An Optimal Quarantine Measure: OJD and the Sheep Industry in Western Australia*

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Abstract
Quarantine programs have generally provided an essential protection against the importation of exotic diseases, thus protecting both consumers and producers from major health concerns and pests that can potentially destroy local agricultural production. However, quarantine measures also impose costs in the form of expenditures on the quarantine program itself and the welfare losses that are associated with such trade restrictions. This paper develops a simple model to determine the optimal level of quarantine activity for imported livestock by minimizing the present-value of the direct costs of the disease, the cost of the quarantine program and any resulting welfare losses. The result defines an upper-bound on the optimal number of infected livestock that may potentially enter a region in a given year. The model is then applied to the case of Ovine Johne’s Disease (OJD) and its potential entry to the sheep industry in Western Australia (WA). Since all parameter values are subject to random variation, a further simulation determines an expected optimal quarantine activity for WA, up to a ninety percent likelihood of a disease incursion of less than the expected optimal upper-bound, with calibrated (random) normal distributions on all parameters.

JEL Classification: Q17, Q28, R59
Key Words: Quarantine measures, Ovine Johne’s Disease, regional policy, agricultural policy

1. Introduction

The development of trade between regions and countries is an increasingly important characteristic of modern agriculture. In this regard, quarantine programs

*Thanks to Nico Klijn (ABARE) and John Edwards, Chris Hawkins, Tony Higgs, Tony Martin and Peter Morcombe (Agriculture Western Australia) for very helpful comments and valuable assistance with parameter estimates.
have generally provided an essential protection against the importation of exotic diseases, thus protecting both consumers and producers from major health concerns and pests that can potentially destroy local agricultural production. However, quarantine measures also impose costs. Decreasing the likelihood of a disease incursion from imported livestock, for example, requires significant expenditures on items such as blood tests, surveillance and border patrol that vary considerably with the severity of the quarantine activity in place. In addition, quarantine programs, by their design, restrict trade between regions, generating costs in the form of potential welfare losses and higher import prices.

This paper develops a simple model to determine an optimal quarantine measure against the risk of importing an exotic disease in livestock. Put simply, the idea is to minimize the direct cost of a potential disease incursion (the loss in output and productivity and the cost of any export trade restrictions due to the presence of the disease), the cost of the quarantine program and the resulting welfare losses from quarantine restrictions, through a variation in the likely number of infected livestock that enter a region in any given period. Clearly, the larger the expenditure on a quarantine activity the larger are welfare losses and the cost of the quarantine program itself. However, the more severe the quarantine activity the smaller is the risk of a disease incursion and thus the smaller are the direct costs of the disease to the affected industry. In principle, there will be cases where the disease is so devastating that the direct costs of an incursion will require vast expenditures on quarantine services and large welfare losses to guarantee that the risk of a disease entry is virtually zero. On the other hand, for some diseases, reducing the risk of a disease incursion to zero may imply that the cost of the quarantine measures and the resulting welfare losses more than surpass the (present-value) of the direct cost of the disease to the local industry. Finding the correct value of the likelihood a disease entry, and with it the associated expenditure level and optimal quarantine activity, thus requires minimizing all of the (properly discounted) potential and actual costs associated with managing imported livestock.

Section 2.1 of the paper characterizes the damage function for the risk of importing an exotic disease given the average cost that results from the entry of one infected animal. The disease, once it enters a region, is assumed to grow at an exponential rate until it becomes ‘endemic’, or where the number of infected farm-properties is sufficiently large that no ‘local quarantine zones’ within the region are allowed. Until this point, the direct cost of the disease is the discounted value of the cost of the accumulated number of infected sheep that enter each year. After the disease becomes endemic, the direct cost of the disease, given that the number of infected sheep (or farm properties) now remains

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constant, simply extends to a point in time where the present-value of the cost of the disease becomes zero. Section 2.2 defines the expenditure function for a given quarantine activity. Values are defined for the number of infected animals that enter with no quarantine activity in place and the maximum quarantine expenditure that (virtually) guarantees no disease entry. For intermediate cases, lowering the expected value of a disease incursion requires increased expenditures (at an increasing rate) for quarantine services. Given the cost of conformance to a quarantine measure, section 2.3 approximates the welfare loss that results from restricting imports and section 2.4 solves for the optimal quarantine measure. The result defines an upper-bound for the number of infected livestock that may likely enter a region (on average) in a given year, and the associated optimal quarantine activity and expenditure level.

