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

Australia is the sixth largest producer of beef and the second largest exporter of beef. Average beef exports from Australia are approximately 65 per cent 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 optimisation 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). This study reports localised to large scale outbreaks, and suggests that changes in economic surplus due to FMD range from a positive net gain of $57 million to a net loss of $1.7 billion, with impacts on producers and consumers varying depending on the location of the outbreak, control levels and the nature of the trade ban.

1. 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 countries or 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 per cent 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's beef industry 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, each of which has its own advantages and limitations. 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).

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, pasture and feedlot feeding systems, 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. The current study differs to that of Zhao *et al*. (2006) in several different ways. It takes into account cattle supplied from two different zones utilising three different feed sources, pasture – tropical and temperate, and feedlots; allows for alternative forms of producer price expectations; accounts for asset losses; includes *ex post* government costs, and allows for zoning as a control measure.

Our study complements previous research and contributes to the agricultural economics literature in several ways. First, we apply an optimisation approach that is consistent with the profit maximising 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 localised outbreaks.

2. Conceptual model

The model framework is based on Jarvis (1974), Aadland (2004), Zhao *et al*. (2006), and Nogueira *et al* (2011) with the adaptations and extensions for Australia as identified and explained. We extend the framework to a zoned model, whereby Australia is divided into northern and southern breeding herds. This allows for the case wherein only a part of the country may lose its trade status. The Australian beef industry is spread across the country with different production practices due to climatic and geographical variations. The major difference in production systems is based on the temperate – tropical division. This division captures the northern breeding herd, based on *Bos indicus* breeds with a feedbase of tropical grasses. The southern herd, based on *Bos taurus* breeds, utilises various temperate and sub-tropical pasture-based feeding systems. The northern herd produces animals that are heavier, than those turned off from the southern herd, targeted at export markets – live and processed, with some flow into the domestic market. The opposite is the case for the southern herd, where most of the focus is on producing cattle for the domestic market; however this does not imply that the entire focus of one herd is export or domestic (Anon, 1997). The northern breeding herd accounts for approximately 60% of the national herd, the remainder being in the southern herd (ABARE 2010).

The model objective is to maximise the discounted net returns to the representative producer. The conceptual model is an optimisation problem where the decision variable is the culling rate of breeding females in each age cohort *j* at time *t*, KC_t^j. The model is:

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

Subject to:

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

$$H_t = \sum_{j=m}^{s} K_{t-1}^{j-1} . \tag{3}$$

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

where $\beta^t = 0.09$ is the discount factor, reflecting the cost of borrowed capital through inclusion of a risk premium above the long term interest rate (ABARE 2010) and π_t is profit in time period t. K_t^j is the number of breeding cows in age cohort *j* (with maximum age *s*) at time *t*, δ^j is the death rate in age cohort *j*, KC_t^j is the number of females culled from age cohort *j*, *m* is the youngest of the age cohorts in the breeding herd ($m = 3$), 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. The Australian beef breeding herd is a closed herd with no imports or exports of breeding females.

In the base models the reproduction rate, θ, is set at 80 per cent for the southern herd and 50 per cent for the northern herd. The birth rates are 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.

Profit is comprised of revenues and costs. 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. The revenue expression is:

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

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. 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:

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

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 ($0 \le F \le 1$). In the model $F = 0.2$ based on current turnoff levels of 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 in each feeding system.

Domestic supply of fed beef is from the two sources, feedlot and pasture-fed in each breeding area. In each period supply is determined by the price of beef and the costs of feeding animals in each system. Profit maximising 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, $C_{t,d,i,Z}$ ($i = p$ or f for pasture and feedlot, respectively, and Z = NQ or SN for northern or southern breeding system), and the expected future beef price at time t, $PMeat_{t,d}$. This can be represented as:

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

$FP_{t,d,i}$ represents the profit from feeding cattle in each system i, the value $WT_{d,i,Z}$ represents the profit maximising weight of the animals in system i in region Z. 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, see Zhao *et al* (2006).

The total domestic supply of fed beef is then determined by multiplying the weight of animals in each feeding system by the numbers of animals supplied by each system 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. Cattle from the northern zone take longer to reach market weight than do those in the south. The supply is given by

$$S_t = WT_{d,f}[F(KC_{t-1}^0 + M_{t-1}^0)] + WT_{Pd,p}[(1-F)(KC_{t-1}^0 + M_{t-1}^0)] \qquad (8)$$

Non-fed beef is also included in the model. Typically this beef is from cull cows, which is included in exports, and is not in domestic consumption. It is lower valued (i.e. 90 per cent chemical lean, 90CL, beef) and used in processing in importing countries (ABARE 2010). Non-fed beef is also sourced from culled dairy cows. It is assumed, based on ABARE (2010), that dairy cows contribute approximately 5 per cent of the total supply of non-fed beef in the supply model.

