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Modelling the effects of a temporary loss of export markets in case of a foot and mouth disease outbreak in Australia
Preliminary results on costs to Australian beef producers and consumers

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Abstract

The size of the cost to the Australian beef industry of a potential loss of major beef export markets following an outbreak of foot and mouth disease (FMD) in Australia is important in determining appropriate precautions. The size of this cost is evaluated with a dynamic bioeconomic model of Australian beef production, consumption and export trade. The model developed by ABARE represents forward-looking competitive behaviour of beef producers and traders on domestic and export markets based on perfect foresight. The model enables estimation of the cost due to a FMD outbreak under various scenarios regarding the duration of market closure and affected zones.

Introduction

In the meat industry access to many markets is restricted on the basis of whether or not products come from a disease-free country. Australia is relatively free of exotic diseases and, because of this, is able to export agricultural products to most other countries of the world. One of the most significant animal diseases is foot and mouth disease (FMD) (Donaldson 1987; Sanson 1994). It almost exclusively affects cloven-hoofed animals, both wild and domesticated. Cattle, sheep, goats and pigs are the species most commonly infected. Australia's current disease–free status would be undermined if its livestock industries, particularly its beef industry, became affected by FMD.

There are effectively two markets for meat in the world — markets that are free of FMD and markets in countries where the disease is endemic. The Pacific Basin market is made up of countries, which only accept imports from FMD free countries. These quarantine restrictions limit the supply of beef to the Pacific Basin and cause the returns on beef sales to the Pacific Basin markets to be higher than available for the same product in FMD endemic markets.

While FMD is a severe disease in its own right, for an exporting country like Australia the greatest economic impact would be due to the loss of export markets. Approximately 60 per cent of Australia's beef and veal production is currently sold on the world market and over 90 per cent of these are exported to countries in the Pacific Basin. Therefore, the short run impact of a disease incursion on the industry would be substantial, as alternative markets for a large quantity of beef would need to be found. High volumes of Australian beef redirected to these lower priced markets would depress prices further, feeding back to Australian farmers through lower prices at the saleyard.

Estimation of the cost to Australia due to an FMD outbreak has been the subject of a number of studies. Depending on assumptions used in the estimations and the coverage of costs defined, the costs estimated can vary significantly. Bunn (1993) estimated conservatively that an outbreak of FMD would cost Australia $10 million a day. ABARE recently estimated that the value of beef and veal exports would fall by $1209 million in the first year of an outbreak of FMD due to the loss of markets in the Pacific Basin and due to the need to seek buyers in other markets (ABARE 2001).

In the present study, a bioeconomic model is developed and used to quantitatively estimate the cost to the Australian beef industry of a loss of major FMD free markets in the event of an FMD outbreak in Australia. A broad outline of the model and results of model simulations under various scenarios are presented below.

Loss of export markets and farm level impacts

If an FMD outbreak were to occur in Australia, the most significant economic impact on the Australian beef industry would be due to the loss of major FMD free export markets. The impact on the Australian broadacre agriculture sector would be severe. Apart from the direct costs associated with eradication programs and compensation payments to producers, a significant decline in cattle prices would be expected as traditional markets for Australian beef and veal were closed off for a period of time.

Estimates of the costs of an FMD outbreak in Australia depend on a wide range of assumptions regarding the nature of the outbreak, methods and timing of containment and market access conditions. Previous research conducted by ABARE (Lembit and Fisher 1992) contained estimates of the reduction in farm cash incomes due to an FMD outbreak, assuming producers maintained their normal longer term profit maximisation behaviour. Lembit and Fisher (1992) estimated that average broadacre farm incomes would fall by $25 700 per farm during the first year of an Australia wide FMD outbreak. In current dollar values this equates to a fall of $29 574 per farm. With almost 72 000 broadacre farms in Australia, broadacre farm income losses due to an FMD outbreak in Australia are estimated at around $2117 million for the first year.

ABARE has now developed a bioeconomic model of the Australian beef industry, which allows *what if* evaluations of a wide range of disease outbreak, containment and market access scenarios. The model focuses on estimation of costs due to the loss of major beef export markets.

Zoning

Zoning is a way of separating FMD affected from unaffected areas, where the unaffected areas are either not subjected to FMD related trade restrictions or subjected to such restrictions for a shorter period. The application of zoning for FMD in Australia was discussed at the 1994 National Workshop on Zoning for FMD (Anon 1994), where it was concluded that zoning could be used in the event of an FMD outbreak and that it would be particularly attractive where an outbreak takes some time to eradicate. Early studies (eg Barry et al. 1993) showed that the adoption of zoning could significantly reduce the economic impact of an outbreak compared to the situation without zoning. For example, Barry et al. (1993) showed that the adoption of zoning produced substantially smaller losses to the beef industry than those implied by the results of Lembit and Fisher (1992) from an analysis without zoning.

The bioeconomic model developed by ABARE can be used to simulate various scenarios of durations of market closure and zoning. The model enables arbitrary sizes of the zones to be considered.

Model

Based on some assumptions about the relevant biological and economic conditions of the Australian cattle industry, a mathematical representation of the model is provided in appendix 1.

The model is a dynamic bioeconomic model, which represents forward-looking competitive behaviour of beef producers and traders on domestic and export markets based on perfect foresight. At each time step, the model estimates the age and sex composition of cattle herd, number of calves reared, slaughter rates, volumes of beef and prices consistent with a linear demand function. The model also contains estimates at each time step of feed costs, slaughter costs and total revenue as the product of beef produced and the price received.

The model uses a half-year time step. It considers 10 half-year age cohorts for non-breeding cattle (males and non breeding females) and 20 half-year age cohorts for breeding cattle (cows). These numbers of age cohorts are large, given that farmers generally keep cows up to around 7 years of age (14 half-years) and non breeding cattle up to around 3 years of age (6 half-years). The reason for using large numbers of age cohorts is to allow the model to have the flexibility to keep animals longer if a shock (such as FMD) occurs.

The model has an option to adopt zoning, that is, the model can be used to simulate both zoning and no zoning cases. In the case of zoning, two zones with arbitrary sizes are considered. A single domestic beef market is considered in the model in the case of no zoning, and two domestic markets in the case of zoning (one for each zone). There are two export markets in the model; one represents the FMD free market and the other the FMD endemic market. Each market has demands for two types of beef (premium beef and lower quality beef).

Below are some assumptions used for setting up data or parameter values that are used in subsequent model simulations.

Model assumptions

(1) Initial steady state equilibrium

In the absence of FMD, initial steady state equilibrium of the model is assumed to exist, and the system is assumed to stay in the initial steady state equilibrium. This equilibrium is characterised by all variables of the model being stable.

At the prevailing prices and costs, no producer or trader wants to alter decisions about the number of female calves retained for breeding, the slaughtering age, or where to sell. The equilibrium depends on the assumed values of the model parameters (see appendix 2). These parameters are saleable kilograms of beef per head by age and cattle type, feeding costs per head by age and cattle type, slaughtering costs (including other final costs) per head by cattle type, natural mortality rates, demand parameters on beef markets and the rate of discount. Growth in consumption and exports as a result of population and income growth is ignored in the analysis.

(2) Model calibration

The model is calibrated by allowing the parameters of feeding costs and slaughtering costs to be determined so that the initial equilibrium derived from the model is consistent with existing data on the volumes and prices of beef, while values of all other model parameters are given exogenously. Once these feeding and slaughtering costs are determined, they are then fixed as model parameters in all model simulations later on.

(3) Linear demand schedule

The demand schedule is assumed to be linear. The intercepts and slopes of the linear demand functions for two types of beef (premium beef and lower quality beef) at various markets are estimated based on the assumed elasticities and the observed initial data on volumes and prices of beef. The parameters of these linear demand functions are assumed not to change over time.