Section 3 applies the model to the case of Ovine Johne’s Disease (OJD) and its possible entry to the sheep industry in Western Australia (WA). After describing OJD and the characteristics of the sheep industry in WA, including the various quarantine activities that are practically available, section 3.3 calculates the actual value (on average) of the number of infected sheep that may optimally enter WA per year in order to minimize total costs. Since all parameter values (both in the model and in practice) are subject to random variation, section 3.3 also calculates an expected maximum bound for the optimal number of diseased sheep that may enter each year, up to a ninety percent likelihood of a disease incursion of less than the expected optimal upper-bound, with calibrated (random) normal distributions on all parameters. Section 4 concludes.

2. Quarantine Activities and an Optimal Quarantine Measure

2.1. The risk of an incursion of an exotic disease and its potential cost

To structure the problem in a simple way assume a given probability distribution over the event of a disease entering an area and let $x$ be the projected number of infested livestock that enter in any one year. Furthermore, let every probabilistic measure of $x$ correspond to a certain quarantine activity. The more strict the quarantine activity the lower on average is the projected value of $x$. Next, to provide some dynamics, assume that once (or if) an infected livestock enters an economy or region that it transmits the disease to the current non-infected or free flock in that area at an average net transmission rate $g$. Thus, at any year $\tau$, the total number of diseased animals ($Q$) as a result of an initial infestation $x(0)$ from an imported livestock can be given as

$$Q_\tau = x(0)e^{g\tau}.$$  \hspace{1cm} (2.1)

\footnote{This corresponds to the observed growth process (given an average expected life-span for sheep) for OJD in New South Wales (Agriculture New South Wales, 1999), and for typical measured values of $g$ is much less severe, for example, than sheep pox which spreads through a population almost instantly. In any case, the calibrated analysis in Section 3 allows for different probabilistic values of $g$.}
With exponential growth of the disease, define $T_0$ as the point of time at which the disease becomes endemic, indicating either that the disease has saturated the livestock population or, in more practical terms, that the number of infected farm-properties is sufficiently large so that no local quarantine zones are allowed within the region. After $T_0$ there is no further growth in the disease, or the number of infected sheep (or farm properties for any particular livestock) remains unchanged. Every year the importing economy potentially adds an additional $x$ units of infected sheep from other states or regions so that, with a given quarantine activity, a new ‘vintage’ $x$ of infected animals transmits the disease to the remaining free flock according to equation (2.1). At any year $t < T_0$, the total number of diseased livestock is now the accumulated number of infected animals caused by importing $x$ infected animals every year from the initial time period, or

$$Q_t = x \frac{e^{g(t+1)} - 1}{e^g - 1}. \; \; \; \; (2.2)$$

Let the value $c_A$ be the average (economic) cost due to one infected animal, including the costs that result from death or a lower carcass weight due to the disease, the loss in productive capacity, the loss that results in managing the disease, and the cost of potential export trade restrictions due to the presence of a disease in a given region. Define $\beta_t = 1/(1 + r)^t$ as the appropriate discount rate and let $T_1 > T_0$ be the point in time where the present-value of the potential cost of the disease goes (virtually) to zero, given that for any $t > T_0$ the number of infected sheep is constant, or

$$\bar{Q} = \sum_{t=0}^{T_0} x e^{g t} = x \frac{e^{g(T_0+1)} - 1}{e^g - 1}. \; \; \; \; (2.3)$$

The total potential cost ($C$) of a disease incursion is thus

$$C = \sum_{t=0}^{T_0} \beta_t c_A x \frac{e^{g(t+1)} - 1}{e^g - 1} + \sum_{t=T_0+1}^{T_1} \beta_t c_A \bar{Q}. \; \; \; \; (2.4)$$

It is easy to see from equation (2.4) that the higher the projected number of infected animals ($x$) that enter an area in any given year the higher the cost of the disease over the entire time period from 0 to $T_1$. By reducing the level of $x$, say through more rigorous quarantine measures, the potential cost that results from the incursion of an exotic disease from an imported livestock will also be reduced.

