POTENTIAL IMPACT OF FOOT AND MOUTH DISEASE OUTBREAK IN CALIFORNIA

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POTENTIAL IMPACT OF FOOT AND MOUTH DISEASE OUTBREAK IN CALIFORNIA

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1. Introduction

An outbreak of an exotic animal disease such as foot-and-mouth (FMD) can cause major economic losses in a previously non-exposed population. To prevent introduction of highly contagious exotic animal diseases, the U.S. uses trade restrictions as well as border controls on travelers coming from infected countries or regions. However, these measures do not constitute a perfect shield against possible outbreaks. The introduction of FMD into California's livestock population is a real threat.

FMD is probably the most contagious of all animal diseases. Since FMD does not affect humans, its consequences are only economic, yet an outbreak can still have devastating consequences. Constant monitoring and surveillance, rapid diagnosis and preparedness for control and eradication are required to minimize the probability of occurrence and, in case it happens, the cost of an outbreak. The probability of occurrence of an FMD outbreak has changed in recent years, since new potential routes of entry have developed. Historically, it was assumed that the importation of animals and animal products was the most likely source of infection. However, import regulations and border controls, as well as FMD eradication in neighboring countries, have reduced this risk to negligible levels. However, there is probably an increased risk of FMD introduction from travelers coming from countries with FMD, smuggling of infected animal products by such travelers, the disposal of garbage transported in planes and ships, and from eco-terrorism. These alternative paths should be taken into consideration in establishing an appropriate state and national FMD policy.

The cost of an outbreak would come from three different sources: a) control and eradication efforts, including the vaccination of or the slaughtering of infected or exposed animals, compensation for destroyed animals, cleaning and disinfection of infected premises, and quarantine enforcement; b) losses that arise from the interruption of production processes and its effects on upwards and downward linkages; and c) changes in trade flows that result from import restrictions that would be imposed by FMD-free trading partners having zero tolerance for the disease.
This chapter presents […]

2. Epidemiology of FMD

The FMD virus is an aphovirus within the picornaviridae family. The most important characteristics in the epidemiology of the disease include the rapid growth of the virus, its stability under a variety of conditions and the occurrence of serotypes (Donaldson, 1991). There are seven serotypes and several subtypes within each. The infections caused by different serotypes are clinically indistinguishable. The animals that survive an FMD infection become permanently immune to the particular strain that caused the infection; however, there is no cross-protection between stereotypes.

FMD rarely affect humans,¹ but attacks all cloven-hoofed animals. In the U.S. these animals include cattle, sheep, goats, pigs, camels, deer and bison. Cattle, in particular, are important in the epidemiology of FMD because of their high susceptibility to airborne virus, because they may excrete the virus for at least four days before the first symptoms appear, and because of their economic importance. Even though sheep and goats can also be infected, their symptoms are often less severe or are subclinical. Pigs are the most important source of air dissemination of the virus; once infected, they excrete vast quantities of the virus. They also have a high susceptibility to infection by the oral route (Donaldson and Doel, 1994). Thus, pigs can be described as amplifying hosts and cattle as indicators. Sheep can be described as maintenance hosts because they quite often have mild or even inapparent signs that can easily be missed (Donaldson, 1994). In spite of its infectiousness, FMD may infect some susceptible species and spare others in the same area (Dunn and Donaldson, 1997).

The primary methods of FMD transmission are aerosols, direct and indirect contacts with infected animal and ingestion. It is generally accepted that the virus most commonly infects via the respiratory route, especially in ruminant species where very small doses can initiate infection (Donaldson, 1994). Of all FMD transmission mechanisms, movements of infected animals are by far the most important, followed by movements of contaminated animal products (Donaldson, 1994). Humans may inhale and harbor the virus in the respiratory tract for as long as 24 hours, and may serve as a source of infection to animals (APHIS, 1991). Trucks and feed products can

¹ When humans are infected the symptoms are very mild and without consequences.
transport the virus after entering an infected farm. Garbage containing uncooked meat scraps and bones from infected animals has been a source of infection in pigs.

Virus excretion occurs before infected animals manifest clinical signs. With natural routes and high exposure doses, the incubation period can be as short as two to three days, but can take up to 14 days (Donaldson, 1994). The airborne virus is emitted over a four to five day period by an infected animal and excretion of the virus may start up to four days before the onset of the first clinical signs. Airborne virus is believed to have spread 60 km over land and 200 km over sea (Moutou and Durand, 1994; Donaldson, 1991). Factors favoring airborne spread of FMD virus are low to moderate wind speed, high humidity, stable atmospheric conditions, particularly a temperature inversion, absence of heavy precipitation, and high stocking density of cattle downwind (Donaldson, 1994).

