from -1.4 to -0.9, and the two cross-price elasticities were reduced from 0.13 and 0.82 to 0.10 and 0.50. Given the now quite different domestic and export markets for lamb and mutton, the transformation elasticities were reduced from -0.5 to -0.1, while the elasticity of supply of non-specialised inputs into domestic marketing and exporting were increased to 5.0. Finally, the own price elasticity of export demand for live sheep was reduced from -5.0 to -2.0, and the own-price elasticity of supply of lamb was increased to 1.5.

It is also necessary to identify whether there have been any domestic or export policy changes that may have altered product flows or values, and to establish if there have been significant merger or acquisition activities that may have resulted in vertical industry sector consolidation. In recent times concerns have been expressed over the issue of market power in the Australian food marketing chain and increasing concentration in the retail food sector. However Chung and Griffith (2009) found no evidence that the marketing chains for the Australian fresh meat industries are non-competitive.

Estimation and Results

The TSP input file for the EDM as shown in the Appendix was calibrated with the price, quantity, cost share and revenue share data shown in Table 2 and the elasticity values shown in Table 3. A number of hypothetical one per cent shift simulations were run to test the validity of the data and parameter calibrations. The hypothetical simulations are listed in Table 4.

Table 4. Six simulation scenarios

Scenario 1: Lamb Production Research **tx1 = -0.01**, remaining t(.) = 0 and all n(.) = 0. Cost reduction in lamb production resulting from any breeding or farm technologies that reduce the cost of producing lambs. **Scenario 2: Mutton Production Research** **tx2 = -0.01**, remaining t(.) = 0 and all n(.) = 0. Cost reduction in mutton production resulting from any breeding or farm technologies that reduce the cost of producing grown sheep. **Scenario 3: Lamb Processing Research** **tx3 = -0.01**, remaining t(.) = 0 and all n(.) = 0. Other input cost reductions in lamb processing due to new technologies or management strategies in the processing sector. **Scenario 4: Mutton Domestic Marketing Research** **tx12 = -0.01**, remaining t(.) = 0 and all n(.) = 0. Other input cost reductions in mutton domestic marketing due to new technologies or management strategies in the domestic marketing sector. **Scenario 5: Domestic Lamb Promotion** **nx15 = 0.01**, remaining n(.) = 0 and all t(.) = 0. Increase in the willingness to pay by domestic lamb consumers due to lamb promotion or changes in tastes in the domestic market. **Scenario 6: Export Mutton Promotion** **nx14 = 0.01**, remaining n(.) = 0 and all t(.) = 0. Increase in the willingness to pay by export mutton consumers due to mutton promotion or changes in tastes in the export market.

The results from the hypothetical scenarios are presented in Table 5.

Table 5. Economic surplus changes (in $million) and percentage shares of total surplus changes (in %) to various industry groups from alternative scenarios (base data)

