Estimating and exploring the proportions of inter- and intrastate cattle shipments in the United States

Lindsay M. Beck-Johnson[a,*], Clayton Hallman[b], Ryan S. Miller[b], Katie Portacci[b], Erin E. Gorsich[a], Daniel A. Grear[b,1], Katherine Hartmann[a,2], Colleen T. Webb[a,c]

[a] *Department of Biology, Colorado State University, 1878 Campus Delivery, Fort Collins, CO 80523, USA*
[b] *USDA APHIS Veterinary Services, Center for Epidemiology and Animal Health, 2150 Centre Ave, Bldg B Fort Collins, CO 80526*
[c] *Graduate Degree Program in Ecology, Colorado State University, 1021 Campus Delivery, Fort Collins, CO 80523, USA*

Abstract

Mathematical models are key tools for the development of surveillance, preparedness and response plans for the potential events of emerging and introduced foreign animal diseases. Creating these types of plans requires data; when data are incomplete, mathematical models can help fill in missing information, provided they are informed by the data that are available. In the United States, the most complete national-scale data available on cattle shipments are based on Interstate Certificates of Veterinary Inspection, which track the shipment of cattle between states; data on intrastate cattle shipments are lacking. Here we develop four new datasets on intrastate cat-

*Corresponding Author
Email address: `L.Beck-Johnson@colostate.edu` (Lindsay M. Beck-Johnson)
[1] Present address: National Wildlife Health Center, United States Geological Survey, 6006 Schroeder Rd, Madison, WI 53711, USA
[2] Present address: Agricultural and Resource Economics Department, Colorado State University, 1172 Campus Delivery, Fort Collins, CO 80523 USA

tle shipments in the U.S., including an expert elicitation survey covering 19 states and territories and three state-level brand inspection data sets. The expert elicitation survey provides estimates on the proportion of shipments that travel interstate over multiple regions of the U.S. These survey data also identify differences in shipment patterns between regions, cattle commodity types, and sectors of the cattle industry. These survey data cover more states than any other source of interstate data; however, one limitation of these data is the small number of participating experts in many of the states, only seven of the 19 responding states and territories had a group size of three or larger. The brand data sets include origin and destination information for both intra- and interstate shipments. These data, therefore, also provide detailed information on the proportion of interstate shipments in three Western states, including the temporal and geographic variation in shipments. Because the survey and brand data overlap in the Western U.S., they can be compared. We find that in the Western U.S. the expert estimates of the overall proportion of cattle shipments matched the brand data well. However, the experts estimated that there would be larger differences in beef and dairy shipments than the brand data show. This suggests the cattle industries in the West may be sending similar proportions of commodity specific cattle shipments over state lines. We additionally used the expert survey data to explore how differences in the proportion of interstate shipments can change predictions about cattle shipment patterns using the example of model-guided suggestions for targeted surveillance in Texas. Together these four data sets are the most extensive and geographically comprehensive information to date on intrastate cattle shipments. Additionally, our analyses

on predicted shipment patterns suggest that assumptions about intrastate shipments could have consequences for targeted surveillance.

Keywords: cattle shipment, intrastate shipment, interstate shipment, expert elicitation, brand inspection

Introduction

Surveillance, tracing and response plans are critical aspects of preparedness and control for livestock diseases. Previous work has demonstrated that knowledge of livestock shipments is important for understanding disease spread and therefore, for improving the effectiveness of surveillance and outbreak planning and response activities (van Schaik et al., 2002; Green et al., 2006; Ortiz-Pelaez et al., 2006; Kao et al., 2007; Grear et al., 2014; Gorsich et al., 2018). Emerging and re-emerging livestock infections and the potential for an introduced foreign animal disease, require well informed preparedness and response plans both in the United States (U.S.) and around the world. Despite this need, there is a limited amount of information on livestock shipments in the U.S. (Buhnerkempe et al., 2013; Lindström et al., 2013), and this is a considerable hindrance to disease preparedness activities. In particular, for the cattle industry in the U.S., within state shipment patterns are not well described.

In the U.S., the most extensive data on cattle shipments are the Interstate Certificates of Veterinary Inspection (ICVIs) that record interstate (between-state) shipments of livestock (Buhnerkempe et al., 2013; Portacci et al., 2013; Gorsich et al., 2016). These data have been used to build a national model for cattle shipments, called the United States Animal Movement Model (US-

AMM), that can be used to understand general cattle shipment patterns in the U.S. (Buhnerkempe et al., 2013; Lindström et al., 2013) and have also been used to predict movement of at-risk cattle (Grear et al., 2014; Gorsich et al., 2018). USAMM was also coupled with a disease simulation, called the United States Disease Outbreak Simulation (USDOS), to understand the potential for pathogen transmission and disease spread via animal shipments at a national-scale (Buhnerkempe et al., 2014). The USAMM model uses information on interstate shipments to estimate the within state patterns, but complete data to inform this process are lacking, and there is uncertainty in the relative contribution of within versus between state movement to disease spread (Lindström et al., 2013). The characterization of intrastate (within-state) shipment patterns and the relative number of shipments that occur within versus between states are key pieces of information for characterizing shipments at the state, regional or national scale.

In the majority of U.S. states, intrastate shipments of cattle are not recorded; however, it is generally assumed that the majority of cattle shipments occur within states (USDA, 2009). Because there is not a national source of information on intrastate cattle shipments, data describing this process need to be compiled from different sources. Previous studies on cattle shipments have used data compiled from questionnaires and expert opinion to describe intrastate cattle shipments at a local level (Bates et al., 2001; Liu et al., 2012); however, the scale of these studies makes it difficult to extrapolate regional or even state-level patterns. The main source of directly observed data on intrastate shipments are brand inspection data, which some states use when ownership of animals is transferred or when animals are shipped. Largely collected in the Western U.S., brand inspection data capture both intrastate shipments and interstate shipments; however, because these are state-level data, the type of shipments tracked, the information tracked, geographic coverage and the accessibility of the data (i.e. paper versus electronic) vary from state to state. Despite the differences in data accessibility, and the type of data recorded, brand inspection data provide consistently tracked state-level data on intrastate shipments.

The brand inspection data provide detailed information on cattle shipments traveling within and between states in the Western U.S. Despite the brand inspection data being limited to a subset of states, it most likely provides the best data available on intrastate shipments. The differences in cattle infrastructure and regional management practices in the cattle industry make it probable that differences will also be present in shipment patterns across the U.S. Therefore, information gathered from brand inspection data, though invaluable in states where brand inspection is available, may not provide accurate estimates for states in other regions of the U.S. where production systems can be very different (e.g. many small farms or areas with a predominance of dairy production). To fill these gaps in knowledge, we implement an expert elicitation survey to explore differences in intra- and interstate cattle shipments across the U.S. The comparison between brand inspection data and expert elicitation estimates in the Western U.S. can provide information on the accuracy of expert estimates. We combine the novel survey data with brand inspection data from three Western states (California, Wyoming and Montana), and one market data set from Montana to provide the first regional estimates of intrastate cattle shipments for the

U.S. We also use the expert survey data to explore how changing estimates of the proportion of interstate shipments can alter predictions about cattle shipments, and therefore, targeted surveillance of cattle imported to Texas.

Methods

Expert Elicitation Survey Development and Implementation

The survey was developed and implemented as a modified Delphi group process. This method was chosen because it is the most commonly used survey method in ecology and veterinary epidemiology and could be adapted to the large number of expert groups required for this study (Kuhnert et al., 2005; Gustafson et al., 2010; Kuhnert et al., 2010; Gustafson et al., 2013). The goal of this survey was to develop data on intrastate cattle shipments with good geographic coverage of the continental U.S.

Our expert elicitation survey was designed to gather information about the proportion of interstate cattle shipments at the state-level across both the entire cattle industry and different industry subsets. The survey was divided into two sections, one for beef and one for dairy, because management practices differ between these commodities and because it was common for experts to have stronger expertise in one commodity. The survey questions asked about shipments of different types of cattle, and shipments traveling to or from different origin and destination types (market, feedlot, etc). The survey was designed with input from subject matter experts on expert elicitation, and on beef and dairy cattle, respectively. A complete list of the survey questions can be found in Appendix A.

