



## ORIGINAL ARTICLE

# Economic benefits of implementing trading zones for Australian livestock disease outbreaks of limited duration

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**Objective** The objective is to estimate the economic benefits of trading zones as part of foot-and-mouth disease (FMD) control measures for limited duration outbreaks.

**Design** The proposed trading zones for FMD at the state level are determined using multiple tools. Eleven individual incursion scenarios in six Australian states are simulated within the Australian Animal Disease Spread epidemiological model to identify the potential geographic extent of outbreaks, as well as the number of animals infected and the duration of outbreaks. The disease spread information is used to identify the boundaries of trading zones. The outbreak duration data are combined with historical export data to estimate the share of Australian exports that could be embargoed. The market impacts of the potential export embargoes including changes in equilibrium quantities, prices and revenue are simulated within the Australian Bureau of Agricultural and Resource Economics and Sciences' AgEmissions partial equilibrium model of Australian agriculture.

**Results** Results emphasize the importance of jurisdictional and outbreak characteristics in determining trading zones. Should Australia effectively implement trading zones at the state level in response to small FMD outbreaks, the potential reductions of embargoed exports lead to a reduction in estimated producer revenue losses compared with losses under a national embargo. Producer revenue losses are reduced between \$3 billion and \$9 billion estimated in present value terms over 10 years at a 7% discount rate.

**Conclusion** Economic analysis of the implications of trading zones identifies additional investments that would be of value to livestock industries.

**Keywords** implementation resources; livestock disease; trading zones

**Abbreviations** AADIS, Australian Animal Disease Spread Model; FMD, foot-and-mouth disease; OIE, World Animal Health Organization

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Implementation of trading zones in managing livestock disease outbreaks has the potential to markedly reduce the economic impact of trade restrictions placed on countries.<sup>1–5</sup> Although labelled over the past 30 years with multiple terms, such as regionalization, compartmentalization and containment zones, trading zones essentially involve the establishment of areas within a country, which are considered of negligible risk of transmitting disease through livestock and livestock product shipments to other areas of the country or internationally.<sup>6</sup> Creation and recognition of livestock and livestock product trading zones have most often occurred through bilateral arrangements between exporters and their importing customers. Earlier efforts tended to document subnational areas as eligible to trade based on the absence of disease through formal agreements, such as the progression of South American exporters Argentina and Brazil through foot-and-mouth disease (FMD)-free stages: first involving regions practicing vaccination and then regions without vaccination. More recently, subnational trading zones are increasingly being implemented based on the presence of livestock disease in an ongoing outbreak. For example, the Netherlands applied trade zoning after vaccination was used to control their 2001 FMD outbreak.<sup>7</sup> Additionally, the importer response to the large 2015 outbreak of highly pathogenic avian influenza in the United States saw 3 embargoes imposed at the national level, 13 at the state level and 6 at the county level.<sup>2</sup> Some of these trading zones were established under pre-existing bilateral arrangements encouraging subnational levels of embargoes to be put in place where there was negligible disease risk, but most occurred through importing countries' decision-making in the first weeks of the outbreak.

World Organization for Animal Health (OIE) guidelines for a specific form of trading zone allow what is called a 'disease containment zone' to be established, such that uninfected areas may continue to trade in international markets (Article 4.3.7).<sup>8</sup> Bilateral partners are not directly involved in the establishment of a containment zone. Their success depends on importers accepting and following the OIE guidelines as implemented by the exporting country. In 2018, Ausvet Pty Ltd, a commercial consultancy company, completed a report for the Australian Department of Agriculture and Water Resources detailing the potential for establishing

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containment zones for livestock disease outbreaks in Australia. The report recommended ‘implementation of a containment zone would be highly desirable when the extent of ... (a FMD or classical swine fever) outbreak is well understood’.<sup>9</sup>

This paper estimates the potential economic benefits of Australia establishing trading zones in response to a highly infectious livestock disease. Using foot-and-mouth disease as an example, a hybrid of bilaterally established trading zones and the OIE containment zone approach is modelled with 11 disease incursion scenarios from across Australia.

Materials and methods

**Epidemiological modelling inputs into economic analysis**

This economic analysis is based on outputs from previously reported epidemiological model development exploring the extent of potential FMD outbreaks in Australia<sup>10</sup> and historical trade data. Figure 1 labels and details 11 incursion scenarios, selected through jurisdiction and industry stakeholder consultations, which were simulated. Each differs in terms of the set of circumstances leading to the introduction of the virus: time of the year, livestock species, type of seed herd, mode of infection, as well as any delays in detection. The epidemiological Australian Animal Disease Spread (AADIS) model version 2.42 was used to simulate the spread of FMD both within and between herds for these 11 possible incursions.<sup>11</sup> The herd dataset used in the AADIS-FMD model is derived from a blend of agricultural census data, industry reports and expert opinion. It has 240,000 herds with more than 100 million animals. The various livestock

production systems included are beef cattle, dairy cattle, meat sheep, wool sheep and pigs.

The spread of disease between herds is modelled with a stochastic and spatially explicit agent-based approach. The herd agents interact in a model environment that stochastically spreads disease across multiple spread pathways such as direct contacts, indirect contacts, saleyard spread, airborne transmission and local spread. Details of the AADIS-FMD spread pathways can be found in Bradhurst et al.<sup>11</sup> Regional heterogeneity is allowed in disease transmission parameters drawn from the literature, along with jurisdictional variations in control measures and response resourcing based on jurisdictional questionnaires. This offers flexibility to model different outbreak conditions and control measure combinations.

Using each of the 11 herds selected by jurisdictional representatives to be seeded for disease, an initial set of 30–50 runs of the model for 21 days of silent disease spread generated snapshots for the simulations. The run deemed to best represent disease progression consistent with the incursion scenario description was selected, and the population infection state at the end of the simulation is saved. The use of snapshots ensures alternative control strategies can be compared from an identical starting point when the disease is first detected, and control measures commence. The snapshots then become the starting points for running 500 stochastic realisations of each of the 11 incursion scenarios, with model parameter values randomly drawn from accepted specified ranges from the literature.