### 2.2. Expenditures on a quarantine activity

Nevertheless, lowering the level of $x$ clearly requires an expenditure with varies according to the extent or severity of the particular quarantine activity in place. Precise functional forms are not available, but the basic relationship between the
value of \( x \) and the associated expenditure on a quarantine measure is easy to understand. Let \( E \) be the expenditure (e.g., surveillance, testing, enforcement) on a quarantine activity and assume that the \( E = E(x) \) with \( E'(x) < 0 \) and \( E''(x) > 0 \). In other words, the greater the expenditure on a quarantine measure the lower the probability of a disease incursion \( (x) \), with an expenditure value that increases at an increasing rate as the likelihood of an incursion falls to zero. Moreover, assume that if \( E = 0 \) the maximum number of infected animals that may enter in any given time period is \( R_m \) and as \( x \to 0 \) the associated maximum expenditure on a quarantine measure asymptotes to \( E_m \). Under all of these assumptions, the expenditure function takes the form

\[
E(x; \eta) = \frac{E_m(R_m - x)}{R_m(\eta x + 1)}
\]                  (2.5)

where \( \eta \) is a parameter value that determines the precise curvature of \( E(x) \).³

2.3. Welfare losses from import trade restrictions due to quarantine activities

To approximate welfare losses from restricting imports with a quarantine activity assume simple linear supply and demand schedules for sheep.⁴ Define \( p^0 \) as the domestic regional price and \( p^* \) as the import price for \((p^0 - p^*) > 0\). Let the value of imports with no quarantine restrictions be \( M \) at \( p^* \). With a quarantine (partially restricting imports) the import price rises by the cost of conformance (e.g., blood tests and certificate costs) to say \( p^q \). Define this conformance cost per unit as \( m = p^q - p^* \). The welfare cost from the loss in trade is thus approximated by

\[
L_W = \frac{1}{2}(M' + M)(p^q - p^*)
\]                  (2.6)

for

\[
M' = M \frac{(p^0 - p^q)}{(p^0 - p^*)}
\]                  (2.7)

or the volume of imports after the quarantine activity is in place. Substituting gives

\[
L_W = mM - \frac{1}{2} \frac{m^2 M}{(p^0 - p^*)}.
\]                  (2.8)

³In this sense the value of \( \eta \) represents an ‘effectiveness coefficient’ for the overall quarantine system within a region. For example, in Western Australia, the technology (e.g., screening devices, surveillance, blood tests and the required administration of the service) remains unchanged regardless of the exact quarantine program being used. Variations in \( x \) are thus simply the result of expenditure levels or the extent of the quarantine activity that is done. However, across regions and technologies it is reasonable to assume that the value of \( \eta \) varies, so that for a given \( x \) a higher value of \( \eta \) implies that the marginal cost \((\partial E/\partial x)\) of reducing \( x \) by one unit is smaller.

⁴In Western Australia, the demand for imported sheep is due mainly to the demand for breeding stock. See section 3.
In actual practice the cost of conformance is typically paid by the exporter and the cost of the quarantine service at the border (or on arrival) is paid by the host region, with additional follow-up tests in subsequent years. The more strict the quarantine activity the higher the cost of prevention and detection of the disease for both the exporter and importer. Consequently, the cost of conformance can be represented as some fraction \( \alpha \) of the total quarantine expenditure \( E(x) \). The (undiscounted) welfare loss from the restriction in trade now becomes

\[
L_W = \alpha E(x) M - \frac{1}{2} \frac{\alpha^2 E(x)^2 M}{(p^0 - p^*)} \tag{2.9}
\]

for \( E(x) \) given by equation (2.5).

**2.4. An optimal quarantine measure**

The problem for the policy maker is now to minimize total costs by minimizing the potential cost of the disease’s incursion, the expenditure for the quarantine activity and the welfare loss that results from implementing the quarantine restrictions on trade. However, unlike the direct cost of the disease, discounting the value of any welfare loss and quarantine expenditure is only applicable from the initial period to time \( T_0 \). Once the disease becomes endemic there is no point for a quarantine activity and thus no quarantine expenditures or welfare losses from \( T_0 \) to \( T_1 \) to discount. Accordingly, the correct discount factor is

\[
\Phi \equiv \sum_{t=0}^{T_0} \beta_t = \frac{1}{r} \left( 1 + \frac{1}{(1 + r)^T_0} \right) \tag{2.10}
\]

and thus applies to equations (2.5) and (2.9) to obtain the present-value of quarantine expenditures and welfare losses. Define, as well, the critical sum

