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OPTIMAL TRACKING AND TESTING OF US AND CANADIAN HERDS FOR BSE: A VALUE-OF-INFORMATION (VOI) APPROACH

ABSTRACT

The USDA currently tests a subset of cattle slaughtered in the US for BSE. If the origin of the cattle (US versus Canada) were known at the time of testing, improved testing or surveillance policies could be devised for the future, based on the origin of any cattle testing positive. For example, if a Canadian origin cow tests positive for BSE, while no US origin cattle test positive, the US could decide that cattle of Canadian origin should be subject to more stringent testing than US origin cattle. To implement a "tracking decision", any imported cattle already in or entering the US would require some sort of permanent marking and incur implementation costs. This paper introduces a formal decision-analytic value-of-information (VOI) framework to quantify and compare the economic costs to the US of implementing such a tracking program to the costs of not doing so. The economic value of information from a tracking program is estimated to exceed its costs by a factor of over 5 even under conservative assumptions, since such information can potentially be used to avoid or mitigate future losses in export and domestic markets and to reduce costs of future testing required to reassure or win back customers. Sensitivity analyses indicate that the conclusion that implementing a tracking program for any Canadian cattle imported into the US is highly worthwhile appears to be robust to many technical, scientific, and market uncertainties, including the current prevalence of BSE in the US and/or Canada and the likely reactions of consumers to possible future discoveries of BSE in the US and/or Canada. Indeed, the value of tracking information is great enough to justify locating and beginning to track Canadian cattle already in the US when this can be done for a reasonable cost, e.g., less than $35 per head, even under the pessimistic assumption that the US has already permanently lost many of its export markets due to the Washington State BSE case discovered in a Canadian-origin cow in December, 2003. If aggressive tracking and testing can win back lost exports, then the VOI of a tracking program may increase by an order of magnitude, to over half a billion dollars per year.

INTRODUCTION: A RISK MANAGEMENT DILEMMA

For the past several years, Canada has tested thousands of cattle per year for BSE – for example, 3377 animals in 2002. To date, this testing has found only one cow with BSE (Canadian Food Inspection Agency, 2004). In the province of Alberta, "The brains of 2769 targeted cattle were tested from October 1996 to March 31, 2004. One cow, condemned at slaughter (did not enter the human food chain), was confirmed positive for BSE in May 2003… Brain tissue samples from the remaining 2768 cattle had no evidence of BSE" (Government of Alberta, 2004). It is assumed that this prevalence level is representative of and consistent with recent Canadian practices with regards to minimizing BSE in the Canadian herd. Targeted Canadian cattle included animals with neurological signs and/or emaciation, submitted through provincial slaughter facilities and by field veterinarians, as well as samples from cattle submitted to provincial diagnostic laboratories for post-mortem examination. If, based on European experience, targeted animals are about 60 times more likely to have BSE than non-targeted animals as a base case (e.g., Doherr et al., 2001) then a prevalence rate of BSE among non-targeted cattle of (1/2768)*(1/60) = 6.0E-6 might be estimated from this case.

In December, 2003, a second dairy cow from Alberta, imported into the US to the state of Washington, was also diagnosed with BSE. Following a prompt, thorough investigation by The United States Department of Agriculture (USDA) and the Canadian Food Inspection Agency (CFIA), USDA's APHIS Veterinary Services (VS) issued an "Explanatory Note" in February, 2004, concluding that its previous risk analysis of the risks from Canadian cattle and beef products imported into the US remained unchanged by the new case, and that the risks remained low. As stated in the note:

> "Both of the BSE cases of Canadian origin occurred in cattle born before the feed ban was implemented. They were both older than 30 months of age when they were diagnosed as infected. Infection presumably occurred prior to or around the time the Canadian feed ban was enacted. The finding of an imported case in a cow greater than 30 months of age has little relevance to an analysis of risk under the proposed mitigation measures, beyond the implications for BSE prevalence in Canada. The proposed rule was not in effect in 2001 when the imported case, which was more than 4 years old at the time, entered the United States. Under the proposed conditions, the animal would not have been allowed entry into the United States. Therefore, we continue to consider the import controls in the proposed rule to be effective and the results of the analysis unchanged." (USDA, 2004)

From a statistical perspective, the detection of two BSE cases from Alberta in less than eight months raises the question of what the true prevalence of BSE in Canadian cattle may be at present. The statistical inference problem is complicated by the fact that the cow in Washington State was not detected as part of Canada's routine sampling program, and the probability that such cattle will be detected once they have been imported into the US is not known. From a risk management perspective, the key question is what actions, if any, the US should take now in light of uncertainty about the true prevalence rate of BSE among Canadian cattle now and in the future. This decision problem is made more challenging by high economic stakes and by scientific uncertainties regarding BSE sources, reservoirs, and dynamics. As noted by the USDA's Animal and Plant Health Inspection Service in a February, 2004 Position statement entitled "Official diagnosis of Chronic Wasting Disease (CWD) should be performed exclusively by Federal and State regulatory agency laboratories", even false positives might be economically damaging: "In the case of a disease like BSE, a false positive could be devastating, costing the U.S. economy billions of dollars in unnecessary domestic and international market disruption from which it could take years to recover." Subsequent reporting by USDA of unconfirmed BSE cases that turned out to be false positives, starting in July, 2004, suggest that such market impacts can occur quickly. Examples of pertinent scientific uncertainties include:

- Roles of horizontal and vertical transmission (if any) within herds
- Existing and potential BSE reservoirs in Canada and the US and how these are affected by respective ongoing imports
- Transmission dynamics within and between different reservoirs
- Differences in susceptibility among individual cattle of the same age
- The shape of the age versus infectivity curve for cattle
- Distribution of infectivity and differences in virulence among new BSE cases
- Latency period until clinical expression; possibility of subclinical cases (Thackray et al., 2003; Hill and Collinge, 2003;); common definition of clinical BSE expression
- Potential for clustering of rare events within geographic areas, processing plants, affected populations etc.
- Error and compliance rates (such as mislabeling, etc.) in Canada and the US
- Possible heterogeneity of the basic reproductive rate R_0 for BSE in different geographic areas or for different strains of BSE, different types of cattle, etc.
- Detection probabilities per case, given the target and sampling schemes used
- Uncertainty of inferred cattle age measurements (e.g., from dentition, etc)
- Variability and accuracy in testing methods for BSE detection

With so many unknowns, predictive modeling can be highly uncertain. Real-world data on observed cases of BSE can therefore potentially be especially valuable for improving estimates of true BSE prevalence. However, the two BSE cases from Alberta detected in 2003 support alternative interpretations, ranging from (a) the first beginnings of a wave of BSE cases to; (b) the last remnants of a problem from the 1980s and 1990s that has already been fixed and that, by chance, escaped detection until 2003 and (c) possibly scenarios in between. The data do not reveal a unique correct interpretation.