Industry Group	Scenario 1 tx1=-0.01		Scenario 2 tx2=-0.01		Scenario 3 tx3=-0.01		Scenario 4 tx12=-0.01		Scenario 5 nx15=0.01		Scenario 6 nx14=0.01	
	$m	%	$m	%	$m	%	$m	%	$m	%	$m	%
Lamb farmers	**8.18**	**35.9**	-0.75		**0.45**	**30.0**	-0.12		**5.59**	**29.0**	-0.69	
Mutton farmers	-0.02		**3.15**	**56.4**	0.00		**0.04**	**40.0**	-0.03		**4.11**	**61.9**
Live sheep farmers	-0.00		0.04		0.00		0.01	10.0	0.00		0.03	
Farmers subtotal	**8.17**	**35.8**	**2.44**	**43.6**	**0.45**	**30.0**	**-0.07**		**5.56**	**29.0**	**3.45**	**52.0**
Lamb processors	0.34		-0.04		**0.09**	**6.0**	-0.01		0.28		-0.03	
Mutton processors	-0.00		**1.65**	**29.5**	0.00		0.01	10.0	0.00		**0.76**	**11.4**
Lamb exporters	0.35		-0.03		0.02		0.00		0.21		-0.03	
Mutton exporters	-0.00		**0.34**	**6.1**	0.00		0.00		0.00		**0.37**	**5.6**
Live sheep exporters	0.00		-0.43		0.00		0.00		0.00		-0.20	
Lamb retailers	**1.62**	**7.1**	-0.28		**0.11**	**7.3**	-0.04		**2.07**	**10.8**	-0.26	
Mutton retailers	-0.00		**0.28**	**5.0**	0.00		**0.00**		0.00		**0.31**	
Other input suppliers subtotal	**2.31**	**10.1**	**1.49**	**26.7**	**0.22**	**14.7**	**-0.04**		**2.56**	**13.3**	**0.92**	**13.9**
Overseas lamb consumers:	**3.41**	**15.0**	-0.27		**0.23**	**15.3**	-0.04		**1.98**	**10.3**	-0.24	
Overseas mutton consumers	-0.01		1.59	**27.9**	0.00		**0.01**		-0.01		**1.61**	**24.2**
Domestic lamb consumers	**8.87**	**38.9**	1.36		**0.67**	**44.7**	0.22		**9.06**	**47.2**	1.25	18.8
Domestic mutton consumers	0.04		**0.21**		0.00		0.03	**30.0**	0.04		0.19	
Live sheep consumers	0.00		-1.23		0.00		-0.01		0.00		-0.57	
Consumers subtotal	**12.32**	**54.0**	**1.66**	**29.2**	**0.90**	**60.0**	**0.21**		**11.03**	**57.5**	**2.24**	**33.7**
Total Surplus	**22.80**	**100**	**5.69**	**100**	**1.50**	**100**	**0.10**	**100**	**19.18**	**100**	**6.64**	**100**

Note: Percentage shares of total benefits are not calculated where the monetary value is very small or where a loss is incurred.

Total surplus changes

All six scenarios produce positive changes in total surplus to the sheep meat industry, although of vastly different magnitudes. However, it is apparent that, in all cases the total surplus values are approximately one per cent of the total sector value in which the simulation occurs.

Take for example the two on-farm productivity scenarios. The total value of lamb production at the farm gate is estimated as $2,274 million (TV1 at the bottom of Table 2), and the total surplus from a one per cent cost reduction in lamb production (scenario 1) is $22.8 million (bottom of Table 5, scenario 1). Similarly, the total value of mutton production at the farm gate is estimated as $558 million (TV2 at the bottom of Table 2), and the total surplus from a one per cent cost reduction in mutton production (scenario 2) is $5.6 million (bottom of Table 5, scenario 2). The same is true for the two demand shift scenarios: an increase in lamb consumer willingness to pay on the domestic market (scenario 5 – TV15 is $1,914 million and the one per cent total surplus value is $19.2 million), and an increase in mutton consumer willingness to pay on the export market (scenario 6 – TV14 is $660 million and the one per cent total surplus shift is $6.6 million).

So given the data used and the parameter values assumed, the lamb industry would receive approximately similar returns, around $20 million per year, from fully adopted one per cent on-farm productivity gains and fully adopted one per cent increase in consumer willingness to pay on the domestic market. The mutton industry would receive approximately similar returns, around $6 million per year, from fully adopted one per cent on-farm productivity gains and fully adopted one per cent increase in consumer willingness to pay on the export market.

The two value chain improvement scenarios have very much smaller surplus gains. Scenario 3 is a cost reduction in lamb processing (sector value is $151 million (the difference between the total value of lamb inputs (TV1) and the total value of carcase outputs (TV5+TV7)) and the one per cent shift is $1.5 million), while Scenario 4 is a cost reduction in mutton retailing (sector value of $10 million (the difference between the total value of mutton domestic carcase inputs (TV10) and the total value of mutton domestic carcase outputs (TV20)) and $0.1 million change in total surplus). These surplus changes are much smaller than those for primary supply or primary demand shifts because the elasticities of input supply assumed for the processing and retailing inputs are very elastic.