(4) Live cattle

There are no exports of live cattle explicitly considered in the model developed. However, live cattle exports are approximated by their equivalent in exports of lower quality beef. During calibration of the model, the observed live cattle export values are converted to the volumes of lower quality beef by dividing by the observed prices of lower quality beef. The volumes of lower quality beef used in the model calibration are then the sum of the observed volumes of lower quality beef and the converted volumes of lower quality beef from the value of live cattle exports.

Cost of an FMD outbreak

The cost of an FMD outbreak considered in this study only consists of the net cost to Australian beef industry and beef consumers, and does not include any costs related to control of FMD (eg any costs of the human resources involved in controlling the disease). The cost certainly depends on FMD outbreak scenarios, for example, how long the relevant markets are expected to close, whether zoning can be adopted, how many animals are affected, and so on.

Loss of major markets due to FMD, particularly the higher priced FMD-free export markets for some period of time, results in a temporary reallocation of beef produced to the remaining and much smaller export markets and the domestic markets. This will result in lower beef prices in the short term. In the longer term, a new steady state equilibrium, identical to the original steady state, will be established. The temporary reduction in prices and the expectation of prices reverting to initial steady state levels in the near future, results in adjustment in female retention and slaughtering decisions. The model is used to simulate the adjustment path that follows from the decisions by profit maximising producers and traders, operating on competitive markets, using their perfect foresight about market outcomes while discounting future benefits and costs.

The model estimates the net cost to Australia beef industry and beef consumers due to the FMD induced market closure as the net present value of losses and gains to the Australian producers and consumers over the period from the time of FMD outbreak to the time when the system returns to the original steady state.

Simulation results

A number of scenarios were simulated using the model which is implemented in the General Algebraic Modelling System (GAMS). The scenarios selected in this study (table 1) are used to test the FMD impacts on the Australian beef industry with different options which are zoning or no zoning, long closure periods or short closure periods of relevant markets, considering seasonality of beef production or not. In all scenarios, the simulation period is 60 half years (i.e. 30 years).

Table 1: Selected scenarios simulated in this study

Scenario	Zoning		Closure period	Seasonality
A[1]	No		0 months	No
B	No		12 months	No
C	No		18 months	No
D[1]	No		0 months	Yes
E	No		18 months (Jun)[2]	Yes
F	No		18 months (Dec)[2]	Yes
G[1]	Yes	Victoria	0 months	Yes
		The rest of Australia	0 months	Yes
H	Yes	Victoria[3]	18 months (Jun)[2]	Yes
		The rest of Australia	6 months	Yes

Base scenarios with no FMD outbreak and the system staying in the steady state.

18 months (Jun): FMD outbreak in the January to June season; 18 months (Dec): FMD outbreak in the July to December season.

Victoria is assumed to be the FMD affected zone.

There are three base scenarios (scenarios A, D and G) reflecting different cases: scenario A considers no zoning and no seasonality, scenario D no zoning but seasonality, and scenario G both zoning and seasonality.

Scenarios B and C are chosen to compare the impacts of different durations of market closure periods, where 6 month longer closure period is used in scenario C than in scenario B. Scenarios E and F with an FMD outbreak in different seasons are used to test the impacts of consideration of seasonality in beef production. Scenario H is chosen to test the impact of zoning, for comparison with the no zoning scenario E. Detailed simulation results for each scenario are provided below.

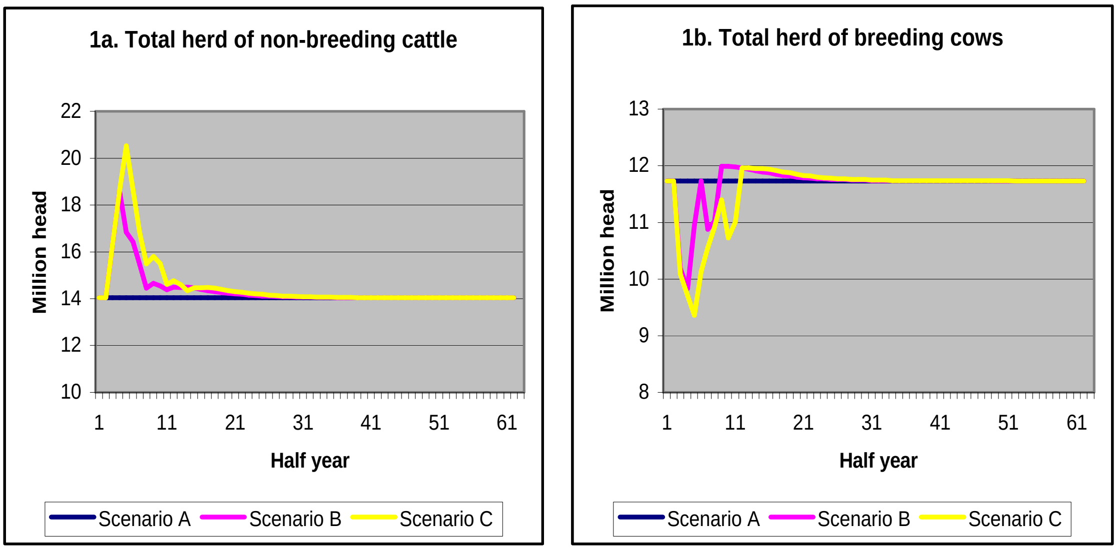
No zoning (scenarios A to F)

If zoning is not adopted, then the FMD free export markets will be closed to all beef produced in Australia. Scenarios A to F in table 1 were simulated for this case.

(1) Scenarios A to C (no seasonality for varying closure periods)

In these scenarios it is assumed that there is no seasonal variation in beef production. To investigate the impact of the duration of the closure period, two scenarios were used. In scenario B there is a closure period of two half years (i.e. 12 months), while in scenario C there is a closure period of three half years (i.e. 18 months). Shown in figure 1 are the resulting time paths for the herds of breeding cows and non-breeding cattle over the 60 half years.

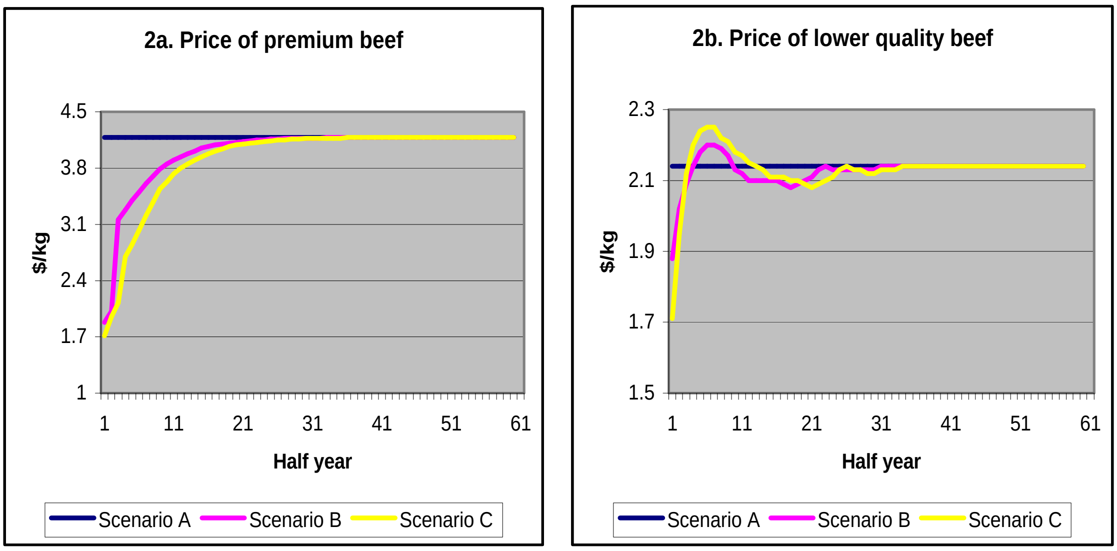
Figure 1: Time paths of herds with market closure periods of two half years (scenario B) and three half years (scenario C), compared with the steady state time path (scenario A)



The figures show that immediately after the market closure, the herd of non breeding cattle rises to reflect the accumulation of non breeding animals due to the closure of major premium beef markets; while the herd of breeding cows declines (slaughter rates increase) during the FMD outbreak because it is not economic to keep cows longer due to higher feeding costs per head. It should be mentioned at this stage that the model uses an assumption that there is no distinction between premium beef and lower quality beef during the market closure period.

