Saving our bacon without hamstringing the industry: Sensitivity of economic losses to post-outbreak management of foot-and-mouth disease vaccinated animals in a simulated US outbreak

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Foot and mouth disease (FMD) is a threat the US currently faces due to its rapid spread, damage to domestic productivity, and implications for trade of susceptible species of livestock and associated animal products. As a result of the economic costs and the controversy associated with extensive suppressive culling as well as the challenges of culling large numbers of animals in a short period of time, renewed interest in emergency vaccination has emerged. Emergency vaccination as a control strategy alternative has been the source of controversy among policy makers and scientists as the inclusion of emergency vaccination in an eradication program has both epidemiologic and economic consequences. Emergency vaccination has the potential to confine virus spread to a smaller region, reduce shedding and thereby reduce the number of infected animals and shorten the duration of an outbreak. FMD vaccination also has the potential, among other factors, to delay the re-opening of international markets.

Historically, countries that have employed emergency vaccination have had to decide how to manage vaccinated animals in the recovery phase of the outbreak. One management option is to depopulate vaccinated animals (vaccinate to die or vaccinate to waste) in the same way infected animals are depopulated. Under this vaccinate to waste approach, vaccinated animals would not enter the food chain. Vaccinate to waste has been used in the past, perhaps in part due to the difficulty of differentiating vaccinated animals from infected/recovered animals. However, advances in companion diagnostics to FMD vaccines that have been sufficiently purified make it possible to identify vaccinated animals that have not been infected. These companion diagnostics open the potential to explore vaccinated animals living out a useful life (vaccinate to live management options) rather than their product being wasted. There is a continuum of ways to apply a vaccinate to live program, but we will explore two for the purpose of this study that focus on the impacts in the recovery phase: vaccinate to retain and vaccinate to salvage. In a vaccinate to retain program, vaccinated animals may live out their productive life before being harvested. In a vaccinate to salvage program, vaccinated animals may be harvested for consumption on an accelerated timeline to potentially speed trade recovery.

We expect domestic markets to be sensitive to the choices made in management of vaccinated animals during the recovery phase of the outbreak, but the extent of that sensitivity is currently unknown. The work proposed for this presentation will address that gap. In this article, we measure the relationship between national economic impacts across a 4 year period to three factors: vaccination implementation strategies during an outbreak, trade partner reaction and recovery when emergency vaccination is used, and producer decision making around inventory turnover in the face of price changes.

The Threat of FMD

FMD can result in large economic impacts associated with trade restrictions, disease eradication, and market disruption; however, the physical consequences of the disease are not trivial. FMD exposure results in almost 100% morbidity, causing reduced milk yield, growth rates, and fertility with consequent increases in culling, as well as high mortality rates in very young animals, and disruption of livestock
production channels and local markets (Doel, 2003). The goal of emergency vaccination is to slow the spread of the disease by providing a barrier of immune animals between the infected region and the non-infected region. At stake is the continuity of local farms and businesses, which is threatened by the disruption of farm practices resulting in lost income, loss of breeding stock and the disruption of livestock improvement programs (Doel, 2003).

Estimates of the economic impact of FMD are quite sensitive to the disease spread and control modeled, business continuity assumptions, assumptions made on trade embargo magnitude and geographic extent, time to trade recovery, and consumer response in the economic model. This makes prior published studies difficult to directly compare. However, across the literature economic impact has ranged from $257 million (Pendell et al. 2007) to $30 billion (Carpenter et al. 2011). Research has suggested that, while vaccination can be efficient in lessening the spread of disease as part of a comprehensive control strategy (Bates et al. 2003), the economic benefit is sensitive to factors such as speed of spread and early vaccination intervention (Schoenbaum and Disney, 2003). Other control options may give a greater economic benefit as compared to vaccination, such as enhanced surveillance (Elbakidze et al. 2009). When vaccinated to salvage is examined compared to vaccinate to waste, given constant trade embargoes between the two, vaccinate to salvage has the potential to lessen the overall impact to the affected industries (Schroeder et al. 2015).

**Methodological Frameworks**

The analytical framework that is applied begins with input from stakeholders and key decision makers. That input feeds into both a national disease spread model and a national partial equilibrium livestock and feed sector economic model.