Demand for Australian beef comes from both domestic, D_t, and export markets, DE_t. Export demand is generated from Japan, Korea, and the United States for beef carcases and cuts, and Indonesia for live cattle. The market clearing condition for the Australian beef market is:

$$S_t = D_t + DE_t \qquad (9)$$

where

$$D_t = \eta(PMeat_t) \qquad (9a)$$

and

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

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

3. Empirical components

3.1 Herd dynamics

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 annually 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. Equation 2 captures the relevant age cohort information.

3.1.1 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 feed 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 the model $\phi = 0.024$), and the ratio of relative size ($WT_{(Pd-1)}$) of the animal to its standard reference size. Pd refers to days on pasture to differentiate this period to days on feed (d) for cattle in the feedlot system.

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

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 its utilisation and efficiency of utilisation by a growing animal.

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

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

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 per cent, 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 per cent, this yields a value of

9.05MJ/kg DM, this gives $k_m = 0.02*M/D + 0.5 = 0.26$ and $k_g = 0.063*M/D - 0.308 = 0.68$. The parameters of the feed model are adjusted from these base levels to take account of differences in feed quality and quantity in the northern and southern feeding systems.

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

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

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:

$$EBG_{Pd} = (6.7 + R_{Pd}) + (20.3 - R_{Pd})/[(1 + \exp(-6*(WT_{Pd}/SRW) - 0.4))] \qquad (13)$$

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

$$R_{Pd} = 2*(k_g((MEI_{Pd} - ME_{m,Pd})/ME_{m,Pd}) - 1) \qquad (14)$$

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

$$LWG_{Pd} = (k_g(MEI_{Pd} - ME_{m,Pd})/(EBG_{Pd}*0.92)) \qquad (15)$$

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

3.1.2 Feedlot model

The feedlot optimisation model is based on the National Research Council's (NRC 2000) Nutrient Requirements of Beef Cattle as in Zhao *et al.* (2006). 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.

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.

3.1.3 Optimisation

The objective function in 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:

$$NP_{i,T} = EP_{i,T} * CW_{i,T} * \exp(-r\frac{T}{365}) - Ration_{i,T} - Yardage_{i,T} \quad (16)$$

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.

3.1.4 Market model for Australian beef

The USA, Japan, and Korea account for approximately 90 per cent of Australian processed beef exports (ABARE 2010). Indonesia imports approximately 55 - 65 per cent of live cattle exported from Australia. To incorporate exports, demand functions were constructed for each of the four countries:

$$D_{x,t} = a_x (PMeat_t * EX_x)^{b_x} \qquad (17)$$

where the importing country is denoted by subscript x. In equation 17, a_x is a constant and b_x is the demand elasticity for beef in country x, $PMeat_t$ is as defined previously, and EX_x is the exchange rate between Australia and country x. Demand elasticities for each country were sourced from published data. Griffith *et al*. (2001) report export demand elasticities for Australian beef into the USA of -1.0 and -0.05 for Japan. 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. The elasticity for live exports was set at -1.0. The model was calibrated such that the demand generated in the model by equation 17 was approximately equal to the data from ABARE (2010).

3.1.5 Invasive species – Foot and Mouth Disease

The FMD component is a state transition Susceptible-Infected-Removed (S-I-R) model (see for example, Berentsen, Dijkhuizen, and Oskam 1992; Mahul and Durand 2000; Miller 1979). Movement from one state to another is determined by the number and type of contacts and the probabilities of these contacts. 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 per cent, but in young animals the rate can be as high as 20 per cent (Blood *et al*. 1983). For the current 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 because of the latent period. In the interim the infected herds and those herds the infected herds come in contact with spread the disease further. After the initial 2 weeks, control measures are implemented and the spread is reduced. In the model the disease spread is halved each week from week three until week eight when it is assumed the disease spread is controlled and no further new infections can occur.

4. Scenarios

Scenarios with and without trade bans in place in either the north or south zone for hypothetical FMD outbreaks are completed and reported. Depopulation of latently infected or potentially infected herds is the method of control. The base case constitutes a two-zone model of Australia with no FMD and no trade ban in place. The first two scenarios tested, Scenarios 1 and 2 (Table 1) are those where a uniform trade ban is placed by all importers of Australian beef. There is good reason to consider a uniform trade ban. The Terrestrial Animal Health Code (OIE 2009) provides recommendations intended to reduce the impact of the affected country or zone in which an outbreak occurs. The FMD status of a country is immediately lost upon the first notification to the OIE, regardless of where in the country an outbreak of FMD occurs. Hence, it would be reasonable to assume that importing countries could wait until the disease control protocols are effective before accepting imports of beef from any part of Australia. This has been observed in the 2010 FMD outbreak in Japan where Russia and China banned all beef imports from Japan even though the outbreak was confined to Hokkaido. Ineffective management protocols or breakdowns in protocols were present in the outbreak of EI which led to closure of much of the equine industry, particularly on the eastern seaboard of Australia (Callinan 2008). In the initial scenarios, 1 and 2 (Table 1), a one year uniform trade ban was imposed immediately on the confirmation of an outbreak, which is consistent with previous research (Paarlberg *et al*. 2008). Also, it assumed that a 5 per cent reduction in domestic demand occurs for beef in the outbreak year.

