Domestic and Trade Impacts of Foot and Mouth Disease
on the Australian Beef Industry

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Abstract

Australia is the sixth largest producer of beef and the second largest exporter of beef. Average beef exports from Australia are approximately 65% of the total amount of beef produced or about 1.3 million metric tonnes. 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 a potentially catastrophic disease, foot and mouth disease (FMD). The study reports localized to large scale outbreaks and suggest that changes in economic surplus due to FMD range from a positive net gain of $309 million to a net loss of $18.3 billion, with the impact on producers and consumers varying depending on the degree of outbreak and control levels.

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Introduction and Background

The Australian beef industry is 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 after Brazil. Australia has a population of 21.3 million with per capita beef consumption of 37kg/year. 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 currently 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 2010). 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.

One such disease is foot-and-mouth disease (FMD). 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 domestic and export 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). Foot-and-mouth disease is not endemic to Australia and the impact on trade and the domestic beef markets could be serious if the disease occurred in Australia. Australia is considered to have a relatively low risk of FMD occurring, 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).

Although low risk, the economic consequences of invasive disease incidents often result in high costs. These have been documented in international contexts. For
example, the estimated cost of the FMD outbreak in the UK in 2001 was £8 billion 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 FMD in Australia has used various modelling approaches. 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) modelled trade restrictions and changes in consumer and producer welfare with a CGE model of the Australian economy and captured 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 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.

The objective in this research is to model the domestic and trade impacts on the Australian beef industry of a hypothetical outbreak of FMD. 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 similar to Zhao et al. (2006). The results of the model will be used to measure changes in revenues, prices, economic surpluses of producers and consumers during the disease outbreak and consequent periods, and government expenditure on compensation and clean up costs.
Our study complements previous research and contributes to the agricultural economics’ literature in several ways. First, we apply an optimization approach that is consistent with the profit maximizing behaviour of a representative producer in Australia constrained by the dynamics of stock replacement, market processes, and FMD spread. This allows us to examine intertemporal outcomes of markets and welfare effects (producer and consumer) across a range of scenarios from large scale to localized outbreaks. The current study differs to that of Zhao et al. (2006) in several different ways. It takes into account cattle supplied from two different feed sources, pasture and feedlots; allows for alternative forms of producer price expectations; accounts for asset losses; and includes ex-post government costs.

**Conceptual Model**

The model is based on Jarvis (1974), Aadland (2004), and Zhao et al. (2006) with the adaptations and extensions for Australia as identified and explained. The objective is to maximise the discounted returns to the representative 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 cohort $j$ at time $t$, $KC_j^t$.

The model can be written as:

\[
\text{(1) } \max_{KC_j^t, \forall j} \left\{ \sum_{t=0}^{\infty} \beta^t E_0(\pi_t) \right\}
\]

Subject to:

\[
\text{(2) } K_j^t = (1 - \delta_{j-1})(K_{j-1}^{t-1} - KC_{j-1}^{t-1})
\]

\[
\text{(3) } H_t = \sum_{j=m}^{k} K_{j-1}^{t-1}.
\]

\[
\text{(4) } K_j^0 = 0.5\delta H_{t-1}, \quad M_j^0 = 0.5\delta H_{t-1}
\]
where $\beta^t$ is the discount factor and $E_0$ is the expectation in time 0 of profit in time period $t$ ($\pi_t$). $K_{\cdot j}^t$ is the number of breeding cows in age cohort $j$, up to a maximum age of $s$, at time $t$, $\delta^j$ is the death rate in age cohort $j$, $KC_{\cdot j}^t$ is the number of females culled from age cohort $j$, $m$ is the youngest of the age cohorts in the breeding herd, in this study $m = 3$, $H_t$ is the breeding herd available in period $t$, $K_{\cdot 0}^t$ is the number of replacement females born in time $t$, $\theta$ is the reproduction rate, and $M_{\cdot 0}^t$ 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 $K_{\cdot j}^t$ included imports and exports of breeding cows. The Australian beef breeding herd can be considered a closed herd where no imports or exports of breeding females occur.

In the model the reproduction rate, $\theta$, is set at 55%, i.e. 55% of the breeding herd give birth to a live calf that survives for one year. The birth rate is derived from ABARE (2010) 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 $\delta^j = 0.02$ for $j > 0$.

