The Economic Impacts of a Hypothetical Foot and Mouth Disease Outbreak in Australia

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The economic impacts of a hypothetical foot and mouth disease outbreak in Australia

Glyn Wittwer, Centre of Policy Studies, December 2022

Abstract

This study uses a multi-country, dynamic quarterly CGE model, GlobeTERM, to estimate the economic impacts of a hypothetical foot and mouth disease outbreak in Australia. State government protocols in response to an outbreak concerning Local Control Areas and disease eradication have local severe short-term economic impacts. However, the national welfare losses arising from the outbreak depend mostly on the duration of trade sanctions by importers of Australian animal products. If an outbreak is contained within several months, and trade sanctions are dropped within a year of the outbreak, the net present value of Australia's welfare losses may be around $10 billion. If all importers restore Australian access within a year, other than China which delays by 5 years, welfare losses are around $21 billion. In a less likely scenario, in which trade sanctions persist in all trading partners for 5 years after the disease has been eradicated, contrary to international guidelines, welfare losses may exceed $85 billion. Trading partners also suffer welfare losses due to trade sanctions.

JEL classification: C68; R10; N50; Q17

Keywords: foot and mouth disease; trade sanctions; welfare; CGE modelling

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Introduction

Agricultural productivity is vulnerable to disease outbreaks. In countries in which agricultural exports account for a significant share of total exports, routine quarantine measures aim to minimize the probability of animal and plant diseases entering the country. Identified outbreaks may raise alarm in other countries. Indonesia reported a foot and mouth outbreak in May 2022. A media release by the Australian Department of Agriculture, Fisheries and Forestry on 9 May 2022 noted:

> In response to the outbreak in Indonesia, the department has advised livestock industries to be alert, raised awareness at the border, particularly in the north, provided advice to state and territory governments, and liaised with Indonesian counterparts. [1]

In part, responses depend on whether an outbreak is more than a threat to farm productivity in importing countries. "Mad cow" disease (bovine spongiform encephalopathy), for example, threatens human health. Australia maintained a ban between 2000 and April 2022 on donations of blood, breast milk and tissues from anyone who lived in the UK between 1980 and 1996 for a period longer than six months (Rigby 2022).

Although international guidelines are in place to encourage resumption of sales of animal products after a foot and mouth outbreak has been eliminated, individual countries may choose to maintain trade sanctions beyond the duration of guidelines. From the perspective of the country suffering the outbreak and the importing nation, the duration of sanctions has a marked impact on welfare outcomes.

The disease

Foot and mouth disease (FMD) causes blister-like sores in the mouth, tongue and lips, on teats and between hooves on affected animals. The Office International des Epizooties (OIE, representing 162 countries of the World Organisation for Animal Health) reports that is rarely fatal in adult animals but has high mortality among young animals. OIE estimates that FMD circulates in 77 percent of the global livestock population.[2] In countries where FMD is endemic, it has adverse impacts on productivity. The share of global costs reported by OIE for FMD prevention and control in Africa are around 50 percent and in Eurasia around 33 percent. The disease is prevalent in Africa, Middle East, Asia and parts of South America. OIE describes FMD status of different countries in four categories, namely

- Endemic;
- Sporadic;
- Free with vaccination; and
- Free without vaccination.

Sources of economic losses

The relevance of FMD status is that the responses within countries following an FMD outbreak differ widely. In many countries in which FMD is endemic, the direct losses through

[1] https://www.agriculture.gov.au/about/news/media-releases/media-statement-foot-and-mouth-disease-detected-indonesia accessed 13 December 2022

[2] https://www.OIE.org/en/disease/foot-and-mouth-disease/ accessed 17 November 2022

diminished productivity account for most of the economic losses. In the event of intervention, the objective is to minimize the direct economic damage from local outbreaks. Many countries in which the disease is endemic may have poor infrastructure and communications. Though there may be high net marginal benefits from countering FMD, institutional arrangements may be too fragile for effective action. Consequently, there is little response in many endemic regions to disease outbreaks.

The source of economic losses differs in countries whose livestock product sales are export-oriented: they aim to maintain OIE free-without-vaccination status, as it is a signal that livestock products imported from these countries entail a minimal chance of disease importation. In the event of trade sanctions arising from FMD outbreaks, economic losses from trade disruption far exceed the direct impacts of disease on livestock productivity or direct losses due to destruction of infected livestock.

Blancou *et al*. (2004) noted that vaccination may be viewed as an admission of the presence of FMD within a country. This contributed to abolition within the European Union of general vaccination of cattle in 1992, increasing the vulnerability of cattle to the disease. The implication is that although it may be optimal for an individual country exporting animal products to be assigned vaccine-free status by the OIE, it may not be optimal from a global perspective. That is, any discouragement of vaccine use may increase the rate of outbreaks across the globe.

Given the concern of trade sanctions, a standard procedure in countries with FMD free-without-vaccination status, when responding to an outbreak, is to vaccinate and destroy all livestock within a defined radius of the outbreak. In such circumstances, OIE restores vaccine-free status after three months from the last case, enabling the possibility of resumption of international trade.

Barnett *et al*. (2015) explore the possibility of OIE restoring vaccine-free status in the event of a vaccinate-to-live strategy. The authors believe that with improved vaccines and sufficient post-outbreak surveillance, this is feasible. They cite the benefits arising from "ethical concerns with respect to social values, the environment, animal welfare and global food security" (Barnett *et al*. 2015, p. 367). The improved mental health impacts on farmers and other residents in disease-affected regions would be additional benefits (Mort *et al.*, 2005).

Lessons from UK outbreaks

A report to the UK government compared the UK FMD outbreaks of 1967-1968, 2001 and 2007 (Anderson, 2008). The 1967-1968 and 2007 outbreaks were reported to veterinary authorities within four days of the onset of clinical signs. Disease spread from the 1967-1968 outbreak was concentrated in the Cheshire Plain; 16 counties in total suffered outbreaks. The first and last confirmed cases were 222 days apart. 2,364 premises suffered infection and 442,000 livestock were slaughtered to control the disease. The latter outbreak was confined to 9 infected premises in a small area of Surrey and Berkshire, and only 2,160 livestock were culled. The first and last cases were only 58 days apart.