Because the survey questions were written at the state-level, multiple groups of state-level experts participated in the survey. We selected ten states to focus on, California, Colorado, Iowa, Minnesota, North Carolina, Nebraska, New York, Pennsylvania, Tennessee, and Texas. These states were selected because they were found in previous work to be important in the cattle shipment network (Gorsich et al., 2016), and they represent major geographic regions in the U.S. The survey targeted cattle experts with deep knowledge of the cattle industry, including cooperative extension professors, state veterinarians, veterinary medical experts, epidemiologists, cattleman's association leadership, and USDA personnel.

Experts were invited to participate in the survey through two routes. The first route of invitation was targeted to the ten focal states. Experts were identified and invited to participate with a letter explaining the survey process. If the expert was unable or unwilling to participate in the survey, we requested that they suggest another qualified expert. The second route of invitation was more broad and did not specifically target the focal states; a brochure explaining and inviting participation in the survey was sent out to the state veterinarians, veterinary medical experts, and to the United States Animal Health Association and the Agricultural Marketing Service. These organizations and officials receiving the brochure invitation were in a position to identify key state-level experts or are experts in cattle shipments in their own right. All experts who participated in the survey worked in the cattle industry and were in positions that allowed for observation of cattle shipment practices. The survey was administered online through eSurveysPro (esurveyspro.com). Additional details regarding the design and implementation of the survey can be found in Appendix B.

Expert Elicitation Survey Analysis

For analysis, survey questions were grouped into shipment categories including, overall, commodity specific (beef or dairy), feeding channel, breeding channel and market shipments (for details on the specific question groupings see Appendix B). One survey question (question 11) was omitted from analyses because the responses and comments from the experts indicated multiple interpretations of the question; responses to the other questions did not indicate any other questions were subject to misinterpretation.

Individual expert estimates were obtained by taking the mean over their responses to the questions in each cattle shipment category analyzed (overall, commodity specific, feeding, or breeding channel and market). State-level estimates of the proportion of interstate shipments were found by taking the mean of the individual expert estimates from the state. State-level estimates were then aggregated into regional and national-level proportions of interstate shipments using both the mean and the median number of interstate shipments out of 100 (or number of farms that ship to interstate destinations).

The national estimate included all contiguous states that responded to the survey. The participating contiguous states were divided into five regions: West, which included California, Idaho, Montana and Nevada; Plains, which included, Colorado, Nebraska, Oklahoma and Texas; Upper Midwest, which included, Iowa, Minnesota and Wisconsin; Northeast, which included, New York and Pennsylvania, and Southeast, which included, Mississippi, North Carolina, Tennessee and Virginia. These regions are loosely based on the USDA Economic Research Service (ERS) farm production regions (Heimlich, 2000); however, because not every ERS region had enough representation, multiple regions had to be grouped. Additionally, the mountain region was not contiguous so Idaho, Montana and Nevada were joined with the pacific region state, California, to create the Western region and Colorado was added to the plains region.

Brand Inspection Forms

Brand inspection data was obtained from three states, California (CA), Montana (MT), and Wyoming (WY). Because each state had its own specific requirements for when a brand inspection is required, the data available from these states were not exactly the same (California Department of Food and Agriculture, 2017; Montana.gov Official State Website, 2017; Wyoming Livestock Board, 2017). The CA and WY data sets each contained one year of data (2009 & 2010, respectively). The data set from MT contained three years of data (2009–2011). From MT we also had a data set of shipments originating at markets for one year (2013). The market data set was similar to the brand inspection data sets in that both intra and interstate shipments are tracked; however, in MT, shipments to and from markets were tracked separately. The inclusion of both the brand inspection and market data from MT provided more complete information on cattle shipments in that state. The datasets are summarized in Table 1 and additional details about the data sets can be found in Appendix B.

For each brand inspection (or market) data set, the proportion of interstate shipments was calculated. Similarly, the proportion of intracounty shipments (shipments that remain in the county of origin), was calculated. The total number of shipments and the proportion of those shipments that were interstate shipments were separated out by month to examine patterns in seasonality. Because the brand inspection data provided information on the origin and destination locations, we could explore the differences in geographic shipment patterns at the county scale. For each state, the total number of shipments leaving a county was found and the proportion of those that travelled interstate was estimated. Each year of brand inspection data from MT was analyzed separately and the between year correlations were estimated.

To examine the relationship between county characteristics and the odds of a shipment traveling to interstate locations, we conducted two logistic regression analyses with the odds of shipping to interstate destinations quantified in the three brand inspection data sets, and in the MT market data. In these analyses, we considered the total number of shipments leaving a county as a covariate and if the county is located on the state border. In addition to these county characteristics, we examined four measures of the cattle industry in our analyses; these include: the number of operations with cattle inventory, including calves; the inventory of cattle, including calves; the proportion of operations that are beef operations; and the number of feedlots (operations with cattle on feed). These measures are publicly available through the National Agricultural Statistics Service (NASS) 2012 Census of Agriculture (USDA, 2014) and have been used to inform cattle shipment models (Lindström et al., 2013; Schumm et al., 2015). For each model, we conducted model selection using backwards elimination based on Akaike information criteria (AIC). The full model included the four measures of the cattle industry defined above, an indicator variable for whether the county is a border county, and a variable defining the total number of shipments leaving the county. The final model was selected when no additional terms could be dropped. All continuous covariates were standardized to allow comparison among predictor variables (Schielzeth, 2010). All models were fit in R version 3.1.0 (R Core Team, 2014).

Comparison of Survey Estimates with Brand Inspection Data

To compare the brand inspection data with the Western region survey results, the brand inspection data had to be combined into a regional estimate. The brand inspection guidelines for each of the three states differ, however, each data set included information on origin, and destination of the shipments. To make the regional brand inspection data estimates comparable with the expert opinion result, we took the mean proportion of interstate shipments across the three states. Additionally, because we had two different intrastate data sets from MT we created two regional brand inspection data sets; the first includes brand inspection data from CA, MT (2010), and WY and the second includes the brand inspection data from CA, WY and the market data from MT (2013).

We also compared the expert estimates for each commodity with the brand inspection regional estimates. The state brand inspection records were separated into beef and dairy first and then combined into regional commodity-specific estimates. The beef and dairy designation was already present in the CA brand data so this data set did not require further development. The brand data from WY included information on the cattle breed. Records for mixed breeds, unknown or unassigned breeds were removed, then the shipments were designated as beef or dairy depending on the breed. The

MT brand data did not include a beef or dairy designation and did not provide any information on breed. Therefore, there was no reliable method to separate out dairy shipments; however, we made the assumption that shipments of steers were beef shipments and were able to separate those out of the data set (Buhnerkempe et al., 2013). The market data from MT did provide information on cattle breed, so it was possible to assign both beef and dairy designations for this data set in the same way as was done for WY.

Application of Expert Survey Estimates to USAMM Predictions about Targeted Surveillance

To evaluate the importance of accurately estimating the proportion of inter- versus intrastate shipments, we explored how these proportions impacted USAMM model predictions about surveillance and connectivity. The shipment network predictions from USAMM can be used to inform targeted risk-based surveillance of cattle in the U.S. (Gorsich et al., 2018). One group of animals that could be targeted for surveillance are cattle that have been imported from other countries. The importation of live animals is an important route by which diseases could be introduced into the U.S. (Humblet et al., 2009; Tsao et al., 2014). However, these animals are not tracked separately from the rest of the U.S. herd. Imported cattle are given a blue ear tag upon entry, so that they can be easily identified, but these tags can be lost. Gorsich et al. (2018) used the USAMM network to predict where cattle imported from Mexico may be shipped. Here we explored how these predictions may be altered by changing the proportion of shipments that are predicted to travel to interstate versus intrastate locations. We focused on shipments leaving Texas in this study because it was previously identified to have the most counties that receive imports of live cattle from Mexico (34 import counties in total) according to the Veterinary Services Import Tracking system (2009) and Veterinary Services Process Streamlining (VSPS) data (2011) (Gorsich et al., 2018) and because the destination location of shipments leaving Texas varied across years (Gorsich et al., 2016). Texas also had the largest number of participants in our expert elicitation survey.