Table 1 near here.

For the comparative scenarios, scenarios 3 and 4, depopulation rates of 90 per cent were used to compare the impacts of regional trade bans on beef supplied from the affected zones on the economic surplus generated. Two further scenarios, 5 and 6, examine the impact of a lower depopulation rate, of 80 per cent, on price, consumers, producers and trade of a disease outbreak in each zone with regional trade bans. Two other control scenarios, Scenarios 7 and 8, were also studied and the difference was to cull 50,000 head (100 per cent) with a 100 per cent rate of depopulation, these scenarios were undertaken to represent a localised outbreak, but with the regional trade bans in place. In these scenarios the infection rate parameter was adjusted to achieve a cull rate of 50,000 head. For the regional trade ban scenarios demand shocks were introduced to account for the reduced demand for beef from the affected zone. The demand shocks were based on the percentage of the herd in each region (ABARE 2010). Interpreting the trade ban scenarios; Scenario 6, for example, means the FMD outbreak occurred in the south zone with a trade ban imposed on the south zone and 80 per cent of the latent infected cattle were depopulated.

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 year 2000 data.

5. 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.

5.1 Herd impacts

After an initialisation period the base breeding herd achieved a steady state range of between 12 and 14 million cows, which is consistent with reported levels in ABARE (2010). Following the FMD outbreak the magnitude of impact is primarily dominated by the herd depopulation rate. As depopulation rate increases (i.e. as the number of latently infected herds slaughtered increases) the breeding herd impacts 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 scenario (Base) exhibits the cyclical nature of the breeding cycle 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 1 and 3, where depopulation rates were 90 per cent and the northern zone was affected by FMD with either a uniform trade ban or a regional trade ban on beef from the northern zone, the total number of animals slaughtered is equal in both cases. However, in scenario 3 the herd impact after the trade ban is lifted shows the price effects filtering through into the decision making process of producers as herds are reduced due to lower prices. For scenarios 7 and 8, or the localised outbreak scenario the herd size is reduced by approximately 0.15 per cent 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 and total herd impacts are higher.

Figure 1 near here

5.2 Price impacts

Due to the closure of export markets in Scenarios 1 and 2 domestic supply increases and domestic prices fall significantly.[1] The impact of outbreak location and trade bans on the carcase price of beef is illustrated in Figure 2. During the trade ban prices declined for all scenarios due to increased domestic supply. In the cases of trade bans imposed on infected zones, i.e. Scenarios 3 and 4, price decreases are lower than in the uniform trade ban scenarios. In scenarios with smaller outbreaks and regional trade bans only, i.e. Scenarios 7 and 8, price decreases are lower than in other scenarios. However, in all scenarios the price trajectories converged closely to the base trajectory by period 33.

Figure 2 near here

5.3 Consumer and producer welfare impacts

Consumer surplus is measured as the sum in changes of consumer surplus relative to the outcomes of the base model for the fed and non-fed beef markets. Producer surplus is the sum of changes in profits.

Figures 3 and 4 near here

Figures 3 and 4 demonstrate the patterns of how producer and consumer surpluses and cumulative surplus change over the duration of the trade ban and subsequent years. During the trade ban there is an increase in consumer surplus due to excess supply on the domestic market (yielding lower prices) and a fall in producer surplus. Conversely, prices tend to increase after the trade ban is lifted. In this case

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[1] Price responsiveness is calculated from the structural economic model (with a standard market clearing mechanism) defined above and based on historical information. As with any modeling effort there are limitations, and these results should be interpreted conditional on assumptions of the model.

producers generate a positive total surplus and consumers are worse off. The impacts on consumers and producers of uniform trade bans and regional trade bans are illustrated in Table 2. Due to the significant fall in price in Scenarios 1 or 2 consumers are substantially better off under a uniform trade ban than a regional ban. However, the opposite effect is observed for producers and the impact on the overall economy is similar whether a trade ban is uniform or regional due to the tradeoffs between producers and consumers.

Table 2 near here.

The effects on consumers and producers in the localised outbreak (Scenarios 7 and 8), show that consumers are better off than in other equivalent scenarios. This can be explained by the amount of beef still in the market, as opposed to other scenarios where more animals are slaughtered to control the FMD outbreak. Conversely, producers are worse off in these scenarios, except for the uniform trade ban scenarios of 1 and 2, due to the lower prices and higher supply in the market. Interestingly, for the localised 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).