The initial control strategy simulated comes from the AUSVETPLAN,<sup>12</sup> and includes movement controls, stamping out of infected herds,

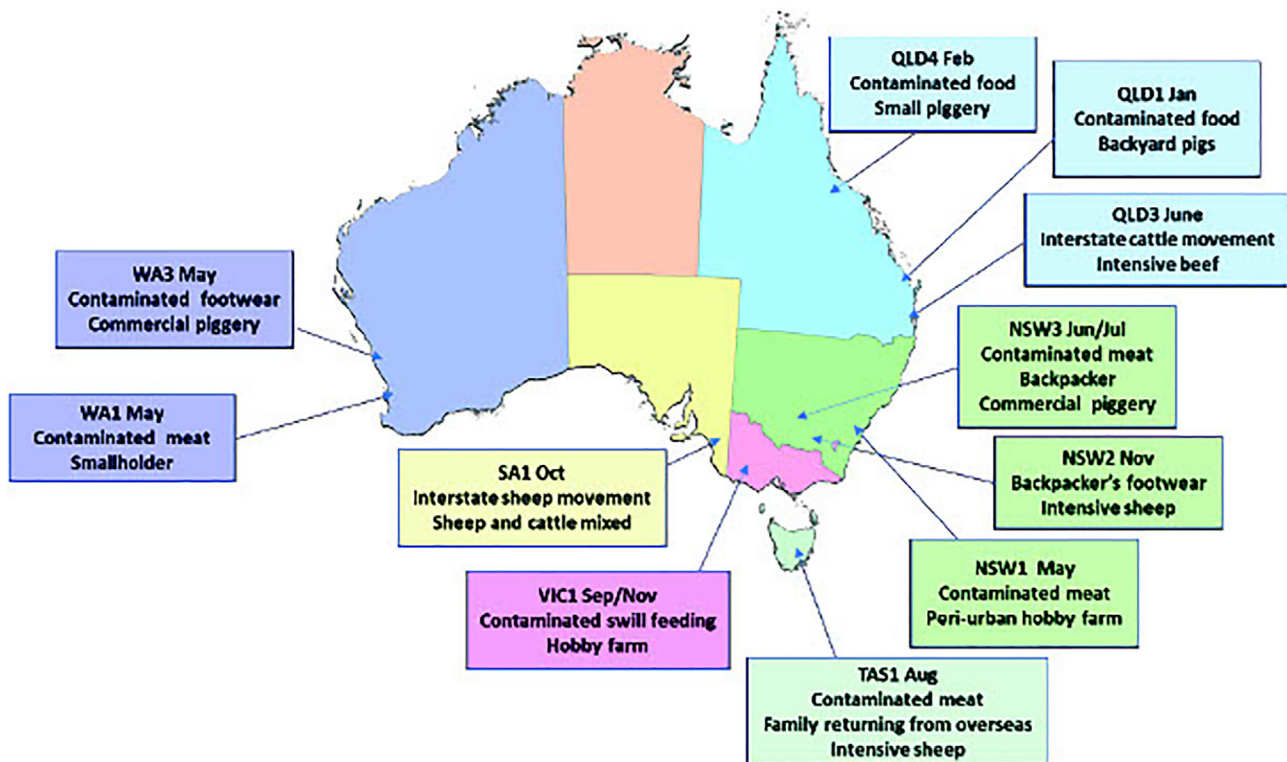


Figure 1. Foot-and-mouth disease incursion scenarios.

appropriate disposal, cleaning and disinfection, and surveillance of susceptible domestic populations. Additional simulations of control strategies included depopulation of dangerous contact herds and alternative targeted vaccination programmes to the stamping-out response. The vaccination strategies were less effective than applying a traditional stamping-out approach for controlling the 11 small incursion scenarios included here.<sup>10</sup> Only the stamping-out control option results were used as inputs into the economic analysis presented in this paper. Separate economic analyses were undertaken for one additional incursion scenario in Victoria where much larger outbreaks were simulated by AADIS, and multiple vaccination strategies led to statistically significant reductions in duration and animals culled. These will be reported at a later date.

Four AADIS epidemiological model outputs provided information for determining inputs into the model estimating economic impacts for this paper: number of animals culled; number of farms where culling took place; day of last cull; and the geographic extent of the outbreaks simulated. A decision was made to use the results at the 75th percentile to capture the higher end of the economic impacts of these potential outbreaks. The incursion scenarios under the stamping-out control strategy alone all yielded limited numbers of animals culled in short outbreaks. The number of animals culled due to disease did not exceed 26,000 animals (Table 1), and the number of farms where culling took place was below 42 at the 75th percentile. Because the model results for the number of animals culled in disease control activities are small (less than 1% of Australia's annual slaughter), no production disruptions, or shocks, due to disease were included as inputs to the economic model.

Trade disruptions, or shocks, are included as two phases. Initially, the trade shocks introduced into the economic model consist of a 14-day national export embargo on susceptible livestock and their products expressed in livestock product equivalents. This is assumed to occur for animal health authorities to evaluate the status of the outbreak, with the first 3 days coinciding with a national livestock standstill as mandated in the AUSVETPLAN.<sup>13</sup> This assumption is

based on Garner et al<sup>14</sup> and Willeberg et al,<sup>15</sup> who looked at early decision indicators for management of FMD outbreaks in nonendemic countries. Their modelling results show that 79%–97% of outbreaks were correctly classified as small or large outbreaks at day 14 after detection.

To calculate the second phase of trade shocks, days of last cull and the extent of geographic spread for the 75th percentile from the AADIS model are combined with historical export trade recovery data from FMD-affected countries to design trading zones that Australia could consider. For all incursion scenarios, the day of last cull was under 37 days at the 75th percentile of the range (Table 1). Figure 2 displays the simulated geographic extent of disease spread by showing the number of times a herd is found to be infected over the 500 stochastic realisations when the stamping-out policy is applied to the 11 incursion scenarios defined in Figure 1. At the 75th percentile, represented by the black and red dots, geographic spread to a second state only occurs for incursion scenario QLD3, with New South Wales also affected. Therefore, from day 15 after detection, trading zones are set at single state borders for all but this one scenario where the two states of New South Wales and Queensland form the affected trade zone. Although OIE containment zone guidelines allow an infected zone and a protection zone to be set at much tighter boundaries than the state borders assumed here, a conservative approach to importers' reactions was adopted by assuming the trading zones fall at the state border. This assumption also corresponds to legislative responsibility for animal disease control being held at the state and territory levels in Australia as well as the state level being the lowest jurisdictional level for which consistent export statistics across Australia can be obtained.