Overall, however, the results are very consistent. As long as the percentage shift in demand or supply is relatively small, the change in total surplus can be closely approximated from the total value of the sector in which the displacement occurs. The key own price elasticity values of supply and demand have no impact on total surplus (Griffith et al., 2010), although cross-price, input substitution and output transformation elasticities do have a very minor impact.

Distribution of surplus changes

Also reported in Table 5 are the distributions of the gross benefits to the various industry sectors associated with each hypothetical scenario.

One thing that is immediately obvious is the strong substitutability relationships between the lamb and mutton and the mutton and live sheep sectors, and the disconnect between the lamb and live sheep sectors. For the three lamb scenarios (1, 3 and 5), surplus changes in all components of the lamb value chain are positive, whereas surplus changes in the mutton value chain are almost always negative and those in the live sheep chain are essentially zero. The opposite is true for the three mutton scenarios (2, 4 and 6). Thus the mutton industry loses from investments in the lamb industry, and the lamb industry and the live sheep industry lose from investments in the mutton industry.

With one exception, the proportion of total benefits accruing to all sheep producers range from a little under 30 per cent to a little over 50 per cent. For individual types of producers, they are uniformly higher in magnitude for mutton producers (40 to 62 percent) than for lamb producers (29 to 36 per cent).

Sheep meat processors, exporters and domestic retailers all receive much smaller shares of gross benefits, generally less than 15 per cent but ranging up to 26 per cent in one instance. The assumed supply elasticities for inputs used in these sectors are very elastic.

Overseas consumers receive between 10 and 28 per cent, while domestic consumers receive between 15 and 47 per cent, depending on the particular scenario.

Most scenarios show results broadly in line with prior expectations. For example, in the on-farm lamb productivity scenario, lamb producers gain 36 per cent of the total surplus changes, other input suppliers gain 10 per cent (with processors, exporters and retailers all sharing in the gains), and consumers gain the remaining 54 per cent. This is as expected given the relative values of the assumed own-price demand and supply elasticities. For comparison, the shares estimated from the much larger Mounter et al. (2008a) model (which also included the wool industry) were 24 per cent, 15 per cent and 61 per cent (p.74). Mutton farmers, processors, exporters, retailers and domestic consumers, and live sheep producers and exporters, all lose from productivity gains in lamb production.

Very similar patterns are evident for the lamb processing productivity improvement and the lamb domestic consumer willingness to pay improvement, with the expected enhanced gains for lamb processors in the first instance, and for domestic lamb consumers in the second.

Opposite patterns of gains and losses are evident in the mutton on-farm productivity improvement and the mutton export market willingness to pay improvement: mutton farmers, processors, exporters, retailers and consumers all share in the gains, while the equivalent lamb and live sheep suppliers and consumers lose.

Scenario 4 (productivity improvement in mutton retailing) is quite different. All the mutton value chain participants gain from this cost saving, but because the mutton retail sector is so small (a total value of just $20 million) compared to the mutton export market and the lamb industry, the positive gains to mutton participants are completely outweighed by large losses to lamb producers and large gains to domestic lamb consumers.

Some of these results can be compared with those results reported in Borrell et al. (2014), although in the latter study the base year is taken as 2005-06 rather than an average of 2012-2016, and they analyse an aggregate sheep meat sector rather than separate lamb and mutton industries. However, their scenario 6 which is an increase in on-farm productivity, produces benefits to farmers of $9.5 million and benefits to processors of $4.1 million, whereas in the current study the equivalent values for Scenario 1 and Scenario 2 combined from Table 5 are $10.61 million and $1.95 million. The benefits to farmers are similar, but the CGE approach produces benefits to the processing sector much larger than the partial equilibrium approach. This pattern is replicated in their other scenarios.