Apart from the respiratory route, less frequent routes of infection are breaks in an animal's integument, i.e., the skin or mucous membrane. Thus, the injection of faulty FMD vaccines, foot-rot in sheep, the feeding of rough fodder, harsh use of milking machines, surgical procedures and damage caused by fingernails during nose restraint of cattle can all provide entry points for the virus. Veterinarians and AI technicians can be very important vectors in the early phases of an outbreak.

During the acute phase of the disease, which generally lasts three to four days, all excretions, secretions and tissues contain virus. Animals in this condition are very potent spreaders of virus. Products made from such animals contain high quantities of virus and many products must be decontaminated or destroyed. However, matured and deboned meat has been shown to be free from the virus, which is inactivated by the drop in pH during rigor mortis. The virus survives in the bone marrow and lymph nodes (Donaldson and Doel, 1994).

FMD infection results in low mortality for adult livestock that usually does not exceed 5%. Mortality is much higher in young animals, especially under conditions of dense stocking, reaching up to 90% (Donaldson, 1994). In addition, infected adults lose weight because they stop eating, cows lose their heat and milk production drops considerably. After a relatively short period (between two to three weeks), most infected adult animals recover from the lesions and become productive again, unless secondary bacterial infection occurs. In some cases, a permanent reduction in productivity has been observed. Tongue lesions in pigs are much less dramatic and heal much more rapidly (Donaldson, 1991). Losses are lower for herds in which FMD is endemic as a result of
building up resistance. However, total production losses in herds with endemic FMD can amount to 10% of annual output.

After recovery from FMD, up to 80% of ruminant animals may become persistently infected. It is believed that these carriers can initiate fresh outbreaks when brought into contact with fully susceptible animals. Vaccinated or immune animals exposed to infection may also become carriers. The duration of the carrier state varies according to the species involved, the strain of the virus and probably other unidentified factors. The maximum recorded periods that infected animals of different species have acted as carriers are over three years for cattle, nine months for sheep, four months for goats, five years for the African buffalo and two months for water buffalo (Donaldson, 1994).

The latest epidemics in Taiwan and Italy illustrate the extreme contagiousness of the FMD virus. In the first case, FMD was detected in a farm on March 14, 1997. New cases were reported on the 17th and 18th. On March 20, the government imposed restrictions on the movements of animals after receiving the results from the tests that confirmed the presence of FMD. By this time, the disease was present in 28 farms, and one week later, it had been confirmed in 217 farms. The number of herds infected reached 1,113 in the fifth week. Mass vaccination was started on March 29. Eventually, depopulation comprised more than 4 million pigs, about 38% of Taiwan's inventory of pigs. The eradication campaign was unable to keep pace with the dissemination of the disease (Yang et al., 1999).

On March 11, 1993, a premise in southern Italy was identified as infected and it was reported that a truck with cattle had left the premise on March 3. The infection was confirmed at the truck’s destination in the northern province of Verona. A private veterinarian noticed FMD symptoms in a group of calves and ordered the appropriate diagnostic tests, but the veterinarian then continued with his daily routine through a number of other farms in the zone. No further action was taken except for monitoring of that farm until the test results confirmed the presence of FMD virus a week later. By that time, several other farms visited by the veterinarian on the day the symptoms had been discovered were reporting symptoms of FMD on their herds. Three more outbreaks were confirmed in this region between March 11 and March 27. The spread of the disease was attributed to the veterinarian, a beet delivery truck and air dissemination. Stamping out was applied on infected animals and those considered “dangerous contacts”. Nine hundred animals were sacrificed and officially no vaccine was used. Depopulation of the 900 animals required three days.
Immediately after confirmation of the outbreak, a 3-5 km radius protection zone and a 10-km radius surveillance zone were established. A spatial simulation model was used to determine the probability and direction of airborne dissemination. When the simulations showed that the risk of airborne infection were low, daily control of the herds was restricted to the protection zone, because the available resources were not enough to monitor the surveillance zone. The area was declared FMD-free on May 1 (Maragon et al., 1994; Kitching, 1998).

In summary, several factors can affect the spread of the disease:

- Weather influences airborne dispersion.
- Animal density affects dissemination. Larger infected herds shed more virus into the air, and animals living in cramped conditions are more susceptible to infections since they are more stressed.
- Husbandry methods crucially affect the rate and extent of disease spread and, in the case of an outbreak, are a key consideration for control and eradication strategies. Because backyard operations usually undergo little sanitary surveillance, it is difficult to identify an infection in its early stages if it occurs in such an establishment. However, large-scale livestock operations involve frequent movements of animals and people that favor rapid spread of the outbreak. Service trucks and people enter and exit several farms per day; every week, milking cows are replaced often, and young animals are sent to stockers or feedlots all over the country.
- Once an outbreak occurs, its consequences depend on how fast the disease is identified and quarantine imposed, the effectiveness of the quarantine, whether animal movements can be traced, the availability of funds for depopulation and cleaning infected premises, and how rapidly depopulation can be carried out.