This implies that the higher supply from the increased slaughter of cows is supplemented by the (lower) supply from the reduced slaughter of non-breeding cattle on the remaining beef markets during the closure period. From figure 1, the longer closure period (scenario C) results in a larger accumulation of non-breeding cattle, and more slaughtering of breeding cows. This time-path for herds is consistent with the time-path of prices shown in figure 2.

Figure 2: Time paths of prices with market closure periods of two half years (scenario B) and three half years (scenario C), compared with the steady state time path (scenario A)



The closure of major export markets reduces the price for both premium beef and lower quality beef. The longer closure period results in even lower prices in the early years of the FMD outbreak. Both figure 1 and figure 2 show that the system gradually returns to the initial steady state, after the shock due to FMD.

The net economic cost to the Australian beef industry and consumers for the scenarios is reported in tables 2 and 3, where the cost is estimated to be around $2408 million in present value terms over 30 years in scenario B. The cost increases to $3792 million in scenario C with a 6 month longer closure period than that in scenario B. The cost in the first year of the FMD outbreak is around $2703 million in scenario B, while this cost slightly decreases to $2695 million in scenario C. This decline in costs is partly explained by increased consumer surplus generated by lower domestic beef prices for the extended closure period. This does not contradict that the total cost over 30 years in scenario C is higher than that in scenario B, because in the subsequent years the costs in scenario C are higher than those in scenario B due to the longer closure period.

(2) Scenarios D to F (seasonality)

In reality beef production follows a seasonal pattern with lower production in the January to June half year. The lower production in the January to June season may be due to the holiday season of Christmas and New Year. In these scenarios, seasonality is added to the model, which allows the steady state data to vary between the January–June season and the July–December season. In this case, the equilibrium is a two-period cycle from the state in January–June to that in July–December, and then back to the same state in January–June, and so on. The length of closure period, 18 months, is the same as in scenario C.

The time-paths of herds and prices for the scenarios D and E with seasonality compared with the results for scenario C without seasonality are shown in figures 3 and 4, where it is assumed that FMD occurs in the January–June season. The results show little difference between the case with seasonality and the case without seasonality.

Figure 3: Time paths of herds for an 18 month closure period, both with and without seasonality (ie scenario E and scenario C), compared with the steady state time path with seasonality (ie scenario D)

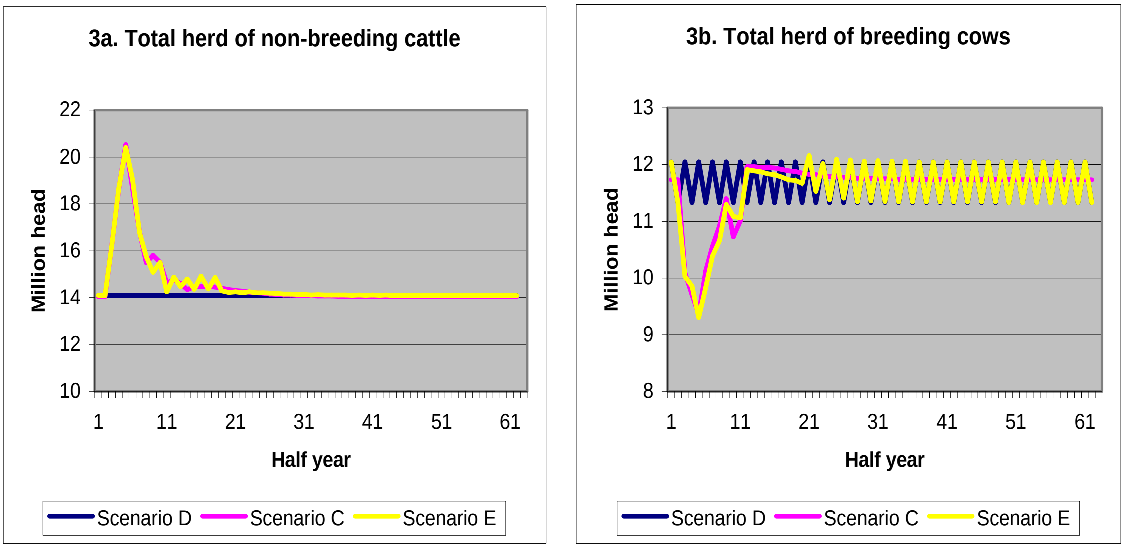
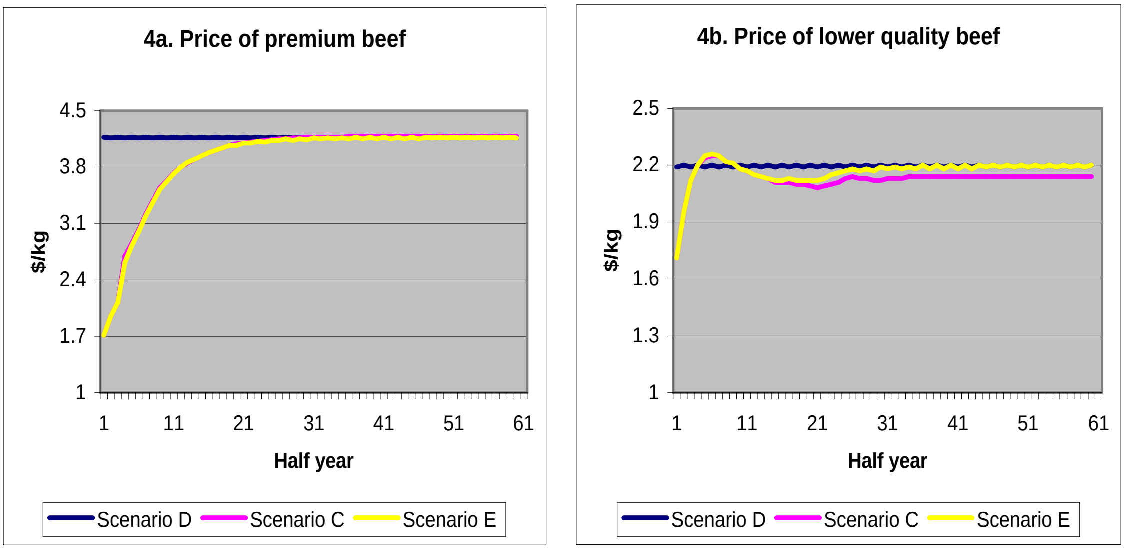


Figure 4: Time paths of prices for an 18 month closure period, both with and without seasonality (ie scenario E and scenario C), compared with the steady state time path with seasonality (ie scenario D)



The small difference between the results with and without seasonality implies that the timing of an FMD outbreak, that is, in January–June or July–December, will not have much effect on the economic cost to the beef industry and consumers. To see this, a simulation assuming an FMD outbreak in July–December (scenario F) was also carried out. Figures 5 and 6 show the comparison of results of an FMD outbreak in January–June (scenario E) and the results of an outbreak in July–December (scenario F).

Figure 5: Time paths of herds with an FMD outbreak in the January–June season (scenario E) and in the July–December season (scenario F), compared with the steady state time path.

