Domestic and Trade Impacts of Foot and Mouth Disease and BSE on the Australian Beef Industry[1]

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Abstract

Although Australia is the sixth largest producer of beef, with production of 2 million metric tonnes, behind regions such as the USA, Brazil and the EU it is the second largest exporter of beef behind Brazil. Average beef exports from Australia are approximately 65% of the total amount of beef produced or about 1.3 million metric tonnes. For these reasons Australia is particularly vulnerable to diseases that are not endemic to the country and could close or disrupt its export markets for beef. In this study we construct a bioeconomic optimization model of the Australian beef industry that captures production and consumption decisions, domestically and internationally, and the impacts on the beef industry of two potentially catastrophic diseases, foot and mouth disease (FMD) and bovine spongiform encephalitis (BSE). The results of the study suggest that depending on control methods losses to the economy of FMD range from \$1.3 - \$20 billion, with the impact on producers and consumers varying depending on control levels. For BSE the effect of trade bans due to the disease is a range with a gain of \$200 million to a loss of \$400 million in total economic welfare, with the negative impacts on producer surplus in all cases and consumer welfare being positive in all cases.

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Introduction and Background

The Australian beef industry is somewhat unique in the world's trade in beef. Although Australia is the sixth largest producer of beef, with production of 2 million metric tonnes behind regions such as the USA, Brazil and the EU, it is the second largest exporter of beef behind Brazil. Average beef exports from Australia are approximately 65% of the total amount of beef produced or about 1.3 million metric tonnes. Beef exports are broken into two segments; chilled or frozen processed beef for export to the major markets of Japan, the USA, and Korea; and live cattle exports principally to South-East Asian countries including Indonesia and the Philippines. Also, Australia does not import any beef for consumption or live animals for slaughter; small numbers of animals enter the country as stud stock but not commercially feasible slaughter numbers (ABARE 2006). For these reasons Australia is particularly vulnerable to diseases that are not endemic to the country and could close or disrupt its export markets for beef.

Two such diseases are foot and mouth disease (FMD) and bovine spongiform encephalitis (BSE) or "mad cow disease". Each of these diseases has particular characteristics that impact on the production or marketing of beef. Foot and mouth disease affects all cloven-footed animals causing blistering on the feet and mouths of animals. The disease can spread rapidly if not identified and controlled, principally through the slaughter of infected or potentially infected animals. The disease itself, whilst reducing productivity of the infected animal, is in most cases non-fatal (Blood et al., 1983). But the rapidity of spread and the loss of markets due to the disease requires governments to prevent the introduction of the disease, in the case where the disease is not endemic, and control the disease when an outbreak occurs (Garner and Lack, 1995). FMD is not considered a human health concern.

On the other hand, BSE is a more difficult disease to identify as it requires slaughter of suspect animals and testing of brain tissue from these animals. Control of BSE is also more difficult due to the problems in identification of the disease. The impact on human health is more serious with BSE being identified as a potential cause of variant Creutzfeldt-Jakob disease (vCJD) a potentially fatal human disease (CDC

2008).[5] The principal method of control of BSE is to not feed mammalian-based meat products, i.e. meat or bone meal to ruminants, hence reducing the acquisition of the disease from meat products that may contain the disease or disease precursors (DEFRA 2006). Both diseases, FMD and BSE, are not endemic to Australia and the impact on trade and the domestic beef markets could be serious if either of these diseases or others such as blue tongue occurred in Australia. Australia is considered to have a "negligible risk" of BSE occurring (OIE 2008), however another non-endemic disease of Australia, Equine Influenza, has recently entered the country, causing significant economic costs, hence the risk is still apparent (Callinan 2008).

The economic consequences of disease incidents have been documented in international contexts. For example, the estimated cost of the FMD outbreak in the UK in 2001 was £8 billion pounds in lost revenue to the beef industry, control costs and other societal impacts such as losses in tourism income (NAO, 2002). Several incidents of BSE in North America cost both the US and Canadian industries billions of dollars through market closures and loss of domestic and trade revenues (Coffey et al., 2005).

Previous research into the potential costs of foot and mouth in Australia has used various modelling methods such as state transition models and simulations. Garner and Lack (1995) used a state transition simulation model coupled with an input-output (I-O) matrix to calculate the localised impacts, and direct and indirect costs of FMD outbreaks of differing sizes and in different regions of Australia. That study did not consider the impacts on consumers, or national or trade effects, i.e. changes in economic welfare or trade bans. Abdalla et al. (2005) using a similar model estimated the immediate market access costs and the expected control costs of various control strategies, however, again the research did not consider the longer term economic welfare costs or benefits to consumers and producers due to the FMD outbreak. The Productivity Commission (PC) (2002) using the same model as Abdalla et al. (2005) attempted to model trade restrictions and changes in consumer and producer welfare through manipulation of the model parameters over the duration of the FMD outbreak and incorporation of a CGE model of the Australian economy to

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[5] Note that compared to other health concerns (e.g., E.Coli) vCJD cases are very rare world wide, hence, we do not estimate long term health effects

capture the impacts on national GDP of the outbreak. In the PC report trade impacts were estimated on a gross basis, i.e. the markets for products were not differentiated, and changes in trade volumes and prices were not impacted by the dynamics of the supply of product coming onto the market during or after the FMD outbreak and trade bans were implemented (PC 2002). Also, dynamic price adjustments caused by changes in supply and demand were negated by imposition of fixed parametric changes in domestic and export prices throughout the modelled timeframe; hence the calculated consumer and producer surpluses may be incorrectly estimated.

Although Australia has implemented similar regulations as the EU and the USA regarding feeding of ruminant-based products to other ruminants to reduce the risk of BSE occurring in the Australian beef herd, no studies have been undertaken to estimate the costs of a potential BSE outbreak in Australia. However, the consequences of a BSE outbreak on trade and markets is similar to those of FMD, hence a similar framework could be used.

One aspect common to all the above mentioned research was the state transition model simulation; an alternative to simulation is to optimize the disease impact problem. Optimizing the problem is consistent with the profit maximizing behaviour of producers and, in the context of a disease spread model, is constrained by the dynamics of stock replacement (Zhao et al., 2006). The objective in this research is to model the domestic and trade impacts on the Australian beef industry of a hypothetical outbreak of FMD or the identification of a BSE-infected animal. The response of the industry to each disease will be different due to the slaughter of cattle as a control method in an FMD outbreak. This will affect the herd dynamics whereas in a BSE case the slaughter of cattle is not necessary for control as the disease does not spread in the same manner as FMD and the major impact will be through market closure. We model the Australian beef industry utilising an integrated bioeconomic model of the breeding inventory of cattle, a pasture and a feedlot feeding system, and the domestic and international demand for Australian beef. The results of the model will be used to measure changes in revenues, prices, and economic surpluses of producers and consumers during the disease outbreak and consequent periods.

Conceptual Model

The conceptual model used by Zhao et al. (2006) is the basis in this research and we will provide a brief overview of this model with the adaptations and extensions for Australia identified and explained. For example, Australia has a closed breeding herd and cattle are finished on pasture and in the feedlot.

The objective is to maximise the discounted returns to the producer, and this is achieved through the number of animals available for sale and the costs associated with rearing these animals. The conceptual model is an optimization problem where the decision variable is the culling rate of breeding females in each age class *j* at time *t*, KC_t^j. This optimization problem can be written as:

(1) $$\max_{KC_t^j}\{\sum_{t=0}^{\infty}\beta^t E_0(\pi_t)\}$$

Subject to:

(2) $$K_t^j = (1-\delta^j)(K_{t-1}^{j-1} - KC_{t-1}^{j-1})$$

(3) $$H_t = \sum_{j=m}^{s} K_{t-1}^{j-1} \text{ for j > 1.}$$

(4) $$K_t^0 = 0.5\theta H_{t-1}, \quad M_t^0 = 0.5\theta H_{t-1}$$

where β^t is the discount rate and E_0 is the expectation in time 0 of profit in time period t (π_t). K_t^j is the number of breeding cows in age class *j*, up to a maximum age of *s*, at time *t*, δ^j is the death rate in age class *j*, KC_t^j is the number of females culled from age class *j*, H_t is the breeding herd available in period *t*, K_t^0 is the number of replacement females born in time *t*, θ is the reproduction rate, and M_t^0 is the number of male offspring born in period *t*. This model is slightly different to that of Zhao et al. (2006) as that model was of the US beef herd and K_t^j included imports and exports of breeding cows. The Australian beef breeding herd can be considered a closed herd where no imports and exports of breeding females occur.