\[
\Psi \equiv \sum_{t=0}^{T_0} \beta_t \frac{e^{\gamma (t+1)}}{e^{\gamma} - 1} - \sum_{t=T_0+1}^{T_1} \left( \sum_{t=0}^{T_0} e^{\gamma t} \right) \beta_t \tag{2.11}
\]

from equations (2.3) and (2.4). Combining all expressions gives

\[
TC = c_A x \Psi + \Phi \left( E(x)(1 + \alpha M) - \frac{\alpha^2}{2} E(x)^2 \frac{M}{p^0 - p^*} \right) \tag{2.12}
\]

or the final measure of total costs \( TC \), properly discounted. The problem now becomes one of minimizing equation (2.12) through a simple variation in \( x \). The first-order necessary condition is

\[
c_A \Psi + \Phi (1 + \alpha M) \gamma + \left( \frac{(R_m - x) E_m^2 (1 + \eta R_m)}{R_m^2 (\eta x + 1)^3} \right) \frac{\Phi \alpha^2 M}{p^0 - p^*} = 0 \tag{2.13}
\]
for

\[ \gamma \equiv -\frac{E_m(1 + \eta R_m)}{R_m(\eta x + 1)^2} = E'(x). \] (2.14)

In general, solving equation (2.13) for a value of \( x \) would require a cubic root, but it is clear that since the third term in (2.13) is positive, since \( x < R_m \) with any quarantine activity in place and \( p^0 > p^* \), it follows that the sum of the first two terms must be less than zero, so that

\[ c_A \Psi R_m(\eta x + 1)^2 < \Phi(1 + \alpha M)E_m(1 + \eta R_m). \] (2.15)

Solving gives

\[ x^* < \frac{1}{\eta} \left( \sqrt{\frac{\Phi(1 + \alpha M)E_m(1 + \eta R_m)}{\Psi c_A R_m}} - 1 \right) \] (2.16)

for \( x^* \) an optimal quarantine measure, or the ‘acceptable’ maximum bound of the number of infected animals that may enter a region in a given period.

In practical terms (see section 3 below), given a risk assessment for the likelihood of an incursion \( x \) under a given quarantine activity, the idea is to compare this value \( x \) to that given by equation (2.16). An optimal quarantine activity is one that corresponds to an incursion less than \( x^* \). Equation (2.16) also makes it clear that there is a negative relationship between the probable value of \( x \) and the potential cost of the disease due to larger production losses and greater resulting trade restrictions \( (c_A) \). The more ‘dangerous’ a disease the lower the optimal level of \( x^* \) and thus the more restrictive should the quarantine activity be. It also follows that an increase in the growth rate of the disease \( (g) \), or a fall in the rate in which future potential costs are discounted \( (r) \) results in an a fall in the value of \( x^* \) and thus requires a more severe quarantine activity. The values of \( M \) and \( \alpha \) are endogenous to prices and the specific quarantine activity in place.

3. Quarantine Activities and Ovine Johne’s Disease in Western Australia

3.1. The sheep industry in Western Australia and Ovine Johne’s disease

The sheep industry is important in Western Australia. The total sheep flock numbers well over 27 million and is a significant supplier for the wool and meat industries, for both domestic and foreign consumption. The meat industry is valued at $198 million and the gross value of the wool industry is $593 million, the second largest in WA agriculture (Agriculture Western Australia, 1999). Many sheep producers of both commercial and stud sheep in WA seek to improve the genetic quality of their flocks by importing sheep from other states, with a gross value for live sheep exports in 1996-1997, for example, of over $140 million (Australian Bureau of Statistics, 1998). Annual importation for this purpose averages
approximately 4,600 sheep from 91 interstate farms. New South Wales and South Australia provided the majority of imported sheep for WA with smaller contributions from Victoria, Tasmania and Queensland (Higgs and Hawkins, 1997).

