Using economic outcomes in the evaluation of metaphylactic antibiotic decision making for control of bovine respiratory disease in feedyard cattle

by

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Abstract

The decision to use metaphylactic antibiotics to control bovine respiratory disease in feedyard cattle has important economic, animal welfare, and antimicrobial stewardship impacts. Models that consider risk factors for benefitting economically from metaphylaxis including cattle characteristics, disease characteristics (i.e. metaphylaxis efficacy), production costs (animal purchase, feed, labor, facilities, etc.), and income value of cattle sold show that these characteristics have complex interactions with each other and the financial outcome of a cohort of cattle. Two modeling methods were used to identify key variables driving economic metaphylactic decisions.

The first economic model evaluated the cohort characteristics of cattle that did not receive metaphylaxis at the feedyard but that would benefit economically. Estimated net returns were calculated for 12,785 cohorts for three metaphylactic options: no metaphylaxis, low-cost/low-efficacy metaphylaxis, and high-cost/high-efficacy metaphylaxis. Logistic regression models were used to determine the probability of cohorts benefiting from metaphylaxis. Results show that cohort demographics such as sex, entry weight category, cohort size, and average daily gain influence the probability of a cohort benefiting economically from metaphylaxis.

Monte Carlo simulation is a technique that uses random sampling of uncertain variable(s) to estimate a range of potential outcomes. While Monte Carlo simulation is used regularly in other disciplines, it is scarcely utilized to determine the economics of health outcomes in veterinary medicine. The use of Monte Carlo simulation to quantify the economic benefits of metaphylaxis is a novel approach to metaphylactic decision making.

A second economic model was developed that used a Monte Carlo-based stochastic approach to evaluate the economic benefits of metaphylactic antibiotics. Original cohort data

(n=16,368 lots) were modeled for the actual and the opposite metaphylactic scenarios, then simulated across 10 years of monthly pricing data to generate cohort-month scenarios. The cohort-month scenarios were replicated 10 times, with each replication randomly sampling a metaphylactic efficacy odds ratio and average daily gain adjustment factor. Linear regression and standardized beta coefficients identified mortality due to bovine respiratory disease as the most influential variable of difference in net returns between metaphylaxis and no metaphylaxis.

Together, these chapters provide evidence-based tools that advance economically sound, welfare-conscious, and stewardship-focused metaphylaxis decisions in feedyard cattle. These findings show that advanced modeling can help to guide more accurate metaphylactic antibiotic use in feedyard cattle.

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To my friends, thank you for your encouragement, understanding, and helping me stay grounded along the way. I could not have done this without you.

To my parents, Dan and Amy; my siblings, Keithen, Kowen, and Addy; and my extended family, thank you for your constant support, encouragement, and patience throughout this process. Whether it was listening, offering advice, or simply being there when I needed it, you made this journey possible. I am incredibly fortunate to have such a strong and supportive foundation behind me.

Dedication

This work is dedicated to my parents, Dan and Amy Kopp. Thank you for encouraging me to pursue veterinary school and for not blinking an eye when I decided to take on a dual master's degree, even though it seemed a little crazy. Your constant belief in me, steady encouragement, and willingness to stand behind every ambitious, and sometimes overwhelming, goal made this journey possible. You pushed me when I needed it most and never doubted that I would see it through. I am incredibly grateful for everything you have done and continue to do for me.

Chapter 1 - Use of Monte Carlo simulation for economic assessment of cattle health interventions: a narrative review of recent literature

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Introduction

The use of economic analysis in veterinary decision-making has become increasingly important for veterinarians and producers, particularly in food animal production systems where financial margins are narrow. Traditionally, many economic models used in veterinary settings involve deterministic variables with fixed values assigned. While this may be effective in other disciplines, biological variability encountered in veterinary medicine is complex. Variables such as disease incidence, treatment efficacy, daily weight gain, milk production, drug or vaccine costs, and market prices fluctuate between animals and production scenarios creating multiple levels of risk and uncertainty that cannot be represented by one fixed estimate. Economic decisions in veterinary medicine require modeling techniques that incorporate and communicate a range of possible outcomes.