The change in total discounted net economic surplus ranges from a positive net gain of $57 million to a net loss of $1.7 billion. It is negatively correlated with depopulation rate in that as depopulation increased total economic surplus decreased, these outcomes are reported in Table 2. For example, compare Scenarios 3, 5, and 7.

Under the 90 per cent depopulation rate (Scenario 3) the loss in consumer surplus is smallest, less than $A 958 million, but as depopulation rate fell to 80 per cent (Scenario 5) the discounted losses in consumer surplus rapidly increased to $A1.6 billion, principally due to increased prices for beef. Conversely, the discounted producer surplus dropped from a gain of $A594 million to a loss of $A577 million as depopulation rates increased from 80 per cent (Scenario 5) to 100 per cent (Scenario 7).

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.

Shown in Table 2 are the asset losses (calculated as the value of animals slaughtered) and *ex post* costs associated with the slaughter of animals due to the depopulation program. As depopulation rates fell from 100 per cent to 80 per cent 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 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 2 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, 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 in table 2[2] (calculated as the number of slaughtered animals times $A600/hd) range from $30 million for a localised outbreak to $1.75 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 - $460 million. In Table 2, compensation payments to producers are assumed to be transfer payments that just equal asset losses and do not enter into the calculation of net economic benefits.

5.4 Trade impacts

The impacts on trade between Australia's major beef importing countries vary across countries due to the price level and price responsiveness (see Figure 5). Importantly, return to pre-outbreak trade levels is not immediate but depends 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 per cent of the base levels expected if no outbreak occurred.

Figure 5 near here

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[2] The cost and benefits reported in this table represent key measures of the economic consequences of FMD outbreaks (Nogueira *et al* 2011). However, other cost, such as economic consequences of an outbreak on non-agricultural sectors, exist and have been addressed in other studies (Garner and Lack 1995).

Japan's imports 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. 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, diminishing producer surplus and increasing consumer surplus even more.

The impact of the type of trade ban on Australian beef, either uniform or regional, on trading partners is limited beyond the immediate impact of market closure in the case of a uniform ban (see figure 6). Most of the effect of the type of trade ban imposed on the beef trade is due to the subsequent price fluctuations in the Australian market[3].

Figure 6 about here.

Two additional scenarios, extensions of Scenario 3, not reported in the tables are provided to analyse return to trade effects over alternative durations of the trade ban. Assume, after a one year trade ban, Japan delays resuming trade for an additional one or two years. Then the impact on producer surplus is a drop of \$226 million and \$287 million, respectively. Consumers gain an additional \$344 million and \$602 million in surplus, respectively. Combining producer losses and consumer gains yields a surplus

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[3] It is difficult to compare the trade impacts to previous research as most research on FMD outbreaks in Australia have concentrated on domestic effects (see for example Garner and Lack 1995) or gross loss in trade (see for example Cao *et al*. 2002 or PC 2002).

of $118 million for the 1-year extension of the trade restriction, when trade is restricted for two years following the ban the gain in welfare is an extra $315 million.

6. 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 localised 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 localised 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 realising 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 to 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. Also, as shown here and in other reports zoning does mitigate the impacts of a disease outbreak, the challenge for policy makers, in the context of zoning, is the development of an effective zoning protocol to ensure disease spread is limited and the impact on producers and consumers, and critical international markets, is minimised.

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Table 1: Scenarios examined across selected location of FMD outbreaks, depopulation levels, and trade ban outcomes.

Scenario	Outbreak location	Depopulation level (per cent)	Trade ban
1	North	90	Uniform (North and South)
2	South	90	Uniform (North and South)
3	North	90	Regional (North)
4	South	90	Regional (South)
5	North	80	Regional (North)
6	South	80	Regional (South)
7	North	100	Regional (North)
8	South	100	Regional (South)

Table 2: Reductions in breeding herd, asset loss, net present value of producer and consumer surpluses, current value of *ex post* costs of cleanup and compensation, and net economic welfare changes due to a FMD outbreak with varying depopulation rates (Discount rate = 9 per cent).

Scenario	Reduction in Breeding Herd (per cent)	Asset Loss in Stock Value ($ millions)	Consumer Surplus ($ millions)	Producer Surplus ($ millions)	*Ex post* Costs ($ millions)	Net Economic Surplus ($ millions)
1	6	$(806)	$(50)	$(464)	$(1,217)	$(925)
2	4	$(480)	$613	$(765)	$(727)	$(399)
3	6	$(806)	$(958)	$285	$(1,217)	$(1,084)
4	4	$(480)	$(604)	$216	$(727)	$(635)
5	9	$(1,165)	$(1,668)	$594	$(1,749)	$(1,658)
6	5	$(687)	$(1,022)	$438	$(1,038)	$(935)
7	0.15	$(20)	$644	$(577)	$(30)	$57
8	0.15	$(20)	$352	$(345)	$(30)	$(3)

Figure 1: Herd impacts of FMD outbreak for Scenarios 1, 2, 3 and 4, with a constant depopulation rate of 90 per cent. Scenario 1 and 2 are those with uniform trade bans in place. Scenarios 3 and 4 are those with regional trade bans in place for beef from the north and south zones, respectively. Base case represents the scenario where no disease outbreak occurs.