The trading zones formed by the affected state(s) remain fully in place from day 15 until the last day of cull, plus a 90-day waiting period for the declaration of return-to-disease freedom in accordance with OIE guidelines (Table 1). No additional time was added to export recovery for the small FMD outbreaks found in the 11 incursion scenarios presented in this paper, based on an

**Table 1.** Australian Animal Disease Spread epidemiological modelling results under stamping-out control strategy

| Incursion scenario | Quarter of outbreak beginning | Number of animals culled 75th percentile | Day of last infected premises 75th percentile | Day of last cull 50th and 75th percentile |      | Return to trade 75th percentile (day of last cull plus 90 days) |
|--------------------|-------------------------------|--|---|---|------|---|
|                    |                               |  |   | 50th                                      | 75th |   |
| NSW1               | Qtr2                          | 1097                                     | 15  | 18  | 20   | 110   |
| NSW2               | Qtr4                          | 1858                                     | 9   | 12  | 12   | 102   |
| NSW3               | Qtr3                          | 23,029                                   | 17  | 21  | 23   | 113   |
| QLD1               | Qtr1                          | 777                                      | 13  | 20  | 21   | 111   |
| QLD3               | Qtr3                          | 8973                                     | 26  | 29  | 37   | 127   |
| QLD4               | Qtr1                          | 6632                                     | 8   | 12  | 13   | 103   |
| SA1                | Qtr4                          | 16,520                                   | 12  | 17  | 21   | 111   |
| TAS1               | Qtr3                          | 4995                                     | 14  | 18  | 20   | 110   |
| VIC1               | Qtr4                          | 2001                                     | 9   | 11  | 11   | 101   |
| WA1                | Qtr2                          | 9848                                     | 27  | 30  | 36   | 126   |
| WA3                | Qtr2                          | 25,279                                   | 18  | 22  | 24   | 114   |

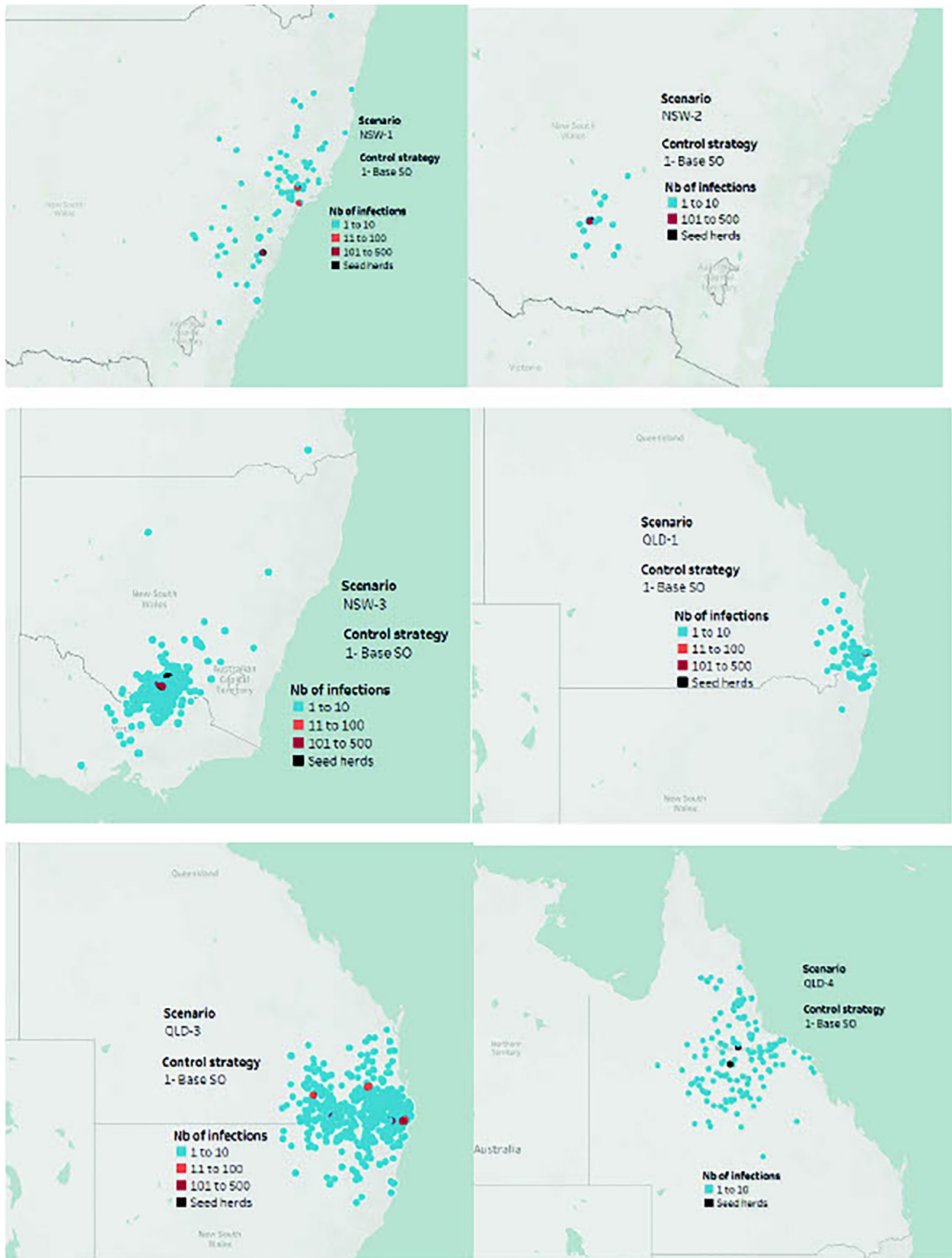


Figure 2. Total number of times a herd has been infected through 500 runs.