The crucial difference with the 2001 outbreak is that it was not reported for three weeks after the onset of clinical signs. By then, the disease had spread widely through markets and dealers. The disease eventually spread across 44 counties, as far north as the Scottish Borders, west to Anglesey and to Cornwall in the far south west. In total, 2,026 premises

were infected implying much greater spread than in 1967-1968 when average farm holdings were several-fold smaller. Four million livestock were destroyed to control the disease. The duration of the outbreak was 221 days.

The shocking outcome of 2001 underlined the importance of responding as soon as FMD symptoms are detected. The Anderson review (2008) listed key lessons in reducing the risk of FMD outbreaks and minimizing the damage.

The first lesson is to maintain vigilance at borders and within facilities aimed at preventing and controlling diseases, such as the source of the 2007 outbreak. This lesson approximates the default position in Australia and New Zealand, where quarantine measures tend to be relatively strict. The second lesson on the review's list is the need for emergency preparedness, with routine testing of the full emergency chain. Preparedness includes being able to vaccinate within five days as a contingency plan. Vaccination is not automatic in response to a given outbreak, depending on internal cost benefit modelling and epidemiological advice on the risk of disease spread. The third lesson is to "[r]eact with speed and certainty to an emergency or escalating crisis by applying well-rehearsed crisis management procedures" (Anderson 2008, p. 37).

Clear communication to explain policies, plans and practices is the fourth lesson. In the Australian context, Victoria Agriculture outlines a plan of action in response to an outbreak online.[3] A nationwide 72 hour livestock standstill would apply, prohibiting any livestock movement in this time. The state would have a designated Control Area for FMD until identification of the source of outbreak. At this point, the Control Area would be a minimum of a 3 kilometre radius around the outbreak. These guidelines are consistent with those of other states.

A fifth is to respect local knowledge. Actions in response to an outbreak that are appropriate in one region may not be as effective or necessary in another. If anything, respect for local knowledge may be even more important in Australia than the UK, given wide differences in geography, climate and market structures for livestock across Australia.

The sixth lesson is the most relevant here: "Apply risk assessment and cost benefit analysis within an appropriate economic model" (Anderson 2008, p. 56). CGE modelling may be important in countries with export-oriented animal products, as trade sanctions are likely account for most of the economic losses.

In countries in which FMD is endemic, and in which livestock products are mainly for domestic consumption, an optimal strategy may entail cost-effective responses to reduce productivity losses from FMD. Other forms of economic analysis are relatively useful in the case of production for domestic use: Do *et al.* (2022) report cost-benefit analysis of a 2006-2010 program within Vietnam to vaccinate livestock against FMD. The program yielded a clear net benefit.

Anderson's (2008) seventh lesson concerns data and information management systems. The report was critical of information systems within UK's Department of Environment, Food and Rural Affairs (DEFRA). The challenge in Australia is potentially greater, involving

[3] See https://agriculture.vic.gov.au/biosecurity/animal-diseases/important-animal-diseases/foot-and-mouth-disease/foot-and-mouth-disease-frequently-asked-questions#h2-2

multiple Commonwealth and state government departments. However, advances in GIS and other technologies may enhance data collection and information compilation. These may contribute to an appropriate rapid response to a disease outbreak.

The final two lessons in Anderson (2008) bear similarities to issues arising in the global responses to COVID. The eighth notes the need for a sound legislative framework concerning emergency responses. The ninth is to base decisions on the best available science. Each of these will have critics and may be the subject of misinformation. There is one difference of context concerning the ninth lesson. Whereas politicians and scientists may have been in conflict concerning COVID responses, FMD responses in countries with export-oriented animal products must align with international trade guidelines.

Impacts on tourism

One major difference between Australia and the UK concerns the interaction between FMD and tourism. Local tourism site closures in the UK had adverse impacts on tourism, particularly during the 2001 outbreak (Blake *et al*., 2003). In the UK, tourism sites and livestock product are adjacent; there are more tourists, and tourism attractions are distributed over a much smaller area than in Australia. There is little comparison with Australia: livestock production occurs on dispersed holdings that are usually remote from tourism sites.

Model description

GlobeTERM is a multi-country CGE model that includes sub-national detail. It is a multi-country version of the multi-regional TERM model (Horridge et al., 2005) documented in Wittwer (2022). The master database of GlobeTERM contains 74 sectors and 525 regions in 150 national regions. The GlobeTERM data relies heavily on the GTAP database for national detail (Corong *et al*., 2017). Sub-national detail for Australia rely on various ABS sources.[4]

For project specific applications, we aggregate GlobeTERM to retain sectors and regions of interest. The aggregated database retains Cattle & sheep, Other livestock and Milk (dairy cattle) as separate primary industries, and Beef products, Other meat products and Dairy products as separate downstream sectors. There are 24 sectors in the aggregation.

The regional aggregation includes 11 regions, including 4 Australian regions and 7 countries or country group. The Australian regions are Warrnambool and South West Victoria SA4, Rest of Victoria, Queensland-Western Australia and Rest of Australia. Other regions include important destinations for Australian animal products. They are China-Hong Kong, Europe, Japan, Korea, United Kingdom, Indonesia and USA. This representation enables us to examine country-specific trade sanctions in response to a hypothetical FMD outbreak.

Countries in the Rest of World group (i.e., countries/regions not listed in the previous paragraph) are removed from the aggregated database. This means that detail concerning production, usage and trade is retained for the 11 regions in the aggregation. International and sub-national trades in this aggregation appear in the "domestic" slices of trade matrices in the database and in associated equations. Imports from the Rest of World group appear in the "import" slices of relevant trade matrices and equations. Exports from all regions to the Rest

[4] https://www.copsmodels.com/archivep.htm item TPGW0196 includes sources used in preparing Australian regional detail. The main source of sub-national in other countries in GlobeTERM is Eurostat, though not relevant to this specific application.

of World are assigned an export column in the use matrix of each region. The model excludes production and usage in the Rest of World, and excludes trades in which both origins and destinations involve the Rest of World.