This creates a dilemma for both health and economic risk management. On the one hand, experience since 2003 has shown that discovery of BSE cases in the US can dramatically reduce US beef exports, even if the infected animals originated in Canada. If the true prevalence of BSE in Canadian cattle shipped to the US were known to be as high as 6.0E-6, then continued prevention of cattle imports from Canada might be expected. On the other hand, if the prevalence of BSE in Canadian cattle were known to be much smaller or zero, then the advantages of resumed trade could be gained by allowing unrestricted imports, without incurring a substantial risk of additional BSE cases. Given the high economic stakes and the uncertainties about the prevalence of BSE in Canadian cattle (and, for that matter, US cattle), it has been difficult to determine what policies would best promote US and international interests – what policies would be optimal based on a solid analytic foundation. Options range from maintaining the *status quo* (e.g., preserving current import restrictions and testing programs) to tightening or loosening current import policies to gathering more information first – for example, by tracking all imported cattle and testing all Canadian cattle in the US – and then using this information and the results of future sampling to decide when and whether to change import restrictions. To discover which of these (or other) options is most desirable, it is necessary to compare their conditional probability distributions of gains and losses.

This paper applies constructive decision-analytic techniques, including value-of-information (VOI) calculations (Yokota and Thompson, 2004), to quantify and compare the economic values of different risk management and information-seeking options available to the US for managing the uncertain risks of BSE originating in Canada. The analysis focuses mainly on a near-term decision – whether to require Canadian cattle in the US to be identified, permanently marked, and tracked to provide information about their origins in case future BSE cases are found – and on the economic consequences of different potential futures whose probabilities can be affected by these near-term decisions. This focus reflects the facts that economic consequences will probably dominate near-term policy decisions, are easier to estimate reliably from available information than possible human health risks, and provide an analytic framework that can later be extended to include health risk considerations. By explicitly representing key uncertainties and assessing the probable consequences of alternative current decisions, the decision-analytic framework presented here may prove useful to policy analysts and decision-makers in considering how best to assess and manage the highly uncertain risks of BSE in the US from imported cattle.

2. METHODS AND DATA

The decision-analytic approach to risk management developed in this paper proceeds through the following steps:

1. Identify a set of *alternative decision rules* or options to be compared. A decision rule specifies the actions to be taken at each time, given the information available at that time. It may be thought of as a plan that specifies what to do under different contingencies.
2. Identify the *consequences* of concern, which the actions may affect.
3. Identify the *probabilities* of different consequences, for each decision rule. This typically requires considering different *scenarios* or assumption sets describing alternative ways in which current uncertainties might be resolved. These are also called "*states of nature*". Often, there is no objective, uniquely correct way to determine the prior probabilities of alternative scenarios. Then, conservative assumptions (tending to favor the *status quo*) and sensitivity analyses (in which various prior probabilities of scenarios are assumed) may be used to determine how robust the conclusions and decision recommendations from the analysis are to variations in scenario probabilities.
4. Identify the *optimal decision rule,* defined as the one with the most desirable probability distribution of consequences, given current information and assuming that future actions will be made optimally given future information.
5. Identify and recommend an *optimal current action*, determined by the optimal decision rule.

This framework is explained in detail in Raiffa, 1968 and Clemen, 1996.

Formulation of the Risk Management Decision Problem as a Decision Tree

The decision rules compared in this paper are structured as follows (see Figure 1). First, an initial ("Stage 1") decision must be made either to track Canadian cattle in the US ("Track CA imports") or not to track them ("Do not track CA imports"). The main purpose of the decision analysis is to compare the probable consequences to the US of these two alternative initial actions. Following this Stage 1 decision, additional information will be obtained from ongoing sampling programs in the US and Canada that perform tests for BSE on both symptomatic (e.g., "downer" cattle) and randomly selected healthy-appearing cattle at slaughter. If the Stage 1 decision was "Track CA imports", then any of the following informative events may be observed over a specified following time period (e.g., 1 year):

- No new BSE cases detected
- BSE case of Canadian origin detected in US
- BSE case of US origin detected in US
- BSE case of Canadian origin detected in Canada

(If several of the last three events occur in a year, we focus on the first to occur as the event of interest.) The probabilities of these events depend on both the unknown true prevalence rates of BSE in the US and Canadian herds (i.e., on which scenario or state of nature is correct) and also on the sampling plans and tests used to examine the herds. If the Stage 1 decision is "Don't track CA imports", then the four possible observations for the next period are aggregated to only the following three:

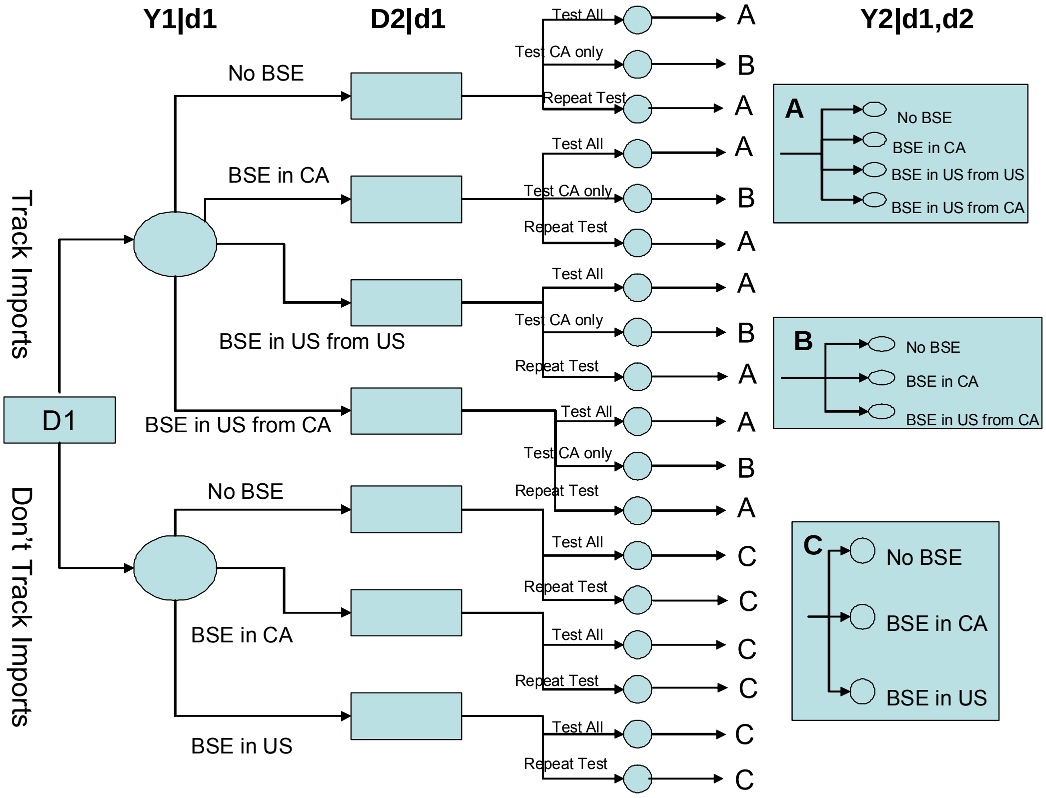
- No new BSE cases detected
- New BSE case detected in Canada
- New BSE case detected in US