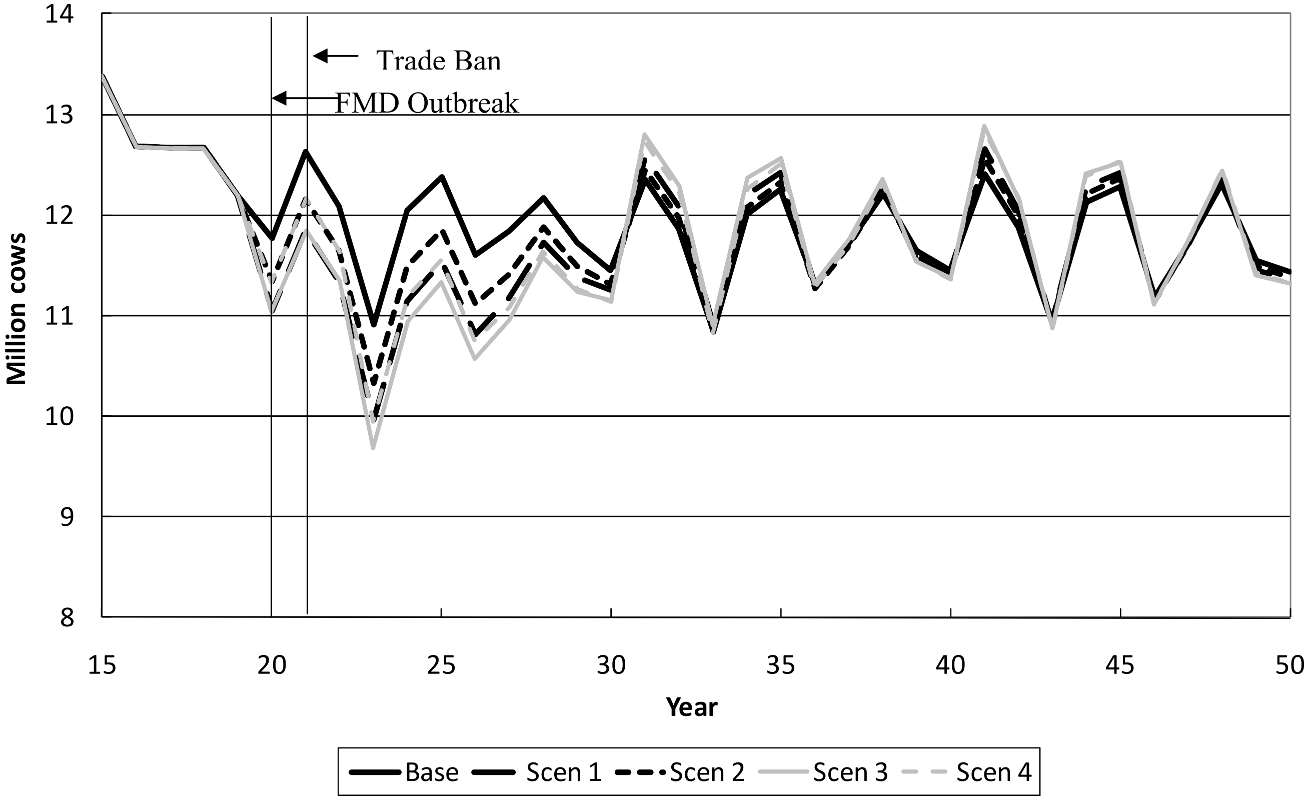

Figure 2: Carcase beef market price in dollars per kilogram in an FMD outbreak for Scenarios 1, 2, 3 and 4, with a constant depopulation rate of 90 per cent. Scenario 1 and 2 are those with uniform trade bans in place. Scenarios 3 and 4 are those with regional trade bans in place for beef from the north and south zones, respectively. Base case represents the scenario where no disease outbreak occurs.