FMD spread and control measure impacts were derived from a spatial, stochastic model that includes 1.8 million farms (Burdett et al. 2014) and more than 900 congregation points (markets) built in InterSpread Plus (ISP) (Stevenson et al. 2013). ISP includes integrated control measures for FMD, including: depopulation of infected herds; movement restrictions; active surveillance and tracing of direct and indirect contacts; passive surveillance (producer observation and reporting of symptoms) both prior to disease detection and after disease detection; and vaccination in rings or donuts around infected premises, other types of polygons (county borders), or targeting certain high-risk species.

The national livestock and crop sector partial equilibrium model (Paarlberg et al., 2008) is used to estimate the impact of reduced livestock inventory and meat supplies due to depopulation, imposing trade embargoes for the duration of the outbreak and slowly lifting those embargoes as the negotiation process proceeds, the impact of consumer avoidance due to risk perceptions or aversion to control methods, and increased slaughter rates due to accelerated harvesting of vaccinated animals. The economic model has 33 livestock categories, including 11 final products as well as primary and intermediate inputs. The changes in prices and quantities in the model are primarily driven by: revenue shares for each agricultural sector, elasticities, the feed-balance calculations that tie the livestock and grain sectors together, and the exogenous shocks that the user imposes. Finally, price changes and costs
to producers in the post-outbreak period are synthesized into a breakeven analysis for producers to support discussion around post-outbreak recovery policy discussions.

**Disease Outbreak Scenarios**

The baseline disease outbreak scenario in the National FMD Standard model is an outbreak starting in the state of Iowa, in a commercial swine farm. The control strategies include slaughter of clinically infected animals, quarantine of herds within a specified radius or geographic boundary around an infected herd, tracing of direct and indirect contacts, passive and active surveillance, movement controls, and emergency vaccination. Emergency vaccination includes blanket vaccination of all bison, cattle, and swine production types within a 10km ring around detected farms where 2.5 million vaccine doses were available within the first 14 weeks after detection. States determine their own vaccination policy, so it is possible that each state involved might have a different vaccination strategy (e.g. size of the ring or species vaccinated). We assume that each state has the same vaccination policy for the purposes of this paper.

**FMD Outbreak Characterization**

Simulated FMD outbreaks were broken into 5 different sizes of outbreaks according to the outbreak typology in figure 1, developed by Roth (2017). This characterization assumed simulated outbreaks exhibited a positive correlation between 3 factors—animals infected, duration of the outbreak, and states affected. As outbreaks increase from type 1 to type 5, the response policies that could be considered may change (FMD RedBook, 2017).

**Economic Scenarios**

For the duration of the outbreak, national trade embargoes are assumed during the outbreak. Post-outbreak regionalization of trade embargoes was assumed to be implemented gradually in the first 180 days of the post-outbreak period. Full trade recovery occurred at 180 days after the last vaccinated animal was removed from the national herd. Consumers are not assumed to begin avoiding affected meat products in large enough numbers to affect national markets until after the disease spread grows to a national level (Type 4-5).

**Sensitivity Analysis**

The results presented for the baseline scenario rely heavily on parameters derived from control strategies selected, and potential deviations in trade impacts from observations in other countries or for other disease situations in the US. To examine whether more general conclusions can be made on the economic consequences in the post-outbreak period, variations on these parameters were examined. Table 1 contains the variations examined in:

1. Length of bilateral negotiation period for trade recovery that affects exports of live animals and fresh/frozen meat products after the last vaccinated animal is removed;
(2) Inability to regionalize trade embargos to the affected states and consequently that affects exports of live animals and fresh/frozen meat products.

Two alternative bilateral trade recovery rates are examined after the last vaccinated animal was removed. The rate of recovery was expanded by one quarter from the baseline (270 days versus 180 days in the baseline) and reduced by one quarter (90 days versus 180 days in the baseline). Given the uncertainty around how long bilateral negotiations will take after the US is eligible to begin exporting products, these two alternatives examine the impact of those processes in the overall economic consequence results.