We conducted our analyses in three steps. First, we generated the mean USAMM network for shipments originating in TX to use as a baseline for comparison. The mean network was created from 1000 USAMM realizations, each one a simulation of all annual cattle shipments. USAMM predicted the probability of shipments occurring between counties, both within the same state and between counties in different states. The USAMM networks were designed such that the counties were nodes and the shipments between counties were edges (Lindström et al., 2013). The probability that a shipment moved between counties in different states and the number of interstate shipments, or edges, predicted by USAMM are informed by ICVI and National Agricultural Statistics Service data. The intrastate shipments predicted by USAMM were estimated by the distance kernel, and therefore, have more uncertainty than the interstate shipment predictions (Lindström et al., 2013).

The second step in our analyses was to alter the network such that the proportion of interstate shipments was more in line with the expert mean, minimum and maximum estimates. To do this, we altered the number of intrastate shipments, or intrastate edges, in the predicted mean TX network while holding the number of interstate shipments constant and consistent with the data that informed the model. Changing the network in this way meant that the overall total number of edges in the network changes but the total number of interstate edges did not. The original USAMM TX network predicted that the proportion of interstate shipments was 0.18 (Lindström et al., 2013). The mean expert estimate from TX predicted that the proportion of interstate shipments was 0.155, with the range of the expert estimates going from 0.0086 to 0.256. To alter the mean USAMM network, we multiplied the intrastate shipments by scalars that increased or decreased the total number of intrastate edges, such that the resulting networks had interstate proportions in line with the expert estimates. This preserved the predicted county to county connections, both within and outside of TX and kept the number of interstate edges constant; only the predicted number of intrastate edges, or shipments, in TX changed. We did this for the mean expert estimates and for the minimum and maximum, which gave us three modified USAMM networks with proportions of interstate shipments of 0.155, 0.0086, and 0.256, respectively.

For the third step in our analyses, we used the methods described in Gorsich et al. (2018), and simulated cattle shipments from the counties receiving imported cattle from Mexico in TX using the original USAMM network and the three modified networks using the expert elicitation data. For these simulations we assumed the probability each imported animal was shipped out of the county that received the imported animals was 1 and varied the probability of not observing an animal, because of random loss of the blue ear tag marking it as an import, from 0 to 1 (Gorsich et al., 2018). We then explored how the three modified networks altered the predicted distribution of counties that subsequently receive shipments of imported cattle and if the percent of cattle that could be unobserved while still capturing that distribution changed between the networks. For consistency with the previous methodology and results, we report the same network summary statistics used previously (Gorsich et al., 2018); these include: the number of unique counties reached, the percentages of re-observed cattle in the 10 and 50 counties that receive the most shipments, respectively, and the percent of observed cattle moving out of TX, and the skewness and the kurtosis of the distribution of observed cattle among counties receiving shipments.

Results and Discussion

Expert Elicitation Survey

In total, 51 experts from 19 states and territories participated in the survey (Table B1). The median response rate from the ten focal states (including experts who where invited and those who responded to the general announcement) was 0.29 (range: 0.1-0.5) and the median final group size from the focal states was 2.5 (range: 1-8) (Table B1). In total, we had seven states with expert group sizes of three or more; these states were Iowa, Minnesota, New York, Oklahoma, Tennessee, Texas and Wisconsin. The remaining 16 states and territory that responded to the survey announcement had one or two expert participants, which was a limitation of this study. The small number of expert groups with size three or more, was one reason the results were collapsed into regional groups. The regional groups leveraged estimates from multiple state groups and provided more power than the individual state groups, particularly for those states with small sample sizes. The Western region in particular, did not have an individual expert group larger than two; however, the regional estimate included 4 state-level estimates. The coverage of expert groups size three or more was better in the Plains, Upper Midwest, Northeast and Southeast. Despite the small number of expert groups size three or more, this study represents the most extensive information on intrastate cattle shipment data in the U.S.

Estimates of interstate shipment numbers differed substantially between states and regions in the country. Over all shipment questions, the experts in the plains and northeastern regions estimated the lowest proportion of interstate shipments and the west and southeastern regions were the highest (Figure 1a, Table B2). The national and regional level results for each survey question are presented in the appendix (Tables A1 & A2). The range of estimates for many questions was large, particularly at the national level. The large variation at the national level was likely due to differences in local and regional shipment patterns, some of which were apparent in the differences between regional estimates from this survey. An additional factor, particularly in regions with few survey participants, may have been the low sample size of experts (Table B1). The high variation in question response at the national scale suggests that a single nationwide interstate shipment estimate may not be appropriate and that regional or state-level estimates will be more accurate.

The proportion of interstate shipments was calculated for specific shipment categories, including market shipments and shipments in the feeding or breeding channel. The estimated proportion of interstate market shipments also varied between regions. Experts in the national, upper midwest and northeast regions all estimated that the proportion of market shipments that cross state lines was between 0.36 and 0.45 (Table B2). The experts in the plains region estimated the proportion of interstate shipments was slightly lower at 0.3. Experts in the western and southeast regions both estimated higher proportions, 0.56 and 0.6, respectively, of interstate market shipments. The feeding channel interstate shipment patterns were estimated to be slightly higher, except for the plains and northeast regions, than for market shipments. However, the general pattern of regional shipment levels remained the same. The regions also held similar positions for breeding channel shipments. In general the proportion of interstate breeding channel shipments was lower than both market and feeding channel estimates (Table B2).

The survey results from the commodity specific (beef or dairy) sections of the Cattle Movement Survey, also showed geographic variation in the estimated proportion of interstate cattle shipments. Experts in neighboring states generally estimated similar levels of interstate shipments for beef shipments (Figure B.1). The survey results for beef shipments showed regional variation that tended to follow the regional pattern of the estimated overall interstate proportion (Figures 1a-1b, Table B2). Regional patterns of estimated proportion of interstate dairy shipments were less well defined than those observed in the interstate beef shipment results and differed slightly in overall pattern from the beef and overall shipment estimates (Figures 1 & B.2, Table B2).

As with the interstate overall shipments, we calculated the estimated proportions of specific types of interstate shipments for the commodity specific shipments. The estimated proportions for market, feed and breeding channel commodity specific shipments differed between regions and between commodity type; however, the differences between commodities were not as marked as those between regions (Table B2). Additional descriptions of the commodity specific results can be found in Appendix B.

Brand Inspection

The brand inspection data from CA estimated a proportion of interstate shipments slightly above 50% (Table B3). The brand data from both MT and WY estimated the proportion of interstate shipments lower than CA with all three years falling slightly below 50%. Similarly, the estimated proportion of interstate shipments from the MT market data also showed proportions of interstate shipments slightly below 50%. The multiple years of data from MT showed that the proportion of interstate shipments in the brand data were fairly consistent from year to year and between data sets. Multiple years of data were not available for CA and WY, so they could not be compared through time.

The data from the state of Montana were available for a three year period of time (2009-2011). The patterns in the number of shipments originating in each county were very stable across all three years (correlations between years 2009 & 2010: 0.989, 2010 & 2011: 0.982, 2009 & 2011: 0.979). A similar pattern was observed for both number of shipments destined for each county (correlations between years 2009 & 2010: 0.992 , 2010 & 2011: 0.990, 2009 & 2011: 0.986) and for the proportions of interstate shipments (correlations between years 2009 & 2010: 0.894, 2010 & 2011: 0.962, 2009 & 2011: 0.854).

The total number of shipments per month showed bimodal seasonality, with peaks in the spring (April to May) and in the fall (Oct. to Nov.) for all years of MT brand, MT market and WY brand data (Figure 2a). The CA brand data showed a similar spring peak in total number of shipments but did not have a second peak in the fall. The proportion of interstate shipments did not scale directly with the total number of shipments for MT or WY, and therefore showed a different pattern in seasonality in these states (Figure 2b). For the MT data sets (both brand and market), and the WY brand data, the proportion of interstate shipments had a single peak in the fall months (Sept. to Nov.). This was particularly apparent in the MT brand data which reported the lowest proportion of interstate shipments in the spring and the highest in the fall. The proportion of interstate shipments reported in the CA brand data did not follow the same pattern as the other states. In CA, the proportion of interstate shipments peaked in May and corresponded with the peak in the total number of shipments.