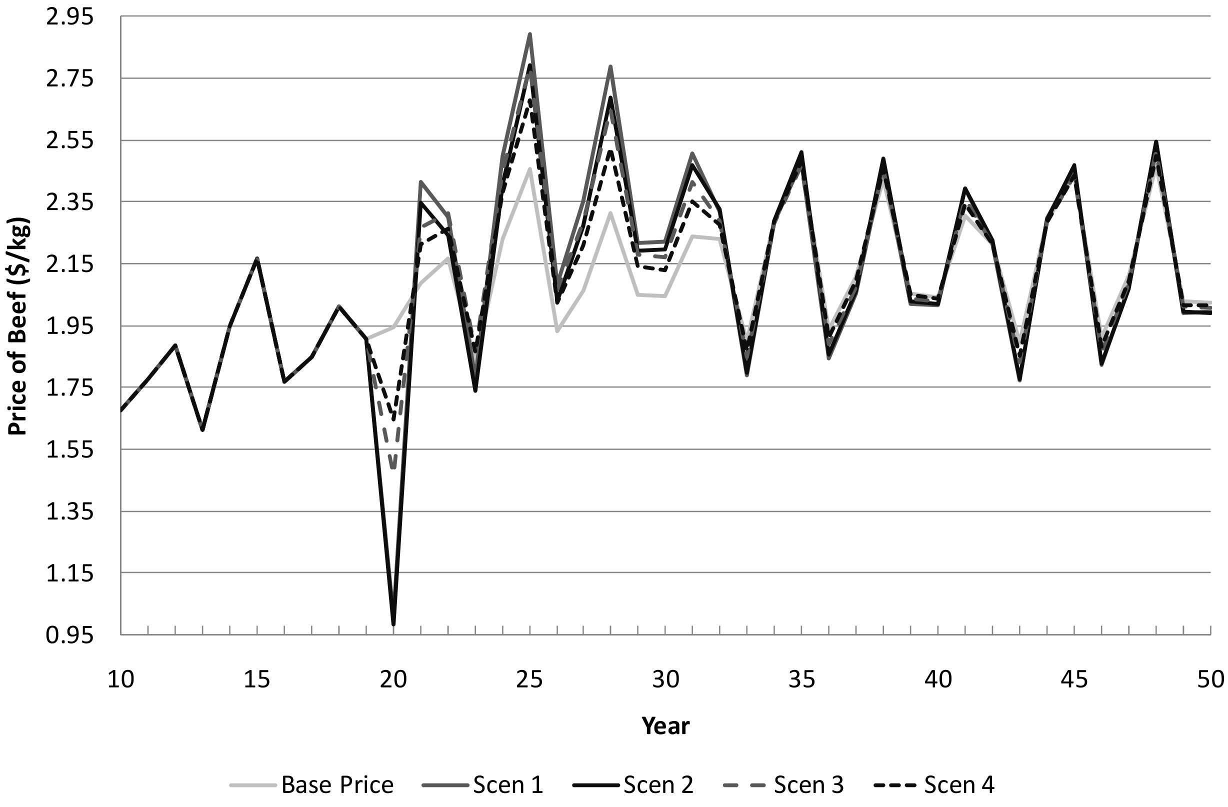

Figure 3: Discounted producer, consumer and total economic surpluses in each year for Scenarios 3 and 4. Discount rate = 9 per cent.