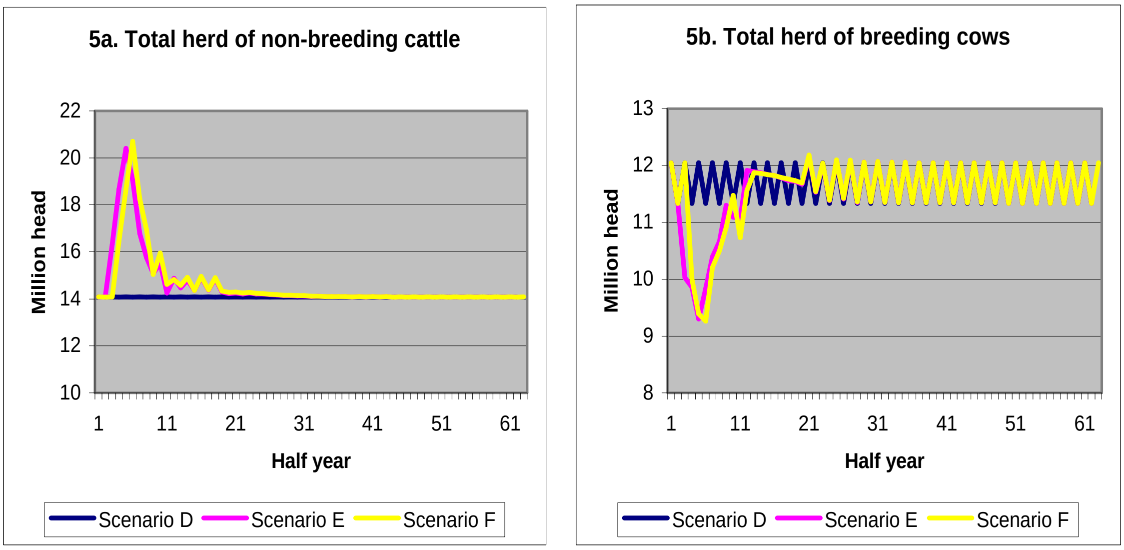
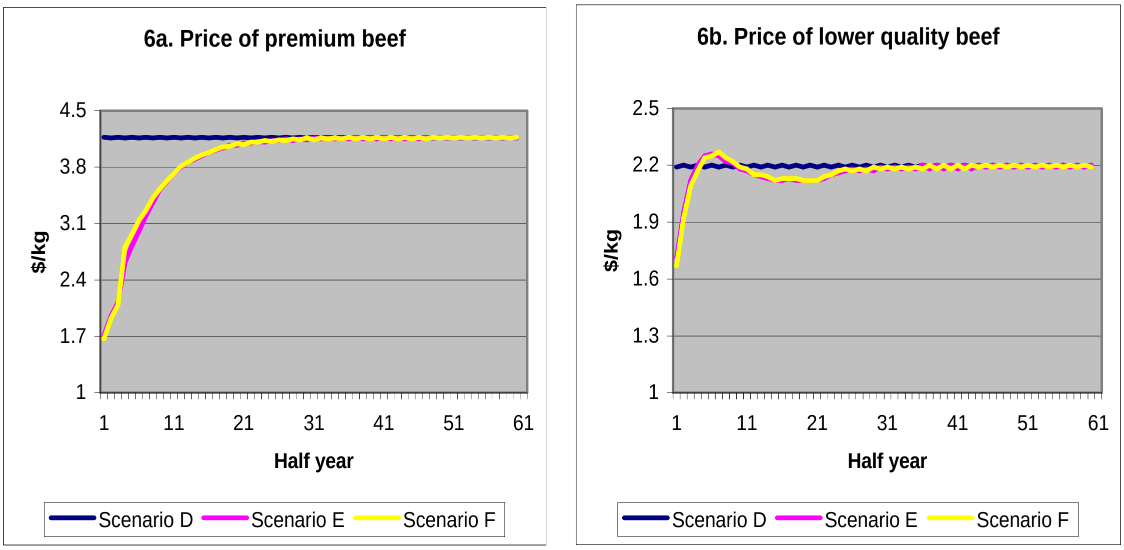


Figure 6: Time paths of prices with an FMD outbreak in the January–June season (scenario E) and in the July–December season (scenario F), compared with the steady state time path.



Again, for all scenarios after the shock due to FMD the system gradually returns to the initial steady state. The net economic cost to the Australian beef industry and beef consumers for these scenarios is reported in tables 2 and 3, where the cost is estimated to be around $3900 million in present value terms over 30 years in the case of an FMD outbreak in the January to June season (scenario E), and around $3846 million in the case of an FMD outbreak in the July to December season (scenario F). As mentioned earlier, the results show little difference in the costs of an FMD outbreak in the January to June season and in the July to December season. This implies that the timing of FMD outbreak does not have much impact on the estimated economic cost of an outbreak although there is some variation in beef production between seasons. The cost in the first year is around $2698 million in the case of an FMD outbreak in the January to June season, and around $2719 million in the case of an FMD outbreak in the July to December season. Comparing the costs for scenarios E and F with seasonality with the cost for scenario C without seasonality, the costs for scenarios E and F are higher than for scenario C.

Zoning (scenarios G to H)

Scenarios were constructed to analyse the effect of zoning on the economic costs of an FMD outbreak. It is assumed that there are two zones, and for illustrative purposes, one zone is chosen to be Victoria and the other is the rest of Australia. Seasonality is included in these scenarios. To make the results comparable with the results from the scenarios without zoning, the closure periods are set at three half years for the FMD affected zone (which is the same as in the corresponding scenario without zoning (i.e. scenario E) and a half year for the FMD free zone. It is assumed that an FMD outbreak occurs in the January to June season. Results for the FMD affected zone (i.e. Victoria) are shown in figures 7 and 8, and results for the FMD free zone (i.e. the Australia excluding Victoria) are shown in figures 9 and 10.

Figure 7: Time paths of herds in the FMD affected zone (ie Victoria) with an FMD outbreak in the January–June season (scenario H), compared with the steady state time path (scenario G).

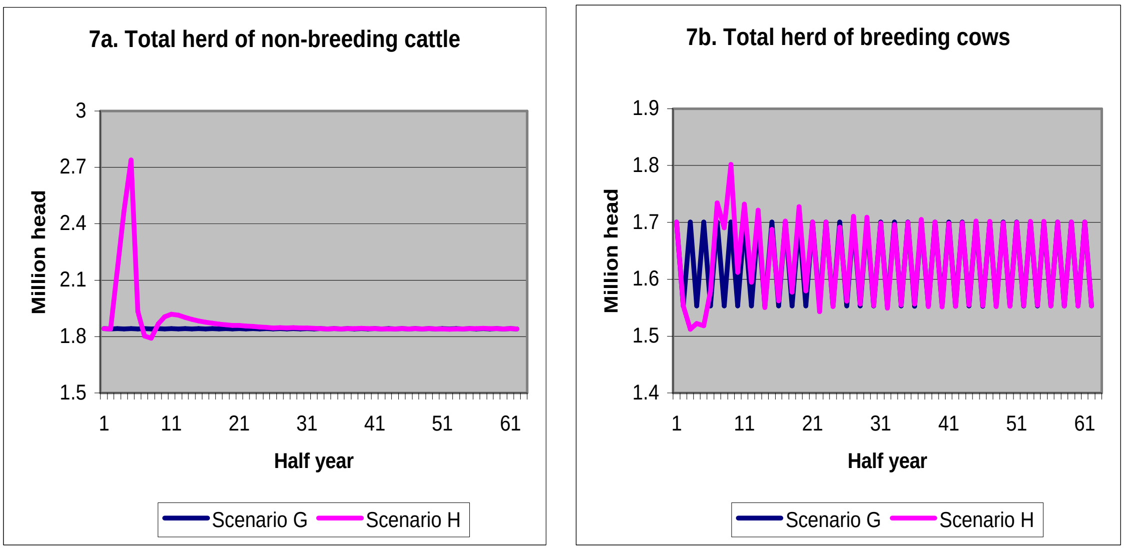


Figure 8: Time paths of prices in the FMD affected zone (ie Victoria) with an FMD outbreak in the January–June season (scenario H), compared with the steady state time path (scenario G).