By omitting Rest of World detail, this dynamic version of GlobeTERM is not Walrasian at the global level. That is, international trades within the model do not sum to zero, nor do net foreign liabilities.

Industries within the model alter investment in line with movements in rates of return on capital. Investment flows are linked formally to capital stocks. Another dynamic feature is that trade balance flows enter the formula for net foreign liabilities.

Scenarios

The modelling is based on the following hypothetical. A foot and mouth outbreak is reported in Victoria. For 72 hours, following the state government's guidelines, there is a livestock standstill. This will entail inconvenience and some costs, maybe around $10 million.[5] The outbreak is identified on a farm in the Warrnambool-South West SA4 region of Victoria. Thereafter, authorities assign a 5 kilometre exclusion zone around the farm of the outbreak. The Warrnambool-South West region includes around 12,000 square kilometres of grazing land.[6] The area of the exclusion zone is 78 square kilometres, which therefore accounts for a small fraction of the region's grazing activity.

In order to eradicate foot and mouth disease, animals in the exclusion zone are vaccinated to die, with the destruction of around 25,000 livestock. This is the main direct form of economic loss. Within GlobeTERM, a negative shock to capital stocks in the livestock sectors in Warrnambool-South West depicts livestock destruction. Bradhurst *et al*. (2019) provide indicative vaccination costs of around $5 per head. Neither these nor the 3 day livestock standstill costs are included in the modelling. Similarly, the costs of emotional stress and trauma among farmers and the local community are excluded from analysis.

The main economic impacts, from a national perspective, are due to bans other countries impose on Australian livestock products, from the discovery of the outbreak. In the scenario, an FMD outbreak is detected in the first quarter and eliminated in the second quarter. The modelling includes variants of trading partner responses.

Variant 1 entails partial restoration of exports of Australian animal products in the third quarter, and full restoration in the fourth. This is consistent with OIE guidelines in which vaccine-free status is restored to a country three months after detection of the last FMD case. The restoration of full trade over two quarters is based on an assumption that it takes time to restore trade logistics fully on resumption. Variant 2 is as for 1, except that in China-Hong Kong, sanctions remain in place for 5 years. In variant 3, sanctions remain in place in all countries for 5 years after eradication of the disease, followed by full resumption over two quarters.

[5] This is based on the annual transport margin for livestock in Australia in the CGE database, approximately $950 million.

[6] From https://www.abs.gov.au/statistics/industry/agriculture/land-management-and-farming-australia/2016-17. Data are for the Glenelg-Hopkins NRM region which approximates the Warrnambool-South West SA4 region.

Variant 1: full resumption of trade in second quarter after FMD is eliminated

Figure 1 shows the impact on income-side GDP in the Warrnambool-South West region. Real GDP falls to around 1.6 per cent below based in the two quarters directly affected by the outbreak. The region's base period real GDP is $6.1 billion annually. Therefore, a fall of 1.6 per cent in real GDP is equivalent to $24.4 million (=0.016x0.25x6100) lost income in one quarter. Trade sanctions reduce the value of livestock output and downstream products. In response, food processing sectors throughout Australia reduce their operating capacity temporarily. The decline in effective capital relative to base in Figure 1 arises from a combination of destroyed livestock and reduced food processing operating capacity. Employment in the region falls by 2.2 per cent relative to base (130 full-time equivalent or FTE jobs).

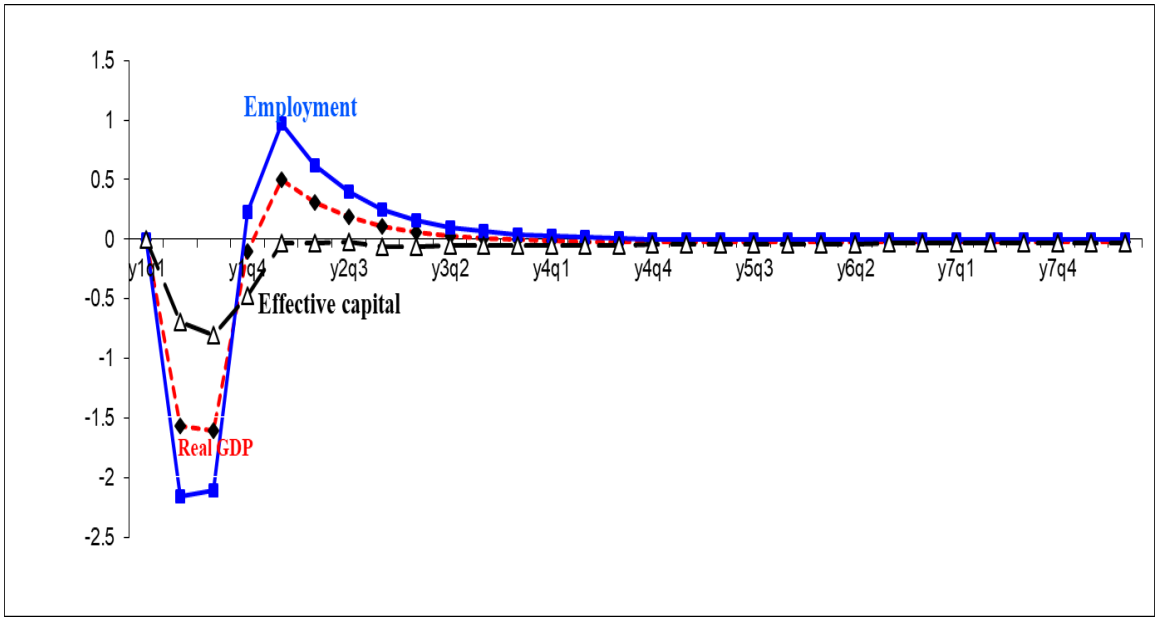

Figure 1 Warrnambool-SW income-side impacts, variant 1 (per cent deviations from base)