Ovine Johne’s Disease is a significant intestinal disease of adult sheep caused by the bacterium *Mycobacterium paratuberculosis*. Infection by this bacterium produces a thickening of the intestinal wall which greatly interferes with the absorption of nutrients and water (Casey, 1997). The disease is usually transmitted through ingesting faeces from the infected animal. There is no known treatment for the disease. Sheep infected with OJD typical shed large numbers of the bacterium in their faeces months before clinical signs of the disease appear. This fact, coupled with the lack of an accurate diagnostic test, makes OJD difficult to control. Although not a devastating disease (such as Sheep Pox or Foot and Mouth Disease), OJD causes serious economic losses from export trade bans, shortened life expectancy, lower productivity of wool and smaller carcass weight at slaughter. Once signs of the disease appear the health of affected animals progressively deteriorates. Within six months they invariably die. The impact of OJD is perhaps most significant in stud flocks, with the cessation of ram sales and reduced returns from cull ewes which can no longer be sold as breeding stock. OJD was first diagnosed in New South Wales (NSW) in 1980, but is thought to have entered Australia as long ago as seventy years. By the middle of 1997, OJD had been confirmed in over 170 flocks in NSW, as well as in flocks in Victoria, Flinders Island and Tasmania (Agriculture New South Wales, 1999). The cost to NSW of the disease is estimated to average about $1726 per property, per annum, in 1997 dollars (ABARE, 1997), and presently costs the sheep industry more than $2 million per year (APP, 2000). Although Western Australia is currently free of OJD, it is clearly at risk of a disease incursion given trade flows, in particular, between states in Australia.

### 3.2. Quarantine activities in Western Australia

The options faced by Western Australia to prevent OJD from entering the state are relatively straightforward. As implied by equation (2.5), variations in the number of potentially infected sheep that may enter WA depend simply on the extent of quarantine expenditures on screening, surveillance, blood tests, and so on. The table below lists four possible quarantine activities and the resulting mean value of the number of infected sheep and are likely to enter WA under each program per year. The estimates of the number of infected sheep are based on historical and scientific data (drawn largely from the experience in NSW), a study by Higgs and Hawkins (1998), as modified by APP (2000), and probabilistic measures based on Beta-distributions (see Vose, 1996) to allow for occasionally large errors (for example) in serological screening tests.5

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5It is important to note that blood tests for OJD may only be up to fifty per cent effective on each trial. The more severe the quarantine activity the more often blood tests and surveillance
### Quarantine Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th># of infected sheep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free entry or no quarantine activity</td>
<td>221</td>
</tr>
<tr>
<td>Australian Sheep Johne’s Disease Market Assurance Program</td>
<td>6</td>
</tr>
<tr>
<td>Movement Restrictions</td>
<td>Less than 1</td>
</tr>
<tr>
<td>National Ovine Johne’s Disease Management Program</td>
<td>Close to 0</td>
</tr>
</tbody>
</table>

Table: Quarantine Activities

Free entry or no quarantine activity is taken as a benchmark case. Without any attempt to prevent OJD from entering WA, the cost of quarantine services and the welfare loss from trade restrictions are obviously zero. However, the threat of a disease incursion is greatest. Estimates suggest (see APP, 2000) that OJD, once endemic, can cost WA agriculture as much as eight million dollars per year. The Australian Sheep Johne’s Disease Market Assurance Program is a program that aims to identify, protect and promote sheep flocks that are most likely to be free of OJD. It employs serological screening tests and the adoption of property management regimes to minimize the risk of the introduction of the disease. Movement restrictions is simply a more extensive application of the Market Assurance program, with added blood tests and surveillance, and a projected error of allowing less than one infected sheep to enter WA in a given year. Clearly, the more severe the quarantine activity the larger the amount spent on quarantine expenditures and the larger the welfare loss through trade restrictions. Finally, the National OJD Management Program (currently not in place) is designed to approach a near eradication of OJD, at least in principle, through an even more extensive testing for the disease and the isolation and eventual elimination of infected flocks.

#### 3.3. A quarantine measure for Western Australia

The calculation of \( x^* \) for Western Australia, and thus the appropriate level of quarantine activity, requires estimates of all parameters in equation (2.16). All values are drawn from data and reports from Agriculture Western Australia and Agriculture New South Wales. Since all reported values are to a certain degree uncertain a calibrated simulation is run with an assumed probability distribution over each parameter value using the package @Risk (Palisade, 1997), with over a thousand trial iterations.