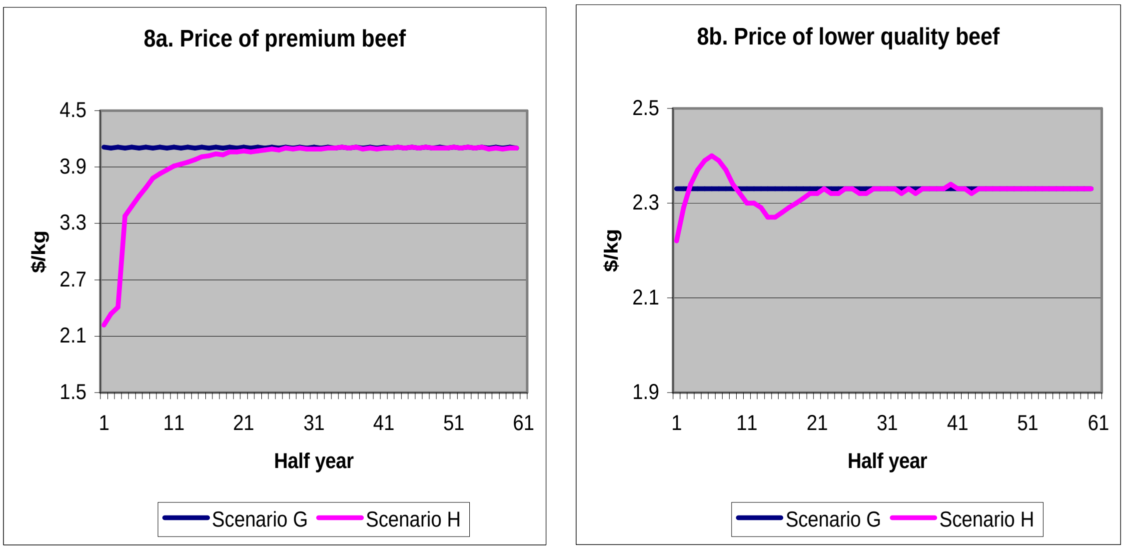


Figure 9: Time paths of herds in the FMD unaffected zone (ie Australia excluding Victoria) with an FMD outbreak in Victoria (scenario H), compared with the steady state time path (scenario G).

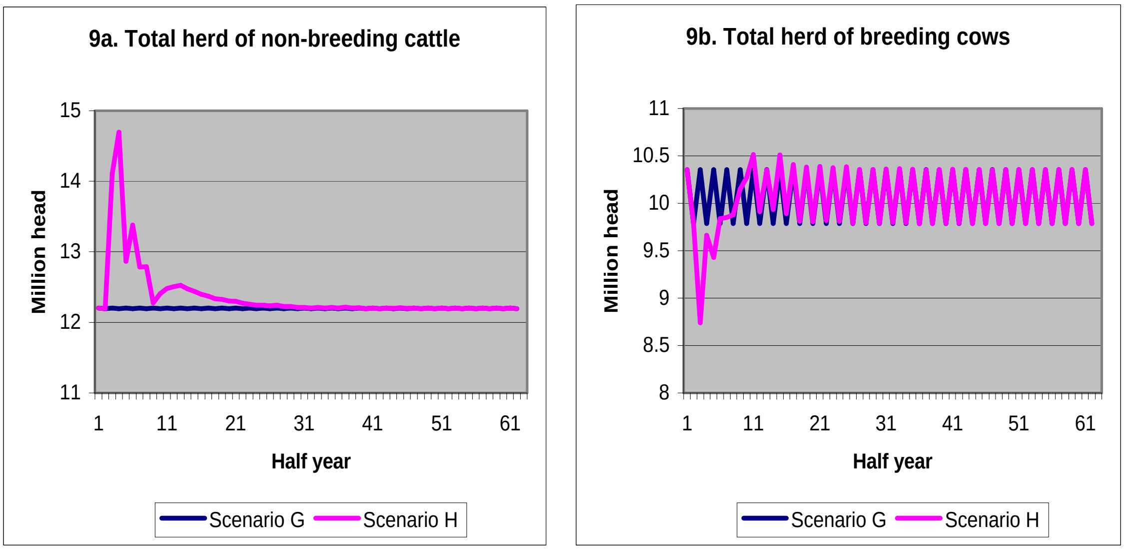
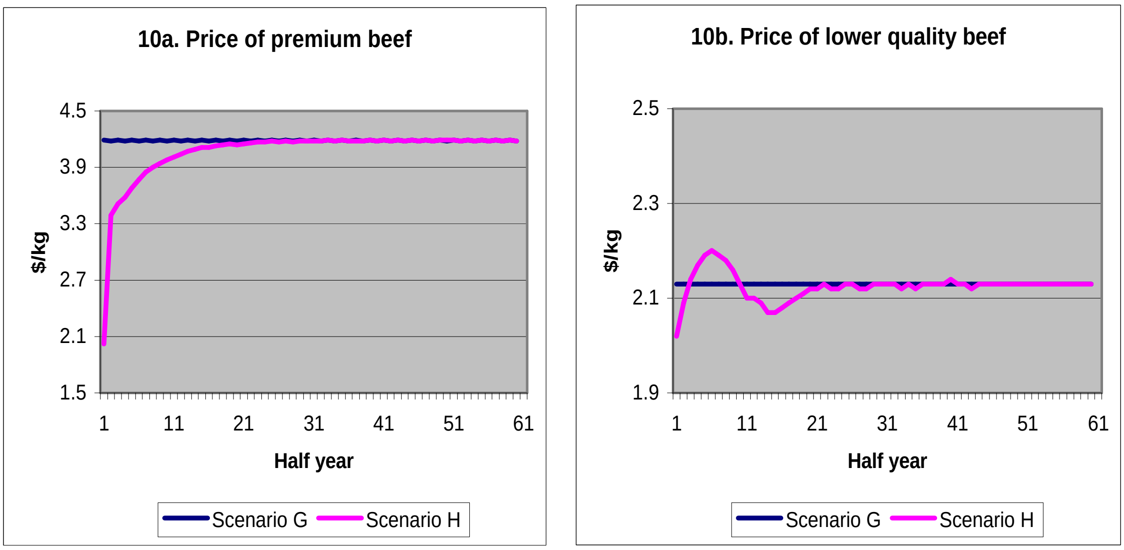


Figure 10: Time paths of prices in the FMD unaffected zone (ie Australia excluding Victoria) with an FMD outbreak in Victoria (scenario H), compared with the steady state time path (scenario G).



Overall the dynamic behaviour with zoning is similar to that shown in the scenarios where zoning is not considered. The impact in terms of changes in herds on the FMD affected zone is greater than on the FMD free zone. The greater impact on the FMD affected zone is caused by the longer period of market closure. To compare the economic impacts for the case with zoning and the case without zoning, see tables 2 and 3 for detailed estimates of economic costs.

For the FMD affected zone there is a loss of around $448 million to beef producers in present value terms over 30 years, however, this loss is offset by a gain of around $485 million to beef consumers due to the low beef prices in earlier years following the FMD outbreak. So, there is a small net gain of $37 million to beef producers and consumers in present value terms over 30 years. For the FMD free zone the net cost is around $1582 million to beef producers and consumers in present value terms over 30 years, where there is a loss of around $2449 million to beef producers and a gain of around $867 million to beef consumers. Also, note that the FMD free zone (i.e. Australia excluding Victoria) is much bigger than the FMD affected zone (i.e. Victoria).