Finally, the baseline assumes that the US will be able to regionalize trade impacts to affected states in the post-outbreak period, and that assumption was removed to examine the impact of national trade bans from the day of disease detection until the last vaccinated animals is removed. The extent of the trade embargoes balanced against the changes in the production parameters from depopulation and post-outbreak management of vaccinated flocks has the potential to test the robustness of conclusions on economic consequences.

Results

Of the 100 simulated outbreaks, 41 outbreaks exhibited the positive correlation between these 3 factors hypothesized in the typology—animals infected, duration of the outbreak, and states affected. As outbreaks increase from type 1 to type 5, the response policies that could be considered may change (FMD RedBook, 2017). A representative iteration (median) from each of the 5 clusters of outbreaks was selected, the outbreak extent and cost summary are presented in table 2. As outbreaks increase in severity, from outbreaks that are contained to the state of Iowa all the way up to national scale outbreaks affecting more than 15 states, the logistics of disease eradication and emergency vaccination program implementation become more challenging, particularly in geographical areas that are densely populated with susceptible livestock species. By the time outbreaks reach a widespread, national outbreak, the median type 5 outbreak results in a million animals depopulated, 15 million vaccinated animals, and a $2 million cost of response in the 139 day outbreak. It was expected that the effectiveness of vaccination in contributing to disease eradication would depend on vaccine distribution capacity, implementation speed and strategy selected. The vaccination strategy in this scenario was a 10km ring vaccination for the sake of consistent comparison, but a more targeted vaccination strategy or a change in vaccination capacity could change the results described here.

The impact on US producer welfare increases from $1 billion to $8.5 billion in a type 1 and type 5 outbreak, respectively, during the outbreak period. This is driven largely by the duration of the outbreak and the total, national trade ban of all affected livestock and fresh/frozen beef, pork, and lamb in that timeframe. In the 4 year post-outbreak period examined, the cost of surveillance of vaccinated animals and non-vaccinated sheep and goats in the vaccination/surveillance zone ranged from $500 million to $3.5 billion. The producer costs of managing vaccinated animals and handling them for testing every 21 days ranged from $9 million to $101 million in the same time period. As with the outbreak period, the producer welfare loss was much higher and reflected the trade and consumer shocks to the industries.
The producer welfare loss in the post-outbreak period ranged from $24 billion to $50 billion for type 1 to type 5 outbreaks, respectively. The greatest portion of this loss is attributed to the swine industry, which suffers from longer trade embargoes while vaccinated cattle are being removed from the national inventory over the course of 2 years.

In the post-outbreak period, producers will have greater latitude to make decisions about marketing animals in the absence of movement restrictions. For some producers these economic losses may mean reducing their herd/flock size or even the inability to remain in business. Furthermore, producers share in the cost of post-outbreak management of vaccinated animals and this impacts their ability to break even. The government invests further money in the diagnostics, labor and supplies to manage vaccinated animals to provide assurance to trade partners around vaccinated animal tracking and disease freedom.

Figure 3 shows the estimated breakeven price by quarter accounting for changes in meat and milk prices, production levels, inventory changes, feed costs and surveillance costs. Small regional outbreaks result in short term spikes in breakeven price that producers might be able to wait out, particularly for beef cattle producers that can hold cattle on pasture, provided they have that ability, until prices can begin recovery. For dairy producers, particularly under type 4 and type 5 outbreaks, the significant decline in calf and cull cow income mean costs must be almost exclusively covered by milk production. Dairy margins are historically tight, and the length of time required for breakeven prices to drop might be enough to drive some dairy producers out of business. Based on the examination of milk prices alone, it might appear that the continued ability to export pasteurized milk products protects dairy producers from significant business impacts; however, the examination of breakeven price reveals that difficulties this sector may face in breaking even while waiting for markets to stabilize in beef and feed markets. For swine producers, breakeven price levels out at a higher level that the baseline examined. This may indicate the potential for structural change and the possible long-term contraction of that industry in the aftermath of an FMD outbreak.