Monte Carlo simulation (MCS) is a stochastic modeling technique that uses a distribution for independent variables to produce a probability distribution for the dependent variable. Rather than producing a single result, MCS repeatedly samples from a probability distribution assigned to key inputs (such as disease risk, treatment efficacy, and price) to generate thousands of simulated outcomes. Each iteration represents a realistic scenario based on a range of possible values. The final output is not a single projected profit or loss, but a distribution of results that show the frequency of possible outcomes. Monte Carlo simulation quantifies and illustrates uncertainty rather than removing or obscuring it, making it uniquely suited for informing the decisions required in veterinary medicine, where biological systems are variable, and environmental effects are unpredictable.

Monte Carlo simulation is increasingly regarded as a preferred approach for evaluating animal health interventions with economic consequences. Current literature shows applications across a variety of cattle related decisions, including foot and mouth disease (FMD)

(Chanchaidechachai et al., 2024; Häsler et al., 2021; Rasmussen, Shaw, et al., 2024), feeder cattle liver abscesses (Taylor et al., 2025), and mastitis control strategies in dairy cattle (Bonestroo et al., 2023; Exel et al., 2022; Fadillah et al., 2025; Le Page et al., 2024; Nakada et al., 2023). In these studies, MCS provides a thorough analysis to quantify risk, economic and biological variability, and the probability of financial loss or gain. The objective of this review is to inform readers of the methods, application, and interpretation of MCS in veterinary medical research.

Materials and Methods

To evaluate how Monte Carlo simulation is used in economic decision-making in veterinary medicine, a structured literature search was conducted using PubMed (National Library of Medicine, 2025). This database was selected as it provided comprehensive indexing of peer-reviewed biomedical and veterinary research.

Initial search terms were selected based on the core concepts of interest: Monte Carlo simulation or stochastic modeling, economic evaluation or cost analysis, and disease in cattle. Search terms were entered into the MeSH database from PubMed (National Library of Medicine, 2025) to identify related vocabulary, synonyms, and preferred search terms. This resulted in the following expanded search string: (((((((("monte carlo") OR (stochastic)) OR ("stochastic processes")) OR ("stochastic process")) OR ("stochastic model")) OR ("stochastic model*")) AND (((cattle) OR (bovine)))) AND ((("infect* disease*") OR (disease)) OR ("contag* disease*"))) AND (((((((((cost-benefit) OR ("cost analysis")) OR ("cost-benefit data")) OR ("benefit and cost")) OR ("cost and benefit")) OR ("economic evaluation*")) OR ("benefit* and cost*")) OR ("cost utility")) OR (economic)). This string was used to search the database in August 2025. Only articles published after 2020 and indexed in English were considered.

Returned articles were first evaluated by title and abstract based on several inclusion and exclusion criteria. The article had to be a primary research study, include cattle as the primary population of interest—with allowance for studies involving cattle alongside other species such as small ruminants or swine—and evaluate a disease process from an economic standpoint.

Following the initial abstract and title review, each article was read in full to extract relevant data. Data were recorded in an Excel spreadsheet. The following variables were collected for each article: diseases included, number of iterations, number of stochastic variables, the outcome, and how results were displayed. Display of results included tables, sensitivity analysis, heat maps, and a variety of graphical options. Additional articles were removed at this time if they did not provide the previously defined variables.

Information about the selected articles was evaluated to characterize the use of MCS in primary research involving economic research within the cattle industry. Patterns in variable selection, model structure, reporting style of results, and economic outcomes were identified to better understand opportunities for improved transparency and standardization when using MCS in future research studies.

Results and Discussion

Our search string in PubMed returned 69 articles that met the search criteria. After abstract and full article evaluation, 37 articles were included in this evaluation. These articles covered a variety of topics including dairy cattle mastitis, brucellosis, tuberculosis, bovine viral diarrhea virus, Johne's disease, highly pathogenic avian influenza, and many more. All articles used MCS or stochastic simulation and economic data for evaluation.

Included articles use a variety of numbers of iterations when running simulation models. The maximum number of iterations used in these articles was 150,000 (Naidu et al., 2025) while the minimum number of iterations was 100 (Ferchiou et al., 2025; Kaniyamattam et al., 2020; Le Page et al., 2024). The most common number of iterations was 10,000 (Adeyemo et al., 2022; Fadillah et al., 2025; Griss, Schüpbach-Regula, Carmo, Meylan, Ottardi, et al., 2025; Griss, Schüpbach-Regula, Carmo, Meylan, & Thomann, 2025; Guétin-Poirier et al., 2020; Hanitravelo et al., 2025; Häsler et al., 2021; Naidu et al., 2025; Ojeda-Rojas et al., 2025; Pérez-Báez et al., 2021; Pfrombeck et al., 2025; Rasmussen et al., 2021, 2022; Rodriguez et al., 2025; Silva et al., 2021; Taylor et al., 2025; Wilson et al., 2020), the mean number of interactions was 12,786, and the median being 10,000 iterations across all models.