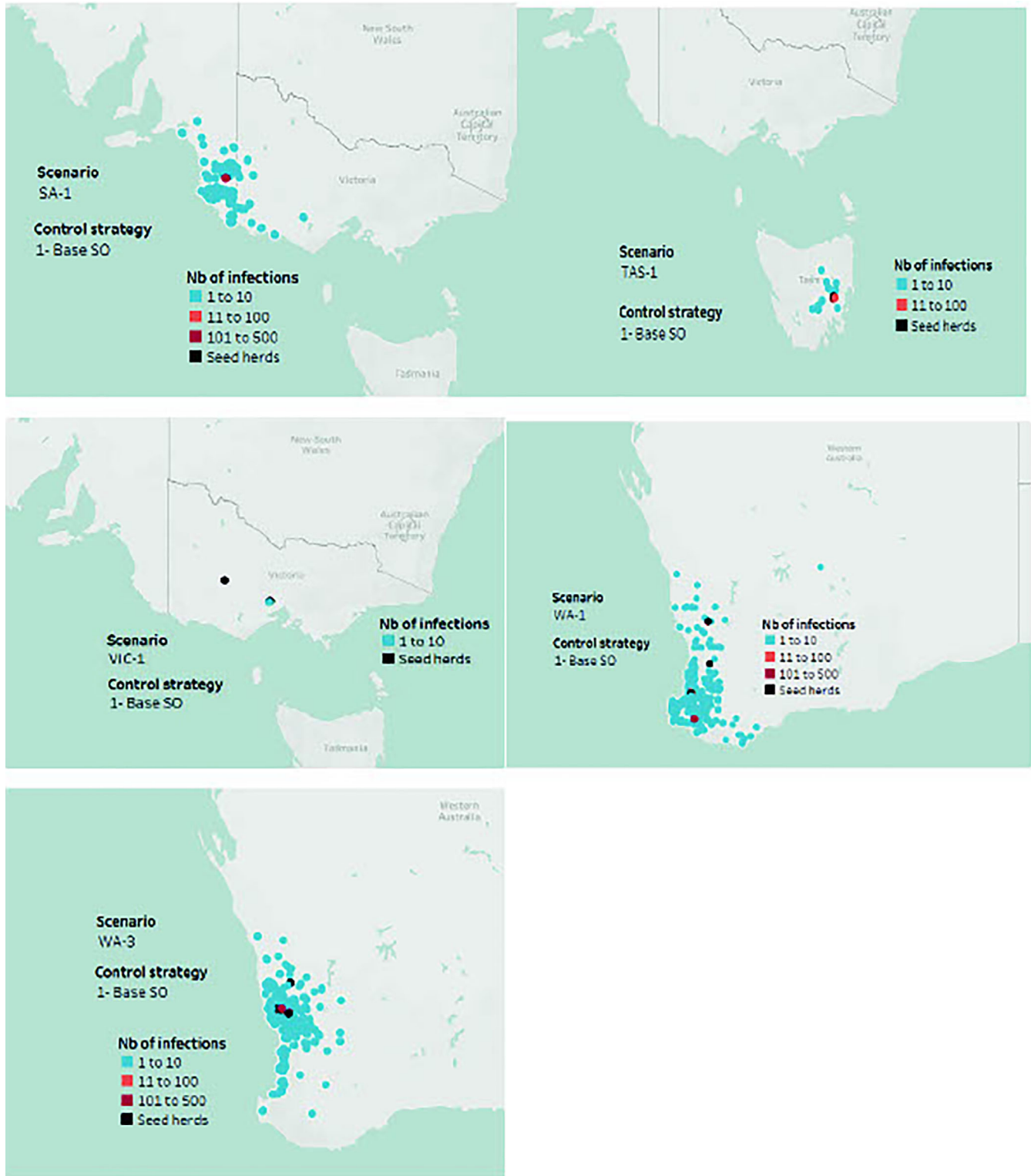


Figure 2. (Continued)

examination of export recovery from historical outbreaks of FMD. As an example, the United Kingdom, a country that was free from FMD without vaccination, experienced an outbreak in mid-2007,

which lasted 2 months. The value of trade recovered to a 4-month moving average of preoutbreak levels in 4 months. Across all the susceptible livestock species, the average minimum level of trade