Recall that \( T_0 \) measures the length of time from when OJD first enters a region to the point in which it becomes endemic. Experience in New Zealand and New South Wales (NSW) suggests this period of time is roughly 20 years. are administered, and hence the larger the quarantine expenditure.
However, since Western Australia is relatively dry and sheep farms are far less concentrated, the length of time over which the disease spreads is undoubtedly longer and estimated to be approximately 33 years. The maximum number of infected sheep that enter WA without any quarantine activity in place, or \( R_m \), is estimated from data on the status of the disease in other regions and the number of consignments to WA. On average, WA imports 4600 sheep per year \( (M) \), mainly from New South Wales (Agriculture Western Australia Statistics, 1999). About twenty-five percent of these sheep are drawn from highly infected areas (Higgs and Hawkins, 1997) and the probability of the number of infected but unidentified sheep in NSW is estimated to be from five to ten percent (Collin, 1996 and Agriculture New South Wales, 2000). The mean value of \( R_m \) is thus estimated (see section 3.2 above) to be 221. The maximum quarantine expenditure \( E_m \) which reduces the risk of disease entry to virtually zero can be approximated by the expenditure required to screen every sheep that enters WA, rather than only a select sample of imported sheep. In practice, in WA, a random check over ten percent of the total imported sheep currently costs about $150,000 (APP, 2000). Since the blood test is inaccurate, doubling the normal screen over all imported sheep would roughly cost $2,000,000.

The average cost of OJD per head is determined by

\[
c_A = \delta_1 c_M + \delta_2 c_S + c_T
\]

(3.1)

where \( \delta_1 \) and \( \delta_2 \) are the proportional shares between commercial and stud farms and \( c_M, c_S \) and \( c_T \) is the average cost per head in commercial and stud farms and the cost of export trade restrictions if the disease is detected. According to Collins and Collins (1996), \( \delta_1 = 0.9 \) and \( \delta_2 = 0.1 \) and \( c_M = $104.00, c_S = $3.37 \) (including the average cost of death from the disease or $0.59 and the cost from selling the sheep from slaughter alone or $2.78) and \( c_T = $0.56 \). The average cost of OJD per head is thus $14. The average cost per property in WA, over infected sheep, is $1080. The value of \( \alpha \) or the proportional share of the quarantine expenditure and conformance cost between WA and the exporting region is 0.625. The current quarantine expenditure on imported sheep for WA is $150,000 and the associated expenditure for the exporter is $5060 (with an average expenditure per head for blood tests and the certificate fee of $1.10). The value of the interest rate \( (r) \) is taken as 0.06 and the growth rate of the disease (adjusted for conditions in WA) is 0.168. Finally, the period of time in which the present value of the potential cost of the disease is near zero, or \( T_1 \), is 130 years.

Given parameter estimates, \( \Phi = 14.2302, \Psi = 308,969.067 \) and \( \eta \) is calculated to be 2996. The value of \( x^* \) in equation (2.16) is thus \( x^* < 0.28 \), or (roughly) a quarantine activity and associated expenditure level that allows on average less

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\( ^6 \) The cost of the ELISA test is roughly $0.30 per head for a single test (at $3 per test for a 250 sheep sample in a flock of 2500). Under current quarantine activities in WA imported sheep are required to be tested three separate times and must also incur a flock certificate fee indicating disease free status (APP, 1998).
than one infected sheep every three or four years. As mentioned, since the parameter values are somewhat uncertain, a simulation is run on equation (2.16) using a (random) normal distribution around mean values. The standard deviation for $g$ is assumed to be 0.02, for $M$, 460, for $E_m$, $200,000$, and for $c_A$, $1.40$. The figure below summarizes the results for the simulated risk assessment. The measure of $x^*$ is reported in values of $10^{-2}$ against the probability of their occurrence. With random variation, there is a 90% likelihood that the optimal value of $x^*$ cannot be greater than 0.336. The results indicate that the Australian Market Assurance Program, augmented by the Movement Restrictions, is best for Western Australia, and should be applied with a severity that approximates a mean value of 0.28 for the number of sheep that enter the region in any given year, with a maximum bound of roughly 0.336.

4. Concluding Remarks

It is not necessarily the case that the best quarantine activity requires a severity or expenditure level that guarantees that the risk of a disease incursion is virtually zero. The direct cost of the disease must be weighed against the amount of quarantine expenditures necessary to reach a target level for the likelihood of a disease entry and the costs incurred from the resulting trade restrictions that must remain in place. Minimizing all costs determines an optimal quarantine activity. In the case of Western Australia, and the potential entry of OJD to the local sheep industry, the upper bound for the optimal number of potentially diseased sheep is strict (with a likelihood of only one infected case every three or four years), but clearly not zero. Nevertheless, it is also clear that the more costly on average the disease is to the local industry, the more quickly it becomes
endemic on entry, or the lower the discount rate on future costs and expenditures as a result of the disease, the lower the optimal value of a likely disease entry and the more severe the optimal quarantine activity.
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