Sensitivity to Domestic Mutton Consumption Estimate

It was noted above that in the base quantity data, the quantity of domestic mutton consumption in cwt (X_8), was derived by the quantity of total mutton production (X_2) less the quantity of that which

Table 6. Economic surplus changes (in $million) and percentage shares of total surplus changes (in %) to various industry groups from alternative scenarios (alternate mutton consumption data)

Industry Group	Scenario 1 tx1=-0.01		Scenario 2 tx2=-0.01		Scenario 3 tx3=-0.01		Scenario 4 tx12=-0.01		Scenario 5 nx15=0.01		Scenario 6 nx14=0.01	
	$m	**%**	**$m**	**%**	**$m**	**%**	**$m**	**%**	**$m**	**%**	**$m**	**%**
Lamb farmers	**8.19**	**35.9**	-0.70		**0.45**	**30.0**	-0.13		**5.59**	**29.1**	-0.62	
Mutton farmers	-0.08		**2.97**	**50.8**	-0.01		**0.13**	**40.0**	-0.08		**3.82**	**57.6**
Live sheep farmers	-0.01		1.59		0.00		0.02		-0.02		0.68	
Farmers subtotal	**8.10**	**35.5**	**3.86**	**66.0**	**0.44**	**30.0**	**0.02**		**5.49**	**28.6**	**3.88**	**58.5**
Lamb processors	0.34		-0.04		**0.09**	**6.0**	-0.01		0.28		-0.03	
Mutton processors	-0.01		**0.33**	**5.6**	0.00		0.01		-0.01		**0.35**	**5.3**
Lamb exporters	0.35		-0.03		0.02		0.00		0.21		-0.02	
Mutton exporters	-0.01		**0.26**		0.00		0.01		-0.01		**0.28**	
Live sheep exporters	0.00		-0.41		0.00		-0.01		0.00		-0.18	
Lamb retailers	**1.63**	**7.2**	-0.26		**0.11**	**7.3**	-0.05		**2.08**	**10.8**	-0.23	
Mutton retailers	-0.02		**0.12**		0.00		**0.04**		-0.02		**0.11**	
Other input suppliers subtotal	**2.29**	**10.0**	**0.03**		**0.22**	**14.7**	**-0.01**		**2.53**	**13.2**	**0.28**	**4.2**
Overseas lamb consumers:	**3.41**	**15.0**	-0.25		**0.23**	**15.3**	-0.05		**1.98**	**10.3**	-0.22	
Overseas mutton consumers	-0.03		1.48	**25.3**	0.00		**0.04**		-0.03		**1.45**	**21.9**
Domestic lamb consumers	**8.87**	**38.9**	1.26		**0.59**	**39.3**	0.24		**9.04**	**47.1**	1.16	17.5
Domestic mutton consumers	0.14		**0.69**		0.01		0.13	**30.0**	0.14		0.61	
Live sheep consumers	0.01		-1.18		0.00		-0.02		0.01		-0.51	
Consumers subtotal	**12.40**	**54.4**	**2.00**	**34.2**	**0.83**	**55.3**	**0.34**		**11.14**	**58.1**	**2.49**	**37.6**
Total Surplus	**22.80**	**100**	**5.85**	**100**	**1.50**	**100**	**0.36**	**100**	**19.18**	**100**	**6.63**	**100**

Note: Percentage shares of total benefits are not calculated where the monetary value is very small or where a loss is incurred.

is exported, $X_8=X_2-X_6$. Both of these series come from ABARES (2017). However, using this calculation resulted in some negative domestic disappearance estimates in a couple of years, with an overall average domestic consumption over 2012-2016 of only 3,200 tonnes cwt or 2,176 tonnes in terms of retail cuts. Productivity improvements related to domestic mutton marketing (scenario 4) therefore provide very small estimates of total surplus (Table 5).

As an alternative, MLA (2017a) reports total mutton consumption (X_8) but only for 2012-2014. In other documents MLA (2016) and MLA (2017b) estimate that the domestic consumption of mutton accounted for nine per cent and eight per cent of total Australian mutton production for 2015 and 2016 respectively. If the reported quantities for 2012-2014 were aligned with the quantities for 2015 and 2016 calculated based on these estimations, average 2012-2016 mutton consumption would be 11,632 tonnes cwt or 7,910 tonnes in terms of retail cuts.