In reality, as in the case of the Washington state cow, forensic efforts might successfully identify the origin of a BSE case even without new tracking measures. The effect of a Stage 1 decision to track imports is then to increase the probability that the origin of a new case can be determined. The formal analysis treats the Track *vs.* Do not track decisions as providing *vs.* failing to provide, respectively, the information needed to identify the origin (Canadian or not) of any new BSE case, while recognizing that partial tracking via ear tags, brands, and tattoos may already be available. (Indeed, the tracking issue is confined to Canadian cattle because Mexican cattle in the US are already well identified.)

After the Stage 1 decision, and given updated information about any new BSE cases, a subsequent ("Stage 2") decision must be made about whether to sell and process healthy-appearing cattle without first requiring them to be tested for BSE ("No required test") *vs.* requiring all US cattle to be tested for BSE before being sold or processed ("Test all") *vs.* requiring only all Canadian cattle in the US to be tested for BSE before being sold or processed ("Require testing for CA cattle only".) The latter option is available only if the Stage 1 decision was "Track CA imports". In addition to any required testing, some cattle will continue to be sampled and tested according to a USDA test program, and this is not affected by the Stage 1 and Stage 2 decisions. The Stage 2 decision presumably will be made to obtain the most desirable outcome possible, given the information available then. For example, if a new BSE case is detected in the US and its origin cannot be ascertained, then the Stage 2 decision might be "Test all" US cattle at slaughter, to reduce export and domestic consumption losses (if the economic benefits outweigh the costs of testing); while if the origin of the case is known to be Canadian and the Stage 1 decision was to "Track CA imports", then the best Stage 2 decision might be "Require testing for CA cattle only".

After Stage 1 and Stage 2 decisions have been made and the future information has been obtained, it becomes possible to evaluate how much beef consumption, if any, has been lost in export and domestic markets due to BSE cases and risk management responses, and how much the Stage 1 and Stage 2 decisions cost to implement. A goal for rational risk management decision-making *today* is to anticipate how current decisions change probable *future* total costs (i.e., the sum of implementation costs and costs from lost domestic and export sales) as they will eventually be assessed in hindsight. Each Stage 1 decision, in conjunction with optimized Stage 2 decisions given future information, determines a probability distribution for total cost. Rational risk management requires making the choice today that induces the most desirable probability distribution for total costs, as they eventually will be evaluated in the future.

Figure 1 presents a decision tree model summarizing the logical structure of the decision problem. In this tree, a *decision rule* specifies which outgoing branch to follow at each decision node (represented by a rectangular node in Figure 1.) "Repeat test" refers to the action of doing nothing other than to continue the routine BSE sampling and testing programs. The notation for Stage 1 and Stage 2 decisions ("choice sets") and observed outcome events ("information sets") listed at the bottom of Figure 1 allows the same framework to be expanded to include additional decisions, scenarios, and information events if so desired to increase the resolution of the problem description. However, the relatively simple, aggregate descriptions of possible decisions and futures in Figure 1 suffice to carry out the decision analysis calculations; analogous calculations can be performed for more detailed descriptions.



Notation for decision problem components

- D1 = Stage 1 choice set = {Track Imports, Do Not Track Imports}
- {Y1 | d1} = information sets of possible outcomes based upon the Stage 1 decision d1 ε D1
- {D2 | d1} = Stage 2 choice set, given the Stage 1 decision d1 ε D1
- {Y2 | d1,d2} = information sets of possible outcomes after decisions d1 ε D1 and d2 ε {D2 | d1}

Figure 1. Decision Tree for BSE Testing Policy

Estimated Economic Consequences of Detecting Additional BSE Cases

To finish describing the decision problem, it is necessary to estimate the economic costs associated with each terminal node (i.e., "leaf" node) at the tips of Figure 1. Only the direct costs of implementing the different Stage 1 decisions and of reduced beef sales in case of detection of new BSE cases will be considered, as a first approximation to the full societal costs. (A refined analysis could estimate economic multiplier effects and reductions in consumer surplus from reduced domestic sales, which would increase their impacts further. However, sensitivity analysis suggests that the main conclusions, which are dominated by loss-of-export-related impacts, would not be changed by these refinements.) The decision model incorporates the following three types of cost: Tracking Costs, Testing Costs, and Market Costs. Tracking costs represent the cost of permanently marking each live cow coming into the US, including labor and materials. Testing costs represent the costs per BSE test, including kits, labor, shipping, holding, laboratory facilities, and expenses. Market costs represent market losses (or gains) associated with each second stage outcome as a function of all that occurred up to that point. Baseline values for each of these costs are estimated next. These are then varied to obtain sensitivity analyses.

Market Impacts

The main economic impacts on the US of discovering a new BSE case are assumed to be as follows for the baseline scenario.

- If a new BSE case of *unknown origin* is discovered in the US, then both domestic demand and remaining exports of US beef will immediately decline. Following the discovery of the BSE-positive cow in Washington State in 2003, US exports declined by approximately 50%. For the baseline scenario, we assume that discovery of a new BSE case of unknown origin in the US will result in a further loss of –12.27B dollars per year in cattle sales, corresponding to a 25% assumed reduction in consumer demand. The situation where full testing identifies a BSE case of known US origin in the US provides a similar loss.
- If a new BSE case is found in the US that is not specifically known to be of Canadian origin, but subsequent full testing does not find a similar case, a smaller loss of –6.14B dollars per year will occur.
- If a new BSE case is discovered *in Canada*, then US exports may increase to replace decreased Canadian exports. The magnitude of this effect is estimated as a gain of +1.382B dollars per year in the base case.
- If a new BSE case *known to be of Canadian origin* is discovered in the US, and if Canadian cattle are then removed from US exports and from the food supply, the net impact on the US is a loss of –2.683B dollars per year in the base case, primarily from additional lost exports. (The US domestic markets responded only relatively slightly to the Canadian BSE cases discovered in 2003, suggesting that the main economic impacts come from the closing of export markets to US beef.)