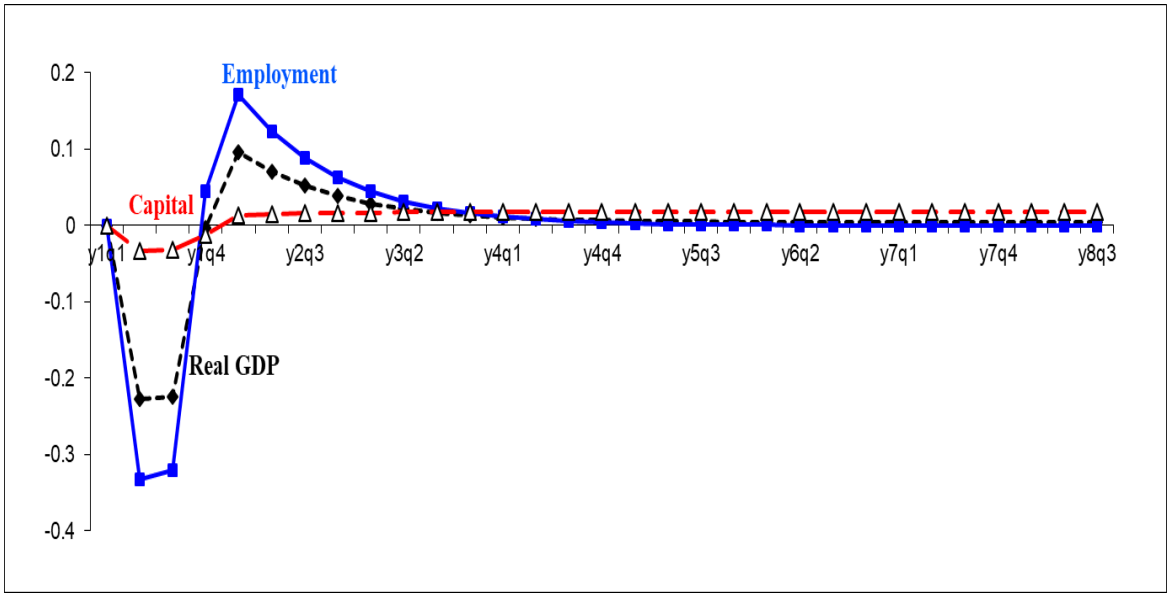

Figure 2 National income-side impacts, variant 1 (per cent deviations from base)

At the national level, effective capital falls below base in the two periods of the outbreak due mainly to reduced food processing operating capacity. Trade sanctions have impacts at the national level. Employment falls to 0.33 per cent below base (more than 40,000 FTE jobs) in the first period of the outbreak, driven by a fall in the terms of trade and sluggishly adjusting real wages. As the labour market strengthens (weakens), real wages rise (fall) over time (Wittwer *et al*., 2005). With the recovery in Australia's export markets for animal products, employment rises above base by as much as 0.17 per cent (around 20,000 FTE jobs) in period y2q1. In recovery, labour demand exceeds labour supply, which imposes upward pressure on real wages. Real wages flatten when excess labour demand has been choked off (Figure 3).

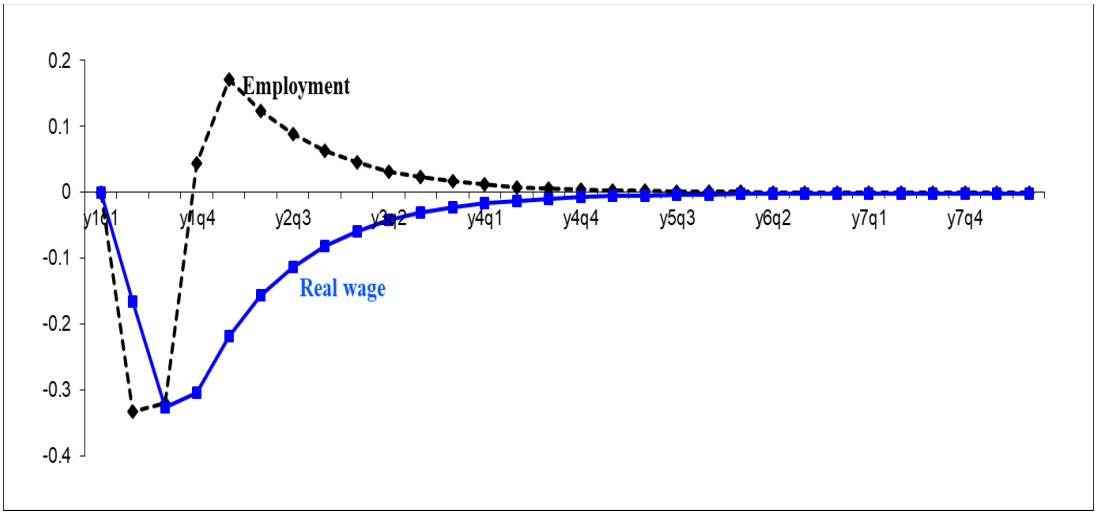

Figure 3 National labour market, variant 1 (per cent deviations from base)

At the macroeconomic level, trade sanctions drive down Australia's terms of trade relative to base. With trade sanctions removed entirely by the 4th quarter (y2q1 in Figure 4) following the outbreak, Australia's terms of trade return to base. The temporary loss in national spending power arising from the terms-of-trade loss forces aggregate household consumption below base (Figure 4). Whereas real GDP falls is only 0.22 per cent below base in period y1q3, aggregate consumption is 0.4 per cent below base due to the terms-of-trade decline. In addition, as shown in Table 1, the trade deficit worsens.