For all three states, the brand inspection data showed that there were differences in the number of outgoing shipments between counties within the respective states (Figures 3a, 3c, 3e, & B.3a, B.3c). The proportion of interstate shipments also varied between counties in the same state (Figures 3b, 3d, 3f, & B.3b, B.3d). The odds of counties shipping to interstate destinations in the brand inspection data were influenced by all covariates considered, but the magnitude and direction of each co-variate varied by state (Figure 4a). In CA, the best predictors were the total number of shipments and the number of feedlots (operations with cattle on feed). In MT and WY, the best predictors were whether the county was on a border, the total number of shipments, and the proportion of operations in the county that were beef. Border counties consistently shipped more out of state shipments, 1.12, 2.17, and 3.03 times higher odds of shipping out of state in CA, MT, and WY, respectively (95% CI CA: 1.03–1.22; MT: 2.07–2.28; WY: 2.70–3.41). In contrast, associations with the total number of shipments and the proportion of operations with beef cattle were variable by state. In MT, counties sending more shipments and those with a higher proportion of beef operations were more likely to ship interstate while in WY, counties with a higher proportion of beef shipments were less likely to ship interstate.

Similar to the brand data, there was variation between market counties in both total outgoing shipments and proportion of interstate shipments in the MT market data (Figure B.4). The final model predicting the odds of shipping to interstate destinations in the MT market data included the number of cattle operations, the proportion of operations that are beef, the total inventory of cattle, and the total number of shipments leaving that county. The best predictors were the total number of shipments, the total inventory of cattle in the county, and the proportion of operations that are beef (Figure 4b). Market counties with one standard deviation more cattle were associated with a 1.45 times higher odds of shipping interstate (95% CI: 1.38–1.52) and counties with higher proportions of beef operations were associated with a 1.27 times higher odds of shipping interstate (95% CI: 1.07–1.50). Conversely, counties with markets sending a larger number of shipments were less likely to send out of state, as one standard deviation more shipments was associated with a 0.65 times lower odds of shipping interstate (95% CI: 0.60–0.71).

The brand inspection data provided detailed information on within and between state shipments for three western states, CA, MT and WY. The level of detail in the data sets allowed us to investigate both the proportion of interstate shipments and the proportion of intracounty shipments (shipments that remain within the county of origin). Additionally, we were able to explore the temporal and geographic differences in the number of outgoing shipments and the proportion of those which were interstate at the monthly and county level, respectively. The temporal patterns in the total number of shipments originating in MT (both brand and market data sets) and WY followed the same bimodal pattern of shipments peaking in spring and fall that was reported in ICVIs (Gorsich et al., 2016). CA showed the same spring peak in shipments but did not show the second fall peak. The differences in these temporal patterns between states could be attributed to the differences in brand inspection requirements (California Department of Food and Agriculture, 2017; Montana.gov Official State Website, 2017; Wyoming Livestock Board, 2017), differences in the cattle industry or a combination of both. These data sets also provided a unique look at the temporal changes in the proportion of interstate shipments in different states. In CA the proportion of interstate shipments increased at the same time the total number of shipments increased. However, for MT and WY the seasonal patterns of the proportion of interstate shipments did not follow the total number of shipments. These data suggested that in the fall the proportion of interstate shipments increases. The pattern of seasonality in the proportion of interstate shipments could affect the potential for cross state border spread of disease outbreaks, such that chance of long distance spread could increase during the seasons when the proportion of interstate shipments peaks.

We explored the geographic differences in the total number of shipments and the proportion of interstate shipments at the county level for each brand and market data set. We found that all the covariates that we considered influenced the odds of shipping interstate, but that these covariates acted in different ways and to varying degrees depending on the state. However, our analysis suggested that border counties have higher odds of shipping to interstate destinations in all three brand inspection data sets. In both the brand inspection and market data analysis the total number of shipments and proportion of beef operations were important covariates but they acted on the odds of interstate shipping in different ways. Interestingly, the covariates varied between the MT data sets (brand and market) as well. The cattle inventory seemed to be more important for determining interstate shipment odds in the market data than in the brand data, and total shipments had a positive influence on the brand data and a negative influence on the market data. This could suggest that large beef movements use markets. These results also suggested that the proportion of shipments that leave counties are correlated to the total number of shipments and to other indicators of the cattle industry and infrastructure, such as proportion of operations which are beef.

County level heterogeneity was also found in analyses of cattle shipment networks based on ICVI data (Buhnerkempe et al., 2013). Buhnerkempe et al. (2013) found that though the cattle shipment network was highly connected, the county level heterogeneity was such that state-level networks would most likely be too coarse for examining disease outbreaks. The brand inspection data sets showed similar patterns in county level heterogeneity some of which was explained by the total number of shipments leaving a county, and additional covariates. This indicated that interstate shipment data, such as ICVIs, in combination with generally available covariates such as, proximity to a border, the proportion of beef operations and potentially the presence of a market or feedlot, can be used to inform intrastate shipment predictions such as those developed by Lindström et al. (2013). Given that the overall estimate of the proportion of interstate shipments from the experts in the western region was close to that of the brand data, it is possible that expert estimates, though on a much coarser scale than brand or NASS data, could also be used to help inform shipment patterns in areas of the U.S. where additional intrastate data are unavailable. This has important implications for development of national-scale cattle shipment models with the objective of modeling disease spread (Buhnerkempe et al., 2014) or for identifying counties and states of increased risk for receiving shipments of at-risk animals (Gorsich et al., 2018). These findings make the development of national-scale shipment predictions more tractable because within state shipment data are not available for most of the U.S. and ICVI data are currently the best source for all regions of the U.S. This also has potential implications for foreign animal disease preparedness planning in that counties that connect within state shipment patterns to interstate shipments can be identified based on number of interstate shipments and covariates that are easily accessible. This information alone is valuable for planning surveillance activities or risk mitigations such as movement controls when detailed information is not available or too time consuming to develop during a emergency response event.

Finally, the brand data provided an opportunity to explore the possibility of changes to the proportion of interstate shipments through the year. Surprisingly, the proportion of interstate shipments did not directly follow the seasonality in total number of shipments for MT or WY. This suggests that there may be differences in interstate shipment seasonality in other states as well; information that could be very valuable in determining the probability of a disease spreading over state lines.

Comparison of Survey Estimates with Brand Inspection Data

The comparison between the western region (CA, ID, MT, NV) expert elicitation survey results and the western region brand inspection results (CA, MT Brand 2010, & WY, and CA, MT Market, & WY, respectively) on the proportion of interstate shipments showed that estimates from these two data sets were quite similar (Figure 5). The similarity between the overall survey estimate and the brand inspection data suggested that the overall estimated level of interstate shipments by region were in the range of the observed number.

The brand inspection regional estimates changed slightly when the data were broken out into beef and dairy commodity types, with the proportion of beef interstate shipments remaining close to the overall estimate and the dairy estimate increasing. However, the expert elicitation results when broken out into beef and dairy changed more substantially, with the estimated proportion of interstate shipments increasing for beef and decreasing for dairy. The brand inspection data and expert survey estimates for the commodity specific (beef or dairy) proportions of interstate shipments did not agree as well as they did for the overall estimate; the estimates for dairy were particularly divergent. This could suggest that the shipment patterns of individual commodities, especially dairy, are less well understood than the overall shipment patterns.

The variation within the commodity specific expert estimates, and the comparison of these estimates with brand inspection data suggested that the the amount of interstate shipments between beef and dairy is less well understood, at least for western states, than the overall level of interstate shipments. The high degree of variation in the results of the expert survey may be caused by more than uncertainty in the system; different interpretations of the questions and the clarity of the questions being asked could also play a role in the amount of variation seen in the results. Gathering additional commodity specific shipment data will help identify causes of uncertainty and will be beneficial for building data driven shipment models and for developing effective response plans.