Table 1 summarizes the baseline economic impacts for each of the possible futures (i.e., branches through the decision tree to a leaf node) in Figure 1. Appendix A provides the supporting rationale and data for the estimated market impacts.

TABLE 1: Economic Impact Estimates

Stage 1		Stage 2		Economic Impacts			
Decision	Outcome	Decision	Outcome	Market Impacts	Tracking Costs	Testing Costs	Total Economic Impact
Track Imports	No BSE	Test All	No BSE	0	-30,774,300	-1,099,200,000	-1,129,974,300
			BSE in CA	1,382,000,000	-30,774,300	-1,099,200,000	252,025,700
			BSE in US from US	-12,270,000,000	-30,774,300	-1,099,200,000	-13,399,974,300
			BSE in US from CA	-2,863,000,000	-30,774,300	-1,099,200,000	-3,992,974,300
		Test CA Only	No BSE	0	-30,774,300	-47,361,450	-78,135,750
			BSE in CA	1,382,000,000	-30,774,300	-47,361,450	1,303,864,250
			BSE in US from CA	-2,863,000,000	-30,774,300	-47,361,450	-2,941,135,750
		Repeat Test	No BSE	0	-30,774,300	-2,400,000	-33,174,300
			BSE in CA	1,382,000,000	-30,774,300	-2,400,000	1,348,825,700
			BSE in US from US	-12,270,000,000	-30,774,300	-2,400,000	-12,303,174,300
			BSE in US from CA	-2,863,000,000	-30,774,300	-2,400,000	-2,896,174,300
	BSE in CA	Test All	No BSE	1,382,000,000	-30,774,300	-1,099,200,000	252,025,700
			BSE in CA	1,382,000,000	-30,774,300	-1,099,200,000	252,025,700
			BSE in US from US	-12,270,000,000	-30,774,300	-1,099,200,000	-13,399,974,300
			BSE in US from CA	-2,863,000,000	-30,774,300	-1,099,200,000	-3,992,974,300
		Test CA Only	No BSE	1,382,000,000	-30,774,300	-47,361,450	1,303,864,250
			BSE in CA	1,382,000,000	-30,774,300	-47,361,450	1,303,864,250
			BSE in US from CA	-2,863,000,000	-30,774,300	-47,361,450	-2,941,135,750
		Repeat Test	No BSE	1,382,000,000	-30,774,300	-2,400,000	1,348,825,700
			BSE in CA	1,382,000,000	-30,774,300	-2,400,000	1,348,825,700
			BSE in US from US	-12,270,000,000	-30,774,300	-2,400,000	-12,303,174,300
			BSE in US from CA	-2,863,000,000	-30,774,300	-2,400,000	-2,896,174,300
	BSE in US from US	Test All	No BSE	-6,140,000,000	-30,774,300	-1,099,200,000	-7,269,974,300
			BSE in CA	-6,140,000,000	-30,774,300	-1,099,200,000	-7,269,974,300
			BSE in US from US	-12,270,000,000	-30,774,300	-1,099,200,000	-13,399,974,300
			BSE in US from CA	-6,140,000,000	-30,774,300	-1,099,200,000	-7,269,974,300
		Test CA Only	No BSE	-12,270,000,000	-30,774,300	-47,361,450	-12,348,135,750
			BSE in CA	-12,270,000,000	-30,774,300	-47,361,450	-12,348,135,750
			BSE in US from CA	-12,270,000,000	-30,774,300	-47,361,450	-12,348,135,750
		Repeat Test	No BSE	-6,140,000,000	-30,774,300	-2,400,000	-6,173,174,300
			BSE in CA	-6,140,000,000	-30,774,300	-2,400,000	-6,173,174,300
			BSE in US from US	-12,270,000,000	-30,774,300	-2,400,000	-12,303,174,300

			BSE in US from CA	-6,140,000,000	-30,774,300	-2,400,000	-6,173,174,300
	BSE in US from CA	Test All	No BSE	0	-30,774,300	-1,099,200,000	-1,129,974,300
			BSE in CA	0	-30,774,300	-1,099,200,000	-1,129,974,300
			BSE in US from US	-12,270,000,000	-30,774,300	-1,099,200,000	-13,399,974,300
			BSE in US from CA	-2,863,000,000	-30,774,300	-1,099,200,000	-3,992,974,300
		Test CA Only	No BSE	0	-30,774,300	-47,361,450	-78,135,750
			BSE in CA	0	-30,774,300	-47,361,450	-78,135,750
			BSE in US from CA	-2,863,000,000	-30,774,300	-47,361,450	-2,941,135,750
		Repeat Test	No BSE	0	-30,774,300	-2,400,000	-33,174,300
			BSE in CA	0	-30,774,300	-2,400,000	-33,174,300
			BSE in US from US	-12,270,000,000	-30,774,300	-2,400,000	-12,303,174,300
			BSE in US from CA	-2,863,000,000	-30,774,300	-2,400,000	-2,896,174,300
Don't Track	No BSE	Test All	No BSE	0	0	-1,099,200,000	-1,099,200,000
			BSE in CA	0	0	-1,099,200,000	-1,099,200,000
			BSE in US	-12,270,000,000	0	-1,099,200,000	-13,369,200,000
		Repeat Test	No BSE	0	0	-2,400,000	-2,400,000
			BSE in CA	0	0	-2,400,000	-2,400,000
			BSE in US	-12,270,000,000	0	-2,400,000	-12,272,400,000
	BSE in CA	Test All	No BSE	0	0	-1,099,200,000	-1,099,200,000
			BSE in CA	0	0	-1,099,200,000	-1,099,200,000
			BSE in US	-12,270,000,000	0	-1,099,200,000	-13,369,200,000
		Repeat Test	No BSE	0	0	-2,400,000	-2,400,000
			BSE in CA	0	0	-2,400,000	-2,400,000
			BSE in US	-12,270,000,000	0	-2,400,000	-12,272,400,000
	BSE in US	Test All	No BSE	-6,140,000,000	0	-1,099,200,000	-7,239,200,000
			BSE in CA	-6,140,000,000	0	-1,099,200,000	-7,239,200,000
			BSE in US	-12,270,000,000	0	-1,099,200,000	-13,369,200,000
		Repeat Test	No BSE	-6,140,000,000	0	-2,400,000	-6,142,400,000
			BSE in CA	-6,140,000,000	0	-2,400,000	-6,142,400,000
			BSE in US	-12,270,000,000	0	-2,400,000	-12,272,400,000

Tracking Costs

Table 1 also shows the estimated costs of tracking and testing cattle that are included in the model. Annual cattle-tracking costs are calculated by multiplying an estimated unit cost-per-animal by the number of live cattle imported annually into the US from Canada. In 2002, prior to any BSE detections, this number was 1,538,715 cattle (http://cattle.guelph.on.ca/statistics/livetrade-withus.html). The annual cost of tracking any newly imported cattle is estimated as $10 to cover tags, labor, and compliance checks.