Revenue ($R_t$) 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 (Aadland 2004). Producers will then reduce the culling rate of younger females. Therefore,

$$ R_t = P_t^t ((1 - \delta^0)(1 - \delta^3)(KC_{\cdot 0}^t + M_{\cdot 0}^t)) + \sum_{j=1}^{\infty} P_t^j KC_{\cdot j}^t $$
where \( P_t^s \) is the price of younger animals, including surplus females and all male offspring, and \( P_t^j \) is the price of cull cattle, the price 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. 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 \((TC_t)\), excluding disease clean up, compensation costs and other outbreak associated costs can be represented in the following manner:

\[
TC_t = \sum_{j=0}^{i} \psi K_i + \frac{1}{2} MAC(\sum_{j=0}^{i} (K_i - KC_i) - \sum_{j=0}^{i} (K_{i-1} - KC_{i-1}))^2 + (1 - \delta^d)(C_j F(KC_{i-1} + M^0_{i-1})) + C_p (1 - F)(KC_{i-1} + M^0_{i-1})
\]

The maintenance cost of a breeding cow is \( \psi \), \( C_f \) 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 2010). 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. The model of Zhao et al (2006) considered beef from one source, feedlots, the current model differs in that there are two sources of fed beef from pasture or feedlots, because of this costs and optimal weights of the animals from each source will in most cases differ.

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 \text{ or } f \text{ for pasture and})
feedlot, respectively), and the expected future beef price at time \( t \), \( P_{Meat, t} \). This can be represented as:

\[
\text{Max } F_{P, t, d, i} = P_{Meat, t, d} \times W_{T, t, d, i} - C_{t, d, i} - P_0
\]

\( F_{P, t, d, i} \) represents the profit from feeding cattle in each system \( i \), the value \( W_{T, t, d, i} \) represents the profit maximizing weight of the animals in system \( i \). 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 \( P_0 \) is the opportunity or purchase cost of putting young animals into either feeding system, see Zhao et al (2006) for details.

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 \( (P_d) \) to capture the slower growth rate and loss of energy due to maintenance activities including walking.

\[
S_t = W_{T, t, d, i} \times (F(C_{t-1} + M_{t-1}^0)) + W_{T, t, d, i} \times (1 - F)(K_{C_{t-1}} + M_{t-1}^0)
\]

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 is from cull cows and it is assumed in the model that this type of beef 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 2010).

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:
\[ (9) \quad S_t = D_t + DE_t \]

where

\[ (9b) \quad D_t = \eta(PMeat_t) \]

and

\[ (9b) \quad DE_t = \nu(PMeat_t) \]

where \( \eta \) and \( \nu \) 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 cohort information and the variable \( KC_i^j = 0 \) in all cohorts except for \( j = 0 \). In age cohort 0, \( KC_i^0 \) 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, \( \phi \), (in the model \( \phi = 0.024 \)), 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.

\[
D_{MI_Pd} = \phi \ast SRW \ast (WT_{(Pd-1)}/SRW) \ast (1.7 - WT_{(Pd-1)}/SRW)
\]

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*), the level of *ME* available per unit of dry matter intake (*M/D*) can be estimated as:

\[
M/D = 0.17 \ast DMD\% - 2.0.
\]

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%, this yields a value of 9.05MJ/kg DM, this gives *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:

\[
ME_{m} = \frac{\kappa(0.28 \ast WT_{Pd}^{0.75} \exp(-0.03 \ast A))}{k_m} + \frac{EGRAZE}{k_m} + 0.09MEI_{Pd}
\]

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:
\( EGRAZE = [(C \cdot DMI \cdot (0.9 - DMD)) + (0.05 \cdot \tau/(GF+3))] \cdot WTPd \)

where \( C \) is a species constant for sheep or cattle and in this study \( C = 0.006 \), 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:

\( EBG_{pd} = (6.7 + R_{pd}) + (20.3 - R_{pd})/[\left(1 + \exp(-6*(WTPd/SRW) - 0.4)\right)] \)

\( EBG \) is empty bodyweight growth, \( SRW \) is as defined before and \( R_{pd} \) is:

\( R_{pd} = 2* (k_g ((MEI_{pd} - ME_{m,pd})/ME_{m,pd}) - 1) \)

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

\( LWG_{pd} = (k_g (MEI_{pd} - ME_{m,pd})/(EBG_{pd} \cdot 0.92)) \)

Hence, weight on any day on pasture is simply the weight carried forward from the previous day plus \( LWG_{pd} \), i.e. \( WTP_{pd} = WTP_{pd-1} + LWG_{pd} \).