Expert estimates on proportion of interstate shipment varied regionally in the United States. Similarly, experts estimated that differences exist in the proportion of interstate shipments between the cattle commodities, beef and dairy. Though we were unable to do a comprehensive validation of the expert estimates, we were able to compare the western region to the regional brand inspection data. We found that the mean expert estimate for overall proportion of interstate shipments was similar to the brand inspection estimate, but that the commodity specific expert estimates were more divergent from the brand estimate. This large variation for some types of shipments may indicate that certain aspects of the cattle industry are generally less understood or that there is a diversity of mechanisms that influence shipments for some parts of the cattle industry and that no one expert possessed all of the information. This large variation also highlights the importance of developing empirical data to inform descriptions of cattle shipments and that relying solely on expert knowledge could provide biased estimates. This could also have implications for other types of livestock shipment models that rely heavily on expert opinion (Pines et al., 2007; Wongsathapornchai et al., 2008).

Our results identify several aspects of intrastate shipments in the U.S. that may not be well understood. It is generally thought that different regions of the country have different cattle shipment patterns and the empirical interstate data suggest that this is true (Gorsich et al., 2016). The expert estimates support the theory that different regions have different shipment patterns, though due to the small sample size of some states and regions it is difficult to verify the regional pattern with these data. The differences in shipment seasonality that were present in the brand inspection data between states also suggest that there are differences between states that could lead to regional differences in shipment patterns. However, because we only have empirical data for the western U.S., we are unable to fully validate how shipments might vary by region in the U.S. Similarly, the differences in the expert estimated proportions of different types of interstate cattle shipments (i.e. market, feeding channel or breeding channel shipments) are not fully observable in the brand inspection data. Gathering empirical data to support or refute regional and shipment type differences in the proportions of interstate shipments would be a valuable addition for both modeling and decision-making efforts.

Application of Expert Survey Estimates to USAMM Predictions about Targeted Surveillance

The simulations of imported cattle to TX for the original USAMM network and the three modified networks suggested that while the skewness and kurtosis were variable across the differing levels of proportion of interstate shipments, the predicted total number of unique counties reached, and the percent of imported cattle re-observed in the 10 and 50 counties that receive the most shipments, respectively, were fairly stable (Table B4). Similarly, the distribution of unique counties reached were similar and fairly stable until around 90% of the cattle are unobserved (Figure 6) for all four networks. These patterns are consistent with those reported when using the full USAMM network rather than just a shipment originating in a single state (Gorsich et al., 2018). The modified network with the proportion of interstate shipments corresponding to the expert estimate minimum (0.0086) showed the most difference from the original USAMM network. The predicted number of unique counties reached was substantially lower (on average 41% lower) than the other networks; however, the shape of the distribution was similar to those predicted by the other networks.

The other clear difference between the original network predictions from TX and the modified networks was the percent of cattle predicted to leave TX, the state of importation. The prediction from the original TX network was that 50.28% of cattle (individual animals, not shipments) will leave the state when all cattle are observed. The predictions from the modified networks ranged from 5.73% to 59.01% cattle leaving TX, when all cattle are observed. These predicted percentages were fairly consistent over the varying levels of the percent of observed cattle. While the difference in predictions between the maximum and minimum expert estimates were considerable, there did appear to be some robustness to uncertainty in the proportion of interstate shipments in the system. The predictions from the mean and maximum modified network and the original network ranged from 46.80% to 59.01% cattle leaving TX. This would suggest that for some range of TX proportions, the predictions of cattle leaving the state would not substantially change. However, the minimum expert estimate cannot be completely dismissed as an outlier since there is currently no observed intrastate data from TX to compare to and from a surveillance perspective the difference between 94% of cattle remaining in their state of importation versus 41% of the cattle remaining is an important difference to examine. The network connections and the distribution of the network summary statistics were fairly consistent between the four explored networks, but the amount of resources (e.g. number of tests, staff) required for surveillance and the spatial distribution of those resources could be altered depending on the proportion of interstate shipments. More importantly the change in the expected number of cattle remaining in their state of importation could significantly alter surveillance strategies and interpretation of surveillance results because sample sizes required may be based on the wrong number of animals.

The data sets and results we present here indicate the importance of understanding intra- and interstate shipment patterns. The relationship between intra- and interstate shipment patterns we observed and their consistency with previous analyses of national-scale shipment patterns (Buhnerkempe et al., 2013) provides evidence that current methods to predict cattle shipments such as those developed by Lindström et al. (2013) and the application of these methods to predict movement of at-risk animals are consistent with industry shipment patterns. Additionally, our results can be used to identify aspects of cattle shipment practices that require additional study and data collection, such as the characterization of regional-, temporal-, and commodity-specific shipment patterns.

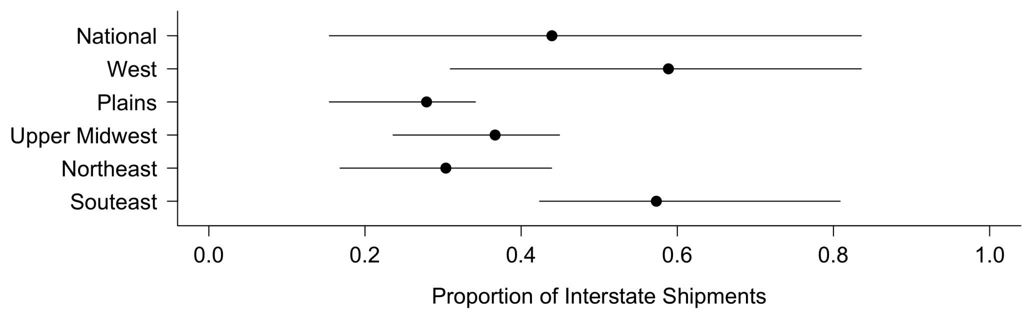
Conclusions

The development of and comparisons among these four data sets is an important step for improving our understanding of intrastate cattle shipments in the United States. Our results both corroborate existing literature that predicts U.S. cattle shipments and indicate that regional differences exist in cattle shipments as well as highlight potential gaps in current knowledge about cattle shipment patterns and industry practices. As we demonstrate with our application of expert data to targeted surveillance of import cattle in TX, the data sets developed here can also be used to inform modeling efforts, such as the previously developed models on cattle shipments and disease spread (USAMM and USDOS), which can be used for national-level preparedness and response plans, as well as for tracing and surveillance applications.

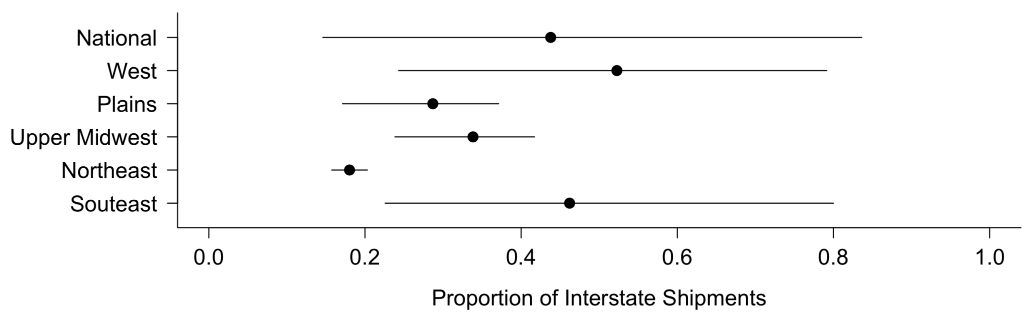
Acknowledgements

This work is supported by the Department of Homeland Security Science and Technology Directorate's Homeland Security Advanced Research Projects Agency under contract number HSHQDC-13-C-B0028 and the United

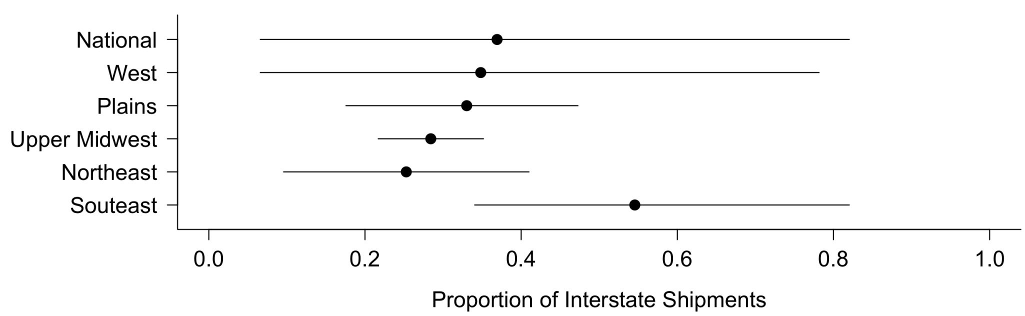
States Department of Agriculture under cooperative agreement 13-9208-0344-CA. We thank Dave Dargatz, Lori Gustafson, and Jason Lombard for invaluable feedback on the design and implementation of this survey. We also thank Courtney Larson, Evan Rosenlieb and Benjamin Abbey for assistance with data entry, and management. We thank Clifton D. McKee for assistance with the application of the survey data to USAMM shipment network predictions. We extend a particular thank you to the experts who participated in this survey. Without the support of the 51 experts who participated, this survey would not have been a success. Brand inspection data were provided by the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Veterinary Services. However, the analyses, views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the regulatory opinions, official policies, either expressed or implied, of the USDA-APHIS-Veterinary Services or the U.S. Department of Homeland Security.