In the model the reproduction rate, θ, is set at 50%, i.e. 50% of the breeding herd give birth to a live calf that survives for one year. The birth rate is derived from ABARE (2006) cattle inventory data. The death rate of calves or young animals is $\delta^0 = 0.10$. These values maintain the breeding herd at steady state at levels similar to the original data. The adult death rate is set at $\delta^{j>0} = 0.02$.

Revenue (R) is generated from three sources in the beef industry; sales of slaughter age and quality young animals, sales of live cattle for export, and culled breeding females. Young animals are derived from two sources, all male offspring, except those that die, are available for slaughter, and surplus replacement females. All females born are not required to keep the herd at the maximum level of production. This is the factor that contributes to the cattle cycle phenomena, as in some periods of time it is more profitable to sell younger females for slaughter as beef prices are relatively low, than keep them as breeders, let the herd size fall, and beef prices will become relatively higher as supply contracts making breeding profitable again. Producers will then reduce the culling rate of younger females. Therefore,

$$(5) \qquad \mathrm{R} = P_t^s((1-\delta^0)(1-\delta^1)(KC_{t-2}^0 + M_{t-2}^0)) + \sum_{j=1}^{s} P_t^j KC_t^j$$

where P_t^s is the value of younger animals and P_t^j is the value of cull cattle, the value of younger animals, P_t^s, is determined by the weight of the animals at slaughter and the price of meat at time *t*. In the model it is assumed that cattle sold for live export are valued at their slaughter value, hence the model differs in this aspect to that of Zhao et al., (2006) who included a component for the value of live cattle exports, principally breeder exports not feeders or live fed beef. Total costs are derived from three sources, maintaining the breeding herd including breeding costs, and growing out animals in either the feedlot or on pasture. Hence, total costs (TC) can be represented in the following manner:

$$(6)\qquad \begin{aligned} TC_t = \sum_{j=0}^{s}\psi K_t^j + \frac{1}{2}MAC\Big(\sum_{j=1}^{s}(K_t^j - KC_t^j) - \sum_{j=1}^{s}(K_{t-1}^j - KC_{t-1}^j)\Big)^2 + \\ (1-\delta^0)(C_f F(KC_{t-1}^0 + M_{t-1}^0) + C_p(1-F)(KC_{t-1}^0 + M_{t-1}^0)) \end{aligned}$$

The maintenance cost of a breeding cow is ψ, C_f is the total cost of feeding an animal in a feedlot, and F is the proportion of calves placed in a feedlot ($0 \leq F \leq 1$). In the model $F = 0.2$ based on current turnoff levels from beef cattle in feedlots in Australia and the total herd size (ALFA various issues, ABARE 2006). The second term in equation 6 accounts for the marginal adjustment costs of changing herd size and captures the costs associated with increasing or decreasing herd size. The third term in this equation calculates the costs of feeding younger animals in either the feedlot or on pasture. C_p is the total cost of feeding an animal on pasture. Both C_f and C_p depend on the growth rates of animals in each feeding system and the costs of each feed source.

Domestic supply of fed beef is from the two sources, feedlot and pasture-fed. In each period this supply is determined by the price of beef and the costs of feeding animals in each system. Profit maximizing producers will determine the optimal feeding period, d, based on entry weight and cost of animals entering into each feeding system, the costs of feeding in each system, $C_{t,d,i}$ (i = p or f for pasture and feedlot, respectively), and the expected future beef price at time t, $PM_{t,d}$. This can be represented as:

$$(7)\qquad \underset{d}{Max}\, FP_{t,d} = PMeat_{t,d} * WT_{d,i} - C_{t,d,i} - P_t^0$$

$FP_{t,d}$ represents the profit from feeding cattle in each system, the value $WT_{d,i}$ represents the profit maximizing weight of the animals. The optimal bodyweight for each system was allowed to differ to capture the differences in feeding costs, growth rates and days on feed. The price P_t^0 is the opportunity or purchase cost of putting young animals into either feeding system.

The total domestic supply of fed beef is then determined simply by multiplying the weight of animals from each feeding system by the numbers of animals supplied by each of these systems at time t after d days on feed. Days on feed are longer for the animals on pasture (Pd) to capture the slower growth rate and loss of energy due to maintenance activities including walking.

(8) $$S_t = WT_{d,f}[F(KC^0_{t-1} + M^0_{t-1})] + WT_{Pd,p}[(1-F)(KC^0_{t-1} + M^0_{t-1})]$$

One other source of beef is included in the model and that is what is classified in this model as non-fed beef. Typically this beef from cull cows and it is assumed in the model that this type of beef is included in exports, is not used for domestic consumption, and is lower valued (i.e. 90% chemical lean, 90CL, beef) used in processing in the importing country (ABARE 2006).

Demand for Australian beef comes from both domestic, D_t, and export markets, DE_t. In the context of this model export demand is generated from Japan, Korea, and the United States representing demand for beef carcases and cuts, and Indonesia, representing the demand for live cattle. The demand for beef in each country is determined by the price of Australian beef, the exchange rate, and the domestic import demand elasticity for Australian beef. Given that there are no import supplies of beef into Australia, the market clearing condition for the Australian beef market is:

(9) $S_t = D_t + DE_t$

Where

(9b) $D_t = \eta(PMeat_t)$

And

(9b) $DE_t = \nu(PMeat_t)$

where η and ν are the functional relationships between income, exchange rates, and meat demand elasticities for domestic or exported consumption of beef.

Empirical Model

Herd Dynamics

Given that the reproductive cycle of beef cattle, in most regions is approximately one year, an annual model is the ideal model for this aspect of the overall model. It is assumed that heifers enter the breeding herd at the age of two and remain in the herd until the age of 10 years, after this age they are culled from the herd. No other culling occurs, except in the first age group where the females are separated into those kept for breeding and, those, surplus to requirements that are fed for the beef market. In the context of this model, equation 2 captures the age class information and the variable $KC_t^j = 0$ in all classes except for $j = 0$. In age class 0, KC_t^0 varies depending on the expected profitability of retaining heifers as breeding animals.

Pasture Feeding Model.

The pasture feeding model is based on the feeding standards provided in SCARM (1990). This system takes into account energy required for activity related to searching for graze and grazing. Dry matter intake (DMI_{Pd}) is determined by the standard reference weight for the breed of cattle (SRW), a species constant, ϕ, (in this model the species constant is 0.024), and the ratio of relative size ($WT_{(Pd-1)}$) of the animal to it's standard reference size. Pd refers to days on pasture to differentiate this period to days on feed (d) for cattle in the feedlot system.

(10) $DMI_{Pd} = \phi * SRW * (WT_{(Pd-1)}/SRW) * (1.7 - WT_{(Pd-1)}/SRW)$

Cattle derive energy and protein from pasture consumed. Energy and protein are then utilised by the animal for maintenance, growth, reproduction and lactation. It is assumed that protein, derived from pasture is adequate for all processes and that energy is the limiting factor, hence the focus of the remainder of this section is on energy and it's utilisation and efficiency of utilisation by a growing animal.

Energy can be partitioned into metabolizable energy (ME) and the level of ME available per unit of dry matter intake (M/D) can be estimated as:

(11) $M/D = 0.17 * DMD\% - 2.0$.