3. Control and eradication policies

Our analysis indicates that the time that is required to diagnosis FMD and initiate a stamping-out policy is the most important factor in determining the outbreak’s ultimate effect. Because the clinical signs of FMD are similar to those of other vesicular diseases present in the US, and because FMD has been absent from the U.S. for more than seven decades, it is possible that the first cases of FMD will not be properly diagnosed. In addition, since any farm on which a vesicular disease is detected must go through a costly quarantine period, farmers may choose not to report the symptoms, hoping that it is not FMD and that it will pass promptly. Once FMD has appeared, at least four alternative control and eradication strategies are available:
a) total stamping-out (i.e., depopulation of all symptomatic and apparently healthy animals that have been exposed, directly or indirectly, to the virus); depopulation can be complemented with ring vaccination, specially in densely populated areas.

b) partial stamping-out (i.e., depopulation of only symptomatic animals) with early or late ring vaccination;

c) partial stamping-out without vaccination; and

d) eradication through vaccination only.

Total stamping out is the current US strategy and thus the policy that would be implemented if an outbreak should occur in California (APHIS, 1991). However, alternative policies could be a more economical way of dealing with an outbreak (Garner and Lack, 1995). As the model’s simulations show, an outbreak could require depopulating California’s entire cattle herd. If it were known in advance that this result was probable, the state might find it more economical to vaccinate the entire herd and quarantine movements with the rest of the US. Stamping out would then be applied only to animals that are clearly infected. This approach would result in depopulating many fewer animals and would thus maintain livestock production at a higher level in the years immediately following the outbreak. After several years of no visible outbreaks, vaccination would cease and after several more years of production with no FMD outbreaks, California would be able to export beef again. However, the conditions under which alternative policies would be preferable should be evaluated in advance because once an outbreak has occurred, eradication strategies are largely irreversible.

The feasibility of stamping-out depends on the number of animals to be depopulated, as the costs and resources required for rapid depopulation escalate very fast. Vaccination could be used if stamping out becomes unfeasible, but under the present guidelines this would only be known after a substantial number of animals has been slaughtered. Given the production conditions prevailing in California and the U.S., the threshold above which stamping-out is no longer the best policy is not known.

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2 Vaccination can be used if: a) the disease has not been contained within six months of the outbreak; b) the outbreak reaches epidemic proportions (25% of the susceptible population in areas of high density livestock); c) the cost/benefit ratio of the slaughter program approaches 1:2; d) FMD becomes endemic in wildlife of three or more states; e) legal restrictions prevent carrying out the slaughter program (APHIS).
4. Estimating the cost of a FMD outbreak in California’s South Valley

The expected cost of an outbreak is defined as the estimated cost of the outbreak multiplied by the probability of occurrence. The FMD virus could be introduced into California through a number of routes and the risks of each of these routes is not well understood. Such risks have changed over time and there are no up-to-date estimates of risk levels. It is important to analyze these risks since an understanding of their magnitudes is important to the appropriate design of an FMD control policy. However, this research is concerned only with estimating the cost of an outbreak, should one occur in California.

4.1. The Model

A FMD outbreak in California’s South Valley and, eventually, its dissemination throughout the entire San Joaquin and Chino Valleys was simulated with an epidemiological model. The simulation results provided inputs for an economic model that was then used to estimate the outbreak’s costs.

The epidemiological model is a random state-transition model developed from a Markov chain. Several authors have used similar models to simulate FMD outbreaks (Miller, 1979; Dijkhuizen, 1989; Berentsen et al., 1992b; Garner and Lack, 1995; Perry et al., 1999). Because the potential behavior of an FMD outbreak under current production conditions in California is unknown, the model’s parameters were based on (1) a review of production conditions in the South Valley, (2) overseas experiences and (3) expert opinions.

The state-transition model has two components: states and transition probabilities. The states are different disease-related herd categories, i.e., susceptible to the disease, latent, infected with the disease, or dead as a result of depopulation (slaughter). A transition probability is the probability that an individual herd will move to state j in the next period when it is presently in state i. These probabilities, and consequently the number of susceptible, latent and depopulated herds that the model will simulate in each period, depend on production and environmental conditions and on the control strategies used.

Stamping-out is currently preferred option in dealing with an FMD outbreak in the U.S. and California. It requires banning all movements of susceptible animals that might have been exposed

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3 The South Valley includes Fresno, Kern, Kings and Tulare counties.

4 For a more detailed description of the model and its assumptions, refer to Ekboir (1999a), Chapter 7.
to the virus for about two weeks,\(^5\) prompt and rigid control of the movements of animals and animal products, vehicles, equipment and people in a surveillance area around any outbreak area; the rapid depopulation and the cleaning and disinfecting of infected or exposed premises; and intense surveillance of suspected herds. The efficiency of this policy depends on the timely availability of sufficient human, physical and financial resources. If the policy cannot be quickly implemented with a high degree of efficiency, the final eradication cost may be higher than if alternative policies are implemented. Study of alternative policies, however, is beyond this paper.