(a) Proportion of Interstate Shipments

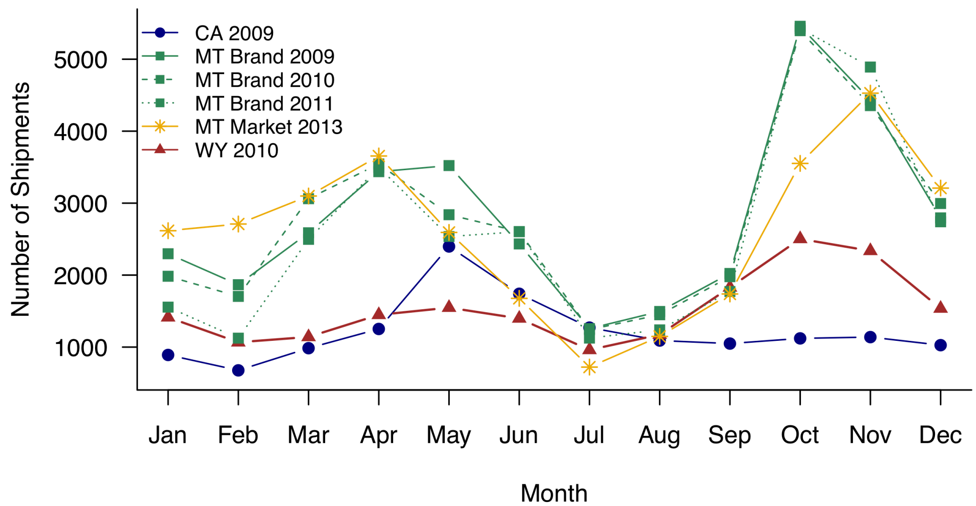


(b) Proportion of Interstate Beef Shipments

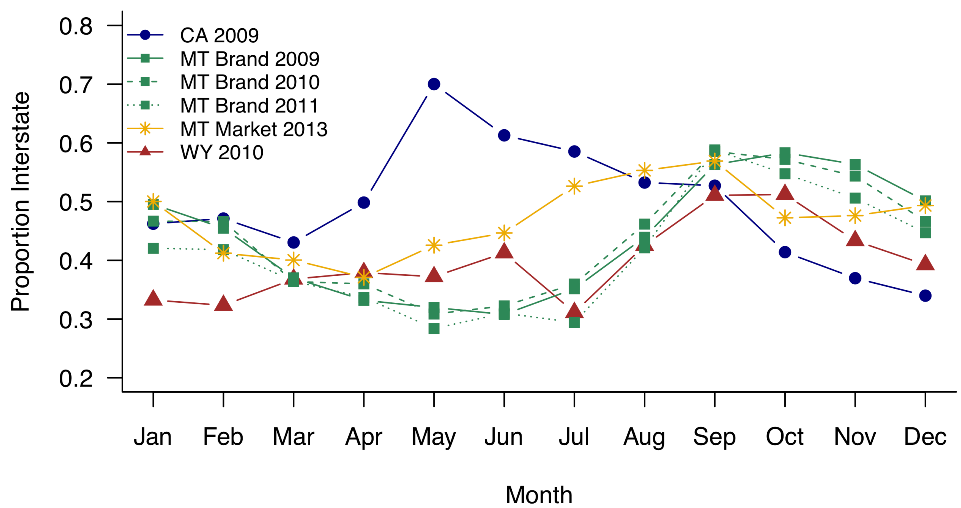


(c) Proportion of Interstate Dairy Shipments

Figure 1: **Proportion of interstate shipments by region.** a) The proportion of interstate shipment overall by region. b) The proportion of interstate beef shipments and c) the proportion of interstate dairy shipments by region. The ordering of the national and regional estimates is the same for all three plots. The black point shows the mean of all cattle (a), or beef cattle (b) or dairy cattle (c). The lines show the range of expert estimates.

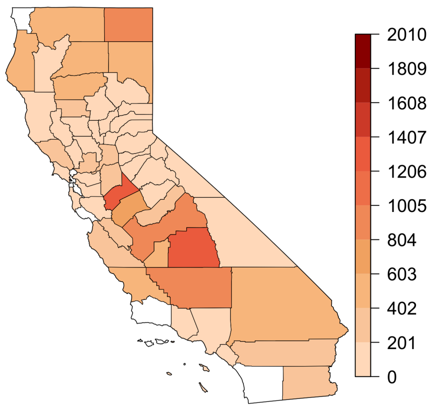


(a) Total Shipments by Month

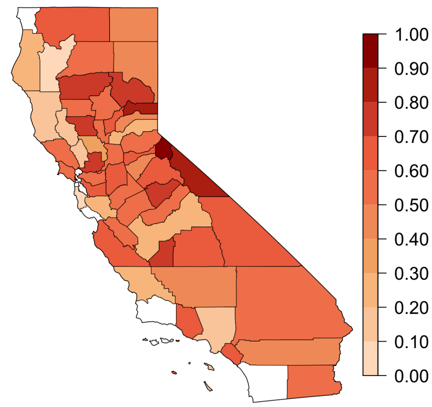


(b) Proportion of Interstate Shipments by Month

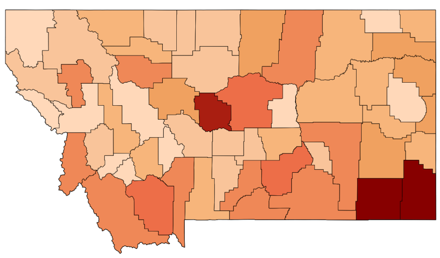
Figure 2: **Shipment characteristics by month.** a) The number of total outgoing shipments (intra- and interstate) by month. b) The proportion of shipments that travel to interstate destinations by month. The different points and colored lines represent the four different brand inspection and market data sets. The different years in the MT brand data are shown with different types of lines. CA: navy, circles; MT brand: green, squares; MT market: yellow, stars; WY: red, triangles.