Sensitivity Analysis

Sensitivity analysis results are shown in figure 4. The greatest sensitivity in producer returns was to regionalization for all types of outbreaks; however, as the outbreak grows in geographic size, the sensitivity to regionalization, as expected, reduces. In addition, we would expect that the degree of sensitivity will depend on the region where infected animals are as well. Since this outbreak started in Iowa, we expect that will impact the regionalization sensitivity analysis results. The largest benefits to regionalization accrue to swine producers. The net present value of difference between producer returns with and without regionalization across 4 years of $17 billion under a type 1 outbreak to $4 billion under a type 5 outbreak. Cattle producers benefited from regionalization as well. For cattle producers the net present value of the difference between producer returns with and without regionalization across 4 years ranged from $9 billion under a type 1 outbreak to $3.7 billion under a type 5 outbreak. Dairy producers do not derive significant benefits from regionalization, nor do sheep and goat producers. If trade negotiations can occur more quickly, the swine industry stands to gain approximately $500 million (range $433 to $528 million) in NPV of producer returns from reducing the
time to reopen trade by 1 quarter in the 4 year period. Slower trade recovery from the baseline results in higher losses, as expected. The results of this sensitivity analysis indicate that there are significant benefits to limiting geographic spread when combined with the ability to regionalize. This result corresponds to observed effects of regionalization for highly pathogenic avian influenza in the US (Thompson, 2018).

Conclusion

FMD poses a serious threat to the health and value of US livestock sectors. As such, decision making on control strategy selection is complex and depends on factor such as size, length of response and location of the outbreak. This analysis broke disease spread results into different categories (type 1 to type 5) where outbreaks increased the numbers of animals infected, the duration of the outbreak and the numbers of states with infected herds. As outbreaks increased in complexity, so did the demands on response resources such as vaccine doses and response costs. Post-outbreak recovery surveillance costs also increased as outbreaks grew in complexity, for both the government animal health authorities and for producers. The high cost of surveillance in the post-outbreak period provides motivation to further explore options like pooled sampling in vaccinated herds and bulk milk tank testing for dairy herds.

Results also provide insights into how different industries may view the benefits and costs of vaccination, and the management of animals in the post-outbreak period. In this particular outbreak scenario, the swine industry had the greatest losses and would benefit from efforts into achieving regionalization of trade embargoes. However, the dairy industry, by contrast, would benefit greatly from business continuity into domestic markets, particularly given their main export good is pasteurized and therefore exempt from trade restrictions in most cases. Examining the breakeven price results, all industries will struggle in the quarters following an outbreak, but the swine industry in particular may face significant structural change as a result of the outbreak. These results motivate further discussion of the economic tradeoffs in the management of vaccinated animals in the post-outbreak period.
References


Burdett, C.L., Kraus, B., Bjork, K.E., Miller, R.S., Oryang, D., & Garza, S.J. (2014). Predicting the location and populations of individual livestock farms in the United States (ab). Retrieved from http://eco.confex.com/eco/2014/webprogram/ Paper48870. html (Distribution of farm locations and populations for individual facilities were received through personal communication.)


Table 1. Local sensitivity analysis scenarios around vaccination implementation strategy, length of trade recovery after the last vaccinated animal is removed and regionalization of trade embargoes.

<table>
<thead>
<tr>
<th>Control Strategy</th>
<th>Outbreak Characterization</th>
<th>Regionalization during the post-outbreak period</th>
<th>Days to Negotiate Trade Access After the Last Vx Animal is Removed</th>
<th>Consumer Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline:</strong> 10Km ring vaccination with 2.5 million doses</td>
<td>Type 1</td>
<td>Yes</td>
<td>180</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
<td>Yes</td>
<td>180</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 3</td>
<td>Yes</td>
<td>180</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>Yes</td>
<td>180</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Type 5</td>
<td>Yes</td>
<td>180</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>Slower Trade Recovery:</strong> 10Km ring vaccination with 2.5 million doses</td>
<td>Type 1</td>
<td>Yes</td>
<td>270</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
<td>Yes</td>
<td>270</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 3</td>
<td>Yes</td>
<td>270</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>Yes</td>
<td>270</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Type 5</td>
<td>Yes</td>
<td>270</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>Faster Trade Recovery:</strong> 10Km ring vaccination with 2.5 million doses</td>
<td>Type 1</td>
<td>Yes</td>
<td>90</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
<td>Yes</td>
<td>90</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 3</td>
<td>Yes</td>
<td>90</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>Yes</td>
<td>90</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Type 5</td>
<td>Yes</td>
<td>90</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>No Regionalization:</strong> 10Km ring vaccination with 2.5 million doses</td>
<td>Type 1</td>
<td>No</td>
<td>180</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
<td>No</td>
<td>180</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 3</td>
<td>No</td>
<td>180</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>No</td>
<td>180</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Type 5</td>
<td>No</td>
<td>180</td>
<td>1.0%</td>
</tr>
</tbody>
</table>
Table 2. Baseline epidemiologic and economic impacts