The model estimates the number of latent infections as well as the number of infectious premises. Since it is expected that the logistics associated with the depopulation of dangerous contacts could be a major constraint on the eradication of an outbreak in California, the transition state “latent to infectious” was introduced to explicitly explore the consequences of partial stamping out and of beginning depopulation at different stages of the epidemic. The results shows that the extent and duration of an epidemic depend on (1) the delay between infection and diagnosis of the disease, (2) the type of control strategy applied, (3) the availability of human and financial resources, and (4) the effectiveness of animal health authorities in executing the eradication polices.

Given the high density of susceptible animals in California’s South Valley and the intensive technologies used by farming establishments in the area, the transition probabilities used in this paper’s simulations were higher than those used in similar models developed for use in other contexts. Seven scenarios were simulated. Scenarios 1 through 4 use high dissemination rates that reflect the information collected in the South Valley, while scenarios 5 through 7 use lower dissemination rates taken from the literature, though here the highest published rates were used. All dissemination rates were allowed to change randomly up to 30% in any direction during each simulation. The model was run one hundred times, and the means and variances for each scenario were calculated.

The model incorporates three major epidemiological assumptions: a) the outbreak is successfully contained within California's borders, b) the disease is eradicated in a limited period of time; in other words, it does not become endemic, and c) the outbreak is a one-time event, i.e. the disease is completely eradicated after the occurrence of one outbreak. We believe that these assumptions are optimistic. An FMD outbreak would likely spread to neighboring US states. More

\(^5\) Under current production practices, this would involve all major livestock states.
than one outbreak would probably occur and FMD might well become endemic for some period of time. The results are thus a lower bound of the expected cost of an outbreak.

The economic model estimates three cost components: 1) the direct cost of depopulation, cleaning and disinfection and quarantine enforcement; 2) the cost of the direct, indirect and induced losses caused by the outbreak, estimated with an input-output model of the California economy; and 3) the cost of the losses caused by trade restrictions. The production losses include only the cattle, dairy, pigs, and related industries. Losses in other livestock industries, in wildlife and in outdoor activities are not included.

4.2. Results

The seven scenarios and the main results are presented in Table 1. Each scenario is characterized by different dissemination rate and depopulation effectiveness.

Table 1- Simulation results: % of the South Valley herds destroyed under seven different scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Dissemination Rate</th>
<th>% Depopulation per week</th>
<th>Depopulation starts @ week #</th>
<th>% of total herds destroyed</th>
<th>Total animals destroyed (ooo's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High</td>
<td>none</td>
<td>90</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>90</td>
<td>90</td>
<td>3</td>
<td>93</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>95</td>
<td>95</td>
<td>3</td>
<td>93</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>95</td>
<td>95</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>none</td>
<td>90</td>
<td>3</td>
<td>86</td>
</tr>
<tr>
<td>6</td>
<td>Low</td>
<td>90</td>
<td>95</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>Low</td>
<td>none</td>
<td>50</td>
<td>3</td>
<td>97</td>
</tr>
</tbody>
</table>

Source: Ekboir, J. (1999a)

The simulations show that even when the dissemination rates are high, early intervention combined with high efficiency in identifying latent infections and depopulating can substantially reduce the magnitude of an epidemic. Increasing the efficiency from 90 to 95% of depopulating latent infections and infectious herds has only a minor impact; the key factor is the rapidity with which depopulation begins after an outbreak occurs. Given the conditions prevailing in California’s South Valley, the opportunity for decisive intervention lasts only one week. If depopulation starts in the second week, about 19 percent of the herd must be depopulated to stamp out the outbreak. If depopulation begins in the third week of the outbreak, about 87% of the herds must be depopulated to stamp out the disease--assuming the same efficiency in quarantine control and in depopulation.

Scenario 1 represents the worst possible set of assumptions considered in this study. However, these assumptions could still be optimistic because California currently has only limited
financial resources available to respond to an animal health emergency. The inability to recognize and to commit adequate financial resources to deal with an outbreak is a factor that has not been explicitly modeled. Scenarios 2-4 demonstrate that California could significantly reduce the number of animals depopulated if it is able to identify an outbreak quickly and initiate an effective control/depopulation strategy. Scenarios 5-7 are somewhat more optimistic, using lower dissemination rates. However, scenarios 5, 6 and 7 make clear that containment of an epidemic requires depopulation of dangerous contacts even when dissemination rates are relatively low. An increase in the depopulation rate of infectious herds from 50% (scenario 7) to 90% (scenario 5, when latent infections are not removed) increases the proportion of surviving herds from about 2.2% to only about 13%. However, when latent infections are removed as well as a high proportion of infectious herds (scenario 6), the proportion of surviving herds increases to about 74%.