These MCS models used different numbers of stochastic variables–ranging anywhere from 1 (Molento et al., 2020) to 86 (Rasmussen, Barkema, et al., 2024) per model. Results from MCS are portrayed in a variety of ways. Table 1.1 shows a quantitative list of the ways that results were presented to readers, with example images of each. A majority of articles used multiple ways to present results; thus, articles are represented multiple times within the table.

There were a few other ways data were displayed only once throughout the literature review. A histogram of the MCS output for differences in weight between those that were infected with *Fasciola hepatica* and the control groups was used (Molento et al., 2020). A spider graph was used to describe the mean change across percentile range of 5 input variables that contributed to the economic outcome (Ojeda-Rojas et al., 2025). A mean cost-effectiveness index was used to compare to different surveillance protocols to control bovine tuberculosis (Guétin-Poirier et al., 2020).

The examples of stochastic modeling identified in this review show several different ways of displaying results from research studies that clearly include representations of the variability associated with the outcomes. This is useful in veterinary decision making because deterministic models, while accurately showing the mean or median of expected results, often by reporting that as the main outcome, obscure variability. Veterinary decision makers are often charged with considering not only the benefits of diagnostic or therapeutic intervention; they must consider the probability of success, the potential negative effects, and other factors associated with the variability of outcomes. While deterministic methods relying on statistical tests of the mean or median and potential differences between those central tendencies have value for understanding underlying biology and economics decisions, other important aspects of variability are lost when results are reported as deterministic or statistical tests of central tendencies.

Deterministic methods are based on a statistical analysis of inference and allow us to test the difference between the central tendencies of options and the probability that those differences are not due to chance. That is a different question than we often ask with stochastic models, particularly stochastic models focused on economic decisions that allow the decision maker to identify trade-offs and the probability of the intervention exceeding the cost of the intervention

Although MCS offer important advantages for representing the uncertainty in biological and economic decision-making, it has several limitations that must be considered when interpreting results. First, MCS is highly dependent on the accuracy of input distributions used within the model. While many model-inputs come from specific primary literature sources, expert opinion is used to identify those that are not readily available from previous research. Weaknesses in the accuracy or appropriateness of distribution inputs results in weakness in the MCS output. While we did not quantify the number of variables that were assigned by expert opinion, specific research addressing many variables is not available, therefore, expert opinion is relied on frequently.

Second, MCS reported in the veterinary literature typically treats all variables as independent variables. There are limited studies that include interactions between stochastic variables, and those that do are simply making educated assumptions about the interaction distribution. There were few research papers that addressed comorbidity odds ratios between associated diseases. While two-way interactions are occasionally addressed in MCS investigating veterinary questions, the interface of biology and economics includes many three-way or more complex interactions that are particularly difficult to address both in MCS and deterministic methods. The variables and interactions between them that drive veterinary and economic questions are extremely complex and not easily valued with assumptions. Lastly, MCS output should not be interpreted as a perfect prediction of the real world. The output should be held within the constraints of the model assumptions.

Challenges and cautions from the articles included in this literature review highlight area for improvement in how MCS is presented in veterinary research. Although most were well written and interpretable, others would pose difficulties for readers who are unfamiliar with stochastic modeling. The author found that when clear objectives were not presented in the title, abstract, and early in the paper, ambiguity was created which limited the reader's ability to evaluate whether the simulation was designed and implemented appropriately. When variables, especially those that are stochastic in value, are not clearly defined or interpretable, readers struggle to completely digest the variability allowed within the model. To enhance clarity, authors should provide lists and/or tables outlining stochastic variables and their distributions. While the use of creative or unconventional methods of displaying results could provide a deeper understanding of complex questions and outcomes, without well-defined methods for interpreting results in the novel approach, clarity of conclusions may not be achieved. There are multiple articles that include extensive equations, some with minimal explanation or interpretation. Including equations used for modeling may improve the transparency of a modeling approach but it does not make the article easier to interpret, especially when the equations are not well-defined.