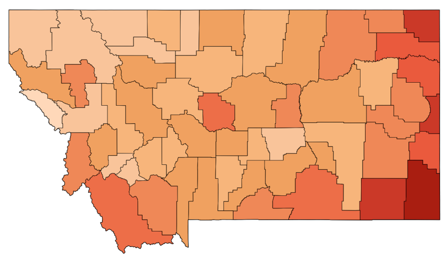
(a) CA Total Shipments



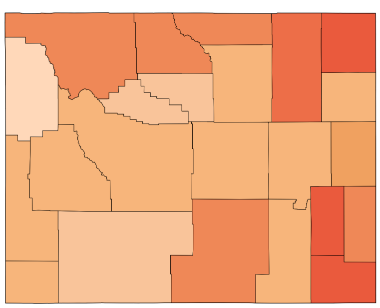
(b) CA Proportion Interstate



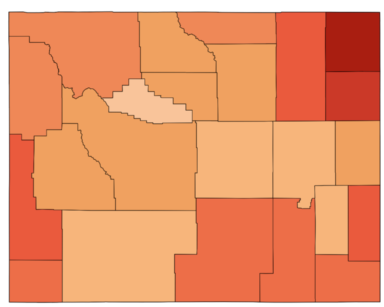
(c) MT Total Shipments



(d) MT Proportion Interstate

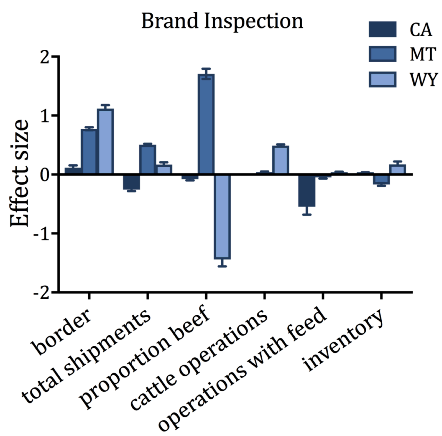


(e) WY Total Shipments

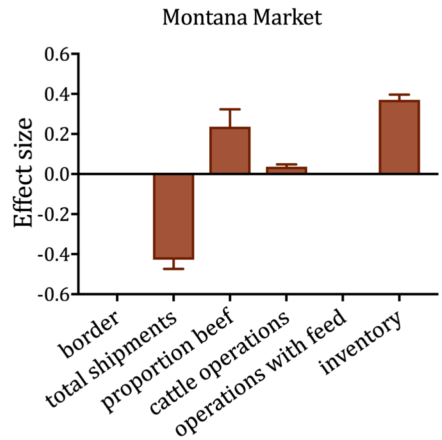


(f) WY Proportion Interstate

Figure 3: **Brand inspection county shipment characteristics by state.** a, c, e) The number of total outgoing shipments (intra- and interstate) by county. b, d, f) The proportion of interstate shipments by county. The scale increases moving from light orange to dark red. Note that the scale of the legend changes between the to total shipment and proportion of interstate shipment plots. Counties shaded in white have no data. Panels a & b show CA, c & d show MT 2010 and e & f show WY.

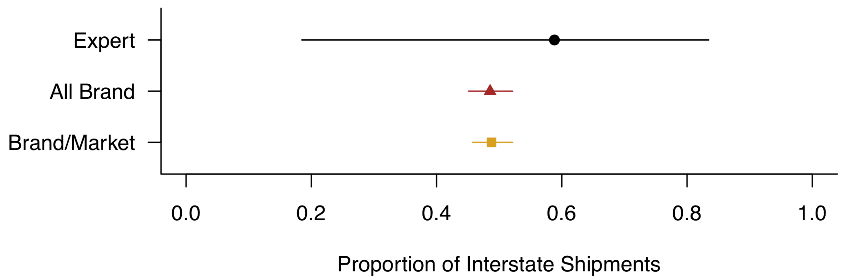


(a)

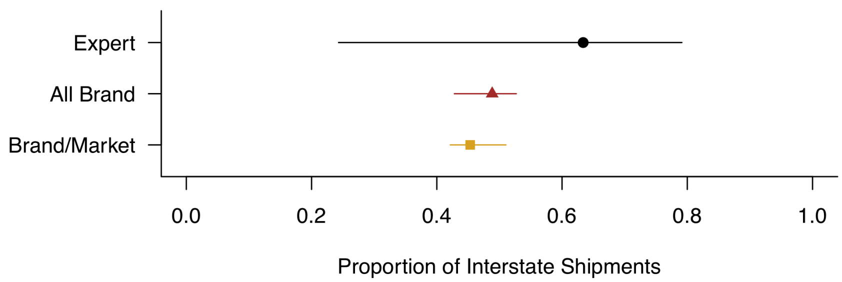


(b)

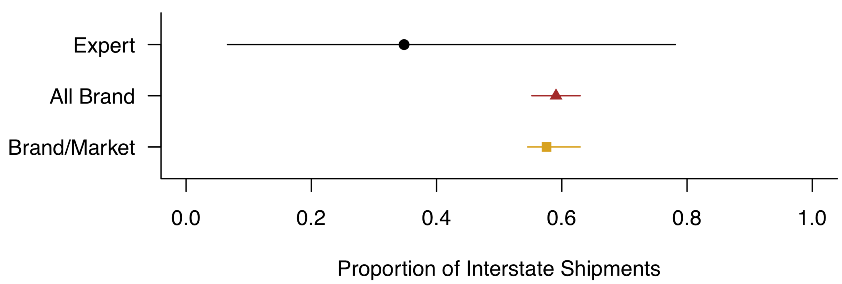
Figure 4: **Effect size and standard error for standardized co-variates in logistic regression analyses.** The analyses predict the odds of out-of-state shipment in a) the brand inspection data sets (CA, MT 2010 & WY) and b) the MT market dataset. Independent variables are displayed on the x-axis and represent an indicator variable for whether the county is on the state border (border), the total number of shipments in the dataset (total shipments), the proportion of operations that were beef (proportion beef), the number of operations on feed, the total number of operations with cattle, including calves (cattle operations), and the total inventory of cattle (inventory). All coefficients retained in the model were significant. Note that the y-axes on the two plots are on different scales.



(a) Proportion of Interstate Shipments



(b) Proportion of Interstate Beef Shipments



(c) Proportion of Interstate Dairy Shipments

Figure 5: **Proportion of interstate shipments in the West.** a) The proportion of interstate shipments overall. b) The proportion of interstate beef shipments and c) the proportion of interstate dairy shipments. The black points are Western region (CA, ID, MT, and NV) expert elicitation survey data, the dark red points are regional brand inspection (CA, MT and WY) results and the orange points are regional brand inspection (CA and WY) and market data (MT) results. The lines show the ranges of the expert estimates and the state-level brand inspection results, respectively.

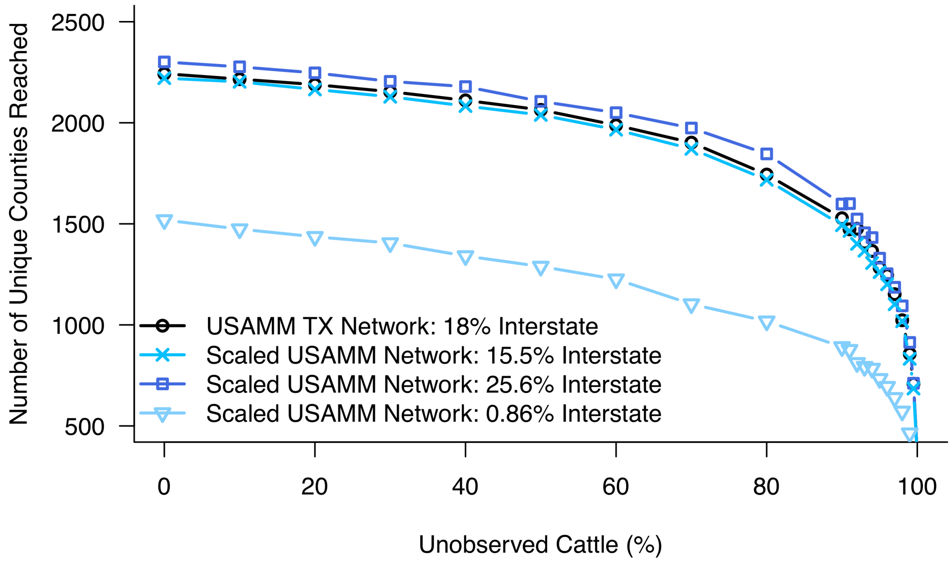


Figure 6: **The predicted number of unique counties reached after shipment from initial import county.** The lines show the predictions by the original TX USAMM network (black line, circles), and the TX network with interstate proportions scaled to be in line with the expert survey predicted mean (teal line, X's) and range (min: light blue line, triangles; max: dark blue line, squares).

Table 1: Summary of the Brand Inspection and Market Data.

State	**Year**	**Reasons for Inspection**	**Information in Data**	**Reference**
California (CA)	2009	Change of ownership; Interstate, slaughter, or market shipments; Entering feedlots; Movements out of specific designated areas	Inter- or intrastate shipment; commodity type	Bureau of Livestock Identification, (2017)
Montana (MT)	2009 to 2011	Change of ownership; Inter-county or state shipments; prior to slaughter or auction	Inter- or intrastate shipment; reason for the movement	MT Department of Livestock (2017)
MT market data	2013	Animal-level records of market shipments	Inter- or intrastate shipment; name of market; breed	MT Department of Livestock (2017)
Wyoming (WY)	2010	Change of ownership; Inter-county or state shipments; shipments to markets	Inter- or intrastate shipment; breed; purpose of shipment	WY Livestock Board (2017)

Bates, T.W., Thurmond, M.C., Carpenter, T.E., 2001. Direct and indirect contact rates among beef, dairy, goat, sheep, and swine herds in three California counties, with reference to control of potential foot-and-mouth disease transmission. Am. J. Vet. Res. 62, 1121–1129. doi:10.2460/ajvr.2001.62.1121.