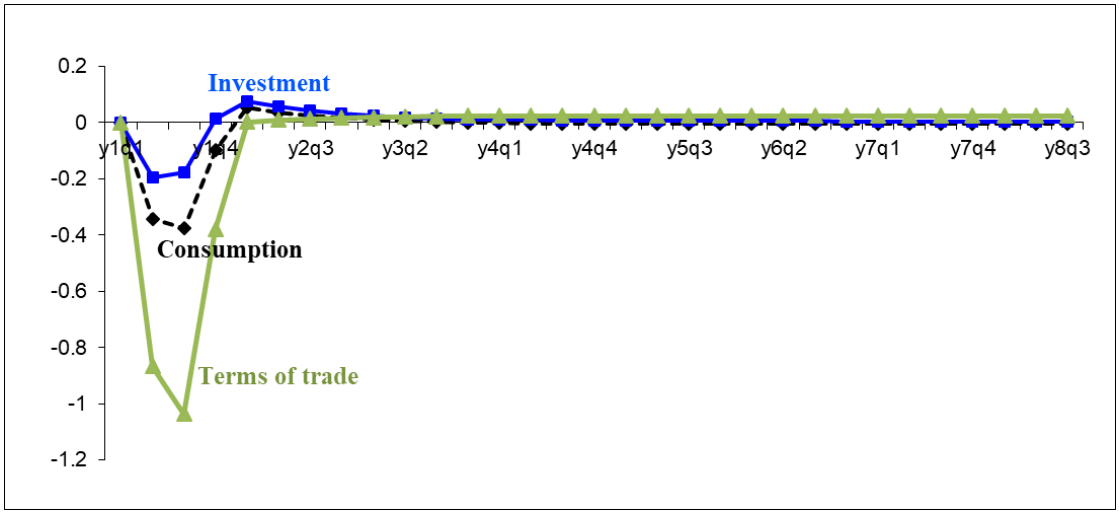

Figure 4 National aggregate consumption, investment and terms of trade impacts (per cent deviations from base)

The deviation in welfare (dWELF) at the national level is calculated from the CGE modelling as:

$$\text{dWELF} = \sum_{d}\sum_{t} \frac{\text{dCON}_t^d + \text{dGOV}_t^d}{(1+r)^t} - \frac{\text{dNFL}_z}{(1+r)^z} + \frac{\text{dKstock}_z}{(1+r)^z} \qquad (1)$$

In (1), dCON and dGOV are the deviations in real household and government spending (i.e, current consumption) in region *d* (summed across all Australian regions) and period *t*; dNFL is the deviation in real net foreign liabilities in the final period (*z*) of the simulation; dKstock is the deviation in the real value of the capital stock in the final period (*z*) of the simulation; and *r* is the discount rate.

Table 1 Simplified contributions to welfare impact, variant 1 ($m)

Period	y1q2	y1q3	y1q4	y2q1
(1) Direct TofT loss	-845	-1010	-357	26
(2) Consumption	-1158	-1303	-408	102
(3) Balance of trade	-2663	-3312	-1086	51
(4) Welfare =(2)+(3)	-3821	-4615	-1494	153
(5) Discounted welfare	-3797	-4558	-1467	149

Table 1 shows the main components of the welfare impact for the three periods in which there are substantial trade sanctions. Row (1) shows the direct export revenue loss, the terms-of-trade change multiplied by the value of exports. The national welfare loss will be substantially larger than the export revenue losses from the fall in terms of trade, as the balance of trade goes into deficit relative to base with the loss in export revenue.[7] Row (2) shows the modelled change in current consumption (household plus government). Row (3) shows the balance of trade, which feeds into the formula for net foreign liabilities:

[7] If we exogenize the national balance of trade, the terms of trade worsen further as export products unaffected by trade sanctions move along down-sloping export demand curves, thereby lowering export prices.

$$NFL_t = (1+i)^* NFL_{t-1} - delb_{t-1} \quad (2)$$

In (2), present period NFL is linked to the previous period NFL minus the previous period balance of trade surplus (delb), where *i* denotes the nominal interest rate.

Row (4), the contribution to welfare, sums (2) plus (3). Row (5) discounts the welfare contributions back to the period *y1q1*, using an annual discount rate of 2.5%. The sum of the four periods in row (5) is minus $9.7 billion. This is approximates the modelled welfare outcome from equation (1) over the simulation period, which is minus $10.0 billion. This exercise illustrates the link between welfare losses and the duration of trade sanctions. In a scenario in which either one or all trading partners delay the restoration of imports of Australian animal products, the welfare losses will be larger.

Variant 2: China-Hong Kong delays resumption of imports for 5 years, other importers as for variant 1

In this variant of the FMD outbreak, all importers of Australian animal products resume full trade by the 4th quarter (y2q1) except China-HK. China-HK resumes imports five years after the outbreak is eradicated (y5q3), with full trade by the following quarter (y5q4).

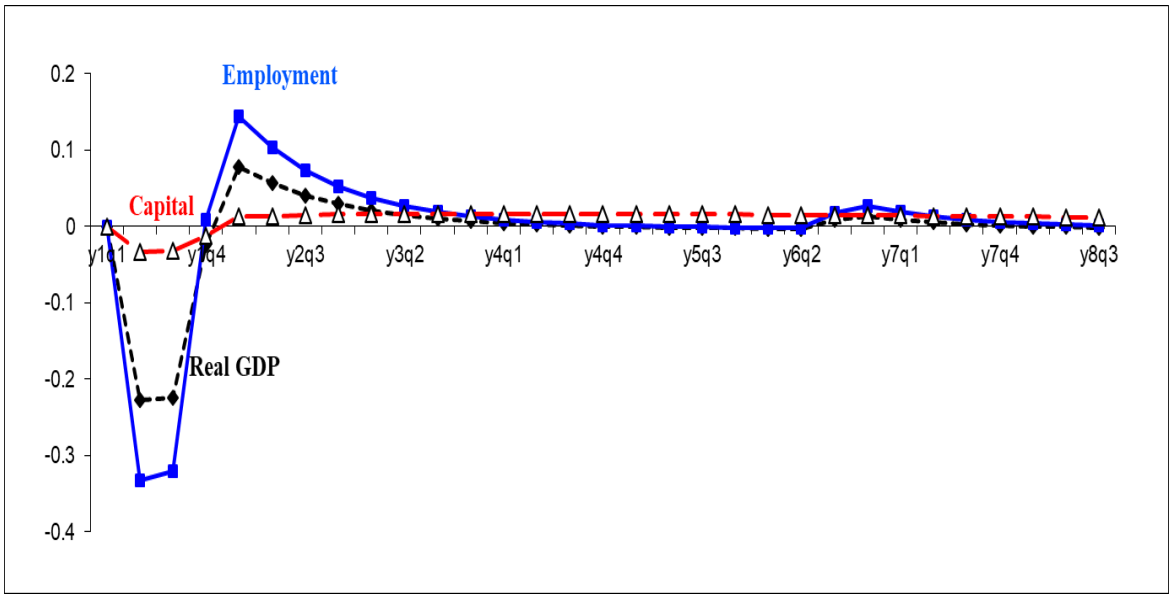

Figure 5 National income-side impacts, variant 2 (per cent deviations from base)