For the whole of Australia, the net loss is around $1545 million in present value terms over 30 years with the adoption of zoning. This loss is significantly smaller than the loss of $3900 million for the corresponding scenario without zoning (i.e. scenario E). Looking at the costs in the first year only of an FMD outbreak, the cost for the FMD affected zone is around $433 million, while for the FMD unaffected zone the cost is around $1228 million. Taking Australia as a whole, the cost is around $1662 million in the first year of an FMD outbreak. Again this cost is significantly smaller than the cost of $2698 million for the corresponding scenario without zoning (i.e. scenario E). These results show that the application of zoning can have a significant impact on reducing the costs to Australia if an FMD outbreak were to occur.

Table 2: Present values (million Australian dollars) over 30 years

Scenario	Closure period	Seasonality	1.1.1.1 Total Revenue (TR)	1.1.1.2 Total Cost (TC)	1.1.1.3 Producer Surplus (PS = TR – TC)	1.1.1.4 Loss of Producer Surplus (LPS)		1.1.1.5 Australian Consumer Surplus	1.1.1.6 Gain of Consumer Surplus (GCS)		1.1.1.7 Australian Loss/Gain LPS+GCS
No zoning scenarios											
A	0 months	No	75984	61213	14771			708			
B	12 months	No	71730	61353	10377	-4394	(cf A [1])	1681	973	(cf A)	-2703
C	18 months	No	69416	61334	8082	-6689	(cf A)	1754	1046	(cf A)	-2695
D	0 months	Yes	76147	61317	14830			712			
E	18 months (Jun)	Yes	69272	61288	7984	-6846	(cf D)	1764	1053	(cf D)	-2698
F	18 months (Dec)	Yes	69547	61267	8281	-6549	(cf D)	1759	1048	(cf D)	-2719
Zoning scenario											
(1) FMD affected zone (Victoria)											
G1	0 months	Yes	10231	8221	2010			93			
H1	18 months	Yes	9875	8313	1582	-448	(cf G1)	160	67	(cf G1)	-433
(2) FMD free zone (the rest of Australia)											
G2	0 months	Yes	65861	52998	12863			614			
H2	6 months	Yes	63372	52959	10414	-2449	(cf G2)	1225	610	(cf G2)	-1228
(3) Whole Australia											
I	0 months	Yes	76092	61219	14872			707			
J	6,18 months (Jun)	Yes	73247	61272	11975	-2897	(cf I)	1385	678	(cf I)	-1662

'cf A' means compared with Scenario A. Similar meaning for 'cf D' and others.

Table 3: Present values (million Australian dollars) in the first year of FMD outbreak

Scenario	Closure period	Seasonality	1.1.1.1 Total Revenue (TR)	1.1.1.2 Total Cost (TC)	1.1.1.3 Producer Surplus (PS = TR – TC)	1.1.1.4 Loss of Producer Surplus (LPS)		1.1.1.5 Australian Consumer Surplus	1.1.1.6 Gain of Consumer Surplus (GCS)		1.1.1.7 Australian Loss/Gain LPS+GCS
No zoning scenarios											
A	0 months	No	5787	4662	1125			708			
B	12 months	No	1747	4299	-2552	-3677	(cf A)	1681	973	(cf A)	-2703
C	18 months	No	1682	4298	-2616	-3741	(cf A)	1754	1046	(cf A)	-2695
D	0 months	Yes	5799	4670	1129			712			
E	18 months (Jun)	Yes	1675	4296	-2621	-3750	(cf D)	1764	1053	(cf D)	-2698
F	18 months (Dec)	Yes	1668	4306	-2638	-3767	(cf D)	1759	1048	(cf D)	-2719
Zoning scenario											
(1) FMD affected zone (Victoria)											
G1	0 months	Yes	779	626	153			93			
H1	18 months	Yes	227	575	-348	-501	(cf G1)	160	67	(cf G1)	-433
(2) FMD free zone (the rest of Australia)											
G2	0 months	Yes	5016	4036	980			614			
H2	6 months	Yes	3029	3888	-859	-1839	(cf G2)	1225	610	(cf G2)	-1228
(3) Whole Australia											
I	0 months	Yes	5795	4662	1133			707			
J	6,18 months (Jun)	Yes	3256	4462	-1207	-2339	(cf I)	1385	678	(cf I)	-1662

'cf A' means compared with Scenario A. Similar meaning for 'cf D' and others.

Conclusion and discussion

A dynamic bioeconomic model was developed to estimate the net economic costs to the Australian beef industry and beef consumers were an FMD outbreak to occur in Australia. A number of scenarios were tested to demonstrate the model capabilities. Zoning and seasonality were analysed under different outbreak conditions.

The results showed that a longer closure period of FMD free export markets would result in significantly higher net costs to the Australian beef industry and beef consumers. Adding seasonality into the model to more accurately model Australian beef production results in a slight increase in the estimated loss from an FMD outbreak. With respect to zoning, the model results showed that the adoption of zoning could significantly reduce the net costs to the Australian beef industry and beef consumers were an FMD outbreak to occur.

Two issues need to be addressed. One is destruction of FMD affected animals, and the other is the value of the price elasticities of demand. In the current model, there is no consideration of destruction of FMD affected animals. However, this issue is to be considered in further modelling work, given that destruction of affected animals was used in the UK FMD outbreak to limit the spread of the disease. The price elasticities of demand are assumed to be –1 for all domestic and export markets in the present study. Other values of the price elasticity of demand for beef in FMD endemic markets will be considered in a further study, after more investigation on the demand and supply conditions in these markets.

One other point should be mentioned. The model assumed competitive behaviour of beef producers and traders on domestic and export markets. However, in principle, the model can be modified to deal with some forms of non-competitive behaviour of producers and traders.

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Appendix 1: Mathematical specification of the model

Model notation:

Indexes

t half a year (*t* = 1, 2, …, *T*)

z zone/region (*z* = 1, 2, …, *Z*), where *Z* = 1 indicates no adoption of zoning

s beef type or cattle type (*s* = *m*, *c*), where *m* indicates beef from young steers and young female cattle raised for fattening and *c* indicates beef from females used for breeding.

a age cohort ($a = 1,2,...,A_s$), where $A_m = 10$ for *s* = *m* and $A_c = 20$ for *s* = *c*

k beef market ($k = e_f, e_{e,} d_1, d_2, ..., d_Z$), where e indicates export market (e_f : FMD free export market; e_e : FMD endemic export market) and d indicates domestic markets (total *Z* domestic markets).

Variables

Note: All variables are time dependent and represent values at the start of a time period or during a time period.