Buhnerkempe, M.G., Grear, D.A., Portacci, K., Miller, R.S., Lombard, J.E., Webb, C.T., 2013. A national-scale picture of U.S. cattle movements obtained from Interstate Certificate of Veterinary Inspection data. Prev. Vet. Med. 112, 318–329. doi:10.1016/j.prevetmed.2013.08.002.

Buhnerkempe, M.G., Tildesley, M.J., Lindström, T., Grear, D.A., Portacci, K., Miller, R.S., Lombard, J.E., Werkman, M., Keeling, M.J., Wennergren, U., Webb, C.T., 2014. The impact of movements and animal density on continental scale cattle disease outbreaks in the United States. PLoS One 9, e91724. doi:10.1371/journal.pone.0091724.

California Department of Food and Agriculture, 2017. Bureau of Livestock Identification. `https://www.cdfa.ca.gov/ahfss/livestock_id/` (accessed 2 October 2017).

Gorsich, E.E., Luis, A.D., Buhnerkempe, M.G., Grear, D.A., Portacci, K., Miller, R.S., Webb, C.T., 2016. Mapping U.S. cattle shipment networks: Spatial and temporal patterns of trade communities from 2009 to 2011. Prev. Vet. Med. 134, 82–91. doi:10.1016/j.prevetmed.2016.09.023.

Gorsich, E.E., McKee, C.D., Grear, D.A., Miller, R.S., Portacci, K., Lindström, T., Webb, C.T., 2018. Model-guided suggestions for targeted surveillance based on cattle shipments in the U.S. Prev. Vet. Med. 150, 52–59. doi:10.1016/j.prevetmed.2017.12.004.

Grear, D.A., Kaneene, J.B., Averill, J.J., Webb, C.T., 2014. Local cattle movements in response to ongoing bovine tuberculosis zonation and regulations in Michigan, USA. Prev. Vet. Med. 114, 201–212. doi:10.1016/j.prevetmed.2014.03.008.

Green, D.M., Kiss, I.Z., Kao, R.R., 2006. Modelling the initial spread of foot-and-mouth disease through animal movements. Proc. R. Soc. B: Biol. Sci. 273, 2729–2735. doi:10.1098/rspb.2006.3648.

Gustafson, L., Klotins, K., Tomlinson, S., Karreman, G., Cameron, A., Wagner, B., Remmenga, M., Bruneau, N., Scott, A., 2010. Combining surveillance and expert evidence of viral hemorrhagic septicemia freedom: a decision science approach. Prev. Vet. Med. 94, 140–153. doi:10.1016/j.prevetmed.2009.11.021.

Gustafson, L.L., Gustafson, D.H., Antognoli, M.C., Remmenga, M.D., 2013. Integrating expert judgment in veterinary epidemiology: example guidance for disease freedom surveillance. Prev. Vet. Med. 109, 1–9. doi:10.1016/j.prevetmed.2012.11.019.

Heimlich, R., 2000. Farm Resource Regions (No. AIB-760), ers.usda.gov. United States Department of Agriculture, Economic Research Service.

Humblet, M.F., Boscchiroli, M.L., Saegerman, C., 2009. Classification of worldwide bovine tuberculosis risk factors in cattle: a stratified approach. Vet. Res. 40, 50. doi:10.1051/vetres/2009033.

Kao, R.R., Green, D.M., Johnson, J., Kiss, I.Z., 2007. Disease dynamics over very different time-scales: foot-and-mouth disease and scrapie on the network of livestock movements in the UK. J. R. Soc. Lond. Interface 4, 907–916. doi:10.1098/rsif.2007.1129.

Kuhnert, P.M., Martin, T.G., Griffiths, S.P., 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecol. Lett. 13, 900–914. doi:10.1111/j.1461-0248.2010.01477.x.

Kuhnert, P.M., Martin, T.G., Mengersen, K., Possingham, H.P., 2005. Assessing the impacts of grazing levels on bird density in woodland habitat: a Bayesian approach using expert opinion. Environmetrics 16, 717–747. doi:10.1002/env.732.

Lindström, T., Grear, D.A., Buhnerkempe, M.G., Webb, C.T., Miller, R.S., Portacci, K., Wennergren, U., 2013. A bayesian approach for modeling cattle movements in the United States: scaling up a partially observed network. PLoS One 8, e53432. doi:10.1371/journal.pone.0053432.

Liu, H., Schumm, P., Lyubinin, A., Scoglio, C., 2012. Epirur_Cattle: A Spatially Explicit Agent-based Simulator of Beef Cattle Movements. Procedia Comp. Sci. 9, 857–865. doi:10.1016/j.procs.2012.04.092.

Montana.gov, Official State Website, 2017. Montana Department of Livestock Brand Inspection Requirements. http://liv.mt.gov/Brands-Enforcement/Inspection-Requirements (accessed 2 October 2017).

Ortiz-Pelaez, A., Pfeiffer, D.U., Soares-Magalhães, R.J., Guitian, F.J., 2006. Use of social network analysis to characterize the pattern of animal movements in the initial phases of the 2001 foot and mouth disease (FMD) epidemic in the UK. Prev. Vet. Med. 76, 40–55. doi:10.1016/j.prevetmed.2006.04.007.

Pines, M.K., Petherick, J.C., Gaughan, J.B., Phillips, C.J.C., 2007. Stakeholder's assessment of welfare indicators for sheep and cattle exported by sea from Australia. Anim. Welf. 16.

Portacci, K., Miller, R.S., Riggs, P.D., Buhnerkempe, M.G., Abrahamsen, L.M., 2013. Assessment of paper interstate certificates of veterinary inspection used to support disease tracing in cattle. JAVMA–J. Am. Vet. Med. Assoc. 243, 555–560. doi:10.2460/javma.243.4.555.

R Core Team, 2014. R: A Language and Environment for Statistical Computing. Vienna, Austria. http://CRAN.R-project.org.

Schielzeth, H., 2010. Simple means to improve the interpretability of regression coefficients. Methods Ecol. Evol. 1, 103–113. doi:10.1111/j.2041-210X.2010.00012.x.

Schumm, P., Scoglio, C., Scott, H.M., 2015. An estimation of cattle movement parameters in the Central States of the US. Comput. Electron. Agric. 116, 191–200. doi:10.1016/j.compag.2015.06.016.

Tsao, K., Robbe-Austerman, S., Miller, R.S., Portacci, K., Grear, D.A., Webb, C., 2014. Sources of bovine tuberculosis in the United States. Infect. Genet. Evol. 28, 137–143. doi:10.1016/j.compag.2015.06.016.

USDA, 2009. Beef 2007-08 (No. #N512.0209). USDA:APHIS:VS, CEAH, Fort Collins, CO.

USDA, N.A.S.S., 2014. 2012 Census of Agriculture. (No. AC-12-A-51) United States Department fo Agriculture.

van Schaik, G., Schukken, Y.H., Nielen, M., Dijkhuizen, A.A., Barkema, H.W., Benedictus, G., 2002. Probability of and risk factors for introduction of infectious diseases into Dutch SPF dairy farms: a cohort study. Prev. Vet. Med. 54, 279–289.

Wongsathapornchai, K., Salman, M.D., Edwards, J.R., Morley, P.S., Keefe, T.J., Van Campen, H., Weber, S., 2008. Assessment of the likelihood of the introduction of foot-and-mouth disease through importation of live animals into the Malaysia-Thailand-Myanmar peninsula. Am. J. Vet. Res. 69, 252–260. doi:10.2460/ajvr.69.2.252.

Wyoming Livestock Board, 2017. Wyoming Brand Inspection Guide. `https://wlsb.state.wy.us/public/brand-inspection` (accessed 2 October 2017).

Wyoming State Legislature, 2011. Brand Inspection and Brand Recording Fees. `https://legisweb.state.wy.us/ARULES/2011/AR11-009livestock.pdf` (accessed 29 September 2017).