At the national level, there are small differences relative to variant 1. In the recovery period y2q1, employment rises slightly less above base (0.14 per cent, Figure 5, relative to 0.17 per cent in variant 1), reflecting a smaller upswing in demand with China-HK's sanctions still in place. With the lifting of sanctions by China-HK, there is a small upswing in employment from quarter y6q3.

Figure 6 shows the impact of this variant on the terms of trade, national aggregate consumption and national aggregate investment. As long as China-HK's trade sanctions remain, Australia's terms of trade persist around 0.2 per cent below base. Aggregate consumption and investment recover to be only slightly below base after the lifting of trade sanctions in all countries other than China-HK. However, as shown in Table 2, the balance of trade remains in deficit relative to base with China-HK's sanctions in place.

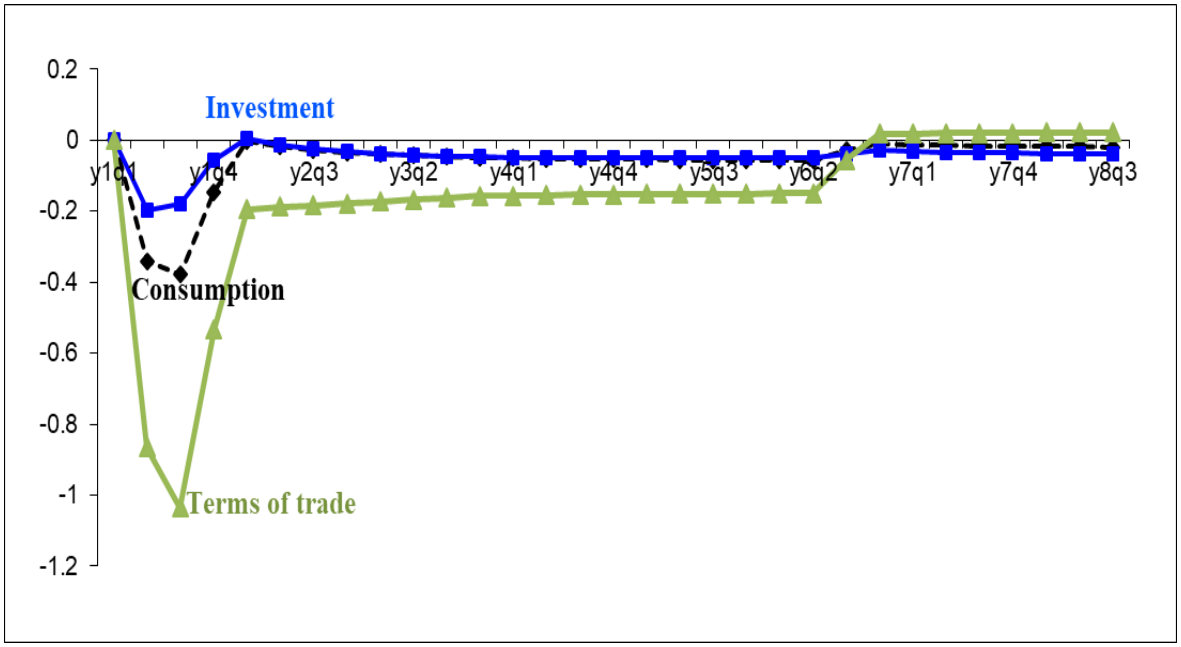

Figure 6 National aggregate consumption, investment and terms of trade impacts, variant 2 (per cent deviations from base)

Table 2 Simplified contributions to welfare impact, variant 2 ($m)

Period	y1q2	y1q3	y1q4	y2q1	y2q2
(1) Direct TofT loss	-845	-1010	-510	-171	-165
(2) Consumption	-1158	-1303	-569	-81	-121
(3) Balance of trade	-2663	-3312	-1419	-334	-334
(4) Welfare =(2)+(3)	-3821	-4615	-1987	-415	-455
(5) Discounted welfare	-3797	-4558	-1951	-405	-455

Table 2 shows identical outcomes as variant 1 for the first two quarters, followed by worse outcomes in the following two quarters in this variant, as China-HK's trade sanctions persist. The net present value of the welfare outcome for this variant is minus $21.3 billion.

Variant 3: All importers keep trade sanctions in place for 5 years after FMD eradication

In variant 3, prolonged trade sanctions remain in place for 5 years after FMD eradication, contrary to international guidelines. There is a movement in investment away from livestock production towards other export-oriented activities, such as mining and cropping. Consequently, aggregate national capital rises as output in relatively capital-intensive sectors grows relative to base.