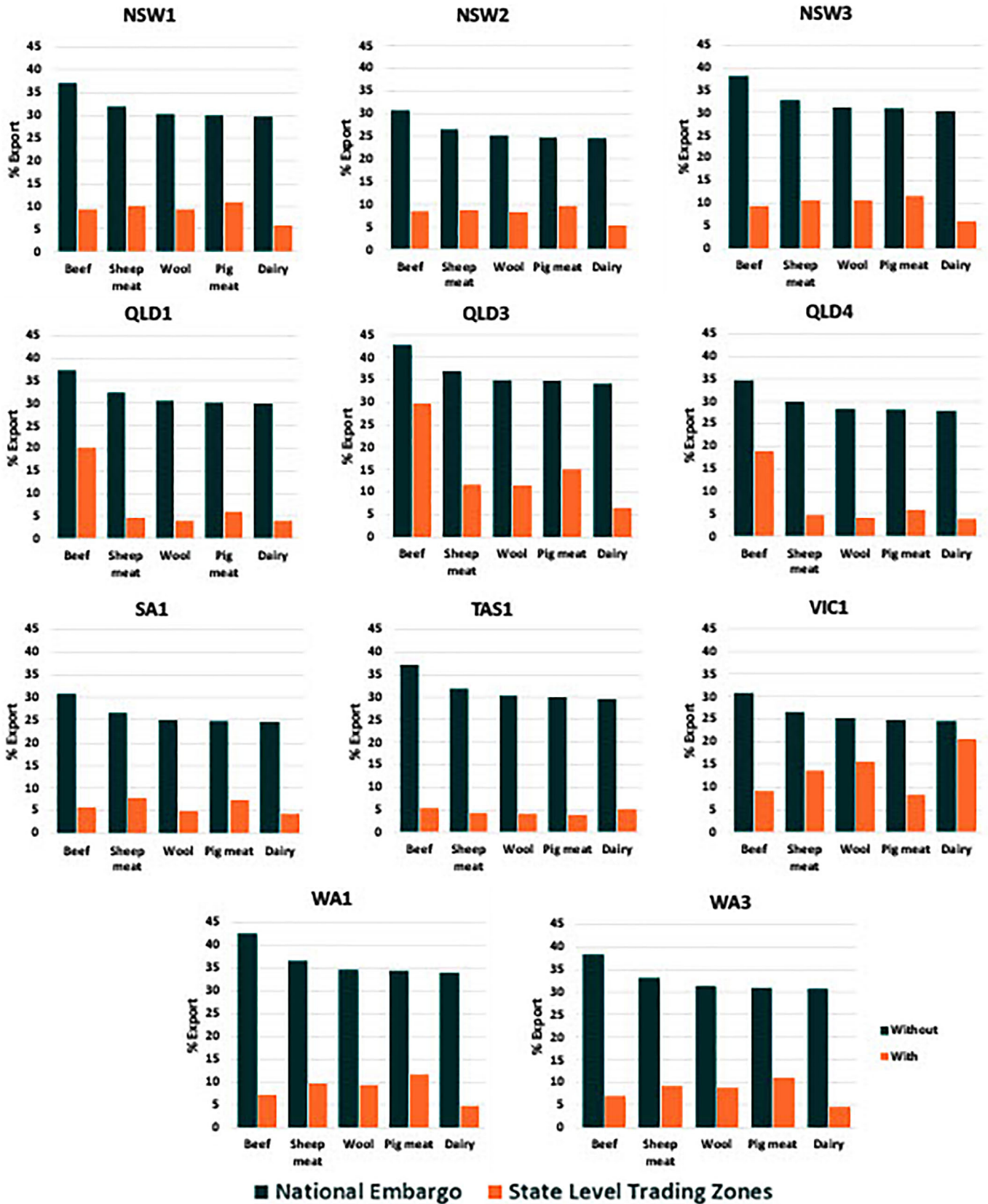
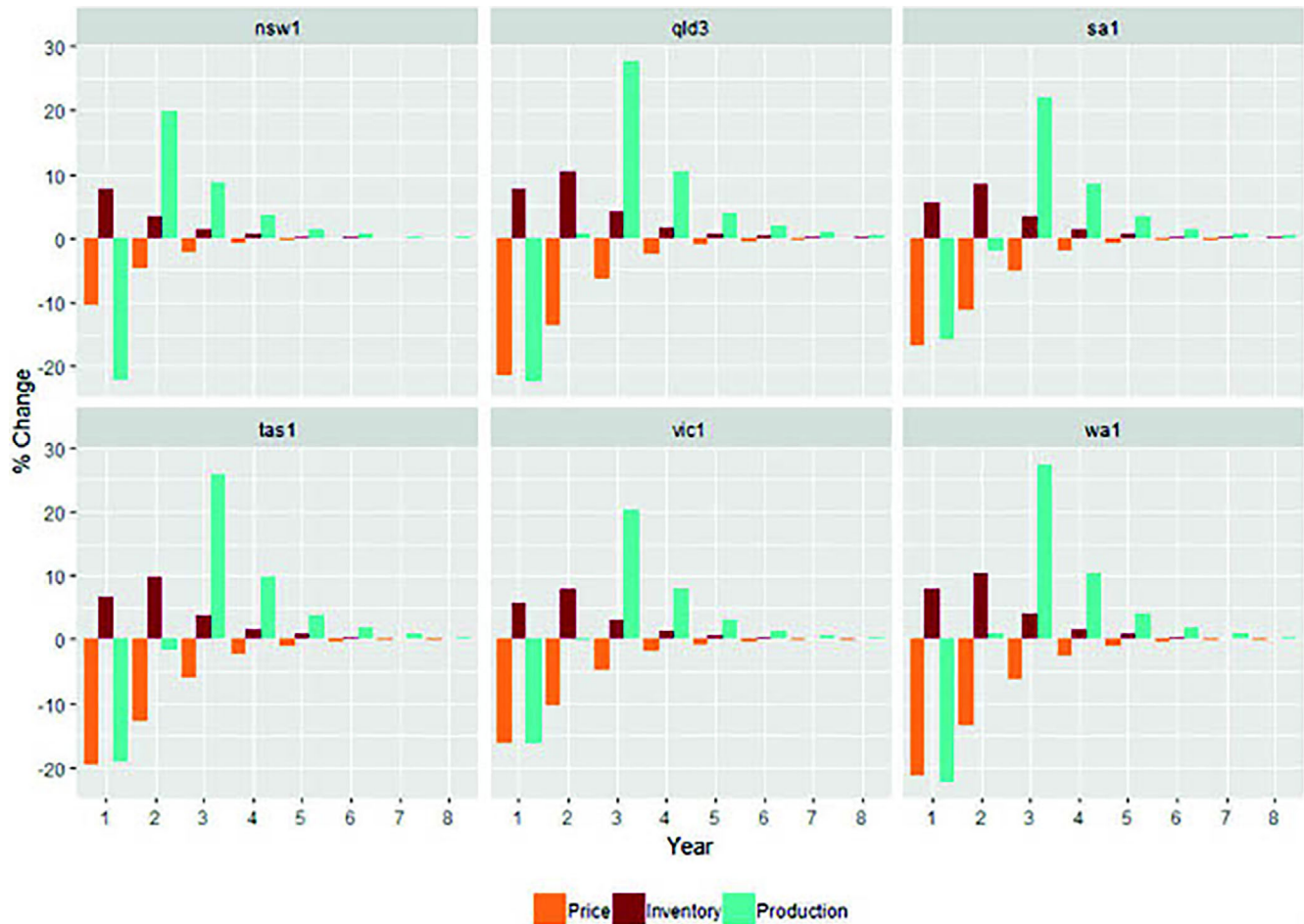


Figure 3. Annual percent reductions in exports by commodity under national embargoes and under state level trading zones.



**Figure 4.** Beef market response to reduction in exports as simulated in AgEmissions model in a sample of incursion scenarios. x-Axis denotes time (measured in years) elapsed since the detection of the outbreak.

after the beginning of the outbreak was between 32% and 39% of preoutbreak trade values. A check of whether and the extent to which importing countries ever returned to preoutbreak trade levels revealed fewer than 10 low-value markets failed to return to trade with the United Kingdom.

