Evaluation of the Potential Spread of BSE in Cattle and Possible Human Exposure Following Introduction of Infectivity into the United States from Canada

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Abstract: This analysis uses the simulation model developed for the U.S. Department of Agriculture by the Harvard Center for Risk Analysis (HCRA) to evaluate the implications of a hypothetical introduction of BSE into the U.S. from Canada. We consider the possibility that BSE may have been introduced into the U.S. between 1990 and 1998 due to the import of infected animals (five bulls) or the import of contaminated feed (infectivity from five infected animals at the preclinical stage of disease). In all the scenarios considered, the number of infected animals in the U.S. and potential human exposure to BSE-contaminated food grow rapidly following the introduction but then fall following the implementation of the FDA mammalian feed ban in 1997. The extent to which the disease spreads prior to 1997 depends strongly on the timing of the introduction. The longer the duration between the introduction and the implementation of the feed ban (*i.e.*, the earlier the assumed date of the introduction), the greater the spread of BSE. In the most pessimistic case (introduction of contaminated feed into the U.S. in 1990), the prevalence of infected animals peaks at 600, with 24 animals showing clinical signs (median simulation predictions). In all cases, however, BSE is eliminated from the U.S. with high probability by the end of the simulation period (2020).

The goal of this effort by the Harvard Center for Risk Analysis (HCRA) is to provide information and analysis to support USDA's evaluation of the implications for the United States of the presence of bovine spongiform encephalopathy (BSE) in Canada. Specifically, we model the consequences of a hypothetical introduction of BSE into the U.S. from Canada in terms its spread in the U.S. cattle population and potential human exposure to BSE infectivity in food. Because there is no information to suggest a specific time frame for such an introduction of BSE into the U.S., we evaluate introductions at different points in time ranging from 1990 to 1998.

Background

In April, 2003 the Canadian Government announced the detection of BSE in a Black Angus cow in the province of Alberta. Some aspects of the animal's life history are not known, including the extent and location of possible exposure to BSE infectivity. Extensive follow-up and epidemiologic study (Canadian Food Inspection Agency 2003) established that the animal was likely to have been around six years of age when it began to exhibit signs of BSE. It was condemned at *antemortem* inspection and did not enter the human food supply. The carcass (with the exception of the head) was rendered.

The Canadian authorities focused on several potential sources of BSE exposure for this animal. Of primary interest was a cohort of cattle imported from the UK that included a BSE case identified in 1993. If additional animals in this group harbored the disease and were slaughtered and rendered, infectivity may have been introduced into the Canadian and U.S. cattle feed supplies before the 1997 feed ban was implemented in both countries (see below). Some of this feed may also have been exported to the U.S. If additional animals were infected, they may have been exported to the U.S. as well.

Additional sources of infection for the index case considered by the Canadian authorities included cross-species transmission of chronic wasting disease (CWD) or scrapie, spontaneous development of BSE, and the import of infected animals or contaminated feed from the U.S. Genetic analysis of the BSE case effectively ruled out CWD, scrapie, or spontaneous BSE as a cause (Canadian Food Inspection Agency 2003). While the Canadian authorities noted the import of feed and animals from the U.S., including thousands of pregnant Black Angus in 2000, there is no evidence that these imports are the source of BSE, although the possibility remains.

Based on the CFIA finding that CWD, scrapie, and the spontaneous development of disease are unlikely to have caused the BSE case in Canada, it appears that any related introduction of BSE into the U.S. from Canada would have been due to the import of either infected animals or contaminated feed. Imports are a plausible source of introduction of BSE into the U.S. from Canada because the American and Canadian beef industries are closely linked. During the last five years, the U.S. has on average imported over 1.2 million cattle and 185,000 tons of feed annually from Canada (personal communication, Victoria Bridges, USDA APHIS, 2003). Other finished and unfinished bovine products also cross the border between the two countries regularly.

Canada implemented a ban on feeding mammalian products to other mammals in 1997 (although this feed ban allowed for some exceptions). The U.S. enacted similar regulations at the same time to help manage the risk of BSE. The timing of the feed ban's implementation is important because, as discussed in this analysis, it has a major impact on the potential spread of BSE if introduced. The longer the duration between the introduction of BSE into the U.S. and the implementation of the feed ban, the greater the potential for amplification of the disease in the food chain. Cohen *et al.* (2001) showed that once the feed ban was implemented, the prevalence of BSE in the U.S., if it was present at all, would have diminished over time. Clearly, any evaluation of the effect of a BSE introduction must carefully consider the timing in relation to introduction of the feed ban.