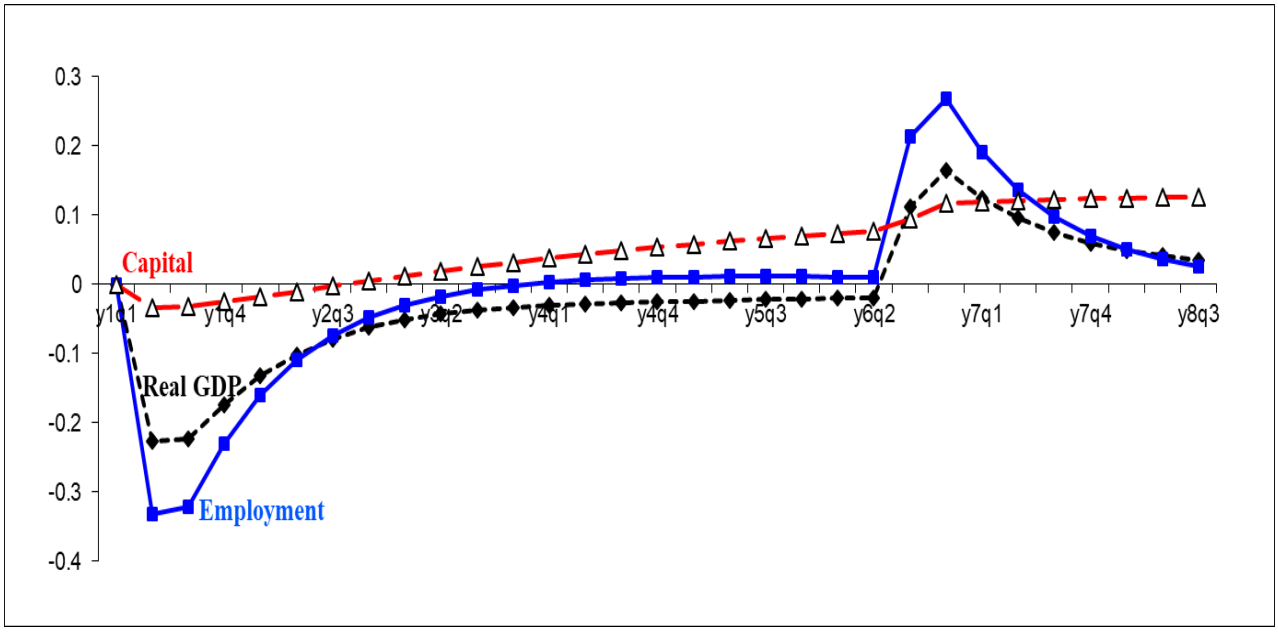

Figure 7 National income-side impacts, variant 3 (per cent deviations from base)

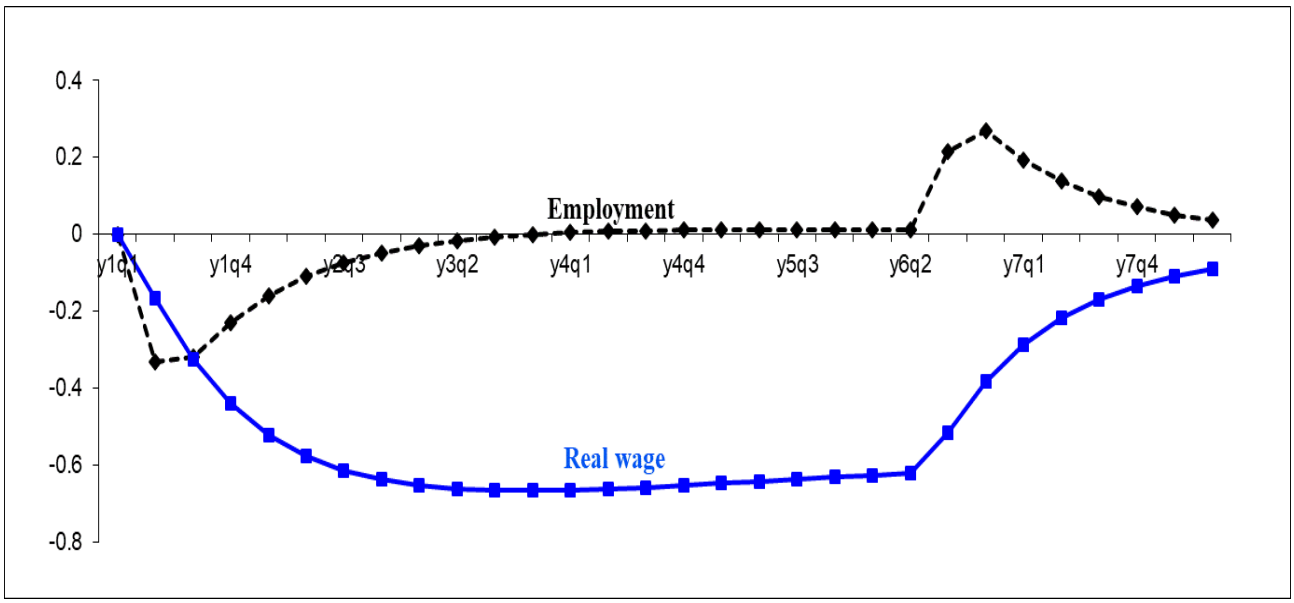

Figure 8 National labour market, variant 3 (per cent deviations from base)

Without an early recovery in the terms of trade, for employment to move back towards base, real wages must adjust downwards, being around 0.6 per cent below base by the time employment adjusts to base levels (Figure 8). There is a small upsurge in employment and

real wages with the eventual lifting of sanctions. But with the terms of trade persisting below base even with sanctions gone, real wages persist below base.

As export volumes of products other than livestock products increase relative to base, their export prices fall as they move along down-sloping export demand curves. A consequence of this is that when trade sanctions on Australia's animal products are eventually lifted, the terms of trade do not recover fully, remaining around 0.2 per cent below base (Figure 9).