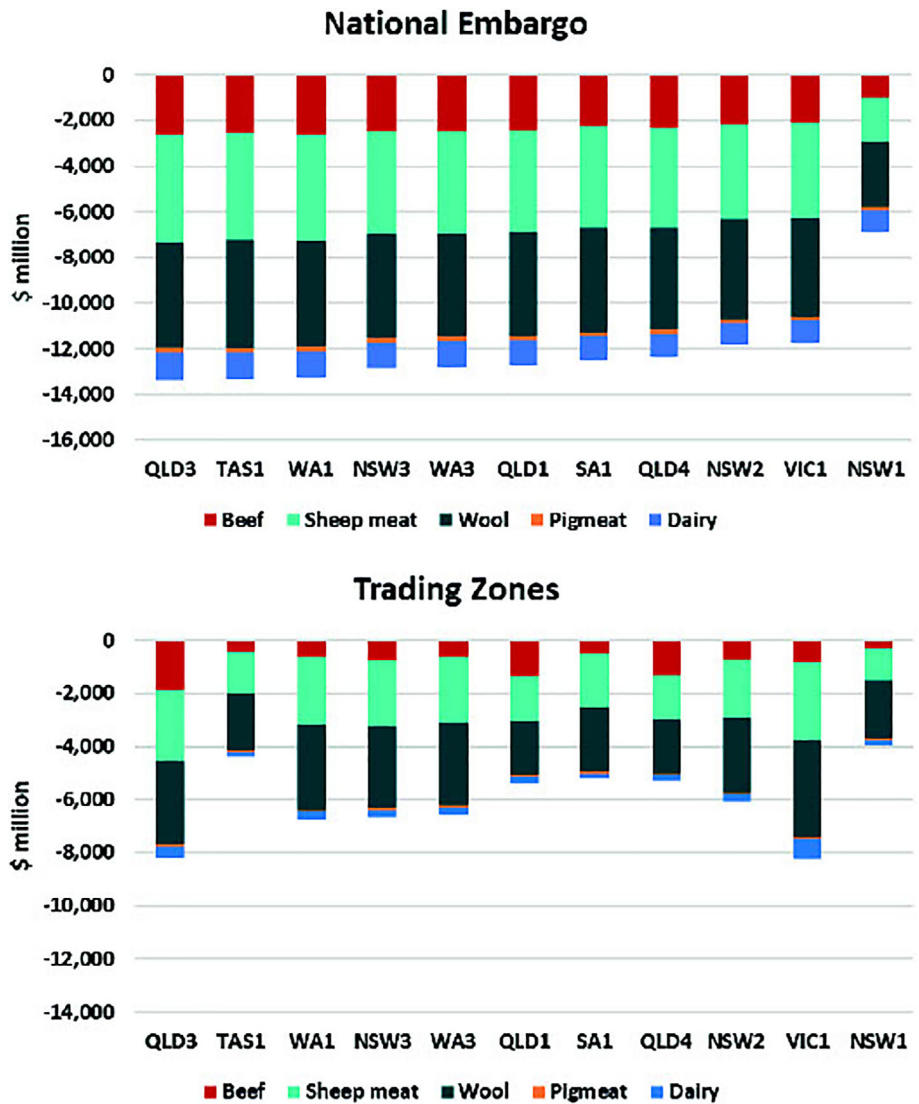
The calculated length of embargoes for different zoning areas from Table 1 are applied to average quarterly Australian state level livestock and livestock product exports from 2016 to 2018 to determine the percent of product equivalent national trade that occurred from each state to each importing country for the Harmonized Tariff 4- and 8-digit codes (Table S1).<sup>16</sup> These percent changes are the trade shock input for the economic model applied to beef, sheep meat, wool, pig meat and dairy products. Using quarterly data allows some recognition of regional and seasonal trade patterns specific to the quarter in which the incursion scenario is set to occur. However, the severity of the impact of a localized livestock disease outbreak felt over a short period is dampened with the introduction of the resulting trade shock in an annual economic model such as AgEmissions. Also, trade from uninfected states is assumed to be able to access current or alternative ports for shipment of their product.

**Partial equilibrium economic model**

The percentage reductions in exports are assumed to reflect export trade demand shocks. These shocks are inputted to an agricultural sector partial equilibrium economic model of Australian feed and livestock markets known as AgEmissions,<sup>17</sup> which has a base year of 2017/2018. It estimates the potential decline in the gross value of production of the livestock industries due to an FMD outbreak. In effect, the economic impact presented here measures the financial impact on producers of large quantities of previously exported product remaining in the domestic market, causing a decline in domestic prices and, in turn, supply. This contrasts with other economic measures of impact, which are typically calculated as a change in export revenue.<sup>18</sup>

Important characteristics of the economic model are described in Buetre et al<sup>17</sup> as follows:

- 1 AgEmissions is a forward-looking model that projects the annual volume of agricultural commodities produced, by state, and consumed domestically, [net] quantities traded with the rest of the world and the national price that balances regional supplies with domestic and export demand for each commodity.



**Figure 5.** Comparison of impacts on gross value of production. Present value over 10 years estimated at 7% discount rate.

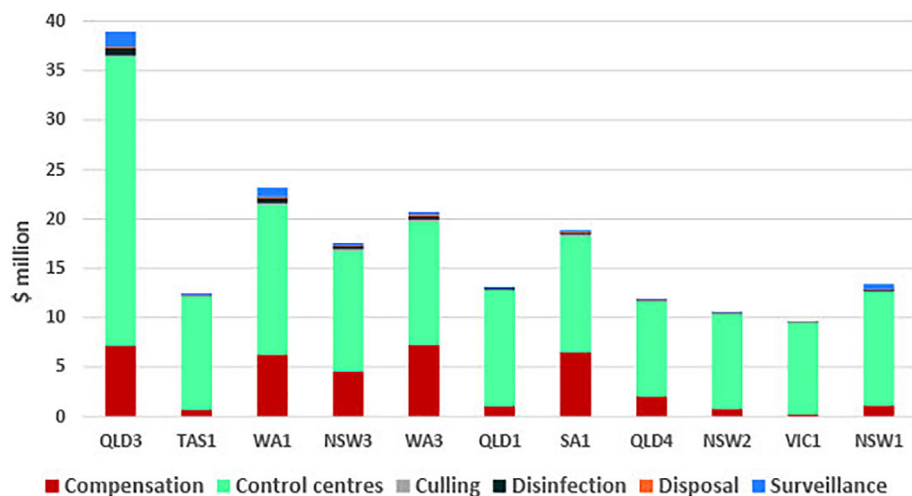
**Table 2.** Change in gross value of production<sup>a</sup> relative to the national embargo scenario as a measure of benefits from trading zones during livestock disease outbreaks

| Scenario | Trading zones gains (\$ million) |
|----------|----------------------------------|
| QLD3     | 5223                             |
| TAS1     | 8950                             |
| WA1      | 6540                             |
| NSW3     | 6146                             |
| WA3      | 6213                             |
| QLD1     | 7339                             |
| SA1      | 7322                             |
| QLD4     | 7073                             |
| NSW2     | 5758                             |
| VIC1     | 3507                             |
| NSW1     | 2925                             |

<sup>a</sup> Present value over 10 years estimated at 7% discount rate.