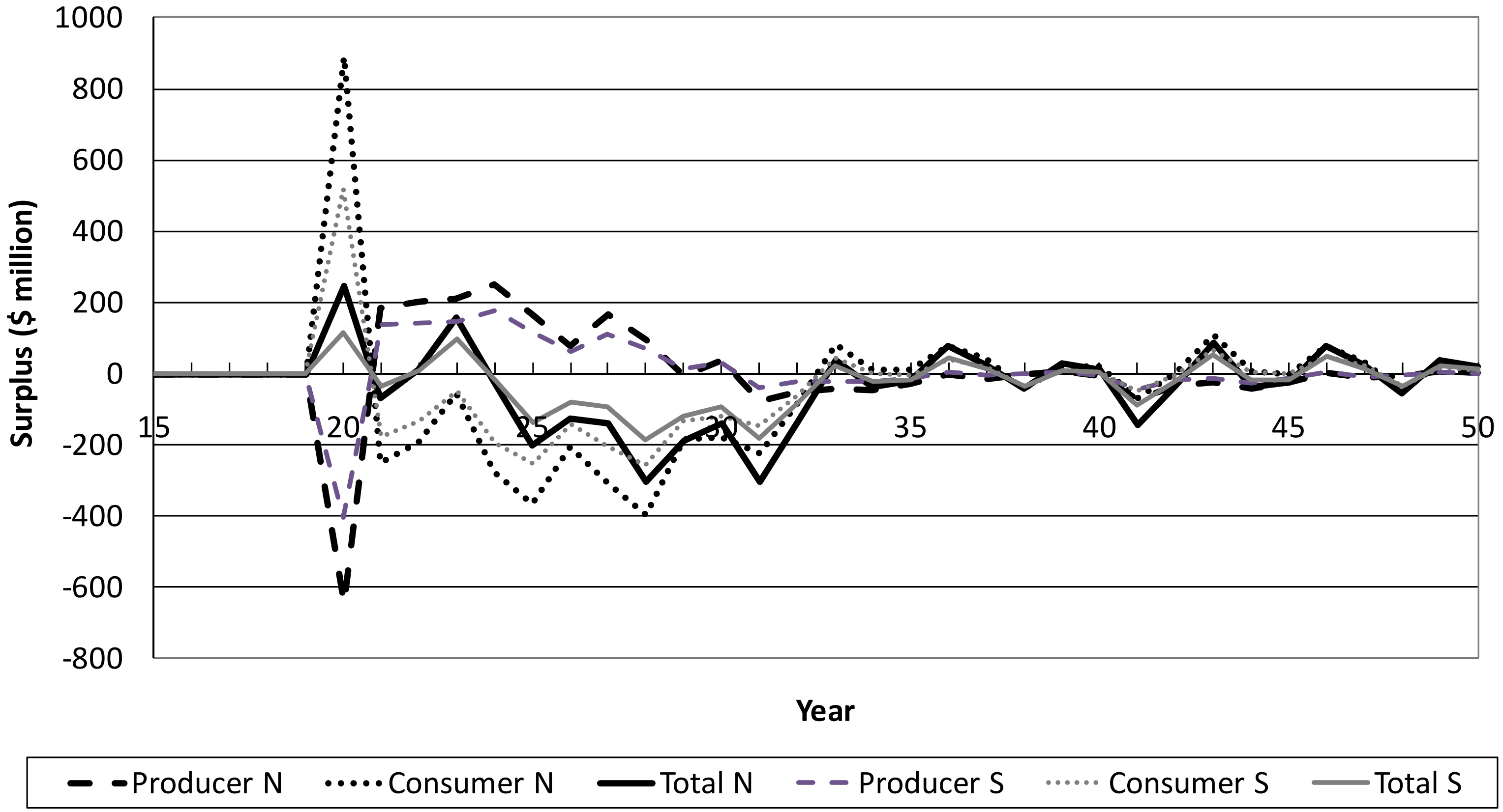

Figure 4: Cumulative discounted producer, consumer and total economic surpluses for Scenarios 3 and 4. Discount rate = 9 per cent.