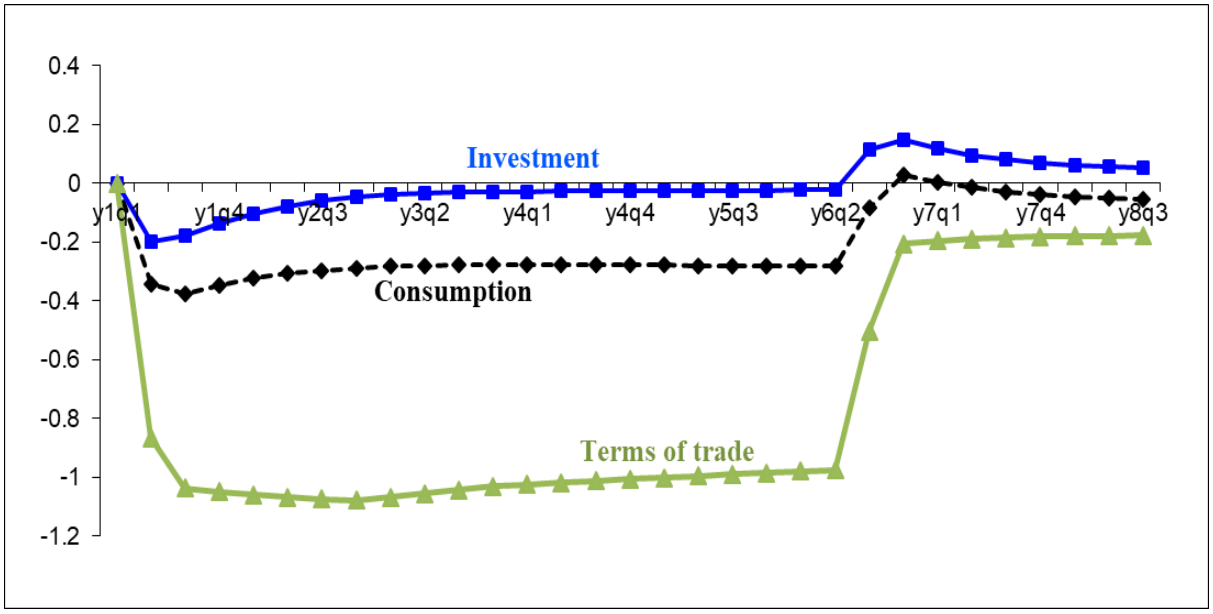

Figure 9 National aggregate consumption, investment and terms of trade impacts, variant 3 (per cent deviations from base)

Without early removal of trade sanctions, welfare losses in Australia accumulate relative to base. Table 3 (row 4) shows that these losses remain in excess of $4 billion per quarter, though later periods will make a slightly smaller contribution to the net present value figure after discounting. A five year delay to the restoration of international trade results in a net present value welfare outcome of minus $85 billion.

Table 3 Simplified contributions to welfare impact, variant 3 ($m)

Period	y1q2	y1q3	y1q4	y2q1	y2q2
(1) Direct TofT loss	-845	-1010	-1021	-1037	-1050
(2) Consumption	-1158	-1303	-1243	-1136	-1050
(3) Balance of trade	-2663	-3312	-3330	-3303	-3277
(4) Welfare =(2)+(3)	-3821	-4615	-4573	-4439	-4327
(5) Discounted welfare	-3797	-4558	-4488	-4329	-4194

Discussion

National terms-of-trade losses arising from trade sanctions far exceed the relatively local direct losses from a small, quickly contained FMD outbreak. Vaccination and destruction of affected livestock, though traumatic for locals in an affected region, is equivalent to monetary losses in the tens of millions of dollars. A three-day livestock standstill in an affected state may cost a further $10 million or so. These losses contrast with welfare losses induced by the terms-of-trade decline in the scenarios presented here, which amount to around $4 billion per

quarter while trade sanctions remain. This outcome provides unequivocal support for a country with vaccine-free FMD status, in event of an outbreak, to respond with a vaccinate-to-die policy for livestock within a certain radius of the outbreak.

What is less clear is whether this is an optimal policy from a global perspective. Optimal strategies concerning vaccination lie in the epidemiological as much as if not more than in the economic field. As countries strive to maintain vaccine-free FMD status, they may increase the chance of an outbreak (Blancou *et al*., 2004). While individual countries may fear the loss of market access if they abandon their vaccine-free status, global economic losses from FMD may diminish with wider and routine application of vaccines.

This assumes that vaccines are effective. At worst, relatively ineffective vaccines may induce a false sense of security. For example, Australia and New Zealand may choose, given routine use of vaccines, to reduce quarantine measures and border inspections. If these vaccines have limited effectiveness, this modified approach has the potential to lead to a worse outcome than current policy.

While nationalist sentiment might favour trade sanctions, the reality is that consumers pay higher prices for goods if there are import restrictions on some sources. In the first variant of the scenario, all nations suffer welfare losses, despite the quick resolution. In the case of China-HK, the welfare loss calculated using equation (1) is AUS $1.8 billion and welfare losses in other countries modelled separately (i.e, Japan, Korea, Europe, UK, Indonesia, USA) sum to AUS $2.4 billion. In the second variant, in which all trading partners other than China resume imports from Australia in the quarter following FMD eradication, China-HK's welfare loss enlarges to AUS $11.8 billion while the sum of losses in other countries shrinks to $0.55 billion. That is, other countries have access to relatively cheaper Australian produce as long as China-HK is out of the market. In the third variant, in which all importers impose sanctions on Australia animal products for five years, all countries suffer substantially larger welfare losses than in variant 1. China-HK's welfare loss is AUS $14.3 billion and the loss in the other six regions sums to AUS $26.4 billion.

These outcomes appear to align with the idea that greater use of vaccines, provided they are not excessively costly, is likely to be welfare enhancing relative to the current system of according vaccine-free status to major exporters. Such a conclusion assumes that vigilance would remain to ensure identification and a rapid response to FMD in event of an outbreak. Part of the issue is that trade sanctions are a blunt instrument, applied to an entire nation even if only one port among many has any risk of FMD carriage. It may optimistic to believe that importers would impose sanctions on individual ports rather than an entire nation.

Beyond improving outcomes in countries that are substantial importers or exporters of animal products, greater efforts to manage FMD in countries where it is endemic may improve welfare in these countries, particularly among the rural poor. Some countries with endemic disease have limited literacy among farmers, poor infrastructure and deficient communications. In these circumstances, there may be many obstacles to successful management of FMD. Other countries with endemic or sporadic status are middle-income countries where efforts to vaccinate livestock and eradicate FMD may yet yield substantial net benefits.

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