**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) that an earlier version of NRC (2000) was 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) model 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:
The dry matter adjustment factor a function of the animal’s weight and other environmental factors (Fox et al., 1988) and $NE_{m} = \text{Net energy for maintenance in the feed consumed measured in mega calories (Mcal)}$. 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 $NEI_{m} = \text{the intake of net energy for maintenance and } NE_{m}$ 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) $G_{d} = 13.91NE_{g}^{0.9116}WE_{d-1}^{-0.6837}$

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:

\[
NP_{i,T} = EP_{i,T} \times CW_{i,T} \times \exp(-r \frac{T}{365}) - Ration_{i,T} - Yardage_{i,T}
\]

where \( i \) is as defined previously, \( T = \) 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 \( T \). Discounted yardage costs account for the capital investment in the feedlot feeding system and is set at $0.25/d.

**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 2010), 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:
was used for each importing country, $x$. In equation 26, $a_x$ is a constant and $b_x$ is the demand elasticity for beef in country $x$, $PMeat_i$ 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 (2010) the term $a_x$ was calculated 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 (2010).

**Invasive Species – Foot and Mouth Disease**

The 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, Dijkstra, and Oskam 1992, Mahul and Durand 2000). In these models animals can move between either of the three states, 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 (Miller 1979). 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 cohort, i.e., $K^{ij}_t$, 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 in week \( w = \omega \) in period \( t \), and that the number of susceptible and infected animals in each cohort \( j \) are, \( S^j_\omega \) and \( I^j_\omega \), respectively, letting \( \varepsilon^{j,k}_\omega \) represent the number of infective contacts between inventory groups \( j \) and \( k \), and \( \rho \) be the probability of disease spread, then the probability of an individual animal becoming infected and infectious is:

\[
\sum \frac{\varepsilon^{j,k}_\omega I^k_\omega}{K^j_t} \rho^{j}_{\omega}
\]

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

\[
\sum \frac{\varepsilon^{j,k}_\omega I^k_\omega}{K^j_t} S^k_\omega \rho^{j}_{\omega}
\]

From equation 24 we can determine the dynamics of the epidemic, as a function of those infected, \( I^j_\omega \), susceptible, \( S^j_\omega \), and recovered after infection, \( R^j_\omega \). This function is:

\[
I^{k}_{\omega+1} = \rho^{j}_{\omega} \sum \frac{\varepsilon^{j,k}_\omega I^k_\omega}{K^j_t} S^k_\omega + I^k_\omega - R^k_\omega \quad \forall \ k=1,..,s.
\]

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 \( I^0_\omega \). 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.

**Scenarios**

In the model constructed, at the outbreak of FMD, it is assumed a trade ban is imposed by all countries importing Australian beef. This trade ban is imposed immediately on the confirmation of an outbreak 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, stamping out via vaccination, movement controls or quarantine zones. The method of control varies in costs and market reactions. Use of 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 or potentially 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 60% 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, this scenario was undertaken to represent a localised outbreak, but with the trade bans in place.

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4 The infection rate parameter was also adjusted to achieve the 50,000 head cull.
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. Rational price expectations for the producer were applied in all scenarios. There were fluctuations in herd size and price in the initial periods, but the trajectories stabilised at approximately period 10. This provides for a further 10 years of stability before the assumed FMD outbreak. 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.

The optimisation model is calibrated to the year 2000 as this was prior to the major outbreak of FMD in the UK and BSE in Canada and the USA. The trade and domestic demand equations, as well as herd dynamics, are calibrated based on 2000 data.

**Results and Discussion**

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 the scenario results provided below should be that they are in effect specific deviations from historical baseline planning trajectories. In reality, after an outbreak, there may be incentives for producers to target and alter multiple production practices (e.g., altering the culling rate, the birth rate efficiency, or both) that could impact actual production outcomes and herd dynamics over time. For example, results reported here only alter the culling rate as a decision variable and do not jointly alter (i.e., increase) the culling rate and efficiency of the birth rate. Alternatively, importing countries may alter their behaviour after a trade ban. Here again, we rely on historical price responsiveness to guide trade recovery in the model, and then provide additional scenarios to suggest likely outcomes for delayed recovery of trade. The intent is that the scenarios delineate specific economic effects and provide important and valuable information when correctly interpreted.