Table 7. Economic surplus changes (in $million) and percentage shares of total surplus changes (in %) to various industry groups from Scenario 1 (alternate mutton consumption data and varying lamb supply elasticity)

Industry Group	**Scenario 1 tx1=-0.01 (ipx1=1.5)**		**Scenario 1 tx1=-0.01 (ipx1=1.0)**		**Scenario 1 tx1=-0.01 (ipx1=0.5)**	
	$m	**%**	**$m**	**%**	**$m**	**%**
Lamb farmers	**8.19**	**35.9**	**10.41**	**45.7**	**14.28**	**62.6**
Mutton farmers	-0.08		-0.07		-0.05	
Live sheep farmers	-0.01		-0.01		-0.01	
Farmers subtotal	**8.10**	**35.5**	**10.33**	**45.3**	**14.22**	**62.4**
Lamb processors	0.34		0.29		0.20	
Mutton processors	-0.01		-0.01		-0.01	
Lamb exporters	0.35		0.30		0.21	
Mutton exporters	-0.01		-0.00		-0.00	
Live sheep exporters	0.00		0.00		0.00	
Lamb retailers	**1.63**	**7.2**	**1.38**	**6.1**	**0.95**	**4.2**
Mutton retailers	-0.02		-0.01		-0.01	
Other input suppliers subtotal	**2.28**	**10.0**	**1.95**	**8.6**	**1.34**	**5.9**
Overseas lamb consumers:	**3.41**	**15.0**	**2.89**	**12.7**	**1.98**	**8.7**
Overseas mutton consumers	-0.03		-0.02		-0.02	
Domestic lamb consumers	**8.87**	**38.9**	**7.51**	**32.9**	**5.16**	**22.6**
Domestic mutton consumers	0.14		0.12		0.08	
Live sheep consumers	0.01		0.01		0.01	
Consumers subtotal	**12.40**	**54.4**	**10.51**	**46.1**	**7.21**	**31.6**
Total Surplus	**22.80**	**100**	**22.80**	**100**	**22.80**	**100**

Here, the impact of this alternate way of calculating domestic mutton consumption is examined. The new value for X_{16} is added to the file, and the total quantity of mutton produced (X_2) and made available for the domestic market (X_8) is increased by 8,432 tonnes cwt to reflect the implied larger availability met out of unreported changes in stocks. Total revenue for mutton domestic demand will increase, and there also will be some very minor changes in some cost and revenue shares. The results of the simulations are reported in Table 6.

The modelled one per cent productivity improvement in mutton retailing (scenario 4) now applied over a larger retail quantity generates a total benefit estimate approximately four times as large as when using the initial mutton domestic consumption assumption. This increased total surplus value is mainly distributed to mutton farmers, mutton retailers and domestic mutton consumers. The lamb sector continues to lose, except overseas consumers of lamb who now have access to relatively greater quantities of lamb that have been displaced by mutton from the domestic market. Live sheep exports are lower, but live sheep farmers benefit from the higher price of older sheep.

All other scenarios show only minor changes, driven by slightly larger values and shares to domestic mutton consumers.

Sensitivity to Elasticity of Supply

A referee has noted that the elasticity of supply of lambs may be less than our assumed value of 1.5. We agree, although there are few empirical estimates available to support alternate assumptions. The most recent estimate available is from Kokic et al. (1993) who estimated medium-term lamb own-price supply elasticities of between 1.37 and 2.17 depending on ABARES regional disaggregation.

A lower supply elasticity should result in increased producer surplus in the farming sector. As noted by Alston et al. (1995, p.64), "When supply shifts in parallel, producers *always* benefit from research unless supply is perfectly elastic…" Hence producer surplus gains are greater the more price-inelastic is supply.

This result is confirmed through discrete sensitivity analysis in the model with lower values of the price elasticity of supply resulting in larger gains in producer surplus at the farm-level (Table 7).