From this relationship ME intake can be calculated as DMI from pasture multiplied by M/D. Where DMD% is the dry matter digestibility as a percentage of the feed intake (SCARM 1990), in the model DMD = 65%, this is the average DMD over a year from several unpublished reports. From this relationship we can derive parameters capturing the net efficiency of ME utilisation for both growth (k_g) and maintenance (k_m). Given that DMD = 65%, which yields a value of 9.05MJ/kg DM, then k_g and k_m which are calculated as $k_m = 0.02*M/D + 0.5 = 0.26$ and $k_g = 0.063*M/D - 0.308 = 0.68$.

Using these parameters and the weight (WT_{Pd}) and age (A) of the animal, the maintenance energy can be estimated as:

(12) $$ME_m = \frac{\kappa(0.28 * WT_{Pd}^{0.75} \exp(-0.03 * A))}{k_m} + \frac{EGRAZE}{k_m} + 0.09 MEI_{Pd}$$

Where $\kappa = 1.2$ for *Bos indicus*, 1.4 for *Bos taurus*, 1.3 for 50/50 crosses, MEI_{Pd} is ME intake and EGRAZE is the additional energy required for grazing compared to housed animal. EGRAZE is calculated as:

(13) $$EGRAZE = [(C*DMI*(0.9 - DMD)) + (0.05*\tau/(GF+3))]*WT_{Pd}$$

C is a species constant for sheep or cattle and in this case C = 0.006, the terrain parameter $\tau = 1.0, 1.5, 2.0$ for flat, undulating or hilly, respectively, and GF is the availability of green forage measured in tonnes of DM/ha . Remaining energy, i.e. that part of intake not required for maintenance, can be used for growth. The growth in bodyweight can be calculated using:

(14) $$EBG_{Pd} = (6.7 + R_{Pd}) + (20.3 - R_{Pd})/[(1 + \exp(-6*(WT_{Pd}/SRW) - 0.4))]$$

EBG is empty bodyweight growth, SRW is as defined before and R_{Pd} is:

(15) $R_{Pd} = 2*(k_g ((MEI_{Pd} - ME_{m,Pd})/ME_{m,Pd}) - 1)$

And from these relationships we can calculate liveweight gain (LWG) as:

(16) $LWG_{Pd} = (k_g (MEI_{Pd} - ME_{m,Pd})/(EBG_{Pd}*0.92))$

Hence, weight on any day on pasture is simply the weight carried forward from the previous day plus LWG_{Pd}, i.e. $WT_{Pd} = WT_{Pd-1} + LWG_{Pd}$.

Feedlot Model

The feedlot optimisation model is based on the National Research Council's (NRC 2000) Nutrient Requirements of Beef Cattle. The NRC (2000) was used as the basis for the feedlot model as it was determined by the SCARM (1990) to be representative of cattle under commercial feeding conditions and the information in the NRC (2000) is more recent than SCARM (1990). Many of the parameters and variables are similar to those used in the pasture feeding model, however the NRC (2000) models uses net energy (NE) rather than ME as a basis of growth. To avoid confusion variables that represent the same factor will be kept and any that vary will be noted and appropriately indexed. Beginning with DMI_d, we have:

(17) $DMI_d = DMA * WT_{d-1}^{0.75}(0.2435NE_m - 0.0466NE_m^2 - 0.0869)/NE_m$

The dry matter adjustment factor a function of the animal's weight and other environmental factors (Fox et al., 1988) and NE_m = Net energy for maintenance in the feed consumed measured in mega-calories (Mcal). The net energy required for maintenance by an animal is a function of empty bodyweight:

(18) $NE_m = 0.077 \text{ per kg } EBW_d^{0.75}$

From equations 17 and 18 it is possible to derive the excess of energy, above that required for maintenance, consumed by the animal. Any excess energy is utilised for growth, however the efficiency of energy for growth is lower than that of maintenance. Therefore, we have,

(19) $$NE_g = (NEI_m - NE_m)$$

Where NEI_m = the intake of net energy for maintenance and NE_m is defined as in equation 18. from this equation we predict the gain in weight (G_d) of the animal as a function of NE_g and adjusted weight (WE_d) as determined by Fox et al., (1988):

(20) $$G_d = 13.91 NE_g^{0.9116} WE_{d-1}^{-0.6837}$$

Finally, we have weight on any one day as a function of the previous day's weight and any growth over that day.

(21) $$WT_d = WT_{d-1} + G_d$$

Zhao et al., (2006) used equations from Fox and Black (1984) to estimate the quality and yield for individual animals from the feedlot, hence the value of these animals. The quality and yield grades are based on carcase fat percentages. In the current model the same equations were used but the values were adjusted for grid prices in Australia.

Optimization

The objective function in both the pasture feeding and feedlot models is to maximise the profit of each model. The two models are optimised individually rather than jointly as there is no decision to be made between allocating stock to either feeding system. Hence, the objective function for each system is:

(22) $$NP_{I,T} = EP_{I,T} * CW_{I,T} * \exp(-r\frac{T}{365}) - Ration_{I,T} - Yardage_{I,T}$$

Where I = pasture, or feedlot, T = slaughter day, which can vary between systems, $NP_{I,T}$ = Net profit from system I at slaughter point T, $EP_{I,T}$ = expected price for an animal discounted on the yield and quality grade of the animal, $CW_{I,T}$ = carcase weight of an animal under either feeding system at the slaughter point for that system, r = the real discount rate, and the third term adjusts the discount rate for the slaughter point of the system, the ration cost, either pasture or feedlot intake, and if necessary yardage costs, are captured by the final two terms. Ration costs are the discounted sum of the product total intake and daily ration cost (either \$0.20/kg dry matter (DM) or \$0.15/kg DM, for feedlot and pasture, respectively) up to the slaughter point, T. Discounted yardage costs account for the capital investment in the feedlot feeding system and is set at \$0.25/d.

Invasive Species – Foot and Mouth Disease

The foot and mouth disease (FMD) component of the model is a Markov chain state-transition model based on the Susceptible-Infected-Removed (S-I-R) models of previous research (see for example, Berentsen, Dijkhuizen, and Oskam 1992, Mahul and Durand 2000). In these models animals can move between either of the three states, but in some sequence, i.e. cattle can move from susceptible to infected (S-I) or from infected to removed (I-R), and the transition from one state to another is determined by the probabilities of a Markov chain process (Rich 2004). Movement from one state to another is determined by the number and type of contacts and the probabilities of these contacts leading to a change in infection status. As well as the contacts and probabilities of infection the number of animals in any one state is also determined by the inventory of animals in each age class, i.e., K_t^j, there are also inventories of young females not used for breeding and all males kept for feeding that could be also infected or carry infection. Separate age inventories, as used in this model, are necessary to measure the effect of FMD on the age population as although the disease in most cases is not fatal, the death rate amongst older cattle is only 2%, but in young animals the rate can be as high as 20% (Blood et al., 1983).

Assuming that the infection phase begins at time, t = ω, and that the number of susceptible and infected animals in each class are, S_ω^j and I_ω^j, respectively, letting $\varepsilon_\omega^{j,k}$ represent the number of infective contacts between inventory groups *j* and *k*, and ρ be the probability of disease spread, then the probability of an individual animal becoming infected and infectious is:

(23) $$\rho \frac{\sum_j \varepsilon_\omega^{j,k} I_\omega^k}{K_t^j}$$

From this we can derive the number of susceptible animals becoming infectious:

(24) $$\rho \frac{\sum_j \varepsilon_\omega^{j,k} I_\omega^k}{K_t^j} S_\omega^k$$

From equation 23 we can determine the dynamics of the epidemic, as a function of those infected, I_ω^j, susceptible, S_ω^j, and recovered after infection, R_ω^j. This function is:

(25) $$I_{\omega+1}^k = \rho \frac{\sum_j \varepsilon_\omega^{j,k} I_\omega^k}{K_t^j} S_\omega^k + I_\omega^k - R_\omega^k \quad \forall \text{ k.}$$

The outbreak of FMD is initiated by an assumed infection from outside the production system, this could be from either human or animal carriers and in the model this initial infection is described as I_0^j. Once FMD is established the disease is spread by contact from infected herds to non-infected herds and the number of contacts from infected to non-infected herds determines the spread of the disease. In this model the number of direct or dangerous contacts per infected herd is set at 3.5. This number of contacts is consistent with that of Garner and Lack (1995), a range of 2.5 to 3.5, and Abdalla et al., (2005), a rate of 4 contacts per herd. Of these direct contacts it is assumed that 80 per cent of them are effective. For two weeks from the initial disease outbreak it is assumed no control is undertaken as the disease symptoms do not appear for approximately 2 weeks. Hence, in the interim the infected herds and those herds the infected herds come in contact with spread the disease further before control measures are implemented. After the initial 2 weeks control measures are implemented and the disease spread is reduced. In the model the disease spread is halved each week from week three until week 8 when it is assumed the disease spread is controlled and no further new infections can occur.