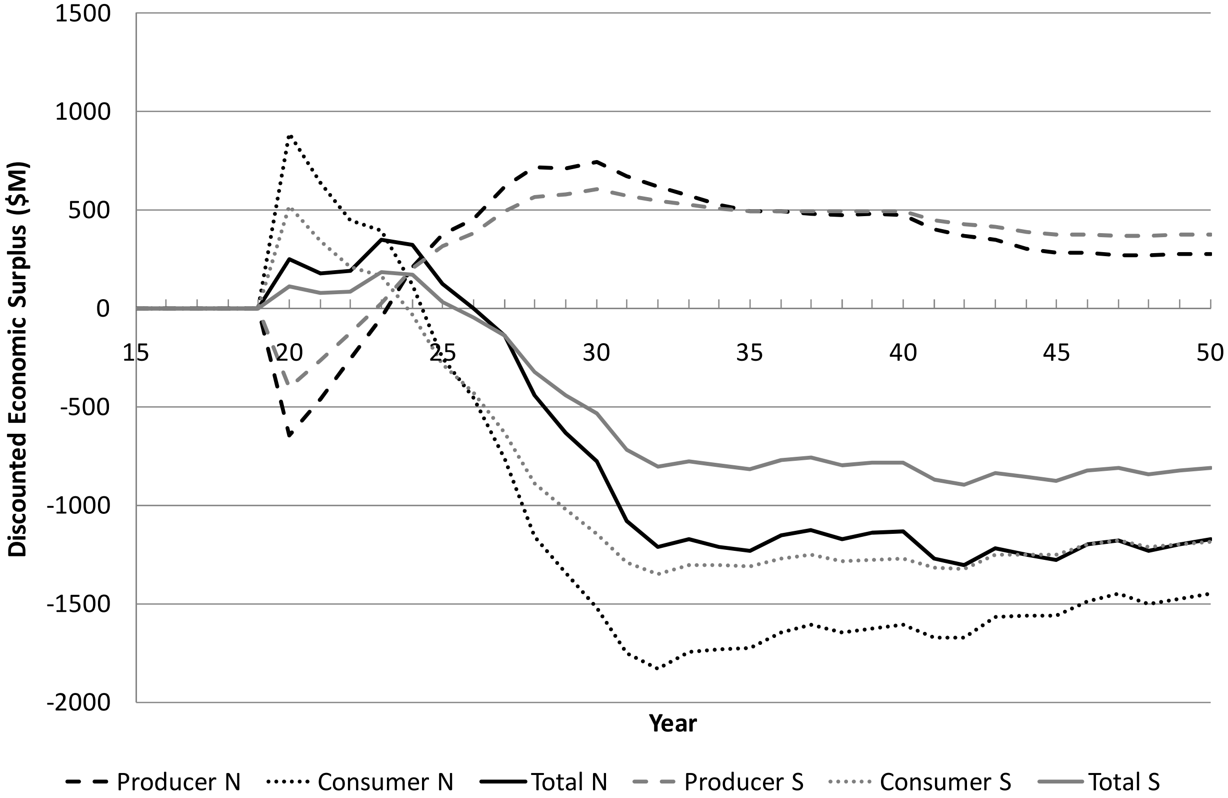

Figure 5: Domestic and trade impacts of foot and mouth outbreak on demand for Australian beef in Australia, USA, Japan, Korea and Indonesia based on Scenarios 3 and 4.

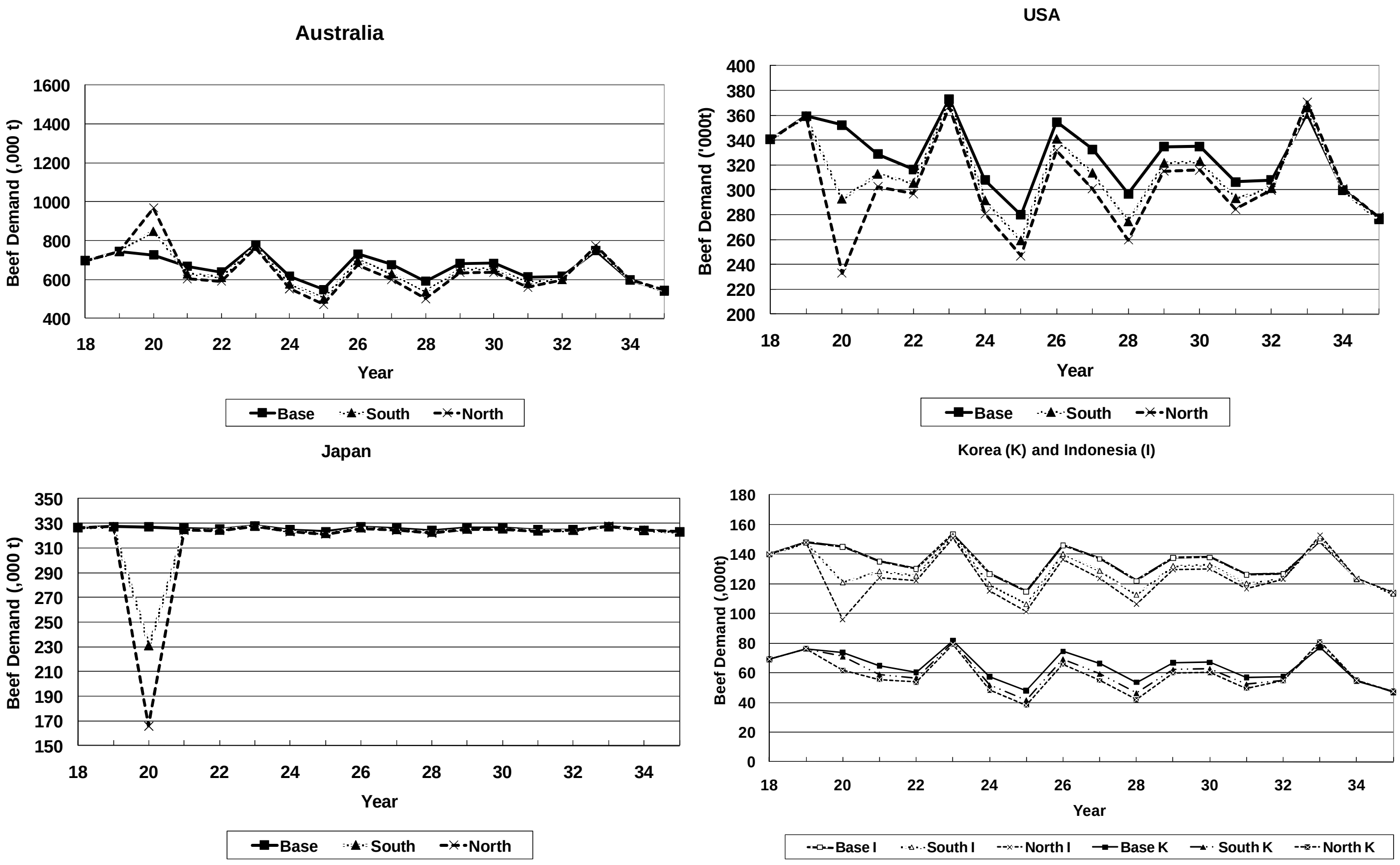

Figure 6: Domestic and trade impacts of foot and mouth outbreak on demand for Australian beef in Australia, USA, Japan, Korea and Indonesia based on Scenarios 1 and 2.