Method

This analysis uses the HCRA BSE simulation model (Cohen 2001; Cohen in press) to evaluate the potential spread of BSE in the cattle population, and possible human exposure, following the hypothetical introduction of BSE into the U.S. This analysis, which builds on the work conducted for the USDA and reported in 2001 (Cohen), altered assumptions made in our earlier evaluation's base case to reflect characteristics (potential sources and timing) of an introduction of BSE into the U.S. from Canada.

We consider two scenarios, one assuming the import of infected animals, and the other assuming the import of contaminated feed. In the absence of strong evidence about the prevalence of BSE in the Canadian herd, information that would allow us to calculate a probability of introduction, we instead posit a hypothetical introduction of five BSE positive bulls

into the U.S. This scenario is based in part on the Canadian epidemiologic investigation of the April, 2003 case. That investigation suggested that five bulls from a potential birth herd of the index case were exported to the U.S. in 1997. While not suggesting that these animals did indeed harbor BSE we use this scenario as a suggestion of the magnitude of a potential introduction into the U.S. Cohen *et al.* (2001) showed that the spread of BSE and the extent of potential human exposure are proportional to the magnitude of the initial introduction. Hence, the results here could be scaled to accommodate a range of potential introductions.

To account for the possibility that cattle feed containing BSE infectivity was introduced into the U.S., we also evaluate a scenario in which contaminated feed is administered to cattle in the U.S. This scenario assumes that the contaminated feed comes from five infected animals, each of which is at an advanced but preclinical stage of BSE disease (average of 2,000 ID_{50}s[1] per animal, *vs.* 10,000 ID_{50}s in a full-blown clinical case). Because the rendering process eliminates some infectivity, and because meat and bone meal (MBM) and feed are in large part diverted to uses that do not potentially expose cattle (Cohen 2001), only a fraction of the total 10,000 ID_{50}s (five animals times 2,000 ID_{50}s per animal) is ultimately administered to cattle. Using the HCRA BSE model, we estimated that prior to the implementation of the feed ban, around 6.5% of the original infectivity in a slaughtered animal would be administered to other cattle (650 of the original 10,000 ID_{50}s). After the implementation of the feed ban, this fraction dropped to 0.25% (25 of the original 10,000 ID_{50}s).

To model the impact of introducing either infected animals or contaminated feed into the U.S., we use the base case simulation parameter assumptions described by Cohen *et al.* (2001) with the following modifications to account for differences in conditions prior to the implementation of the feed ban.

Prior to January, 1993

- No classification of MBM or feed as either prohibited or nonprohibited (all MBM and feed effectively classified as non-prohibited);
- Of all MBM produced, 65% used in feed potentially sent to cattle, while the remaining 35% is diverted to applications that pose no risk of exposing cattle;

[1] A cattle oral ID_{50s} is the amount of infectious tissue that would, on average, cause 50% of exposed cattle to develop BSE.

- Of all feed produced from this 65% of the MBM, 98% available for cattle consumption, while the remaining 2% is diverted to applications that pose no risk of exposing cattle;
- Of all blood collected for animal consumption, 15% is consumed by cattle, while the remaining 85% is used in applications that pose no risk of exposing cattle;
- Among all animals stunned, 15% stunned using pneumatic stunner (*vs.* none in the base case);
- Different slaughter house practices (proportion of cases in which there is a mis-split, and proportion of material sent to automated meat recovery (AMR)).

January 1993 through December, 1996

- Revised slaughter house practices (proportion of cases in which there is a mis-split, and proportion of material sent to automated meat recovery (AMR)).

January 1997 through December, 1998

- Feed ban implemented but compliance not yet as high as base case; 10% of prohibited MBM and prohibited feed mislabeled; prohibited MBM contaminates non-prohibited MBM in mixed facilities with 28% probability; prohibited feed contaminates non-prohibited feed in mixed facilities with 32% probability.

January 1999 and after

- Feed ban compliance improves to base case levels; mislabeling probabilities fall from 10% to 5%; contamination probabilities fall to 14% (MBM) and 16% (feed) in mixed facilities.