Market Model for Australian Beef

Australian beef is exported to numerous countries however the market is dominated by the USA, Japan, and Korea for processed beef and Indonesia for live beef exports. The former three account for approximately 90% of Australian processed beef exports (ABARE 2006), and Indonesia imports approximately 55-65% of cattle exported from Australia. To incorporate exports into the models demand functions were constructed for each of these four countries. An exponential inverse demand function of the form:

$$(26) \qquad D_x = a_x (PMeat * EX_x)^{b_x}$$

was used for each importing country, x. Where a_x is a constant and b_x is the demand elasticity for beef in country *x*, and *PMeat* is as defined previously and EX_x is the exchange rate between Australia and country *x*. Demand elasticities for each country, b_x, were sourced from published data. Griffith et al., (2001) report export demand elasticities for Australian beef into the USA of -0.99 and -0.05 for Japan. Given this information the elasticities of demand for the USA and Japan in the model were set at -1 and -0.05. No export demand data was available for Korea, however Doyle et al., (1995) report an own price elasticity of demand for beef in Korea of -0.69. It would be reasonable to assume that the import demand elasticity would be higher and as no other data is available the elasticity of demand for Australian beef is set at -1.0. Elasticities for live exports were not available and were initially set at -1.0 in testing the model, after calibrating the model for all countries it was found that although -1.0 may not be correct the impact of variations in the elasticity on export levels was not significant to warrant construction of a more accurate elasticity. Using the elasticity data and export data from ABARE (2006) the term a_x was derived for each country. The model was calibrated such that the demand generated in the model by equation 26 was approximately equal to the data from ABARE (2006).

The optimisation model is calibrated in the first instance to the year 2000 as this was prior to the major outbreak of FMD in the UK. The trade and domestic demand equations are calibrated based on elasticities discussed earlier, and herd dynamics are based on these elasticities.

Scenarios

FMD Model

In the model constructed, at the outbreak of FMD a trade ban is imposed by all countries importing Australian beef, this trade ban is assumed to last for 1 year, which is consistent with previous research (Paarlberg et al., 2008). Also, it assumed that the disease causes a 5% reduction in domestic demand for beef in the year of outbreak.

There are several methods of controlling the spread of FMD these include stamping out through depopulation or culling infected herds, or stamping out via vaccination. The method of control varies in costs and market reactions. Use of a vaccination implies that the disease is still present in the country through the vaccination program but the symptoms and spread are controlled (Abdalla et al., 2005). In the current research depopulation of latently infected herds is used as the method of control and the effects of varying rates of depopulation are examined. Depopulation rates of 10% increments declining from a 90% base down to 50% are used to determine the impacts on price, consumers, producers and trade of a disease outbreak. One other control scenario was also studied and that was to cull 50,000 head (100%) with a 100% rate of depopulation[6], this scenario was undertaken to represent a localised outbreak, but with the trade bans in place.

BSE Model.

Whilst BSE is not a disease that spreads like FMD the impacts on trade can be as severe. In this study the same model was used as for FMD, however the control method of depopulation was disabled and trade barriers were implemented for 1, 2 or 3 years from the same base production levels as for the FMD scenarios.

The model is run over a 50-year time period. This allows for the model to adjust to the initial conditions and define a steady state trajectory for each variable of interest. Hence, as observed in Figure 1 or 2 there is some variability in herd size or

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[6] The infection rate parameter was also adjusted to achieve the 50,000 head cull.

price in the initial periods, however the trajectory stabilises at approximately period 10. This provides for 10 years of stability before imposition of the assumed disease outbreak. Data from periods prior to year 20 are not used in any of the proceeding analyses. Given the amount of data generated by the model not all data is reported, only those that assist in the illustration of the impacts of the disease outbreak.

Results and Discussion

The results presented in this section are based on historical patterns of the Australian livestock sector as represented by model parameters and assumptions. Hence, the interpretation of these results should be that they are in effect baseline planning trajectories. For example, it is assumed the producer alters the culling rate as a decision variable. In reality, after an outbreak, there may be incentives for producers to target and alter other production practices (e.g., increase the birth rate) that could impact actual production outcomes and herd dynamics over time.

Foot-and-Mouth Disease

Herd impacts

After an initialisation period the base breeding herd achieved a steady state range of between 12 and 14 million cows. This range is consistent with reported levels in ABARE (2006). After the disease outbreak the herd structure is affected and the level of impact is determined by the depopulation rate. As depopulation rate increases, i.e. as the number of latently infected herds slaughtered increases, the breeding herd affects are reduced. Meaning the number of animals remaining in the breeding herd is higher than with lower depopulation levels. This may sound somewhat counter intuitive but by not controlling the disease spread aggressively by slaughtering more animals earlier, or high depopulation rates, the disease spreads further, hence the total number of animals required to be slaughtered to control the disease is higher. These effects are illustrated in Figure 1. The baseline data, Base, demonstrates the two year breeding cycle of the model through the cyclic shape of the trajectory. However, after the FMD outbreak the breeding herd is reduced, both through culling and by producers reducing herd size as price and profit falls due to lower export demand. Comparing FMD60 and FMD90, where depopulation rates are 60% and 90%, respectively, the total number of animals slaughtered is higher in the former case. In the FMD60 the number of animals slaughtered accounts for 36% of the inventory of breeding animals prior to the outbreak of the disease. Whereas in the FMD90 scenario only 12% of breeding animals are slaughtered (see Table 1). The FMD100 scenario reduced herd size by approximately 0.15% and had a relatively small impact on overall herd size in the two years after the outbreak. Subsequent reductions in the breeding herd are due to lower replacements entering the herd and the cumulative effects of this reduction continue as in the other depopulation scenarios.

After the outbreak of FMD the herd level declines from the base level for 3 years then begins to rebuild. The initial decline in breeding numbers after the outbreak is due to the trade restrictions and reduced demand. After the trade bans are lifted prices increase thereby reducing the domestic and international demand for beef. However, as prices increase further producers have added incentive to increase breeding stocks to lift profits. Breeding stock continue to build until the point where prices reach a minimum, at year 38, then decline until a new stable equilibrium herd size of approximately 13 million is reached.

One point to note is that breeding herd size responses to the different depopulation rates converge to the Base trajectory approximately 8 years after the initial disease outbreak. This is due to the age distribution of the herd, as breeding animals remain in the herd for 8 years and the cohort of animals affected by the disease outbreak and the adjustments to keep/cull decision for young females don't fully eventuate until the females in the youngest age cohort at the time of the outbreak leave the breeding herd. The response also demonstrates that producers are selecting culling rates in each depopulation scenario such that the herd size eventually achieves the profit maximizing level. Another point is that in the FMD60 scenario, after the herd reaches the original herd size it overshot and rose to a new a maximum of approximately 17 million cows. Due to the construct of the model not allowing culling in age groups other than new calves and the oldest cows the new cycle takes approximately 16 years to complete. However, this type of behaviour is typical of the beef cattle cycle as evidenced in Aadland (2004).