$p_s(t,z)$ price of beef of type *s* supplied from zone *z*, fob major port

$p_s^k(t,z)$ price of beef of type *s* on market *k* supplied from zone *z,* fob major port

$q_s^k(t,z)$ quantity of beef of type *s* on market *k* supplied from zone *z*

$sl_a^s(t,z)$ number of cattle of type *s* and age group *a* slaughtered at zone *z*

$x_a^s(t,z)$ number of cattle of type *s* and age group *a* at zone *z*

$xs(t,z)$ number of female calves born during period *t* diverted to fattening in that time period at zone *z*

$l_a^s(t,z)$ price of cattle of type *s* and age group *a* at zone *z*

$ssl_a^s(t,z)$ rent to slaughter of cattle of type *s* and age group *a* at zone *z*

$sxs(t,z)$ rent to female calves born during period *t* diverted to fattening in that time period at zone *z*

Parameters

$a_a(z)$ proportion of calves marked per breeding female at zone *z*

$B_s^k(z)$ intercept parameter in linear inverse demand function for beef of type *s* supplied from zone *z* on market *k*

$C_s^k(z)$ slope parameter in linear inverse demand function for beef of type *s* supplied from zone *z* on market *k*

cfe_a^s half yearly costs per head of cattle of type *s* and age group *a* for each zone*,* ie feeding costs and all other yearly costs to farm gate

$csl_a^s(z)$ cost per head of cattle of type *s* and age group *a* at zone *z* from farm gate to conversion into beef fob major port, ie slaughter costs and other costs excluding transportation costs.

m_a^s proportion of cattle of type *s* and age group *a* dying half yearly from natural causes

r half yearly rate of discount

w_a^s saleable beef weight per head of cattle slaughtered of type *s* and age group *a*

$t^k(z)$ transportation cost of per kilogram of beef from zone *z* to market *k*

Bioeconomic model of Australian beef production, consumption and export trade

The assumptions about the biological and economic conditions of the Australian cattle industry that make up the model are represented as follows: for $t = 1,2,\Lambda\ ,T,$ and $z = 1,2,\Lambda\ ,Z$ [1]

1 - $$x_1^m(t+1,z) = \tfrac{1}{2}\sum_{a=1}^{A_c} a_a(z)x_a^c(t-1,z)/2 + xs(t+1,z),$$ [2]

for each time step, the number of cattle of age one for nonbreeding purposes equals the number of male calves and female calves diverted from breeding. It is assumed that male calves and female calves are equal in number.

2 - $$x_1^c(t+1,z) = \tfrac{1}{2}\sum_{a=1}^{A_c} a_a(z)x_a^c(t-1,z)/2 - xs(t+1,z),$$

for each time step, the number of breeding females of age one equals the number of female calves less the number diverted to nonbreeding purposes.

3 - $$xs(t+1,z) \le \tfrac{1}{2}\sum_{a=1}^{A_c} a_a(z)x_a^c(t-1,z)/2,$$

for each time step, the number of female calves diverted to nonbreeding purposes cannot exceed the number of female calves born.

4 - $$x_{a+1}^s(t+1,z) = (1-m_a^s)x_a^s(t,z) - sl_a^s(t,z) \quad \text{for } a = 1,2,\ldots,A_s - 1 \text{ and}$$

$$\begin{aligned} x_{A_s}^s(t+1,z) = {} & (1-m_{A_s-1}^s)x_{A_s-1}^s(t,z) - sl_{A_s-1}^s(t,z) \\ & + (1-m_{A_s}^s)x_{A_s}^s(t,z) - sl_{A_s}^s(t,z) \end{aligned} \quad , \text{ all for } s = c,m$$ [3]

for each time step, the number of cattle of each type of any age equals the number of that type of cattle that were one age younger the previous time step less a proportional natural mortality and less the number slaughtered.

5 - $$sl_a^s(t,z) \le (1-m_a^s)x_a^s(t,z) \quad \text{for } s = c,m \text{ and } a = 1,2,\ldots,A_s,$$

for each time step, the maximum slaughter of cattle of each age and type cannot exceed the number of surviving cattle of that age and type.

$$p_s^k(t) = B_s^k + C_s^k \sum_z q_s^k(t,z), \text{ for } s = c,m,\ k = d_1, d_2, \Lambda\ , d_Z \text{ (ie domestic markets);}$$

6 - $$p_s^k(t,z) = B_s^k(z) + C_s^k(z)q_s^k(t,z), \quad \text{for } s = c,m,\ \ k = e_f, e_e \text{ (ie export markets)},$$

for each time step, the volume demanded of beef of any type on any market depends on the price of that beef according to a downward sloping linear demand function with parameters that are constant over time. Note that prices of beef in the domestic markets are assumed independent of the origin of beef, while the prices in the export markets are assumed dependent on the origin of beef.

1.1.1.1 ______________________

[1] In the case of no zoning, $Z = 1$ (ie one single zone for the whole of Australia).
[2] Breeding cows produce calves two time steps (ie one year) later. It is assumed that at each time step only half of the cows breed in order to avoid cows breeding twice per year.
[3] The oldest age groups for breeding and nonbreeding cattle are heterogeneous groups containing all animals beyond certain ages. Slightly modified conditions apply for these age groups. However, these terminal age groups are chosen so as to be old enough never to have any surviving animals in them for whatever event or policy simulation.

7 - $$\sum_{k=e_f,e_e,d_1,\ldots,d_Z} q_s^k\ (t,z) \le \sum_{a=1}^{A_s} sl_a^s(t,z)w_a^s\text{, for } s=c,m\text{ ,}$$

when there is no closure of any domestic or export market, then the total quantity of beef sold of a type on all markets cannot exceed the total quantity of that type produced from slaughter.

When there is a foot and mouth disease outbreak in Australia, then

- for the FMD affected zone [4], ie $z = z_{FMD}$,

$$\sum_{s=c,m}\ \sum_{k=e_f,e_e,d_1,\ldots,d_Z} q_s^k\ (t,z_{FMD}) \le \sum_{s=c,m}\ \sum_{a=1}^{A_s} sl_a^s(t,z_{FMD})w_a^s \text{ and}$$

$q_s^{e_f}(t,z_{FMD}) = 0$ for $s = c,m$ and

$q_s^k(t,z_{FMD}) = 0$ for $s = c,m$, and $k = d_z$ for all $z \ne z_{FMD}$

all for $t = 1,T_1$;

- for the unaffected zones, ie $z \ne z_{FMD}$,

$$\sum_{s=c,m}\ \sum_{k=e_f,e_e,d_1,\ldots,d_Z} q_s^k\ (t,z) \le \sum_{s=c,m}\ \sum_{a=1}^{A_s} sl_a^s(t,z)w_a^s \text{ and}$$

$q_s^{e_f}(t,z) = 0$ for $s = c,m$

all for $t = 1,T_2$ $(T_2 \le T_1)$, [5]

when the FMD free export market for all types of beef from the affected region in Australia is closed for T_1 periods and from the unaffected region for T_2 periods due to FMD, and when the unaffected domestic markets for all types of beef from the FMD affected region are also closed for T_1 periods, then for each region the total quantity of beef sold on the remaining markets cannot exceed the total quantity of beef produced from slaughtering regardless of types. After T_1 or T_2 periods, the relevant markets are assumed to reopen.

8 - $$p_s(t,z)w_a^s - csl_a^s(z) - (1+r)^{-1}\ l_{a+1}^s(t+1,z) - s\,sl_a^s(t,z) \le 0\text{, for } a = 1,2,\ldots,A_s - 1$$

and $$p_s(t,z)w_{A_s}^s - csl_{A_s}^s(z) - (1+r)^{-1}\ l_{A_s}^s(t+1,z) - s\,sl_{A_s}^s(t,z) \le 0\text{, for } s = c,m\text{ ,}$$ [2]

for each time step, the revenue from slaughter of a head of cattle of each age or type cannot exceed the sum of the slaughter cost per head, the present value of a one period older animal of the next time step and any slaughter rent. For the period of closure of the FMD free export market for all types of beef due to FMD, there will be one common price for both beef types and the prices $p_s(t,z)$ should be replaced by $p(t,z)$ for the corresponding regions.

1.1.1.1 ______________________

[4] For the case of no zoning, the FMD affected zone means the whole of Australia.
[5] This is just one of the scenarios for the duration of market closure. Other scenarios for the duration of market closure can be specified similarly.

9 - $l_1^m(t+1,z) - l_1^c(t+1,z) - sxs(t+1,z) \le 0$, for $t = 1,2,\dots,T$,

for each time step, the present value of the excess of next time step's value of a one age old nonbreeding animal over that of a breeding animal cannot exceed any rent to female calves.