The baseline total annual tracking costs for such cattle, assuming a return to 2002 levels of imports, are thus 1,538,715 x $10 = $15, 538,715. (Part of this cost may initially be borne by Canadian producers, but it is included in the model as the cost results directly from a Track Imports policy and may ultimately be passed on to US consumers.) The costs of locating and then tracking Canadian cattle already in the US are more difficult to estimate; they are addressed in the Sensitivity Analysis and Discussion sections.

Testing Costs

The Stage 1 testing costs in the US are obtained by multiplying a unit test cost-per-animal by the size of the assumed Stage 1 sample size. In FY2004, the USDA tested 20,543 cattle (http://www.usda.gov/Newsroom/0105.04.html). In the wake of the December, 2003 finding of a BSE-positive cow, the annual number of cattle sampled will probably be at least doubled, to around 40,000, in addition to one-time, much larger sampling efforts (http://usda.mannlib.cornell.edu/reports/nassr/livestock/pct-bb/catl0104.pdf). The per-animal test unit cost has recently been estimated as approximately $30 (http://www.meatnews.com/index.cfm?fuseaction=article&artNum=7345). The Stage 1 annual testing costs in the US are therefore estimated as $30 x 40,000 = $1,200,000.

Approximately 36.6 million cattle were slaughtered in the US in 2003 (USDA, 2004). If each animal is tested at slaughter for a unit cost of $30, then the baseline total annual US testing cost in Stage 2 for "Test All" is approximately $30 per animal x 36.6M animals per year = $1,098,000,000 per year. The corresponding cost for the "Test Canadian-origin cattle only" is estimated by assuming that the Canadian-origin portion of the US herd is approximately in steady state, that is, the number of Canadian origin cattle slaughtered annually is equal to the number imported. Thus, testing costs are 1,538,715 animals per year x $30 per animal tested = $45,161,450 per year.

In Canada, until recently, fewer than 4,000 cattle per year have been tested for BSE nation-wide. In 2002, for example, Canada tested a total of 3377 animals (http://www.inspection.gc.ca/english/anima/heasan/disemala/bseesb/bsefaqe.shtml). In 2003, about 5500 cattle were tested, with plans for 8000 cattle in 2004 (http://www.cbc.ca/stories/2004/01/08/madcow_040108). Canadian testing costs are not included in our US policy model, but the numbers of animals tested are included since they affect the probability of detecting new BSE cases.

Scenario Probabilities

The probable consequences of current decisions, specifically, whether to Track Canadian cattle imports, depend on whether and where BSE is detected next. The probabilities of the different economic consequences in Table 1, i.e., of different rows, given the choices of Stage 1 and Stage 2 decisions, are modeled via the variables and formulas in Table 2.

TABLE 2: Probability Model and Notation for Scenario Outcomes

Variables	Meaning	Formulas and Baseline Values
P_I	proportion of US cattle tested that were imported from CA	1,538,715/36.6M = 4.0%
p_{CA}	probability a Canadian animal test is positive for BSE	See scenarios in Table 3
n_{CA}	number of Canadian tests performed	See scenarios in Table 3
p_{US}	probability a US animal test is positive for BSE	$p_{USUS}*(1- P_I) + p_{USCA}*P_I$
n_{US}	number of US tests performed	$n_{USUS} + n_{USCA}$
p_{USUS}	probability US testing of an animal of US origin is positive	See scenarios in Table 3
p_{USCA}	probability US testing of an animal of CA origin is positive	See scenarios in Table 3
n_{USUS}	number of US tests of animals of US origin	38,400 per year
n_{USCA}	number of US tests of animals of CA origin	1,600 per year
	Pr{no new BSE cases}	$(1-p_{CA})^{n_{CA}}(1-p_{US})^{n_{US}}$
	Pr{case in CA}	$\approx (1-(1-p_{CA})^{n_{CA}})$
	Pr{case in US}	$\approx (1-(1-p_{US})^{n_{US}})$
	Pr{case is of US origin | US case}	$\approx 1-(1-p_{USUS})^{n_{USUS}}$
	Pr{case in US of Canadian origin | a US case}	$\approx 1-(1-p_{USCA})^{n_{USCA}}$
	Pr{case in US of US origin}	$\approx (1-(1-p_{US})^{n_{US}})*\dfrac{1-(1-p_{USUS})^{n_{USUS}}}{1-(1-p_{USUS})^{n_{USUS}}+1-(1-p_{USCA})^{n_{USCA}}}$
	Pr{case in US of CA origin}	$\approx (1-(1-p_{US})^{n_{US}})*\dfrac{1-(1-p_{USCA})^{n_{USCA}}}{1-(1-p_{USUS})^{n_{USUS}}+1-(1-p_{USCA})^{n_{USCA}}}$

These formulas are based on a simple, approximate binomial model, in which only the average probability of detecting BSE per animal tested is used (for each of Canada and the US separately) and details of inter-animal variability are ignored. (In practice, the outcome probabilities in the table are renormalized to sum to 1, since ignoring the possibility of multiple BSE discoveries in the same year may lead to slight departures from 1.)

The probabilities p_{USUS}, p_{USCA}, p_{CA} are estimates of the probabilities of finding one or more BSE positive cattle among each batch of 1000 tested. (Probability per 1000 is more convenient than probability per animal, given the small probabilities involved, but either could be used.) Uncertainty about the correct values of these probabilities is modeled by using five possible scenarios or "states of nature", shown in Table 3. Columns 2-4 show the values of p_{USUS}, p_{USCA}, and p_{CA} for each of the five scenarios.