Price impacts

Outbreaks of FMD affected the market price of beef and the impact was determined by the depopulation rate, the impact of depopulation rate on price is illustrated in Figure 2. Higher depopulation rates reduced the price of beef further than lower depopulation rates during the outbreak and trade restriction years. This was due to more animals remaining in the breeding herd with higher depopulation rates; hence supply was less restricted than with lower depopulation rates, and with constant demand elasticities price dropped further. However, after the trade bans were lifted price immediately responded as demand from exporters increased. After the trade restrictions are lifted, herd dynamics drives the price response; higher slaughter levels under the lower depopulation rates caused prices to increase at a faster rate than under the higher depopulation rates. Again, prices converge to a steady state trajectory by period 38.

Consumers and Producers and Welfare Impacts

As noted above the impacts on consumers and producers vary over the period of disease outbreak and subsequent times. Consumer surplus is measured as the sum of change in surplus from the base model in both the fed and non-fed beef markets. Producer surplus is the sum of change in profits and the adjustment costs incurred due to changes in herd size. Over the year of the trade bans consumers gain in nominal terms, as measured by consumer surplus, between $A161 million and $A1.8 billion. The lower values coincide with lower depopulation rates and higher rates with higher depopulation rates due to the price changes discussed above. Conversely, over the same period producers lose between $A148 million and $A1.6 billion dollars. Summing nominal consumer and producer surpluses yields total gains of economic surpluses of between $A13 million and $A390 million over the period of the trade bans. Figures 3 and 4 demonstrate the patterns of how producer and consumer surpluses change over the duration of the trade ban and subsequent industry adjustments and the cumulative effects of the changes in prices of beef. From this figure we can see the increase in consumer surplus, when the trade bans are imposed, due to excess supply on the domestic market and the fall in producer surplus due to lower prices. However, these positions are reversed after the trade bans are lifted and in sum producers generate a positive total surplus, and consumers are worse off as they are in negative surplus for longer and at a higher level than producers. The effects on consumers and producers in the FMD100 scenario follow somewhat similar trends as in the percentage depopulation cases but at a lower level. However, in this case the positive consumer surplus outweighed the loss in producer surplus and stock loss costs, yielding a positive total economic surplus, principally due to the lower prices paid by consumers after the disease outbreak.

Discounting producer and consumer surplus over the entire trade ban period and remaining years of the model captures the current value change in total welfare of Australia due to the FMD outbreak. The change in total discounted economic surplus is negatively correlated with depopulation rate in that as depopulation increased total economic surplus decreased, these effects are apparent in Table 1. Under the highest depopulation rate the loss in consumer surplus is smallest, less than $A1.3 billion, but as depopulation rates fall the discounted losses in consumer surplus rapidly increased, principally due to relative high prices for beef. Similarly, the discounted producer surplus losses decreased as depopulation rates increased, until the 90% depopulation where producer surplus is higher than the base case. Hence, the additional revenue in this case, even though output is reduced, more than compensated for the loss in output.

The FMD100, or the localized scenario, exhibits different and interesting outcomes. Under the FMD100 scenario the impact on the breeding herd is small and producers do not need to hold back large numbers of heifers to replenish the breeding herd. Hence, there is no intermediate run increases in prices that benefits producers.

Ex-post costs in Table 1 include compensation and cleanup costs. These costs are assumed to be $600/head, which is comparable to the UK costs in 2001 (PC, 2002). The costs are linear in the number of cattle depopulated, ranging from $7.2 to $2.4 billion for FMD60 and FMD90, respectively. Note that in the localized outbreak the compensation and cleanup costs are dominated by consumer and producer surplus.

Also, shown in Table 1 are the costs associated with the slaughter of animals due to the depopulation program. As discussed earlier, as depopulation rates fell from 90% to 50% the number of animals slaughtered to control the disease outbreak increased. Consequently, the value of breeding stock fell with the rise in depopulation rates. The asset loss in the value of breeding stock provides some indication as to potential compensation costs if governments choose to compensate producers for the slaughter of animals to control the outbreak. However, these are only direct costs only and do not include the slaughter and disposal costs of the control program.

Trade impacts

The impacts on trade between Australia's major beef importing countries are illustrated in Figure 5. The major assumption here is that after the trade bans are lifted there are no further restrictions on trade and that trade is determined by demand factors such as the demand elasticities that existed before the trade ban period. As can be seen in Figure 5 the effects vary across countries. Countries with relatively high elasticities reduce their imports of Australian beef or live animals, in the case of Indonesia, significantly in the years immediately after the FMD outbreak, due to the rise in the market price of beef shown in Figure 2. In the longer term, as prices fall importing countries import more beef and beef trade returns to levels approaching those that existed prior to the trade ban. However, in the interim beef exports to the USA, Korea and Indonesia fall, in some years, by over 80% of the base levels expected if no outbreak occurred. In contrast to the three countries just discussed Japan's imports of Australian beef after the trade break are marginally affected by the changes in price due to the herd restructuring post-outbreak. This is principally due to the inelastic demand for Australian beef in Japan.

Bovine Spongiform Encephalitis (BSE)

Herd impacts

Given that a case of BSE does not require slaughter of any animals, except those positively identified with the disease the direct herd impacts of BSE are minimal. Indirect effects occur due to pricing and profit making decisions of producers and consumers. These effects are shown in Figure 6. From this figure it is possible to see the effects of producers responding to lower prices by reducing their herds, however the range of herd sizes is narrower than in the FMD figure (Figure 2) due simply to the lack of reduction due to slaughter. A similar effect over the duration of the model scenarios to those of the FMD outbreaks is observed, that is that the herd returns to a similar level to that prior to the disease and trade bans.

Price impacts

Again the impacts of BSE outbreak are similar to those for FMD except by a lower level. In the event of a BSE episode prices initially fall due to oversupply of beef caused by the trade bans. The level of the fall is affected by the length of the trade bans, but in all three scenarios the price drops follow each other to some degree. For example, in all three cases the price falls to $A1.46 in the first year of the ban, in the two and three year bans prices remain below the Base situation until 5 years after the initialisation of trade bans, then increased above the Base price for approximately another 8 years then converges with this trajectory. The range of prices in any of the BSE scenarios is limited and falls between $A1.46 and $A4.68, compared to a range of between $A1.46 and $A9.53 in the FMD disease outbreak scenarios.

Consumers and Producers and Welfare Impacts

The main difference between the FMD and BSE disease occurrences are in the impacts on consumers and producers, compare Tables 1 and 2. In all three BSE trade ban length scenarios consumers are better off due to the marginal changes in price, as compared to the FMD outbreaks. Also, with the BSE outbreaks the breeding herd returns to near base conditions in a shorter period, except in the 3-year ban case where the return to near base state takes longer. Also, the difference between the base breeding herd size and the herd sizes under each trade ban length is not as large as in the FMD case and price ranges are not as wide, hence consumers are better off than in the FMD case.

In all trade ban length scenarios producers are worse off than prior to the BSE event. This is due to substantial losses in profits incurred in the years of the trade bans. For a 1-year ban producers lose $A5.7 billion, for 2 years the loss is $A6.8. billion, and for three years the loss in profits and additional adjustments costs total $A12.8billion. Following the lifting of the trade bans the increase in producer profits is not sufficient to compensate for the losses incurred over the trade ban period. Overall, total economic losses due to a BSE occurrence in Australia would cost the economy between $A5.4 and $A12 billion, mostly in reduced profit of producers. The effects of a BSE incident on trade are very similar to those for FMD hence they are not presented here.

Conclusions and Implications

The objective in this research was to analyse the international and domestic trade impacts of 1) a hypothetical outbreak of FMD and 2) the identification of an animal with BSE on the Australian beef sector. The results show, depending on the disease, that consumers and/or producers can be positively or negatively affected. Moreover, findings of this study demonstrate that losses due to trade restrictions are large and must not be overlooked when developing policies to mitigate disease outbreaks (especially for localized outbreaks).

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The results for FMD demonstrate that the impact on producers varies with the depopulation rates of latently infected herds (where increased depopulation of latent infected cattle reduces FMD spread). Lower depopulation rates lead to higher losses in producer surplus, whereas higher depopulation rates lead to producers realizing some economic gains in the long run. However, these gains are offset somewhat by losses in the years immediately following the disease outbreak. Consumers gain surplus when prices decrease, but taken cumulatively over time they loose in all cases, except for a localised outbreak. In this case the impact on total herd size is significantly reduced and reinvestment by producers is not necessary.