A key factor affecting the efficiency of eradication policies is the actual value of the dissemination rates. If dissemination rates are low, the stamping-out policy can be started later in the outbreak without disastrous consequences. If the dissemination rates are high--which is more likely in California--and if depopulation starts late, the stamping-out policy may require depopulation of all herds in the affected region. If that were know in advance, the adoption of an alternative strategy, e.g., ring vaccination combined with a slower depopulation rate, might result in a lower economic loss. In any case, it is clear from the simulations that, regardless of the dissemination rates, a high degree of preparedness and timely availability of financial resources are necessary conditions for containment of the epidemic.

Table 2 shows the total, direct and indirect costs of the outbreak. The total cost due to the FMD outbreak in California is equal to the sum of the direct, indirect and induced output losses, plus the cost of cleaning and disinfecting and enforcing the quarantine, plus the losses due to trade restrictions. The direct, indirect and induced output losses were estimated as the direct output loss multiplied by the corresponding output multipliers from the IMPLAN model. In addition to the output losses, a FMD outbreak would trigger trade losses both to both California and the U.S.; given the difficulties in estimating the beef exports originating in California, trade losses were estimated under the assumption that export restrictions would apply to the whole U.S. If the US could be effectively zoned, exports might continue from regions other than California and the results shown would then be too high.
The trade effects include restrictions on all meats, skins and dairy products originating in any state in the U.S. The model assumed that trade restrictions are lifted two years after depopulation of the last infected or exposed herd, and that U.S. exporters regain their market share in the FMD-free market immediately. This is a very optimistic scenario because it assumes that the cleaning and disinfecting efforts would be 100% effective in eliminating the virus from all infected premises, and that other exporters would not permanently capture a portion of the U.S. share of the FMD-free market. The trade losses arise exclusively from a lower export price. It is assumed that exporters in other states are able to maintain the volume of exports they shipped before the outbreak. This assumption is very unlikely, but follows the basic assumption that the outbreak is restricted to the South Valley. It is also assumed that California does not export any pork meat, and that trade restrictions on pork meat are applied only by Japan and Korea.

The calculations are based on the following assumptions: (1) the quarantines are lifted 120 days after depopulation of the last infected or exposed premise; (2) depopulated farms return to production 60 days after depopulation of the last infected or exposed premise; (3) the supply of animals outside the infected region is large enough to repopulate the quarantined premises in a short period of time, (4) the price of cattle remains at the levels prevailing before the outbreak; (5) dairies start selling milk immediately after the quarantines are lifted; (6) dairies that are not depopulated sell milk in the quarantine area without interruption at the same prices they received before the outbreak, (7) feedlots need 130 days after being repopulated to bring the animals to slaughter weight; and (8) hog facilities finish their animals in 40 days after the lifting of the quarantines. These assumptions are considered optimistic.

Table 2 - Total Costs of an FMD outbreak in California (million $)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Direct costs (1)</th>
<th>Production Losses (2)</th>
<th>CA Trade Losses (3)</th>
<th>Total US Trade loss (4)</th>
<th>Total Costs (5)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>1,428</td>
<td>990</td>
<td>1,871</td>
<td>6,098</td>
<td>8,516</td>
</tr>
<tr>
<td>2</td>
<td>1,345</td>
<td>920</td>
<td>1,871</td>
<td>6,101</td>
<td>8,365</td>
</tr>
<tr>
<td>3</td>
<td>545</td>
<td>251</td>
<td>1,871</td>
<td>6,107</td>
<td>6,903</td>
</tr>
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<td>1,056</td>
<td>1,969</td>
<td>6,253</td>
<td>8,630</td>
</tr>
<tr>
<td>6</td>
<td>560</td>
<td>259</td>
<td>1,871</td>
<td>6,113</td>
<td>6,934</td>
</tr>
<tr>
<td>7</td>
<td>1,462</td>
<td>1,239</td>
<td>1,984</td>
<td>6,282</td>
<td>8,983</td>
</tr>
<tr>
<td>8</td>
<td>4,819</td>
<td>2,613</td>
<td>1,871</td>
<td>6,098</td>
<td>13,531</td>
</tr>
</tbody>
</table>

NOTES:

(1) Direct costs include depopulation, including compensation for destroyed animals and materials, cleaning and disinfecting, and the quarantine cost.
(2) Includes direct production losses, plus indirect losses (reduced output in linked industries such as input suppliers, service providers, and milk and livestock buyers), and induced losses (a reduction in employment, sales and consumption throughout the state's economy).
(3) State of California trade only.
(4) Trade losses from the entire U.S., including California.
(5) = (1) + (2) + (4)
Source: Ekboir, J. (1999a)