Conclusion

Monte Carlo simulation provides a better depiction of the complexity of biology and production systems and the uncertainty of pricing markets than deterministic models. It is important to remember that reality is even more complex than stochastic models can define.

There are some examples of MCS used in livestock research and literature, and for the most part, many papers use similar methods, and report results in common graphical and tabular formats. Some limitations of MCS and specific manuscripts should be recognized and considered when integrating the information with other forms of research. It is crucial that authors write articles in easily interpretable ways so that readers can get the most value out of primary research.

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Tables

Table 1.1. Count of results display with examples of each

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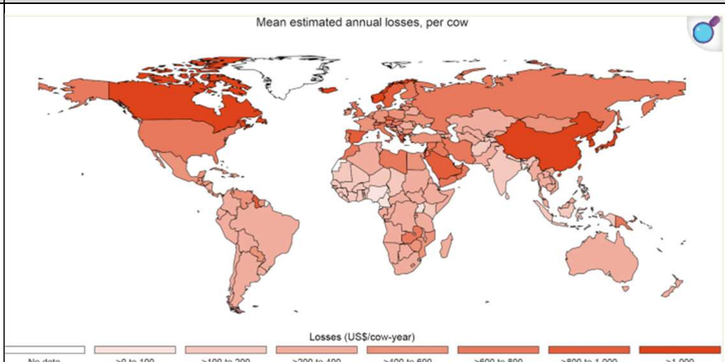
<tr><td>Heat Maps</td><td>4</td><td>

[Figure 5, (Rasmussen, Barkema, et al., 2024)]</td><td>(Exel et al., 2022; Griss, Schüpbach-Regula, Carmo, Meylan, & Thomann, 2025; Rasmussen, Barkema, et al., 2024; Rasmussen, Shaw, et al., 2024)</td></tr>
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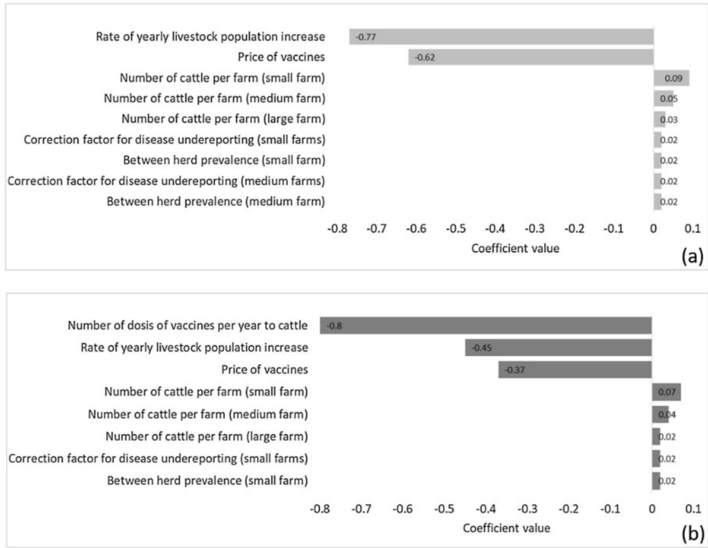
Tornado Graph	16	 [Figure 5a and 5b, (Häsler et al., 2021)]	(Edwardes et al., 2022; Fadillah et al., 2025; Fountain et al., 2022; Griss, Schüpbach-Regula, Carmo, Meylan, Ottardi, et al., 2025; Han et al., 2020; Häsler et al., 2021; Ojeda-Rojas et al., 2025; Pérez-Báez et al., 2021; Rasmussen, Barkema, et al., 2024; Rasmussen et al., 2021, 2022; Rasmussen, Shaw, et al., 2024; Rowe et al., 2021; Taylor et al., 2025; Wicaksono et al., 2025; Wilson et al., 2020)

Bar Graph	12	 [Figure 4, (Chanchaidechachai et al., 2024)]	(Chanchaidechachai et al., 2024; Fountain et al., 2022; Griss, Schüpbach-Regula, Carmo, Meylan, & Thomann, 2025; Mlala et al., 2025; Naidu et al., 2025; Ojeda-Rojas et al., 2025; Pérez-Báez et al., 2021; Rasmussen et al., 2021; Rasmussen, Shaw, et al., 2024; Rodriguez et al., 2025; Rowe et al., 2021; Wicaksono et al., 2025)