Discussion and Conclusion

As with previously reported updates of existing beef and pig meat EDMs (Zhang et al., 2018a,b), quite a lot of data that was readily available to populate the original Mounter et al. (2008a) model of the sheep industry are no longer available. This meant that it was necessary to adjust a number of assumptions and calculations from the original model. The new model detailed in this paper provides a framework that reflects the current sheep meat industry size and structure, based on available information. However, it is important to note that the results from the model are conditional on the price and quantity values specified for each market, their underlying assumptions and calculations, and the parameter values used to represent industry responses to price changes. The results also vary substantially depending on where the investments are made. In the base case, sheep meat producers receive between 29 and 52 per cent of the potential gross benefits from the hypothetical investments, overseas consumers receive between 10 and 28 per cent, while domestic consumers receive between 15 and 47 per cent, depending on the particular scenario. Sheep meat processors, exporters and domestic retailers all receive much smaller shares of gross benefits, generally less than 15 per cent but ranging up to 26 per cent in one instance.

Hence, the accuracy of the results is very much dependent on having accurate estimates of prices, quantities and parameter values. While recent research has been conducted on updating demand elasticities (Mounter et al., 2012; Tighe et al., 2019), up to date estimates of relevant supply elasticities are the main remaining deficiencies. However, in the absence of continuing research in these areas, some further detailed sensitivity analyses are required once these models are transformed into Excel versions. The @Risk add-on is very useful in this role.

References

Alston, J.M., G.W. Norton and Pardey, P.G. (1995), *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*, Cornell University Press, Ithaca and London.

Alston, J.M. and Wohlgenant, M.K. (1990), "Measuring research benefits using linear elasticity equilibrium displacement models", in J.D. Mullen and J.M. Alston, *The Returns to the Australian Wool Industry from Investment in R&D (appendix* 2), Rural & Resource Economics Report No. 10, New South Wales Department of Agriculture & Fisheries, Division of Rural and Resource Economics, Sydney.

Australian Bureau of Agricultural and Resource Economics and Sciences (2017), *Agricultural Commodity Report*, Department of Agriculture and Water Resources, Canberra, March.

Australian Bureau of Statistics (2017), Livestock and Meat, Australian Bureau of Statistics, Canberra. Available at:
http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7218.0.55.001Jan%202018?OpenDocument

Borrell, B., Jiang, T., Pearce, D. and Gould, I. (2014), "Payoffs from research and development along the Australian food value chain: a general equilibrium analysis", *Australian Journal of Agricultural and Resource Economics* 58(3), 409-429.

Chung, K.C. and Griffith, G.R. (2009), "Another look at market power in the Australian fresh meat industries", *Australasian Agribusiness Review* Volume 17, Paper 12, 218-234. Available at: http://www.agrifood.info/review/2009/Chung_Griffith.pdf

Kokic, P., Beare, S., Topp, V. and Tulpule, V. (1993), *Australian Broadacre Agriculture: Forecasting Supply at the Farm Level*, ABARE Research Report 93.7, Australian Bureau of Agricultural and Resource Economics, Canberra.

MLA (2015), Fast Facts: Australia's sheep industry. Sydney. Available at:
https://www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--analysis/fast-facts--maps/mla_sheep-fast-facts-2015.pdf

MLA (2016), Fast Facts: Australia's sheep industry. Sydney. Available at:
https://www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--analysis/fast-facts--maps/mla_sheep-fast-facts-2016.pdf

MLA (2017a), Market Information Statistics Database. Sydney. Available at: http://statistics.mla.com.au/Report/List

MLA (2017b), Fast Facts: Australia's sheep industry. Sydney. Available at:
https://www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--

analysis/fast-facts--maps/mla_sheep-fast-facts-2017_final.pdf

Mounter, S., Griffith, G., Piggott, R., Fleming, E. and Zhao, X. (2008a), *An Equilibrium Displacement Model of the Australian Sheep and Wool Industries*, Economic Research Report 38, NSW DPI, Armidale.