In all cases the parameters characterizing potential human exposure are the same as those used in the base case.

For both the introduction of infected animals and the introduction of contaminated feed, we consider five introduction dates – 1990, 1992, 1994, 1996, and 1998, yielding a total of ten scenarios. All scenarios terminate in December, 2020.

Important model results for this evaluation are the number of cattle infected with BSE following its introduction into the U.S. through the year 2020, and the number of cattle oral ID_{50}s available for potential human exposure during the same time period. The relationship between cattle oral ID_{50}s and the likelihood of human disease is unknown, but European authorities suggest that the cattle disease may be 1,000 to 100,000 times less virulent for humans. Note that actual human exposure is likely to be lower than the simulation model estimate because some contaminated food would not ultimately be consumed (Cohen 2001).

Also key to understanding the implications of a hypothetical BSE introduction is the time course of the disease in the U.S. We also describe how the total number of BSE cases and total potential human exposure depend on the year when the assumed introduction occurs. This pattern provides insight into the length of the disease outbreak in cattle and the effectiveness of risk management measures in eradicating BSE.

Results are presented as distributions reflecting the probabilistic nature of the model. For each scenario, we provide a tabular summary of the results and a series of six figures. Cohen *et al.* (2001) explain the format of these tables (Appendix 1) and figures (Appendix 2). Note that all values in the Appendix 1 tables are rounded to two significant figures. In Appendix 2, each figure consists of two panels, the first of which illustrates the range of values, and the second of which illustrates the probability that the quantities exceeded zero. In the box and whisker plots (the top panel in figures illustrating changes over time) the upper and lower edges of the box correspond to the 25^{th} and 75^{th} percentiles, while the line through the middle of the box represents the median. The whiskers extend to the 5^{th} and 95^{th} percentiles, with values beyond these bounds plotted individually with an "x" character. Figures 1 through 4 below have the same box and whisker format.

Finally, with the exception of investigating the impact of altering the year in which BSE infectivity was introduced into the U.S., we do not conduct any additional sensitivity analyses. The results from Cohen *et al.* (2001) identify the assumptions that have the greatest potential of altering our findings. Cohen *et al.* also found that the extent of disease spread through the cattle population and the extent of human exposure to contaminated food is roughly proportional to the amount of infectivity introduced into the U.S. There is no reason to believe that these findings are not largely applicable to the scenarios investigated here.

Results

As expected, the predicted number of infected U.S. cattle and the potential human exposure to BSE infectivity strongly depends on the year when the introduction is assumed to have occurred (or, more precisely, the duration between the introduction of disease and the implementation of the U.S. feed ban). The earlier the introduction, the greater the number of predicted infected cattle and potential human exposure.

Figure 1 plots by year of BSE introduction into the U.S. (five infected bulls) the model-predicted values for the total number of additional animals in the U.S. to develop BSE by the year 2020. Figure 1 clearly shows that the relationship between the number of additional infected animals and year of BSE introduction is not linear (note the logarithmic scale of the y-axis in this plot and Figures 2, 3, and 4). This divergence from linearity reflects the fact that before the feed ban in 1997, the prevalence of BSE grew exponentially over time. Figure 2, which plots cumulative potential human exposure to BSE-contaminated food through 2020, shows a similar relationship. Appendix 1 Tables 1 through 5 and Appendix 2 Figures 1 through 30 detail our findings.

Figures 3 and 4 illustrate the predicted spread of BSE among cattle and potential human exposure, respectively following the hypothetical introduction of BSE-contaminated feed into the U.S. Appendix 1 Tables 6 through 10 and Appendix 2 Figures 31 through 60 detail our findings. A comparison of Figures 3 and 4 with Figures 1 and 2 indicates that the introduction of contaminated feed into the U.S. results in substantially greater numbers of BSE cases and potential human exposure than does the introduction of infected animals.

The first figure in each set of six figures per scenario in Appendix 2 describes the predicted time course for the number of BSE-infected animals following the introduction of BSE into the U.S. These figures indicate that except for the 1998 introduction scenario, the peak year for both the number of BSE-infected animals and for potential human exposure is 1997 (year 7 in the 1990 introduction scenarios, year 5 in the 1992 introduction scenarios, and so forth). This pattern shows that even the incomplete compliance with the feed ban assumed prior to 1999 is sufficient to reverse the spread of BSE. After the introduction of the feed ban, the disease rate begins to decline so that by 2020, the likelihood of any BSE cases remaining in the U.S. is very low (and declining).