- AgEmissions also contains animal inventory constraints to determine the annual size of livestock herds and the number slaughtered annually in each state. Land resource constraints limit land used for cropping and grazing activities, whereas feed constraints limit diversion of coarse grains to animal feed.
- Inverse demand functions for each commodity are specified as a function of real gross domestic product (income), an index of real prices and the quantity of commodity consumed each year. The marginal cost of producing a commodity is a function of the quantity of the commodity produced and the opportunity cost of land required in production.
- The forward-looking feature in AgEmissions allows for adjustments in livestock herd numbers to meet long-run equilibrium conditions. The feature assumes that producers have perfect information regarding the future state of Australian agricultural production systems and the behaviour of their trading partners. This allows producers to make decisions each year that aim to generate maximum profits in the long term.





**Figure 6.** Governments outbreak response costs at the 75th percentile, without trading zone implementation costs.

The AgEmissions estimates with and without trading zones are compared to examine the avoided economic losses resulting from the application of trading zones. The avoided losses can be used to guide decision-making on whether investment in the implementation of trading zones is warranted. Avoided losses are compared with the additional response costs beyond those incorporated in AADIS estimates necessary to defend the zones.

### Results

Figure 3 compares the results of calculating percent reductions to annual Australian exports, by commodity, for the incursion scenarios defined in Figure 1 under the trading zones described above. The percent reductions assume this trade policy is implemented instead of a national embargo. Potential reductions in the extent of the applied embargoes should Australia effectively implement trade zoning in this manner range from approximately 20% to 80%.

Figure 4 shows the impact of export demand shocks introduced into the AgEmissions model without trade zones, as demonstrated by the percent change in beef prices, inventories and production from a no-disease base. Initially, price falls due to previously exported livestock products remaining in the domestic market exceeding any reduction in production from culling. Knowing that export shocks are only short-lived, and prices will recover due to the assumption of perfect foresight in AgEmissions, farmers would initially reduce slaughtering (production), thereby adding to animal inventory when export shocks are introduced. Then inventory is slowly run down with slaughtering (production) and price recovering over time. All three variables gradually converge back to the long-term equilibrium, in line with the livestock species' biological cycles. Again, this assumes that each industry is forward-looking, and production adjustments are optimal due to perfect foresight.

Impacts appear in Figure 5. Losses in producer returns (as measured by producer revenues) are between \$7 billion and \$13 billion under a national embargo estimated in present value terms at a 7% discount rate (PV10-7%). Those losses are reduced to between \$4 billion and \$8 billion under trading zones. This reduction in losses ranges between 21% and 80% for the 11 incursion scenarios. The

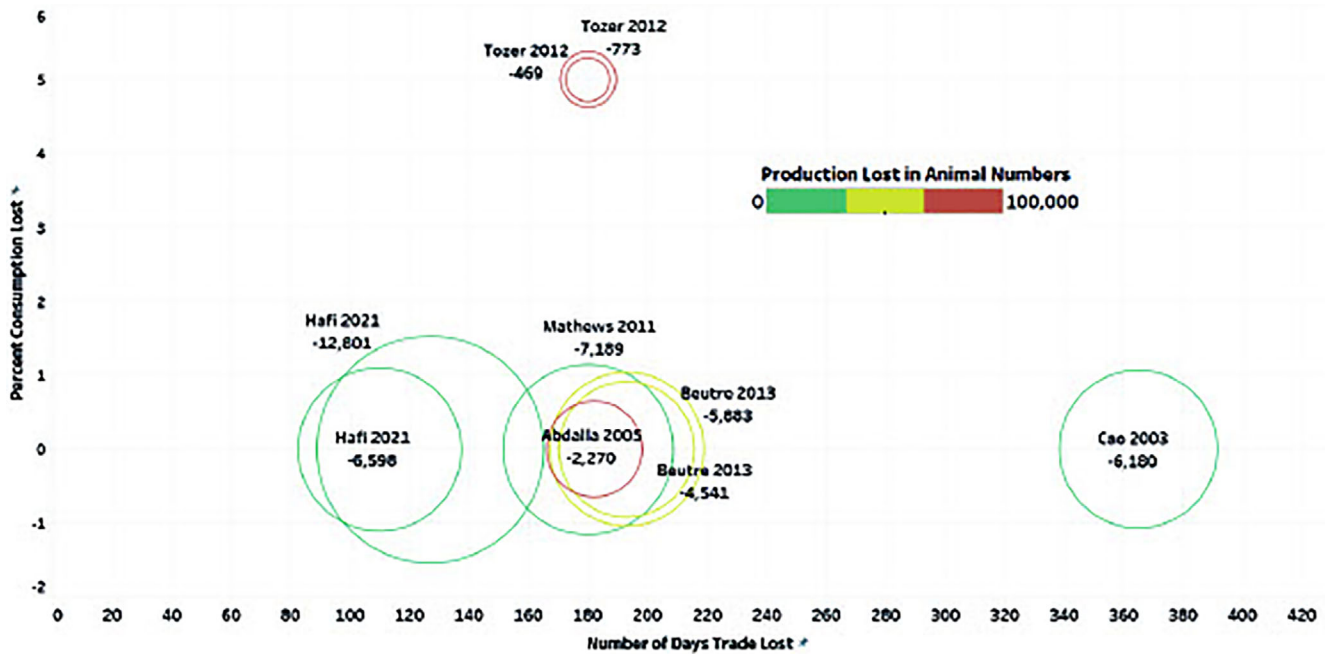
average reduction in losses is highest for dairy at 72%, followed by beef at 63%. Pig meat's average potential losses are reduced by 64%, with losses to sheep meat 49% less and wool 38% less.

The potential gains from trading zones are calculated from the difference between the estimated impacts of the national embargo scenario without trading zones and the scenario with trading zones. The loss in revenue (PV10-7%) decreases by almost \$3 billion for the NSW1 incursion scenario in a hobby farm in the Sydney basin and by almost \$9 billion for the TAS1 incursion scenario in a sheep farm in the Tasmania southern highlands (Table 2). Adjusting these results for a probability of disease entry into Australia of 1 in 50 years,<sup>19</sup> the range of potential gains from trading zones is estimated between \$60 million and \$180 million (PV10-7%).