If the dissemination rates are high, a half-week delay in the start of depopulation increases the cost of an outbreak by $135 million (compare scenarios 3 and 4, column 5). A delay of seven days increases the cost by $1,748 million (scenarios 1 and 4, column 5). If the outbreak spreads to the entire San Joaquin Valley and Chino Valley, the loss increases by $6,763 million over even the most optimistic of the South Valley scenarios (scenarios 4 and 8, column 5). These estimates demonstrate that California could find it profitable to invest in additional resources to monitor and respond to an FMD outbreak, provided that such expenditures significantly increased the probability of identifying an outbreak more quickly and/or bringing it under control. For example, if improved monitoring could reduce the cost of an outbreak by $5 billion and if the probability of an outbreak occurring in any year were 1 in 10,000, a simple calculation suggests that California would find it profitable to spend up to about $700,000 more per year than it is currently spending on monitoring and preparing to respond to an FMD outbreak. Although additional analysis is needed to arrive at more reliable figures, the example suggests that more attention should be paid to this issue.

For example, even in the most optimistic case (scenario 4), public animal health services would need $476 million during weeks two to six of the epidemic to eradicate the outbreak. However, under present legislation only $12 million would be immediately available, and appropriation of additional resources would require legislative intervention which could delay the start of eradication more than one week. In this same scenario, eradication of the outbreak would require depopulation and disposal of 149,000 cows and 2,183 pigs in the first two weeks of the eradication campaign. Past experiences indicate that it is almost impossible to develop so rapidly the capacity for depopulation and disposal. If depopulation and disposal cannot be carried out as rapidly as assumed in scenario 4, it is probable that that an outbreak would then spread still more

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6 Eradication of 900 cows in Italy demanded 3 days. Depopulation of more than 4 million pigs in Taiwan required about a month after the army was called in; 130,000 pigs were killed per day at the peak of the depopulation campaign, after the soldiers had gained considerable experience in killing the pigs and disposing of the carcasses.
rapidly throughout California and perhaps to other states with large livestock industries. Scenario 8 replicates Scenario 1 (high dissemination rates, no depopulation of latent infections and 90% of infectious herds eliminated each week) under the assumption that the outbreak affects the San Joaquin and Chino Valleys as well as the South Valley. Total costs nearly double. Note that the costs associated with the imposition of international trade restrictions on US beef are essentially constant from one scenario to another, since it is assumed that the presence of FMD anywhere in the US will cause importers to restrict beef imports from the US. The increase in costs brought about by the spread of the disease is almost wholly associated with the need to depopulate and dispose of a growing number of animals.

5. Policy issues

The model simulated the economic losses caused by an FMD outbreak based on several relatively optimistic assumptions, e.g., total quarantine effectiveness from the first day it is imposed, rapid depopulation and disposal of infected and exposed animals, comprehensive cleaning and disinfection of infected premises to prevent future contamination, and containment of the outbreak within California. Thus, in these scenarios the disease does not become endemic and production returns to pre-outbreak levels after a relatively short period of time. The success of a control and eradication campaign depends heavily on three factors: 1) the effectiveness of public surveillance programs that allow early identification of the disease, 2) preparedness of all personnel that would eventually be involved (veterinarians, cleaning crews and law enforcement agents), and 3) timely availability of physical, human and financial resources to enforce quarantines and achieve depopulation and disposal.

The effectiveness of the prevention measures depends importantly upon collective action. Producers must be willing to report the disease and cooperate fully with the disease control authority in depopulation, disposal and decontamination. Producers are likely to be willing to cooperate only if they are adequately compensated for animals that must be destroyed and if they have faith that other producers will do the same. If other producers do not take measures to control the disease, it makes no sense for an individual farmer to depopulate his/her farm and repopulate later with non-exposed animals. The decisions taken by a single producer depends crucially on the measures taken by his neighbors. Policy, including producer education prior to and during an
outbreak, are crucial factors in determining the outcome. We turn now to the analysis of these policy issues.

5.1. Outbreak eradication strategies

Stamping out could be partial or total. With partial stamping out, only animals with clinical signs are sacrificed. But because of the risk represented by animals in the latent state, partial stamping out constitutes a risky strategy that can only be justified if the resources available do not allow total stamping out.

5.2. Carcass disposal

The feasibility of stamping out policies depends on the number of affected animals that must be depopulated. Stamping out can only be implemented when the expected number of outbreaks and/or animals infected is relatively small (Donaldson, 1994). The real bottleneck is the logistical and environmental problem of carcass disposal. Since carcasses cannot be left to rot in the open, the speed of depopulation is constrained by disposal capacity --and the longer depopulation is delayed, the greater is the probability that the disease will continue to spread.