TABLE 3. Scenario Definitions and BSE Detection Rates (per 1000 animals tested)

States of Nature	PUSUS	PUSCA	PCA	Prior Estimate
1	0	0	0	0.2
2	0	1.00E-04	1.00E-04	0.2
3	0	1.00E-06	1.00E-06	0.2
4	1.00E-06	1.00E-04	1.00E-04	0.2
5	1.00E-06	1.00E-06	1.00E-06	0.2

The values in Table 3 for each scenario are averages for the entire US and Canadian herds. The rationale for these values is as follows. Past testing suggests that the BSE rate in cattle of US origin is likely very low or zero, since no confirmed cases have been discovered to date. The BSE rate in cattle of Canadian origin may be zero (if there are no new cases to be discovered), very low, or relatively high, with zero being perhaps somewhat less likely than the others, given the two BSE cases detected in 2003. The value corresponding to "relatively high" (1E-4 per 1000) is consistent with the rate provided by the World Organization for Animal Health (http://www.oie.int/eng/info/en_esb.htm), which shows a 2003 incidence rate for Canada of .33 per million. The "very low" rate (1E-6 per 1000 animals) is a plausible high end estimate for the US that considers the large number of cattle slaughtered annually (~36.6M) without any cases detected thus far. We combined these considerations into the five scenarios shown. (Each scenario may also be viewed as the centroid of a cluster representing all possible scenarios that are closer to it than to any of the other four, in which case the discretization of all possible scenarios into only these five represents the relatively low degree of resolution permitted by current data.)

The selection of scenario prior probabilities is potentially controversial. We adopt the following bounding approach to avoid needless controversy. If the main conclusion from the analysis is that the *status quo* is justified (i.e., tracking of Canadian cattle imports is not recommended because the incremental costs exceed the value of the information provided), then little justification may be needed. By contrast, if the analysis shows that a change from the *status quo* to "Track Canadian imports" is recommended (because the value of the tracking information exceeds the costs of acquiring it), then more justification may be needed to persuade stakeholders to adopt the conclusion. Therefore, we will pick values of highly uncertain inputs (such as the scenario probabilities) to favor the *status quo*, so that if the analysis still recommends a change, the result will be relatively strongly supported despite uncertainties in the model inputs. (This intentional bias toward the *status quo* is not strictly rational, but recognizes the reality that any recommended changes from the *status quo* may require an additional burden of robustness.) Given that the limited available evidence favors the hypothesis that Canadian BSE prevalence is higher than US BSE prevalence (as in scenarios 2 and 4), and that these scenarios imply relatively high information values for tracking Canadian cattle, we will use a *uniform distribution* of scenario probabilities as a conservative (i.e., *status quo* favoring) prior distribution, thereby giving more relative weight to scenarios 1 and 5 (no difference between US and Canadian cattle) than the available data might suggest. The uniform prior also represents a maximum-entropy prior, and in this sense imposes as few assumptions as possible.

In the current situation of limited BSE testing, animals that are considered most likely to have BSE are targeted. Testing data from Europe suggests that the BSE rate among this subpopulation is 60 times greater than that of the general cattle population. This factor is applied to the probabilities in Table 3 to obtain the probabilities of positive test results among sampled cattle in Stage 1 with limited testing. The sampling factor will be subject to sensitivity analysis.

Let $s_i \varepsilon S$ represent state of nature, ***i*** with initial probability ps_i. Then

- $P(y1| d1,s_i)$ = Probability of event y1 occurring, given that the first stage decision was d1 and the state of nature is s_i, and
- $P(y1| d1) = \sum_{i=1}^{5} P(Y1 | d1, s_i) ps_i$ = unconditional probability for event y1 given decision d1.

Second Stage Probabilities via Bayes Rule

The states of nature provide a basis for computing second stage probabilities via Bayesian updating. The first stage outcomes {Y1| d1} provide information regarding the likelihood of the states of nature, allowing us to revise the estimates, ps_i. Specifically,

$$ps_i^{'} = \frac{P(Y1 \mid d1, s_i)\, ps_i}{\sum_{j=1}^{5} P(Y1 \mid d1, s_j)\, ps_j}$$

Then similar to the first stage:

$$P(y2|d1,d2) = \sum_{i=1}^{5} P(Y2 \mid d1, d2, s_i)\, ps_i^{'}$$

The conditional probabilities P(y2 | d1, d2, s_i) are computed using the binomial formulas from stage one, but with the test quantities n_{USUS}, $n_{USCA,}$,and n_{CA} revised. In particular, if d2 indicates full testing (of all cattle or all cattle from Canada) n_{USUS}, $n_{USCA,}$, will be greatly increased to reflect full *vs.* partial testing. Second, the probabilities p_{USUS}, p_{USCA}, p_{CA} may be quite different than those in stage 1. In stage 1, the testing regime is targets “downer” cattle and others considered most likely to have BSE. In stage 2, under full testing, the probabilities of a positive batch are diluted by less likely animals and therefore may be much (e.g., 60-fold) lower.

Solution Algorithms

The decision tree in Figure 1, together with the quantitative data in Tables 1-3 which populate it, specify the base case risk management decision problem to be solved. A standard dynamic programming algorithm (Raiffa, 1968) provides the solution and allows variations of the problem with different input values to be solved to yield sensitivity analyses and to characterize the robustness of model recommendations to uncertainties in the input values. We used the TreePlan™ decision tree software package for Excel™ to solve the decision optimization problem for the base case and for sensitivity runs.

3. RESULTS

Optimal Decision Rule for the Base Case

Under the baseline assumptions in Tables 1-3, the expected net cost of Track Imports is $10,385,294 per year while the expected cost of Do Not Track Imports is $90,045,020 per year. Thus, the expected net economic value of the information provided by tracking is $79,658,726 per year, reflecting the much higher probability of large market losses when imports are not tracked, as BSE cases of Canadian origin in the US then are not distinguished from, and so have the same economic impact as, BSE cases of US origin. The optimal decision rule for the base case is as follows: *Track Canadian cattle imports, then continue limited sampling in Stage 2 no matter what occurs.* In other words, the benefit from tracking in this case does *not* come from avoiding the cost of 100% testing of US cattle, since this is too expensive to undertake. Rather, it comes from the reduced loss of US beef sales if the country of origin of a BSE case detected in the US is Canada and this can be ascertained and announced.