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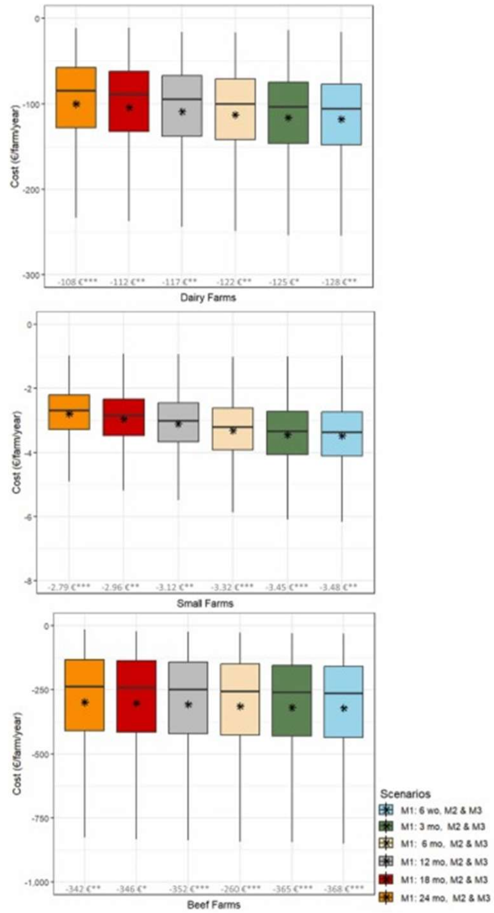
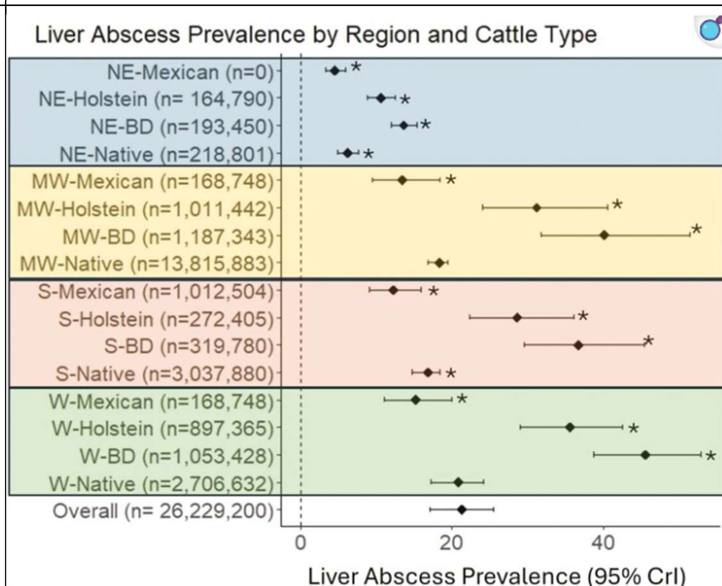
<tr><td>Box Plot</td><td>7</td><td>

[Figure 5, (Hanitravelo et al., 2025)]</td><td>(Chanchaidechachai et al., 2024; Fountain et al., 2021, 2022; Han et al., 2020; Hanitravelo et al., 2025; Häsler et al., 2021; Mlala et al., 2025)</td></tr>
<tr><td>Forest Plot</td><td>2</td><td>