<table>
<thead>
<tr>
<th>Median Summary Statistics</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
<th>Type 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OUTBREAK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animals Depopulated (hd)</td>
<td>44,621</td>
<td>99,828</td>
<td>149,570</td>
<td>218,896</td>
<td>1,036,717</td>
</tr>
<tr>
<td>Animals Vaccinated (hd)</td>
<td>2,446,704</td>
<td>2,286,142</td>
<td>6,275,161</td>
<td>10,943,910</td>
<td>15,848,951</td>
</tr>
<tr>
<td>Duration (days)</td>
<td>18</td>
<td>59</td>
<td>95</td>
<td>133</td>
<td>139</td>
</tr>
<tr>
<td>Disease Response Cost ($ million)</td>
<td>$115 million</td>
<td>$134 million</td>
<td>$426 million</td>
<td>$1,119 million</td>
<td>$2,020 million</td>
</tr>
<tr>
<td>Producer Welfare Impact During the Outbreak ($ million)</td>
<td>$961 million</td>
<td>$2,082 million</td>
<td>$4,680 million</td>
<td>$8,166 million</td>
<td>$8,545 million</td>
</tr>
<tr>
<td><strong>POST-OUTBREAK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Producers ($NPV over 3 years)</td>
<td>$9 million</td>
<td>$7.5 million</td>
<td>$32 million</td>
<td>$73 million</td>
<td>$101 million</td>
</tr>
<tr>
<td>Government ($NPV over 3 years)</td>
<td>$546 million</td>
<td>$540 million</td>
<td>$1,543 million</td>
<td>$3,326 million</td>
<td>$3,723 million</td>
</tr>
<tr>
<td>Producer Welfare Impact ($million NPV until 4 years after the outbreak began)</td>
<td>$23,889 million</td>
<td>$34,272 million</td>
<td>$34,423 million</td>
<td>$38,948 million</td>
<td>$49,961 million</td>
</tr>
</tbody>
</table>

Source: Modeling results

Notes: Baseline Epidemiologic and Economic Impacts for outbreaks that increase in size based on number of animal infected, duration and number of jurisdictions impacted. Outbreaks are managed through a combination of stamping-out of infected animals, movement restrictions, and ring vaccination of all swine, cattle and bison within 10 kilometers of the infected premises. Trade embargoes are assumed to be national and impact all fresh and frozen meat and live animals for the duration of the outbreak, and then gradually move from national to regional (limited to states affected) over the course of two quarters and then remain in place until the last vaccinated animal is removed from the national herd inventory. Vaccinated animals are fully removed in 1.75 years for swine, and 2.25 years for dairy and beef cattle and bison. This represents a rate of accelerated turnover for beef and bison producers, but no other adjustments in producer behavior are assumed.
Figure 1. Disease spread iterations were broken into 5 categories according to the “typology of an FMD outbreak” (Roth, 2017).

Source: Roth, 2017.

Notes: Roth’s original typology contains a 6th type of outbreak, a catastrophic North American FMD Outbreak. A North American outbreak is not being considered in this analysis.
Figure 2. Trade shocks for beef by quarter for the simulated FMD outbreak (Type 1-5) and observed shocks from BSE 2003 and HPAI 2014-2015, 2016 and 2017.

Source: GATS?
Figure 3. Breakeven price changes for type 1 to type 5 outbreaks compared to the ISU breakeven price.

Breakeven Price Beef ($/lb)

Breakeven Price Dairy ($/cwt)

Breakeven Price Swine ($/cwt)

Legend:
- ISU
- Base_Type1
- Base_Type2
- Base_Type3
- Base_Type4
- Base_Type5
Figure 4. Sensitivity analysis results for variation in shocks to the economic model derived from the inability to regionalize and trade recovery in the post-outbreak period.