The fifth figure in each set of six scenario figures in Appendix 2 illustrates the time trend for potential human exposure. Like the number of BSE cases, potential human exposure peaks in 1997. For those scenarios assuming an early BSE introduction date (1990 or 1992), the probability of non-zero human exposure in 2020 remains elevated. Note that the number of ID_{50}s available for human consumption estimates are upper bounds (Cohen 2001) because not all BSE infectivity available for potential human exposure is actually consumed. Rates of waste during distribution and in the home, portion sizes, and other factors influence actual human exposure. Moreover, we assume no further risk management action will be taken after the detection of a case of BSE in the U.S., although such actions would probably be taken and would further speed the eradication of BSE in the U.S.

The second figure in each set of six scenario figures in Appendix 2 illustrates how the predicted number of cattle with clinical signs of BSE changes over time. These values can be compared to estimates of the detection limit for the USDA's BSE surveillance program. The best estimate from USDA suggests that in the year 2000, USDA would have detected the presence of BSE in the U.S. with 95% confidence if there were 500 animals with clinical disease (personal communication, Victoria Bridges, USDA APHIS, 2001). However, the simulation results indicate that in the year 2000 (year 10 in the 1990 scenarios, year 8 in the 1992 scenarios, and so on), the predicted number of cattle with clinical signs of disease was always substantially less than 500. Hence, the simulation predictions are not inconsistent with the fact that USDA has not detected the presence of BSE in the U.S. Note that because the model predicts the number of clinical cases peaks in the year 2000, that year represents the point in time when USDA's ability to detect the presence of BSE would have been greatest.

Discussion

The results of this analysis indicate that the impact on both animal and human health of an introduction of BSE into the U.S. from Canada depends on when it occurred and on whether the source of disease was infected cattle or contaminated feed. In addition, the Cohen *et al.* (2001) analysis found that the impact of such an introduction depends strongly on compliance with the feed ban.

Because the introduction of BSE into the U.S. from Canada is hypothetical, it is impossible to know precisely when it may have occurred. The results of our analysis show that the earlier such an introduction may have occurred, the greater the potential spread of BSE. The strength of this relationship reflects the fact that the number of BSE cases grows exponentially in the absence of the feed ban. The results of the simulation do not directly explain why the introduction of contaminated feed has a much greater impact than the introduction of infected animals, both of which should represent comparable amounts of infectivity. There are several possible explanations. First, because infected animals introduced into the U.S. are not immediately slaughtered, there is a delay between the introduction of infected animals and the exposure of additional animals. As a result, the effective amount of time available for the disease to spread prior to the introduction of the feed ban is less than it is following the introduction of contaminated feed, which we assume is immediately administered to cattle in the U.S. Second, if the introduced animals are slaughtered relatively quickly, the amount of incubation time may not be sufficient for a large infectivity load to develop. Third, the amount of assumed infectivity in feed is sufficient to infect significantly more animals than the five assumed in the animal importation scenarios. The probability that contaminated feed was introduced from Canada into the U.S. dropped substantially when the Canadians enacted their own feed ban in 1997.

None of the introduction scenarios can be ruled out by the fact that USDA's surveillance program had not detected BSE in the U.S. through the year 2000. Even for the scenario yielding the highest clinical case prevalence in 2000 (introduction of contaminated feed in 1990), the predicted BSE prevalence in 2000 is well below the level at which USDA would have detected the presence of disease with a high degree of confidence. In that year, USDA would have discovered the presence of BSE in the U.S. with 95% confidence if the prevalence had reached 500 cases, far greater than the simulation's median prediction (24 cases) or even its maximum prediction (around 100 cases).

Although the possible introduction of BSE into the U.S. from Canada cannot be dismissed, the results of the Cohen *et al.* (2001) study show that the presence of the disease will continue to diminish with time. The degree of compliance with the FDA feed ban and other risk management measures (*e.g.*, (U.S. Department of Agriculture (FSIS) 2002)) will influence the rate at which the disease would be eliminated from the U.S.

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