According to the APHIS guidelines, three disposal methods can be used. In order of preference they are burial, burning and rendering. Burying hundreds of thousands of carcasses in the South Valley would require excavation of miles of trenches, which could not be disturbed for several years. Burying the carcasses would thus a major cost on producers because the land would be lost for most productive uses. Burning the carcasses would require massive amounts of wood or other fuel, which would probably be difficult to acquire in a short time. Burning might also create air pollution problems and could require exemptions from air quality standards. The use of an air curtain, assuming that adequate equipment is available, would reduce the quantity of fuel needed and the environmental impact of massive burning, but would increase the burning time. Disposal in landfills might be limited because carcasses would have to be mixed with waste in a fixed proportion. There is also a cost of faster filling of a landfill.

Because disposal is such a key issue, a cost-benefit analysis of alternative carcass disposal methods should be conducted to identify the best measures for California. Burial was by far the cheapest way of carcasses disposal applied in Taiwan's 1997 outbreak, where rendering and burning were also utilized (Yang et al., 1999).

Exposed animals showing no signs of infection should also be slaughtered, but under the USDA plan they can be diverted to human consumption or protein utilization. However, the
slaughter capacity in the South Valley probably would not be enough to process the required number of animals in a timely manner. Another major obstacle to depopulation of exposed herds could be lack of political or financial support for killing a large number of apparently healthy animals, or of a willingness by consumers to purchase beef resulting from the slaughter of “exposed” animals.

5.3. Resource availability

The efficiency of an eradication campaign depends on the timely availability of trained human resources and financial resources for cleaning and depopulation. Training is a long-term investment that is difficult to justify when FMD has been absent for such a long period. Availability of financial resources depends on the amounts required and the urgency of the situation. Factors that could delay the Legislature’s allocation of funds are a lack of consensus on the feasibility of eradicating the disease at a reasonable cost, and a lack of understanding by lawmakers and executive officers of the veterinary and economic issues involved. Delays in the eradication can be reduced with appropriate regulations that would increase the amount of funds available to public animal health officials in an emergency.

5.4. Compensation for losses

In economic terms, FMD eradication is a measure taken to eliminate the externality caused by the high infectivity of the disease and thus reduce societal costs in the long run. Application of stamping out requires total cooperation by farmers and a basic condition of their cooperation is an adequate compensation policy for animals that are to be depopulated. If compensation is set too low, producers have no incentive to report sick animals and they may try to sell them, thus disseminating the disease. However, if compensation is set too high, producers may introduce healthy animals into infected premises to claim compensation for their destruction.

Under current regulations, indemnity payments cover only the direct cost of animals and materials destroyed. It has been documented, though, that because of trade restrictions, total economic losses can exceed by several times the costs covered by indemnity payments (Berentsen et al., 1990; Yang et al., 1999). Moreover, these “consequential losses” may be incurred not only by the livestock producers but also by all related industries. It is impossible, however, to estimate the consequential losses with any degree of accuracy. Therefore, these losses should be addressed by other measures such as those used to provide relief after natural disasters—e.g., low cost loans, tax relief, and special unemployment payments.
Given the expected magnitude of the consequential losses, it may be difficult for the livestock and dairy industries to return to business after the lifting of the quarantines. The industry should study the creation of a self-insurance scheme to cover the indemnification of consequential losses. The basis could be a fund that would be invested in the financial markets until needed. Because of the low probability of an outbreak, the initial investment could be relatively small and constituted over a number of years. The main limitation in following this policy would be to convince producers of its long-term social benefits (Ekboir, 1999b).

6. Trade issues.

Under any conceivable scenario, an FMD outbreak in California would impact significantly on the State's livestock trade, on a local and regional basis, for a period that may span from a few months to several years. An outbreak would also greatly affect international trade by eliminating the FMD free status that the U.S. currently enjoys and that permits the US access to other high-priced FMD-free markets. A major FMD outbreak that resulted in trade restrictions on beef imports would cause large trade losses. The US would be forced to sell its animal products in FMD-endemic markets, where prices are lower than in the FMD-free market. Since most U.S. beef exports are currently shipped to Japan and Korea, which do not recognize the regionalization principle, the outbreak would probably affect all U.S. exports.7

6.1. Local impacts

Once an outbreak is confirmed, trade routes from and into the infected area would be closed, and a quarantine area would be set up. The quarantine area could include a few miles around the infected premises, or, in case of a rapid spread of the disease, it could include the entire state or several states.

Because of the quarantine and depopulation, the livestock and dairy industries in the quarantine area will be affected. In the early days of the outbreak there would be a localized excess supply of livestock, because products originating in the infected region could only be consumed in the quarantine area. This excess supply may last a negligible period of time and may not have any effect on prices.