[Figure 2, (Taylor et al., 2025)]</td><td>(Fountain et al., 2021; Taylor et al., 2025)</td></tr>
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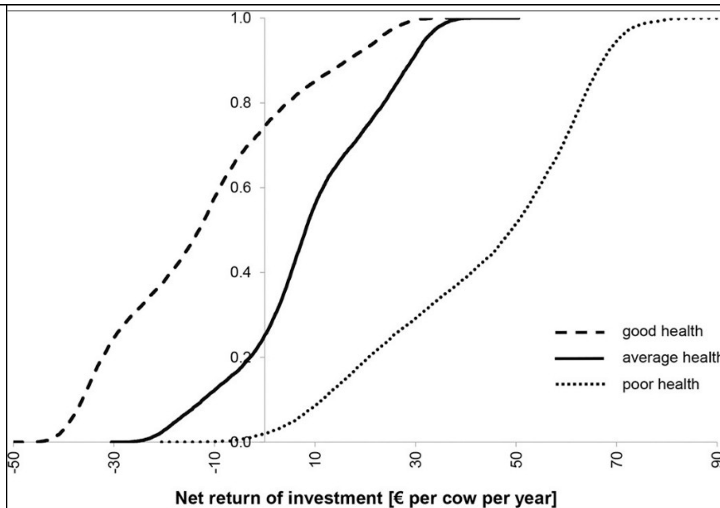
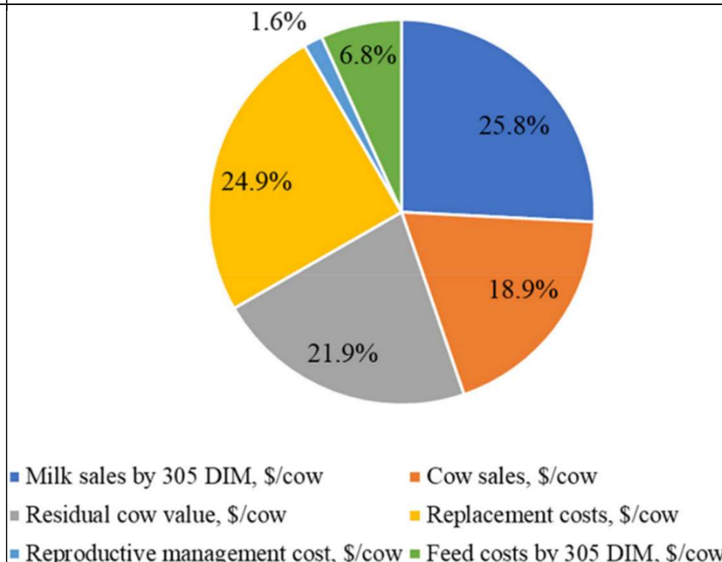
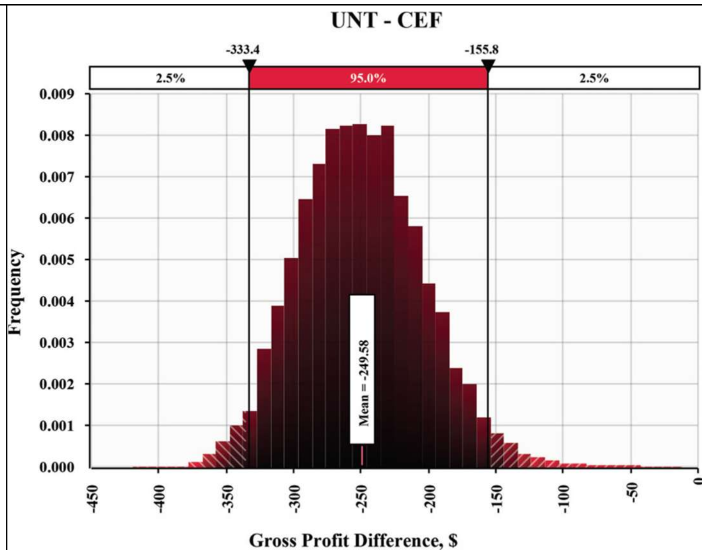
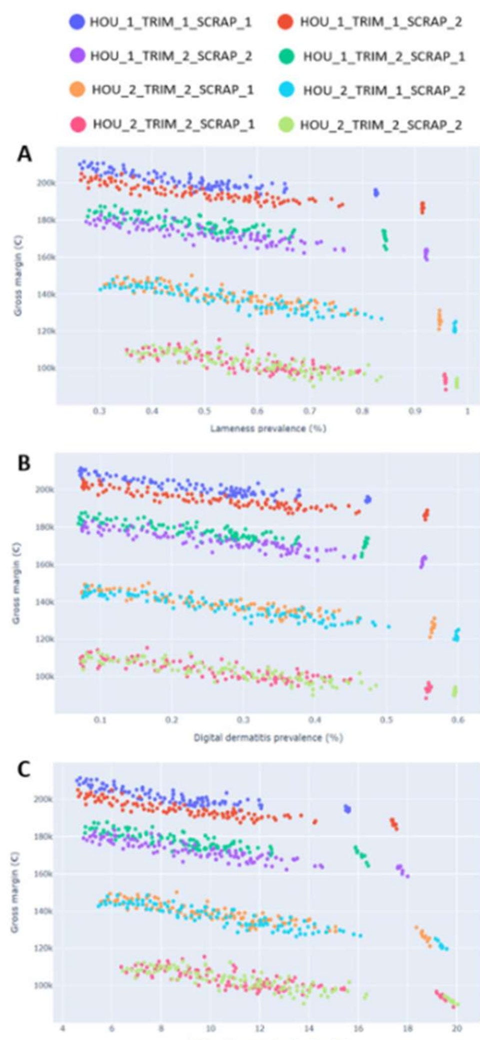
Line Graph	7	 [Figure 2, (Pfrombeck et al., 2025)]	(Griss, Schüpbach-Regula, Carmo, Meylan, & Thomann, 2025; Hanitravelo et al., 2025; Häsler et al., 2021; Kaniyamattam et al., 2020; Molento et al., 2020; Pérez-Báez et al., 2021; Pfrombeck et al., 2025; Rasmussen et al., 2021)
Pie Chart	2	 [Figure 3, (Ojeda-Rojas et al., 2025)]	(Ojeda-Rojas et al., 2025; Steeneveld et al., 2020)