BSE the outcomes are different. Consumers gain due to prices falling (ignoring any long term health effects). For producers the impacts of all the trade ban scenarios are all negative for BSE. Total losses can be positive or negative depending on the length of the ban.

One of the challenges for policy makers is how adequately compensate producers and or consumers affected by the disease outbreak. The intertemporal nature of livestock production provides an environment of gains or losses for consumers or producers given the nature and severity of the outbreak. For example, in the case of high depopulation rates in an FMD outbreak, producers lose valuable breeding stock in the short run but as prices rise producer surplus increases to be positive in the long. In contrast as price rise consumers are much worse off. The question then arises how are compensation packages designed to reduce the burden of disease on producers in the short run and prices impacts on consumers in the long run.

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Table 1: Reductions in breeding herd, stock loss costs, discounted producer and consumer surpluses, ex-post control costs including compensation and clean-up costs, and total economic welfare changes due to a FMD outbreak with varying depopulation rates.

Depopulation Rate	Reduction in Breeding Herd	Loss in Breeding Stock Value	Consumer Surplus	Producer Surplus	Ex-Post Costs	Total Economic Surplus
60%	36%	$ (959)	$(6,411)	$(3,767)	$(7,195)	$(18,333)
70%	25%	$ (660)	$(3,520)	$(2,389)	$(4,950)	$(11,520)
80%	17%	$ (463)	$(2,324)	$66	$(3,471)	$(6,191)
90%	12%	$ (324)	$(1,268)	$275	$(2,432)	$(3,749)
100%	0.15%	$ (4)	$ 1,289	$ (945)	$ (31)	$309

Table 2: Consumer, producer, and total welfare surplus changes due to a BSE identification and trade bans of varying length

Trade Ban Length	Consumer Surplus	Producer Surplus	Total
1	\$1,186	\$(969)	\$218
2	\$2,240	\$(1,969)	\$271
3	\$3,460	\$(3,865)	\$(405)

Figure 1: Herd impacts of foot and mouth disease outbreak and different depopulation rates. FMD 90 and FMD 60 represent depopulation rates of 90% and 60%, respectively, of latently infected herds and FMD100 represents depopulation of 50,000 breeding cows. Base represents the scenario where no disease outbreak occurs.

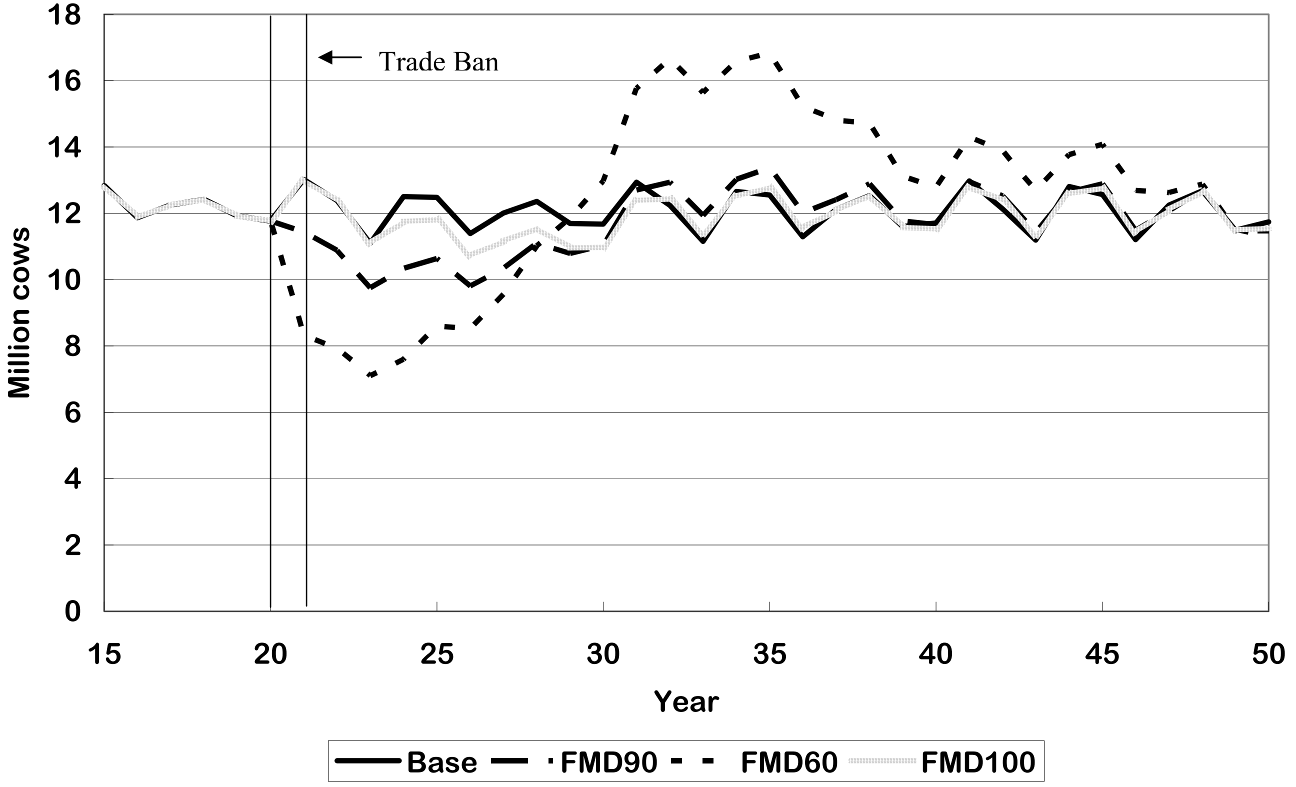

Figure 2: Market price for carcase beef in different depopulation rate scenarios due to a FMD outbreak.