Mounter, S., Griffith, G., Piggott, R., Fleming, E. and Zhao, X. (2008b), "Potential returns to the Australian sheep and wool industries from effective R&D and promotion investments and their sensitivities to assumed elasticity values", *Australasian Agribusiness Review* Volume 16, Paper 1. Available at: http://www.agrifood.info/review/2008/mounter_et_al.pdf

Mounter, S., Griffith, G., Piggott, R., Fleming, E. and Zhao, X. (2009), "An ex ante analysis of the incidence of the relative returns from R&D and promotion investments in the Australian sheep and wool industries", *International Journal of Sheep and Wool Science* Volume 57, No. 1, Paper 5, 62-82. Available at: http://sheepjournal.une.edu.au/sheepjournal/vol57/iss1/paper5

Mounter, S., Villano, R. and Griffith, G. (2012), *Updating a Model of Meat Demand in Australia to Test for the Impact of MSA*, Final Report to Meat and Livestock Australia on Project B COM 0336, University of New England, Armidale.

Rose, R.N. (1980), "Supply shifts and research benefits: a comment", *American Journal of Agricultural Economics* 62 (4, November), 834-44.

Tighe, K., Piggott, N., Cacho, O., Mounter, S. and Villano, R. (2019), "Testing for pre-committed quantities of Australian meat demand", *Australian Journal of Agricultural and Resource Economics* 63(2, April), 247-264.

Vere, D.T. and G.R. Griffith (1995), "Forecasting in the Australian lamb industry: the influence of alternate price determination processes", *Review of Marketing and Agricultural Economics* 63(3), 408-418.

Vere, D.T., Jones, R.E. and G.R. Griffith (1997), *An Integrated Economic Methodology for Evaluating the Impacts of Weeds in Agricultural Production Systems and the Farm and Industry Benefits of Improved Weed Management*, CRC for Weed Management Systems, Technical Series No. 2, University of Adelaide, Adelaide.

Vere, D.T., Griffith, G.R. and R.E. Jones (2000), *The Specification, Estimation and Validation of a Quarterly Structural Econometric Model of the Australian Grazing Industries*, CRC for Weed Management Systems, Technical Series No. 5, University of Adelaide, Adelaide.

Vere, D.T. and Griffith, G.R. (2004), "Structural econometric modelling in Australia's livestock production and marketing systems: the potential benefits of model integration for industry analysis", *Agricultural Systems* 81(2), 115-131.

Wittwer, G., Vere, D.T., Jones, R.E. and Griffith, G.R. (2005), "Dynamic general equilibrium analysis of improved weed management in Australia's winter cropping systems", *Australian Journal of Agricultural and Resource Economics* 49(4), 363-377.

Zhang, Y., Mounter, S. and Griffith, G. (2018a), "Updating and recalibrating equilibrium displacement models of the Australian livestock industries: beef", *Australasian Agribusiness Review* Volume 26, Paper 4, 48-67.

Zhang, Y., Mounter, S. and Griffith, G. (2018b), "Updating and recalibrating equilibrium displacement models of the Australian livestock industries: pig meat", *Australasian Agribusiness Review* Volume 26, Paper 5, 68-81.

Appendix. Model equations in displacement form with integrability conditions imposed

1 Supply of lambs

ex1-ipx1*(ew1-tx1)

2 Supply of other lamb slaughtering and processing inputs

ex3-ipx3*(ew3-tx3)

3-4 Input-constrained output supply functions for the lamb slaughtering and processing sector

ex5+(rx7*taux5x7)*ew5-rx7*taux5x7*ew7-ezl

ex7-(rx5*taux5x7)*ew5+rx5*taux5x7*ew7-ezl

5-6 Output-constrained input demand functions for the lamb slaughtering and processing sector

ex1+kx3*sigx1x3*ew1-kx3*sigx1x3*ew3-eyl

ex3-kx1*sigx1x3*ew1+kx1*sigx1x3*ew3-eyl

7-8 Equilibrium conditions for the lamb slaughtering and processing sector

kx3*ex3+kx1*ex1-rx5*ex5-rx7*ex7

kx3*ew3+kx1*ew1-rx5*ew5-rx7*ew7

9 Supply of other lamb export marketing inputs

ex9-ipx9*(ew9-tx9)