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7 The regionalization principle allows for continued beef exports from clean areas within a country where a FMD outbreak has occurred, if the outbreak can be contained within a quarantined area. Quarantine effectiveness is evaluated by importing countries.
As depopulation advances, the supply of livestock and milk to processing plants would fall because farms cannot be repopulated until the quarantine is lifted. In order to minimize the lost revenue and to maintain their market share, processing plants might be forced to import raw materials from outside the quarantine area.

**6.2. Regional impacts**

California is a net importer of meat and dairy products. For this reason, the impact of an FMD outbreak would be less devastating to California than to other regions that are net exporters. To some extent the state would be able to substitute the lost production with imports. However, if depopulation is significant, output would decrease to a level in which imports would have an effect on the other states trade flows and on meat and dairy prices.

The dairy and livestock industries are linked forward and backwards to a number of industries, i.e., input suppliers, service providers, and milk and livestock buyers. A serious disruption of the dairy and livestock industries would also affect the linked industries. Live cattle would not be allowed to leave the quarantine area, so calves that are not depopulated would normally be sent out of the state for raising would have to be retained in the state. This alternative could pose serious logistic and economic problems if vaccination is applied.

**6.3. International impacts**

The Uruguay Round Agreement established a new regulatory framework for international trade. In respect to beef, trade was affected in various aspects. Over time, subsidies and tariffs are to be reduced, and protected markets approved minimum access commitments. The SPS protocol led to growing acceptance of regionalization, dependence on science-based risk assessment, and prohibition of the use of sanitary barriers as barriers to trade. The OIE has become the international authority that sets sanitary standards, though countries are not forced to accept them.

Almost all countries accept the principle of regionalization. Japan and South Korea are noticeable exceptions that would play a significant role in case of an FMD outbreak in California because they import 62% of the US beef and pork exports, by value. If Japan and South Korea were to ban imports from the US, it would impact the international meat markets substantially, with significant movements in prices and trade flows.

If Japan and South Korea banned beef imports from the US, the US would be forced to sell in the FMD-endemic market. Considering the volumes that would have to be re-routed, beef prices in the FMD-endemic market would fall abruptly, while prices in the FMD-free market would
increase. The reduced profitability of foreign markets should increase the domestic supply (as less beef would be exported), reducing the demand for Australian and New Zealand beef. The mid- and long-term impacts on world beef markets are difficult to predict as they will depend both on the response of livestock producers in the U.S. and in other major exporting countries (South America, Australia and New Zealand) and also on changes in demand in the largest importers.

Would Japan and SK maintain a "zero tolerance" policy if the US, their major beef provider, suffered from a major FMD outbreak? A shortage of red meats would push the price up sharply. Local consumers would want to substitute chicken and pork for beef. Local producers are not capable of increasing the beef supply, so other exporters, especially Australia, would be able in the short run to partially replace U.S. beef in the Asian countries. But because Australia and New Zealand would not be able to completely replace the U.S. in the Asian markets, prices would still be higher than before the outbreak. This might induce Japanese and Korean authorities to revise their zero tolerance policy.

7. Final Comments and Recommendations

An outbreak of FMD in California would have major impact in the whole U.S. livestock and linked industries. It would be impossible to maintain proper surveillance mechanisms and to conduct a successful eradication campaign without the commitment of government and the livestock industry and farmers' organizations.

California livestock industry is characterized by the existence of two clearly different types of premises: large commercial farms and backyard operations. The backyard operations could be a potential entry route for the FMD virus because they maintain very lax biosefatey policies. From a policy point of view, these operations are a major threat because they are difficult to identify and costly to monitor. Current programs that target small and backyard operations should be reviewed to increase their efficiency.

The presence of large number of commercial premises, and consequently of a high density of animals, would represent a major logistical problem in the case of a FMD outbreak. A large number of potentially dangerous movements in and out of these premises occur every day: feed and milk truck, veterinarians, AI technicians and move of calves and replacement cows. Additionally, the high density of animals favors airborne diffusion of the infection. Because infected animals shed the virus before the onset of clinical signs, it is probable that by the time FMD is identified, several thousands of animals would already be infected.
Depopulation of such a large number of animals would require substantial physical, human and financial resources. Training of animal health official and helpers would increase the effectiveness of the first efforts (which are crucial in reducing the damage caused by the outbreak). New regulations are required so that the financial resources needed for the control and eradication campaign are available when needed.

The simulations presented here show that the effectiveness of the eradication campaign depends crucially on the date it is started. A one-week delay in starting depopulation could increase the proportion of infected premises from 18% to more than 90%.

Establishing a tight quarantine that would cover most of the state would be extremely difficult, as it would affect other economic activities. Another problem would be the training of law enforcement agents and technicians on how to properly clean and disinfect vehicles.

Considering the considerable obstacles that a total stamping out policy would face, other policies could be more efficient. Further research is needed to determine the conditions under which each policy would be preferable.
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