Sensitivity Analysis Results

The base case is of limited interest by itself, since it is not clear how robust the optimal current decision (Track Canadian imports) is to plausible variations in the inputs. However, the following sensitivity analysis results indicate that this recommended initial decision is very robust to key input uncertainties:

- *Robustness to market benefit estimates.* Suppose that the positive market impacts (of 1,382,000,000) for the US of another BSE discovery in Canada in some rows of Table 2 may have been estimated incorrectly. What degree of error would change the optimal decision from “Track Canadian imports” to “Don’t track Canadian imports”? The answer is that the optimal base case decision (Track CA imports) remains optimal when all positive market outcomes (those with a value of 1,382,000,000 in Table 2) are multiplied by *any* positive number, whether less than 1 (scaled down benefit estimate) or greater than 1 (scaled up benefit estimate). Indeed, the VOI for tracking remains positive for any benefit multiplier > -.58.
- *Robustness to market loss estimates.* Similarly, if all outcomes with a negative Market Impact in Table 2 are multiplied by *any* positive factor (and, indeed, any factor > -1.57), the optimal Stage 1 decision remains Track Canadian imports. (The

optimal second stage decision changes as a function of the scaling factor, with full testing of Canadian-only or all-US cattle becoming optimal for some values, but the VOI increases linearly for all positive values of the loss multiplier.)

- *Robustness to targeting efficiency.* Define the *targeting efficiency factor* as the ratio of the probability of a positive BSE test in a targeted animal *vs.* a purely randomly sampled animal. Its baseline value is 60. The VOI for tracking Canadian imports increases linearly as this factor is increased; it is negative (expected cost > expected benefit) only for values less than 17. European experience suggests that the true value of this factor could be as high as 186 in some areas (based on Swiss data, http://europa.eu.int/comm/food/fs/bse/bse21_en.html), although it varies among countries.
- *Robustness to consumer loss of confidence.* Suppose that baseline negative consequences are multiplied by a "fear factor" when the Repeat Test decision is chosen at the second stage and the market impact is negative, to reflect greater-than-estimated consumer fear and adverse reaction (loss of confidence in beef safety) that could occur if BSE is found in the second stage, but only limited sampling (the "Repeat Test" decision in Figure 1) is used. The VOI for tracking Canadian imports increases as this factor is increased, by over 50% when the "fear factor" is 2 (i.e., if the loss of beef sales due to consumer fear is twice as great as estimated in the base case.) The optimal Stage 1 decision remains Track Canadian imports for *all* positive values of the "fear factor", indicating considerable robustness to uncertainty about how customers would react to further BSE cases. (Interestingly, the optimal Stage 2 decision shifts from *Repeat Test* to *Test All* if the first stage detects BSE in the US, and the fear factor is greater than about 1.20, as seems quite plausible.)
- *Robustness to tracking costs.* The base case assumes a tracking cost per animal per year of $10. This cost could be as high as $35.00 while leaving the VOI from tracking greater than zero. Therefore, for locating and tracking Canadian cattle already in the US appears to be worthwhile when the cost is less than $35.00/head.
- *Robustness to scenario probabilities.* Figure 2 shows the results of varying the probability of each of the individual scenarios in Table 3 from 0 to 1, while leaving the remaining probability spread evenly among the other four scenarios. The VOI (= desirability index for tracking imports) increases with the probabilities of scenarios 2 and 4 and decreases with the probabilities of scenarios 1, 3, and 5. Scenarios 2 and 4 are those with a high probability for BSE in CA and low (or zero) probability for

BSE in the US. Scenarios 1, 3, and 5 each have a zero or very low probability of BSE in the US or CA. They have the potential for a negative VOI, but only at high values (exceeding approximately 0.78). All available data are most consistent with scenarios 2 and 4, which imply a positive VOI for tracking Canadian cattle.

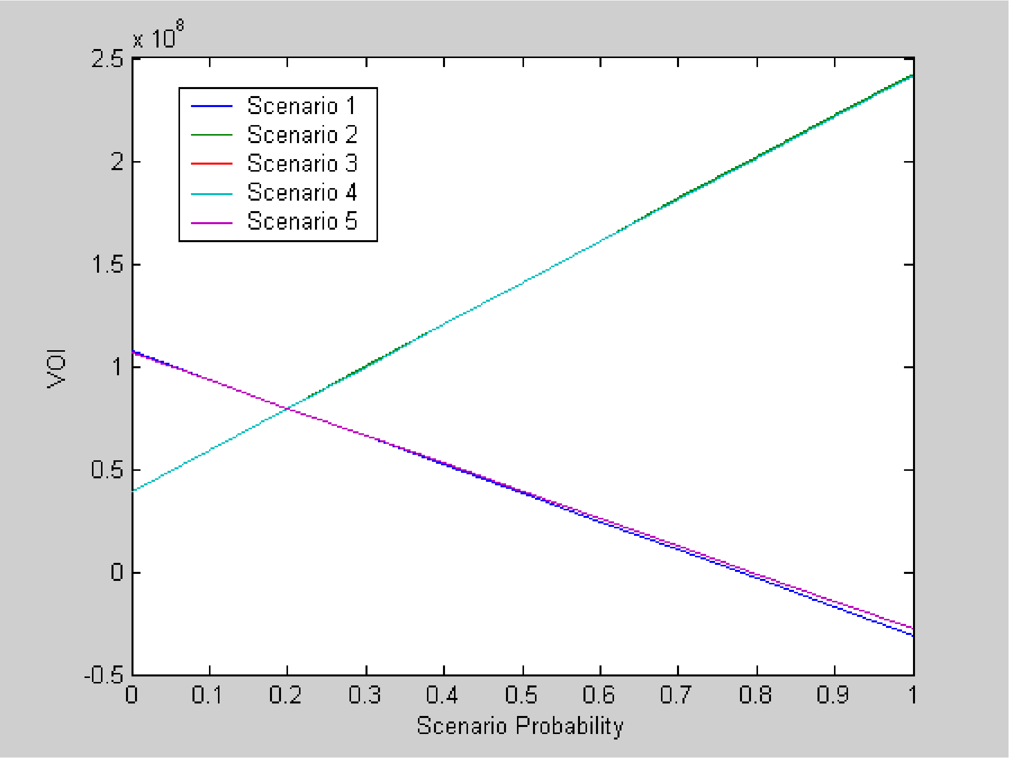


FIGURE 2: Sensitivity Analysis Plot for Scenario Probabilities

In summary, the optimal decision for the base case, Track Canadian imports, appears to be very robust to a wide range of plausible variations in the input data, as well as to combinations of variations (not shown). Thus, the model's recommendation to begin tracking appears to be well justified, even if conservative assumptions are made that tend to discount the value of tracking information. The economic value of tracking information in some sensitivity analyses comes primarily from limited export losses if the next case of BSE detected in the US can be shown to be of Canadian origin; while in others, it comes primarily from avoiding the need to test all US cattle, as opposed to just those of Canadian origin, to win back customers. Although the second-stage decisions that benefit from a first-stage decision to track Canadian cattle imports vary across sensitivity analysis cases, most of the sensitivity analyses agree that this is the optimal current decision, even while differing in their precise (Stage 2 planning) reasons.