10-11 Output-constrained input demand functions for lamb export marketing

ex5+kx9*sigx5x9*ew5-kx9*sigx5x9*ew9-ex13

ex9-kx5*sigx5x9*ew5+kx5*sigx5x9*ew9-ex13

12 Equilibrium condition for lamb export marketing

ew13-kx5*ew5-kx9*ew9

13 Export demand for lamb

ex13-itx13*(ew13-nx13)

14 Supply of other lamb domestic marketing inputs

ex11-ipx11*(ew11-tx11)

15-16 Output-constrained input demand functions for lamb domestic marketing ex7+kx11*sigx7x11*ew7-kx11*sigx7x11*ew11-ex15

ex11-kx7*sigx7x11*ew7+kx7*sigx7x11*ew11-ex15

17 Equilibrium condition for lamb domestic marketing

ew15-kx7*ew7-kx11*ew11

18 Demand for domestic lamb

ex15-itx15*(ew15-nx15)-itx15x16*(ew16-nx16)

19-20 Supply of mutton

qx2*ex2+qx17*ex17-ipx2*ew2+ipx2*tx2

ew17-tx17-ipx*ew2+ipx1*tx2

21 Supply of other mutton slaughtering and processing inputs

ex4-ipx4*(ew4-tx4)

22-23 Input-constrained output supply functions for the mutton slaughtering and processing sector

ex6+(rx8*taux6x8)*ew6-rx8*taux6x8*ew8-ezm

ex8-(rx6*taux6x8)*ew6+rx6*taux6x8*ew8-ezm

24-25 Output-constrained input demand functions for the mutton slaughtering and processing sector

ex2+kx4*sigx2x4*ew2-kx4*sigx2x4*ew4-eym

ex4-kx2*sigx2x4*ew2+kx2*sigx2x4*ew4-eym

26-27 Equilibrium conditions for the mutton slaughtering and processing sector

kx4*ex4+kx2*ex2-rx6*ex6-rx8*ex8

kx4*ew4+kx2*ew2-rx6*ew6-rx8*ew8

28 Supply of other mutton export marketing inputs

ex10-ipx10*(ew10-tx10)

29-30 Output-constrained input demand functions for the mutton export marketing sector

ex6+kx10*sigx6x10*ew6-kx10*sigx6x10*ew10-ex14

ex10-kx6*sigx6x10*ew6+kx6*sigx6x10*ew10-ex14

31 Equilibrium condition for the mutton export marketing sector

ew14-kx6*ew6-kx10*ew10

32 Export demand for mutton

ex14-itx14*(ew14-nx14)

33 Supply of other mutton domestic marketing inputs

ex12-ipx12*(ew12-tx12)

34-35 Output-constrained input demand functions for the mutton domestic marketing sector

ex8+kx12*sigx8x12*ew8-kx12*sigx8x12*ew12-ex16

ex12-kx8*sigx8x12*ew8+kx8*sigx8x12*ew12-ex16

36 Equilibrium condition for the mutton domestic marketing sector

ew16-kx8*ew8-kx12*ew12

37 Demand for domestic mutton

ex16-itx16*(ew16-nx16)-itx16x15*(ew15-nx15)

38 Supply of other live sheep export marketing inputs

ex18-ipx18*(ew18-tx18)

39-40 Output-constrained input demand functions for the live sheep export marketing sector

ex17+kx18*sigx17x18*ew17-kx18*sigx17x18*ew18-ex19

ex18-kx17*sigx17x18*ew17+kx17*sigx17x18*ew18-ex19

41 Equilibrium condition for the live sheep export marketing sector

ew19-kx17*ew17-kx18*ew18

42 Live sheep export demand

ex19-itx19*(ew19-nx19)