10 - $l_a^s(t,z) \ge (1+r)^{-1} l_{a+1}^s(t+1,z)(1-m_a^s) + ssl_a^s(t,z)(1-m_a^s) - cfe_a^s$

$+ \frac{a_a(z)}{4}\left\{(1+r)^{-2}[l_1^c(t+2,z) + l_1^m(t+2,z) + sxs(t+2,z)]\right\}$, for $a = 1,2,\dots,A_s - 1$ and

$l_{A_s}^s(t,z) \ge (1+r)^{-1} l_{A_s}^s(t+1,z)(1-m_{A_s}^s) + ssl_{A_s}^s(t,z)(1-m_{A_s}^s) - cfe_{A_s}^s$

$+ \frac{a_{A_c}(z)}{4}\left\{(1+r)^{-2}[l_1^c(t+2,z) + l_1^m(t+2,z) + sxs(t+2,z)]\right\}$, all for $s = c,m$,

for each time step, the value of an animal of any age and type cannot be less than the present value at the next time step of a surviving one period older animal of that type plus any slaughter rent minus annual feeding cost plus, for breeding cattle only, the present value of offspring at age one two time steps later.

11 - $p_s^k(t) - t^k(z) - p_s(t,z) \le 0$, for $s = c,m$ and $k = d_1, d_2, \Lambda, d_Z$ (ie domestic markets) ;

$p_s^k(t,z) - t^k(z) - p_s(t,z) \le 0$, for $s = c,m$ and $k = e_f, e_e$ (ie export markets) ,

for each time step, the price of beef of type *s* on any market *k* cannot exceed the price of that type of beef plus the transportation cost. When there is market closure due to a FMD for a number of periods, all types of beef will be sold on the remaining markets at a single price, $p(t,z)$, regardless of types. For those periods with market closure the following conditions would apply:

- for $z = z_{FMD}$,

  for $k = d_{z_{FMD}}$ (ie domestic market), $p_s^k(t) - t^k(z_{FMD}) - p(t, z_{FMD}) \le 0$ and

  for $k = e_e$ (ie export market), $p_s^k(t, z_{FMD}) - t^k(z_{FMD}) - p(t, z_{FMD}) \le 0$,

  all for $s = c,m$ and $t = 1,\dots,T_1$;

- for $z \ne z_{FMD}$,

  for any domestic market, $p_s^k(t) - t^k(z) - p(t,z) \le 0$ and

  for $k = e_e$ (ie export market), $p_s^k(t,z) - t^k(z) - p(t,z) \le 0$,

  all for $s = c,m$ and $t = 1,\dots,T_2$.

The problem is to find the model solution, ie the values of all variables in the model that satisfy the conditions (1)–(11) and for which pure profits for each time step and thus over the whole time horizon are maximised and equal to zero. This guarantees that no market participant is in a position to gain from changing any decision from the value in the model solution.

For this problem, the numbers in the cattle herd by age and type for the first time step, $x_a^s(1,z)$, are given. Also, the numbers of breeding cows by age immediately before the first time step, $x_a^c(0,z)$, are given. However, there are multiple possible end conditions. For example, terminal cattle numbers or terminal cattle prices could be prescribed.

The approach that is followed here is to assume that the cattle industry is currently in the (optimal) steady state of the above system. In the absence of any disturbance, the system would remain in that steady state, and $x_a^s(t,z) = x_a^s(z),\ l_a^s(t,z) = l_a^s(z)$ [6], for $t = 1,2,...,T+1$. For all policy or event simulations to be reviewed, the prescribed end-state is the same (optimal) steady state. The time horizon is chosen far enough out to allow the system to reach this prescribed end-state.

The pure profit criterion, C, to be maximised over the time horizon is

$$C = \sum_{t=1}^{T} (1+r)^{-t} \{ \sum_z \sum_s \sum_k (p_s^k(t,z) - t^k(z)) q_s^k(t,z) - \sum_z \sum_s \sum_a csl_a^s(z) sl_a^s(t,z)$$
$$- \sum_z \sum_s \sum_a cfe_a^s x_a^s(t,z) \}$$
$$+ (1+r)^{-(T+1)} \sum_z \sum_s \sum_a l_a^s(T+1,z) x_a^s(T+1,z) - (1+r)^{-1} \sum_z \sum_s \sum_a l_a^s(1,z) x_a^s(1,z)$$
$$+ (1+r)^{-(T+2)} \sum_z \sum_s l_1^s(T+2,z) x_1^s(T+2,z) - (1+r)^{-2} \sum_z \sum_s l_1^s(2,z) x_1^s(2,z).$$

This criterion is the sum of discounted revenue minus slaughter costs minus feeding costs over all time steps of the time horizon plus the increase in the present value of the livestock from time step 1 to time step *T*+1, plus the increase in the present value of the calves born at time step 2 from the breeding cows before the time step started and the calves to be born at the time step *T*+2 from the breeding cows at the time step *T*.

When there is market closure for a number of periods due to FMD industry participants will alter their decisions. From the initial state cattle numbers, $x_a^s(1,z) = x_a^s(z)$, an adjustment path will be followed that will extend beyond the reopening of the corresponding markets at the corresponding period ($T_1 + 1$ or $T_2 + 1$).

The cost to Australia of the FMD induced export market closure is estimated as the net present value of losses and gains to Australian producers and consumers for the time of the deviation of the adjustment path from the (optimal) steady state path.

1.1.1.1

[6] Given the time step is half a year, if it is considered that numbers in the herds differ in the first half year from those in the second half year, then a periodic steady state can be specified as follows:

$$x_a^s(t+2,z) = x_a^s(t,z) = x1_a^s(z);\ x_a^s(t+3,z) = x_a^s(t+1,z) = x2_a^s(z);$$
$$l_a^s(t+2,z) = l_a^s(t,z) = l1_a^s(z);\ l_a^s(t+3,z) = l_a^s(t+1,z) = l2_a^s(z),$$
for $t = 1,2,...,T-3$.

Appendix 2. Data and values of parameters

Table A1: Cattle weights w_a^s (saleable kilograms of beef per head) by age and type

	Age cohorts									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Non-breeding	42.8	85.6	124.	163.	184.	204.	227.	250	250	250
Cow	42.2	84.5	101.	119.	137.	155.	157.	159.	161.	163.
	Age cohorts									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Non-breeding										
Cow	165.	167.	170.	174	175.	177.	178.	180	181	182

Table A2: Estimated feeding costs and slaughtering costs in Australian dollars

(i) feeding costs cfe_a^s including all variable costs to the farm gate, per head and time step

	Age cohorts									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Non-breeding	60	50	55	60	65	71.0	76.0	88.9	95	100
Cow	60	50	80.5	85.5	90.5	95.5	100.	105.	110.	115.
	Age cohorts									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Non-breeding										
Cow	120.	125.	130.	135.	140.	145.	154	176.	185	190

(ii) slaughtering costs $csl_a^s(z)$ including all variable costs from farm gate to beef ex abattoir, per head and time step

$csl_a^s(z)$ = 90 for nonbreeding cattle (ie s = m) at age *a* and zone *z*;

$csl_a^s(z)$ = 70 for cow (ie s = c) at age *a* and zone *z*.

Table A3: Values of other parameters

Half yearly natural mortality m_a^s = 0.005 for all *a* and *s*;

Fecundity rate $\alpha_a(z)$ = 0.9 for *a* > 2 and all *z*, and = 0 for *a* = 1,2 and all *z*;

Transportation cost $t^k(z)$ = 0.2 for domestic markets *k* beyond the zone *z*, = 0 for the domestic market within the zone *z*, and = 0.3 for export markets *k*;

Elasticity = –1 for all markets and all types of beef;

Half yearly discount rate r = 0.035.