**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 (2010). Following the FMD 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, i.e., the number of animals remaining in the breeding herd is higher than with lower depopulation levels. These effects are illustrated in Figure 1. The baseline data, Base, exhibits the breeding cycle of the model through the cyclic shape of the trajectory as described by Aadland (2004). However, after the FMD outbreak the breeding herd is reduced, both through standard culling and by producers reducing herd size as price and profit falls due to lower export demand. Comparing scenarios 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 scenario 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. In the lower depopulation rate scenarios, due to the lower culling rate, the disease spreads further than in the higher depopulation cases, hence more cattle in total need to be culled before the disease is under control.

One point to note is that, except for FMD60 breeding herd size responses, the different depopulation rates converge to the Base trajectory approximately 8 years after the initial disease outbreak.\(^5\) 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 the 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 reached 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

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\(^5\) Note that increasing the calf birth rate tended to influenced the breeding herd dynamic. It narrowed the eight year window and reduced the time for the herd numbers to return to equilibrium.
approximately 16 years to complete. However, this type of behaviour is typical of the beef cattle cycle as evidenced in Aadland (2004).

Price impacts

Due to the immediate closure of export markets domestic supply increases. Hence, domestic prices fall rapidly if producers already have ample stock on hand ready for slaughter and need to clear inventories of older stock to make way for the current year’s animals. The impact of depopulation rate on the price of beef in the case of an FMD outbreak is illustrated in Figure 2. During the trade ban prices declined for all scenarios due to increased domestic supply. After the trade restrictions are lifted, herd dynamics drive the price response, i.e. higher slaughter levels under the lower depopulation rates caused prices to increase at a faster rate than under the higher depopulation rates. While smaller outbreaks result in decreased deviations from the base trajectory, and all price trajectories converge closely to the base by period 33.

Consumers and Producers Welfare Impacts

An important attribute of an intertemporal model is that fluctuations in the welfare impacts can be observed for both consumers and producers over the disease outbreak and subsequent periods. Consumer surplus is measured as the sum of changes in consumer surplus from the base model in both the fed and non-fed beef markets. Producer surplus is the sum of changes in profits and asset loss of the herd.

Figures 3 and 4 demonstrate the patterns of how producer and consumer surpluses change over the duration of the trade ban and subsequent years. From figures 3 and 4 we can see that during the trade ban the increase in consumer surplus due to excess supply on the domestic market (yielding lower prices) and we observe the fall in producer surplus. Conversely, prices tend to increase after the trade ban is lifted. In this case producers generate a positive total surplus and consumers are worse off. The effects on consumers and producers in the FMD100 scenario follow similar trends as in the lower depopulation cases (but at a lower level). Interestingly, for the localized outbreak, positive consumer surplus outweighed the loss in producer surplus and asset loss, yielding a positive total economic surplus. Paarlberg et al (2008) also report positive benefits to consumers due to lower prices for an FMD.
outbreak in the U.S. This is principally due to the lower prices paid by consumers after the disease outbreak and because the stock loss was minimal, requiring no reinvestment into the breeding herd (i.e., producers were not holding back replacement heifers for the breeding herd).

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 90% depopulation rate the loss in consumer surplus is smallest, less than $1.3 billion, but as depopulation rates fall to 60% the discounted losses in consumer surplus rapidly increased to $6.4 billion, principally due to increased prices for beef. The discounted producer surplus changed from a loss of $3.8 billion to a gain of $275 million improved as depopulation rates increased from 60% to 90% depopulation. Here, even though output is reduced, the additional revenue more than compensated for the loss in output.

The PC (2002) reports a net present value revenue loss, at the wholesale level, to the beef industry of between $3 and $8 billion dollars, with the range varying with the length of the outbreak from 3 months to 12 months. In the same report the PC (2002) estimates a producer loss of $7.5 billion and a consumer surplus of $5 billion, yielding a net loss to society of $2.5 billion. However, this loss is across all animal industries affected by FMD, including sheep, cattle and pigs, rather than the beef industry alone as estimated in the current study.