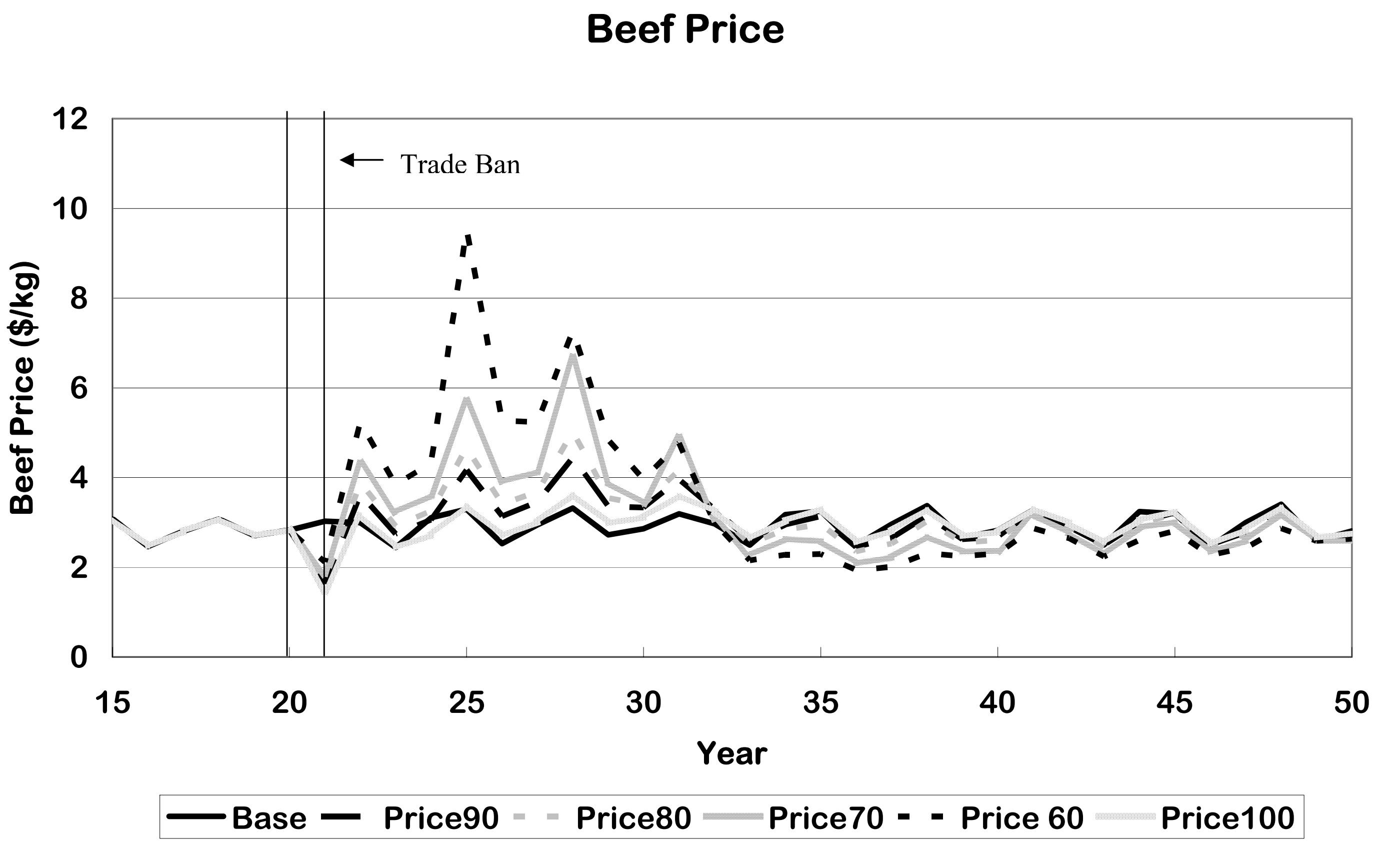

Figure 3: Producer, consumer and total economic surplus in each year for the 90% depopulation scenario.

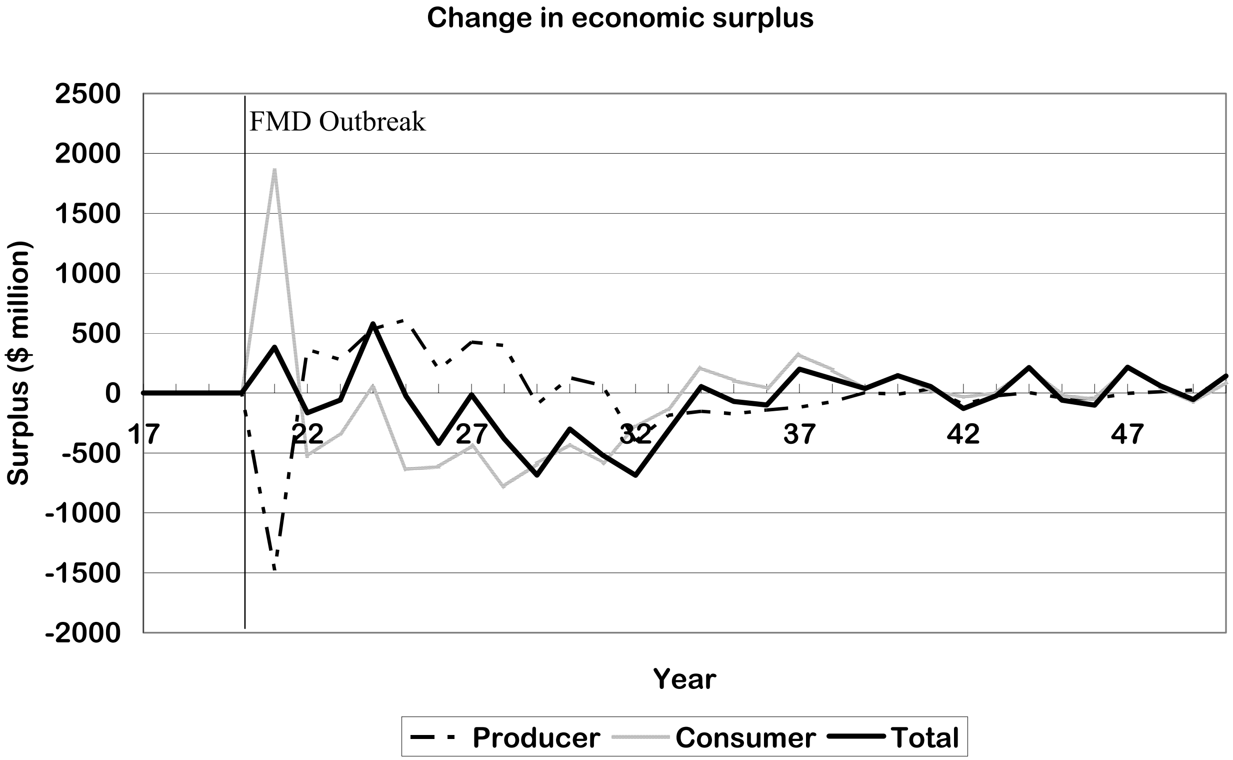

Figure 4: Cumulative producer, consumer and total economic surplus for the 90% depopulation scenario.

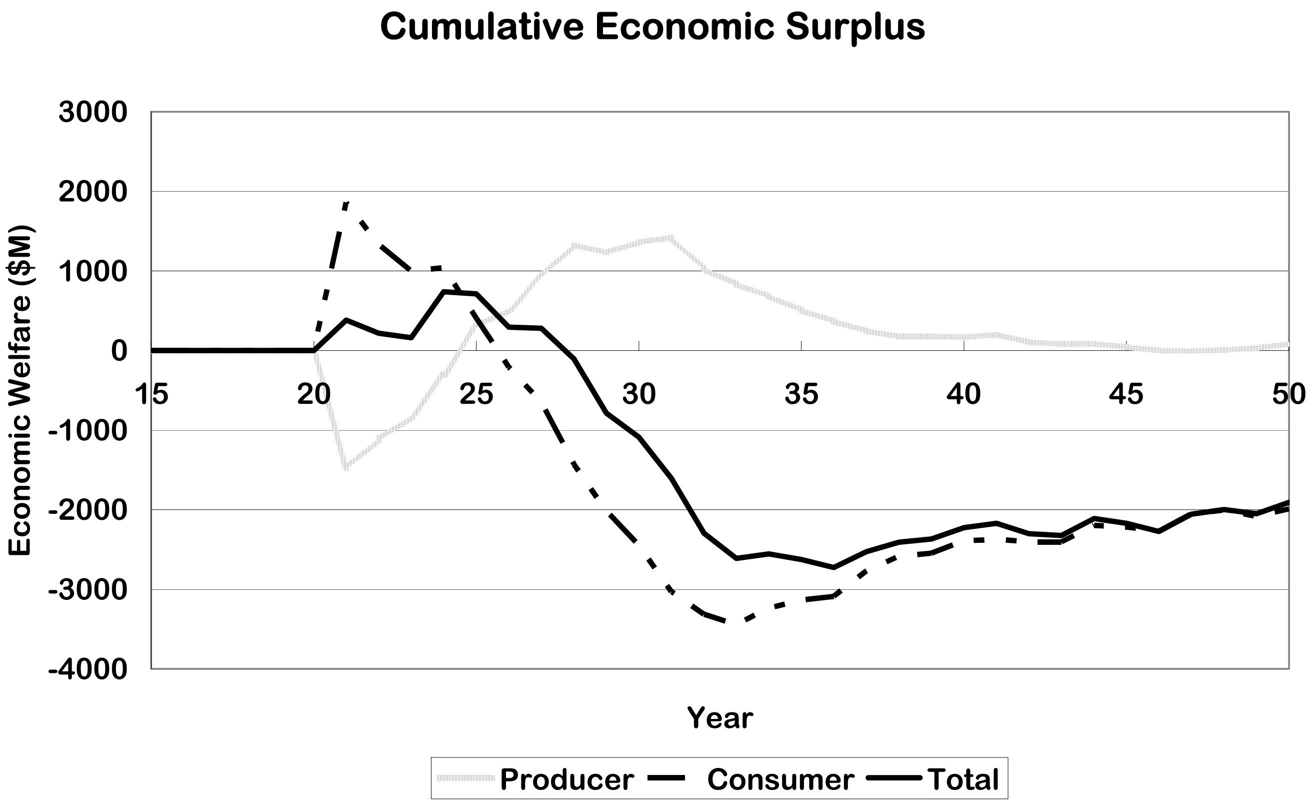

Figure 5: Domestic and trade impacts of foot and mouth outbreak on demand for Australian beef in Australia, USA, Japan, Korea and Indonesia.