In addition to the economic impact of trade restrictions estimated by the AgEmissions model, government outbreak response costs – which do not include costs of implementing trading zones – are calculated in AADIS for the individual incursion scenarios and are reported in Figure 6. Control centre costs dominate, accounting for 60% or more of expenditures, which range from \$9.4 million to \$29.3 million. Compensation costs to producers for depopulating livestock are the second highest, ranging from \$226,000 to \$7.2 million. Outbreak surveillance costs are between \$29,400 and \$1.5 million. Therefore, even for the smaller outbreaks in the 11 incursion scenarios, it is evident that total response costs would start at approximately \$10 million for VIC1, a limited hobby farm incursion, and rise to around \$38 million for QLD3, an intensive beef cattle farm incursion.

### Discussion and conclusions

An outbreak of FMD in Australia will result in large costs to both producers and the government. How such an outbreak is managed from the outset has a substantial impact on the economic outcome. Figure 7 provides estimates of the economic impact on producers of stamping out alone from five previous Australian studies,<sup>17, 20-23</sup> which occurred between 2003 and 2013. In these studies, the producer losses for small FMD outbreaks controlled by stamping



**Figure 7.** Estimates of producer economic impacts from potential foot-and-mouth disease outbreaks in Australia under stamping out alone (2015 million dollars). Abdalla and Cao estimates are for beef only. *Source:* References 17, 20–23

out alone and met with embargoes at the national level are estimated to be between \$0.5 billion and \$7.2 billion (PV10-7%) in 2015 dollars as indicated by the size of each study's circle. These impacts are at the lower end of the estimates of this paper, which range from \$6.6 billion to \$12.8 billion (PV10-7%) in 2015 dollars even though the lengths of national export embargoes are at least 2 months shorter than the previous studies. This discrepancy is in part explained by higher livestock and livestock product export value between 2016 and 2018 of \$21.0 billion to \$24.7 billion compared with \$14.9 billion to \$21.3 billion between 2003 and 2013, both calculated in 2015 dollars. Additionally, other things being equal, aggregate impacts on producers are smaller when larger numbers of animals in a particular outbreak site are culled due to disease, reducing the downward pressure on domestic average prices. More recent estimates based on epidemiological modelling predict smaller numbers of animals affected in the outbreaks than previous literature.

While Cao et al<sup>21</sup> and Abdalla et al<sup>20</sup> consider effects on only the beef market, they add estimates of the impact of zoning. They find reductions of 44% and 34%, respectively, in producer losses for a potential FMD outbreak with the implementation of zoning at the state level. This compares to the \$3 billion to \$9 billion (PV10-7%), or 42% to 69%, declines in producer losses under trading zones found in this paper for susceptible species and their products.

The distribution of this favourable outcome of trade zoning must be noted. Even for the limited outbreaks presented here, the benefits of trading zones would be concentrated in the uninfected states, which are able to return to trade, and they would sell more products at higher prices than they would under a national embargo. Embargoed states will sell less products and whether they benefit from higher

prices depends on the balance in their marketing position. If the infected state were a net exporter to domestic and international markets, prices would be expected to be even lower within the infected zone because products would be prohibited from both export and inter-state sale and would remain within the embargoed state. Permitted movement of negligible-risk-product within and outside of the trading zones could be considered as a means of mitigating the impact on the infected state. Extended application of permitted movement schemes could also be examined for addressing shipping bottlenecks that might arise for export products typically moving through infected state's ports. As trading zone implementation investments are considered, this uneven distribution in benefits indicates it may be desirable for some of the economic benefits in the uninfected zones to be shared with the infected state to support their response.

As is true in previous studies where both economic impacts and government control costs are presented, Australia's position as an exporter of a large percentage of its livestock and livestock product output leads to trade-related economic losses exceeding the costs of any government response. However, constraints on jurisdictional budgets require careful consideration of government response cost levels. Additional government costs not included in AADIS are involved in defending trading zones beyond those associated with the standard outbreak response. Ausvet Pty Ltd<sup>9</sup> lists the following categories that would entail increased costs:

- 1 Enhanced disease surveillance in the uninfected zones, such as
  - a Enhanced passive surveillance to support disease freedom status;
  - b Live export chain inspections on departure from the operation and at ports;

- c Abattoir ante- and postmortem inspections;
  - d PCR batch testing of exported product; and
- 2 Enhanced biosecurity along the entire supply chain.

There could also be the increased costs related to implementing a permit system for movement of livestock and livestock products within and between states, and internationally. These cost components are the subject of future work.

Epidemiological model simulations at the 75th percentile were used to incorporate the upper range of the smaller outbreak results from AADIS. To present a conservative estimate of the reduction in producer losses due to implementation of trading zones for a potential FMD outbreak, trading zone borders were set at the Australian state levels. Historical experience during outbreaks as well as OIE containment zone guidelines do allow borders to be set at narrower boundaries if disease control efforts merit this. In addition, a 100% reduction in livestock product export trade from the infected state level trading zone is assumed for the entire recovery period even though export recovery in historical outbreaks indicates less extreme impacts.

However, there is uncertainty in the literature about how long an exporting country such as Australia might be excluded from importing markets if an FMD outbreak occurs. In this analysis, following OIE guidelines for return-to-disease freedom, the time out of market is assumed to be 90 days after the day of last cull. This is a reasonable assumption for smaller outbreaks simulated in the study and based on export recovery times reported for similar outbreaks in other countries. Nevertheless, the results show the benefits of trading zones at the state level in Australia would still hold if the length of embargoes were increased beyond 90 days if even a portion of importers accept the state level, or even tighter areas, of negligible risk for spreading disease. Prior discussions with importing countries facilitate the implementation of trading zones from the beginning of an outbreak. A recent example of such a discussion occurred between Australia and Singapore for an African swine fever pre-emptive zoning arrangement in September 2020, before any outbreak.<sup>24</sup>

Australian industry and government could secure gains from trading zones by building on existing industry and jurisdictional disease management plans. For example, consideration could be given to collecting additional livestock product stocks data to assist in developing product flow management options for these sudden, deep shocks to the livestock economy. Currently, consistent product stock holding data are not publicly available for incorporating into the economic model. As a result, existing flexibility of the supply chain to handle some uncertainty is not reflected in the above economic estimates.

Finally, trading zone benefits combined with other control options, such as vaccination, are being further analysed to understand how targeting of an emergency response to a larger highly infectious disease outbreak can reduce its impacts.

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#### Conflicts of interest

The authors declare no conflicts of interest for the work presented here.

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### Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site: <http://onlinelibrary.wiley.com/doi/10.1111/avj.13141/supinfo>.

**Table S1.** Harmonised System tariff codes included to calculate product equivalent trade values by species.

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