Also, shown in Table 1 are the asset losses and ex post costs associated with the slaughter of animals due to the depopulation program. As depopulation rates fell from 90% to 60% the number of animals slaughtered to control the disease outbreak increased. Consequently, the value of breeding stock fell with the rise in depopulation rates. These asset losses in the extreme case of a 60% depopulation rate are approaching $1 billion. The 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.
Post outbreak costs are also included in Table 1 to provide some indication as to the potential clean up and compensation costs to government of an FMD outbreak. Although Australia has not had an FMD outbreak the Abdalla et al (2005) estimated that the costs of clean up and compensation would be approximately $A600 per head of cattle culled. The range of *ex-post* costs reported table 1 (calculated as the number of slaughtered animals times $A600/hd) range from $31 million for a localized outbreak to $7.2 billion for a large scale outbreak. Abdalla et al (2005) estimated the control costs alone for an outbreak of FMD in Australia would range from $68 - $250 million and the PC (2002) estimates control costs of $25 to $460 million.

*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 return to trade is determined by market factors such as the elasticities that embody history information from before the outbreak. As can be seen in Figure 5 the effects vary across countries due to the price level and price responsiveness. Importantly, return to pre-outbreak trade levels is not immediate but depend on market conditions and estimated elasticities. 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. 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. The response in the model of Japan to renewed trade after a disease outbreak is due to the construct of the model. However, based on previous experience, Japan would not immediately return to some form of “status quo” in the beef trade with Australia but wait to ensure food safety concerns were addressed and
trade may resume at lower levels than prior to the outbreak. After the BSE incidents in Japan and the USA in 2001 and 2003, respectively, Japanese imports of beef from the USA fell sharply and did not return to pre-incident levels as consumers substituted pork and fish in their diets (Jin, 2006). Therefore, it is anticipated that this type of response would further reduce demand further diminishing producer surplus and increasing consumer surplus. Two additional FMD90 scenarios are provided to analyse return to trade effects. Assuming, after the one year trade ban, Japan delays resuming trade for an additional one or two years the impact on producer surplus is a drop of $143 million and $758 million. Consumers gain an additional $213 million and $474 million in surplus, respectively. Combining producer losses and consumer gains yields a surplus of $70 million for the 1-year extension of the trade restriction, but when trade is restricted for two years following the ban the loss in welfare is an extra $284 million.

Conclusions and Implications.

The objective in this research was to analyse the international and domestic trade impacts of a hypothetical outbreak of FMD on the Australian beef sector. The results are based on localized and large scale outbreaks and show that consumers and/or producers can be positively or negatively affected over time contingent upon market conditions. Moreover, findings of this study demonstrate that losses due to trade restrictions are large for specific sectors and must not be overlooked when developing policies to mitigate disease outbreaks (especially for localized outbreaks).

The results also 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 lose in all cases, except for a localised outbreak. In this case the impact on total herd size is significantly reduced and reinvestment back into the breeding herd by producers is not necessary.
One of the challenges for policy makers is how adequately compensate individuals 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 run. 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.
References


ALFA (Australian Lotfeeders Association (various). Media release.


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

Breeding stock value, surpluses and costs on $million

<table>
<thead>
<tr>
<th>Depopulation Rate</th>
<th>Reduction in Breeding Herd</th>
<th>Asset Loss in Stock Value</th>
<th>Consumer Surplus</th>
<th>Producer Surplus</th>
<th>Ex-Post Costs</th>
<th>Total Economic Surplus</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>36%</td>
<td>$(959)</td>
<td>$(6,411)</td>
<td>$(3,767)</td>
<td>$(7,195)</td>
<td>$(18,333)</td>
</tr>
<tr>
<td>70%</td>
<td>25%</td>
<td>$(660)</td>
<td>$(3,520)</td>
<td>$(2,389)</td>
<td>$(4,950)</td>
<td>$(11,520)</td>
</tr>
<tr>
<td>80%</td>
<td>17%</td>
<td>$(463)</td>
<td>$(2,324)</td>
<td>$66</td>
<td>$(3,471)</td>
<td>$(6,191)</td>
</tr>
<tr>
<td>90%</td>
<td>12%</td>
<td>$(324)</td>
<td>$(1,268)</td>
<td>$275</td>
<td>$(2,432)</td>
<td>$(3,749)</td>
</tr>
<tr>
<td>100%</td>
<td>0.15%</td>
<td>$(4)</td>
<td>$1,289</td>
<td>$(945)</td>
<td>$(31)</td>
<td>$309</td>
</tr>
</tbody>
</table>
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 an FMD outbreak. Price90, Price80, Price70, and Price60 refer to depopulation rates of 90%, 80%, 70% and 60%, Price100 refers to the localised outbreak where 50,000 are culled.
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: Cumulative producer, consumer and total economic surplus for the 100% depopulation scenario.