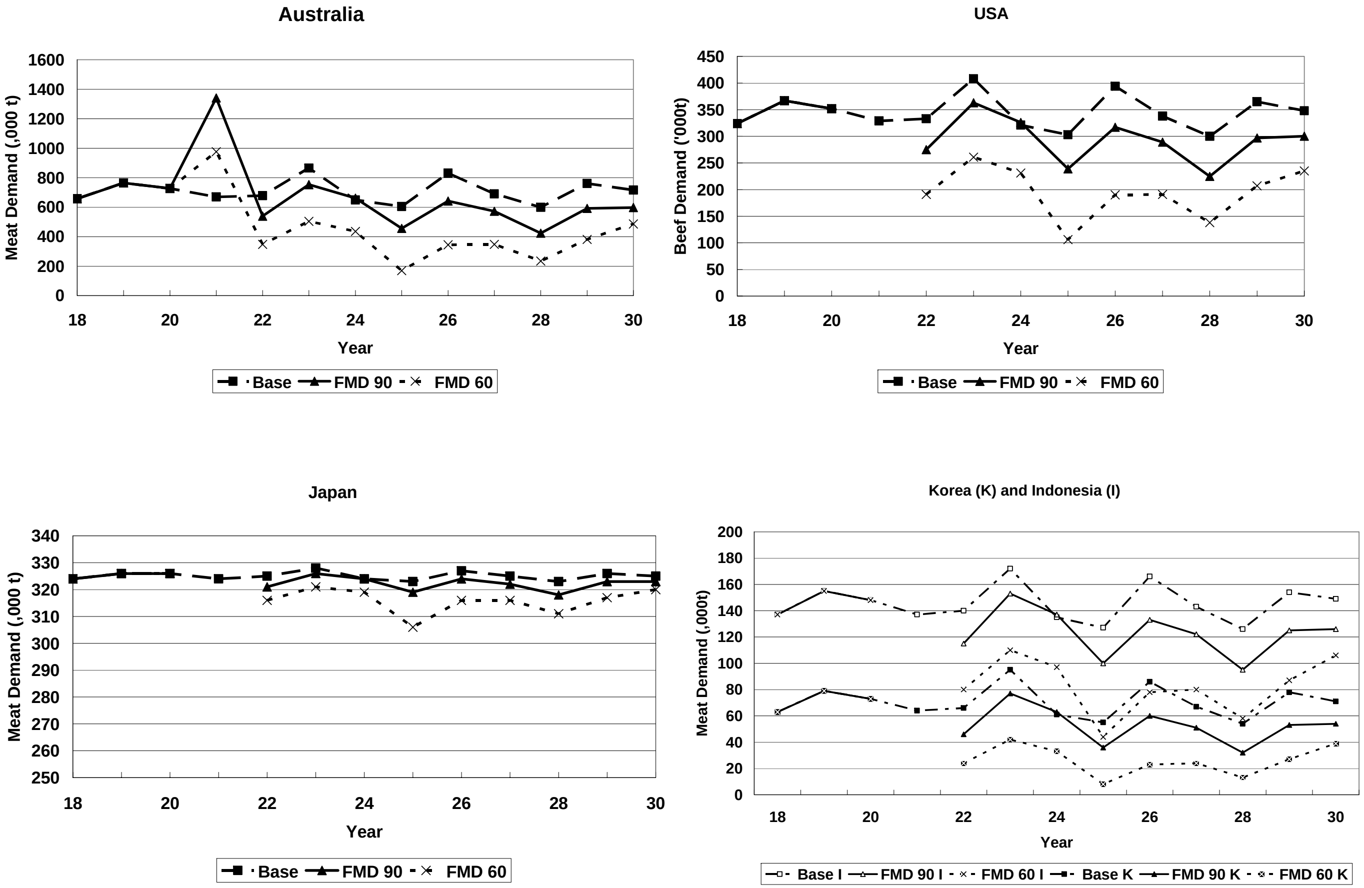

Figure 6: Herd impacts of BSE outbreak and different trade ban lengths. BSE1, BSE2 and BSE3 represent trade ban lengths of 1, 2, and 3, respectively. Base represents the scenario where no disease outbreak occurs.

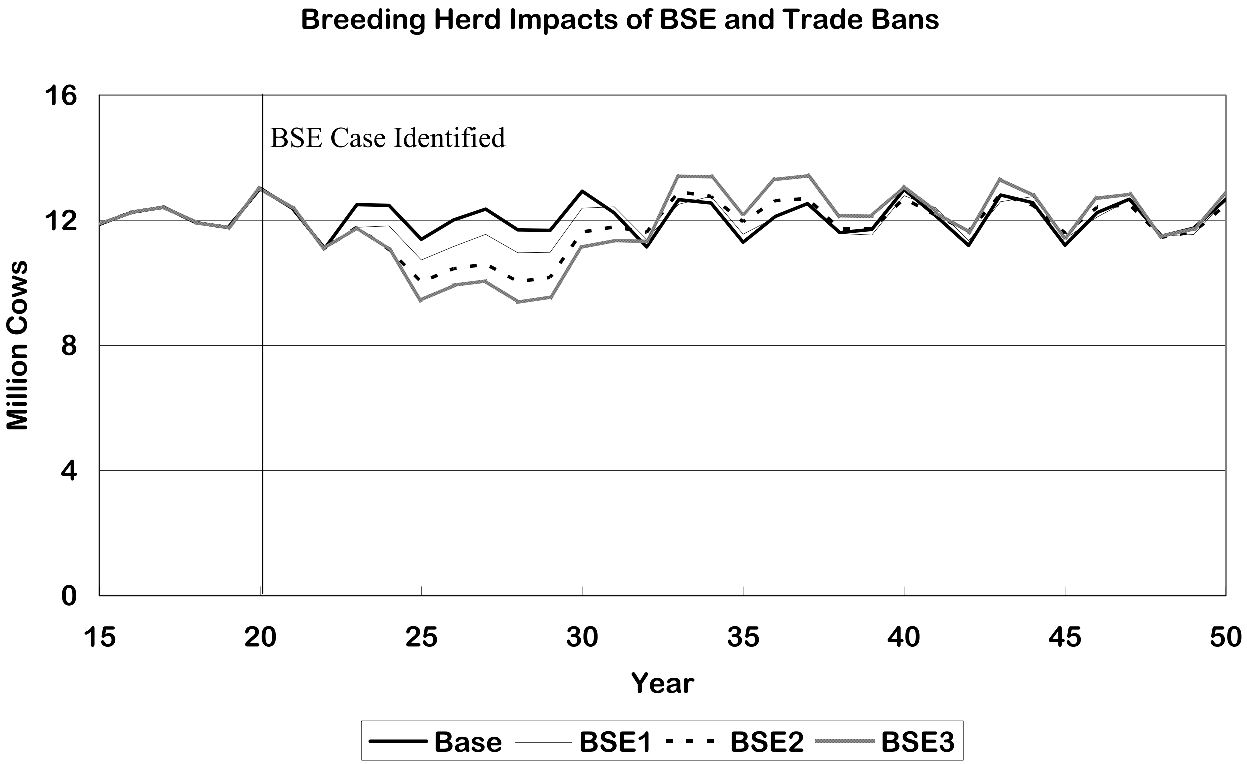

Figure 7: Market price for carcase beef due to different length trade bans due to BSE identification. BSE1, BSE2 and BSE3 represent trade ban lengths of 1, 2, and 3, respectively. Base represents the scenario where no disease outbreak occurs.