Impacts of Possible Win-Back of Export Markets

The base case analysis and the assumptions in Table 1 are perhaps pessimistic, in that they assume that the losses of US cattle and beef export markets following the discovery of a Canadian-origin BSE case in December 2003 are persistent and irreversible. Depending on the evolution of international risk perceptions and harmonization of risk management standards and plans, it is possible that aggressive tracking and testing policies in the US might result in recovery of some lost export markets. If so, the economic impacts from tracking and testing could dwarf those calculated for the base case. For example, under an assumption that aggressive testing would allow the US to regain its lost exports (as long as no confirmed BSE case of US origin is discovered), the optimal strategy becomes to immediately start tracking all Canadian cattle and, if a confirmed BSE case of Canadian origin is found, to test all Canadian-origin cattle in the US prior to export. In this case, the expected net economic value of the information provided by tracking increases to $771,570,514 per year, i.e., by close to an order of magnitude.

4. DISCUSSION AND CONCLUSIONS

This paper has developed and applied a decision-analytic value-of-information (VOI) framework to identify robustly optimal decision recommendations for whether to track Canadian cattle imported into the US. The major conclusion is that the economic value of such information to the US greatly exceeds its costs for cattle that may be imported in future (by a ratio of 79,658,726 to 15,538,715 ≈ 5 in the base case, and more in many sensitivity analyses). For "legacy" Canadian cattle that have already entered the US, moving quickly to locate and start tracking them before any additional BSE cases are detected appears to be well justified for almost any plausible set of input assumptions, provided that the cost per head is kept within bounds (e.g., up to $35 per head, based on the sensitivity analyses for the base case). If the costs per head are too great to justify locating all legacy animals, then location and tracking efforts should focus on the oldest animals – those with the greatest risk of becoming new BSE cases.

The analysis in this paper has focused on potential economic consequences and risk management options for possibly mitigating them if another BSE case is discovered in the US. The possibility that some BSE cases might pose health risks of vCJD to humans reinforces the conclusions from this economic analysis, insofar as they make it even more important to be able to identify the origin of any new BSE cases quickly to enable effective targeting of interventions to reduce possible human health risks as soon and as fully as possible.

That tracking and testing may be imperfect has sometimes been advanced as a qualitative argument for restricting or rejecting them. The quantitative comparisons carried out in our sensitivity analyses suggest that this reasoning is usually not justified: measures that help to identify the origins and prevalence of BSE cases have high information value for improving future risk management decisions and creating additional risk management options, even if they are less than perfect.

APPENDIX A: Market Impact Assumptions and Calculations

This Appendix lists the main assumptions used in the market impact calculations referred to in the text. Table 1 summarizes the expected economic impacts for each set of potential future events, i.e., each branch through the decision tree to a leaf node in Figure 1. The impacts are calculated starting from a baseline situation in which BSE has already been discovered in Canadian cattle (May, 2003) and the impacts of the discovery have been absorbed in the market. The impacts also assume that BSE has been discovered in a Canadian animal in the U.S. (December, 2003), resulting in a roughly 50 percent of the previous US export market.

Major assumptions for estimating expected market outcomes following these events are listed below.

1) If the U.S. tracks all imports and tests all animals and no subsequent BSE case is discovered, then the exports lost following the discovery of the BSE-positive cow in Washington State in 2003 will gradually be regained. Analysis of a proposed rule for designating minimal risk regions presented by USDA in 2004 indicates that producer surplus would decline $1.91 billion as a result of U.S. producers losing 50 percent of their export market (excluding Canada and Mexico). The impact on producer revenues from this decline is estimated to be $2.864 billion ($1.02 billion from lower values on beef continuing to be sold and $1.84 billion on the value of beef no longer produced because of lower prices). It is assumed that tracking and testing will restore confidence in the international community and allow that market to be restored.

2) If the U.S. chooses to track all imports and test only Canadian animals, then it will only gain back half of the export market lost in the baseline model. Therefore, the impact of this scenario is assumed to be half of that estimated in assumption 1, i.e., $1.432 billion

3) If a case of BSE is discovered in Canada, it is assumed that loss of confidence in the Canadian beef supply will increase demand for U.S. beef in domestic and international markets by another $1.382 billion (roughly half of the estimated gains the U.S. experienced following the first case of BSE in Canada). The gains the U.S. realized from the first discovery of BSE in Canada was estimated from the USDA

study on the proposed rule for minimal risk regions. USDA estimated that reintroduction of all beef from Canada into the U.S. market would result in a decline in producer surplus of $1.545 billion. The impact on producer revenues from this decline is $2.765 billion ($1.375 billion price impact and a $1.39 billion quantity impact). Because most of the US revenue gains to be expected from a subsequent discovery of BSE in Canada were realized in the first discovery, revenue gains to U.S. producers are assumed to be half of that value ($1.382 billion).

4) A discovery of BSE in a U.S. animal inside the U.S. border (Stage 2 outcome) is expected to cause a decline in domestic demand for U.S. beef and also result in the loss of most remaining exports. A study completed by Jin et al. (2004) indicated that a discovery of BSE in a U.S. animal was expected to cause a 25 percent decline in domestic demand for U.S. beef, equal to $12.27 billion in producer revenues from our base model analysis. This result combined with the loss of exports markets equal to $2.864 billion (see discussion in assumption 1) results in a combined impact on producer revenues of $15.14 billion.

5) A discovery of BSE in a U.S. animal inside the U.S. border as a Stage 1 outcome followed by rigorous testing (test all) with no additional discoveries of BSE in the U.S. is assumed to have half the impact of a Stage 2 outcome of BSE in the U.S. It is assumed in this scenario that rigorous testing with no additional discoveries of BSE will mitigate the impacts resulting from a decline in domestic demand. It is assumed that consumer demand will decline by half that of a Stage 2 outcome of BSE in the U.S. ($6.14 billion) and that all remaining export markets will be lost ($2.863 billion), resulting in a total impact of $9.003 billion.

6) A discovery of BSE in a Canadian animal in the U.S. is assumed to cause a decline in U.S. producer revenues of $1.432 billion. This result is assumed to occur from a loss equal to one half the remaining export earnings from beef (see discussion in assumption 1).

The $4.246 B impact for Stage 1 No BSE and Stage 2 BSE in Canada is a combination of Assumptions 1 and 2.

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