Relative Frequency Distribu-tion	3	 [Figure 3, (Silva et al., 2021)]	(Rodriguez et al., 2025; Rowe et al., 2021; Silva et al., 2021)
Scatter Plot	2	 [Figure 4, (Robcis et al., 2023)]	(Le Page et al., 2024; Robcis et al., 2023)

Chapter 2 - Determining the economically optimum metaphylactic strategy for cattle cohorts of varied demographic characteristics

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Simple Summary

The administration of antibiotics to a whole cohort of high-risk feedlot cattle upon arrival to the feedlot is a common practice used by producers to control respiratory disease. A model was developed that utilizes an economic endpoint to determine the best application of antibiotics based on demographics of the cattle typically included in feedlot records. Determining the best situations to use and not use antibiotics helps to not only decrease cases of respiratory disease but also to ensure continued usefulness of antimicrobials. The goal of this study is to identify key characteristics of cohorts of cattle that did not receive metaphylaxis but that would benefit economically from the use of arrival antibiotics.

Abstract

Metaphylactic antibiotic use in feeder cattle is a common practice to control respiratory disease. Antimicrobial stewardship is important to ensure continued efficacy and to protect animal welfare. The objective of this study is to identify characteristics of cohorts of cattle that had not received metaphylaxis that would have benefited economically from the use of metaphylaxis.

Cohorts (n = 12,785; 2,206,338 head) from 13 feedlots that did not receive metaphylaxis were modeled using an economic model to estimate net returns for three metaphylactic options. Logistic regression models with covariates for entry weight, sex, average daily weight gain, number of animals per cohort, and days on feed, with feedlot as a random effect, were used to determine the model-adjusted probability of cohorts benefiting economically from metaphylaxis. Most (72%) cohorts in this data set that had not received metaphylaxis at arrival would not economically benefit from metaphylaxis. Sex, entry weight category, number of cattle in the cohort, and average daily weight gain were associated with the likelihood of benefitting economically from metaphylaxis. The results illustrated that cattle cohort demographics influenced the probability that cohorts would benefit economically from metaphylaxis and the type of metaphylaxis utilized, and integrating this information has the potential to influence the metaphylaxis decision.
Keywords: bovine respiratory disease; economics; metaphylactic antibiotics

Introduction

The bovine respiratory disease (BRD) complex is a multi-faceted disease involving bacterial and viral agents, environmental factors, commingling, transport, and other stressors(Griffin et al., 2010; Martin et al., 1989; Martin & Bohac, 1986; R. A. Smith et al., 2020; Taylor et al., 2010). In 2010, cattle death losses in the United States due to respiratory problems equated to $643,146,000 (USDA NASS, 2011). While mortality due to BRD may be a major economic loss, BRD morbidity is also important when including costs of treatment, labor, reduced average daily weight gain (ADG), and feed conversion (Blakebrough-Hall et al., 2020; Brooks et al., 2011; R. A. Smith, 1998; Thompson et al., 2006; Wittum et al., 1996). Negative effects on ADG result in smaller, lower-marbling carcasses, with losses ranging from $23.23 to $54.01 per carcass for cattle treated for BRD (Schneider et al., 2009). Cattle treated for BRD more than once also result in lower carcass grades compared to those that were only treated once or not at all (Fulton et al., 2002). Combining all sources of potential loss, BRD leads to substantial economic losses for cattle producers. Decreased prevalence of BRD within the livestock industry can also lead to varied effects on many sectors of the industry, including potentially lowering beef prices for the consumer and benefiting society (Johnson & Pendell, 2017). A true evaluation of BRD cost should include mortality and all the expenses associated with morbidity (White & Larson, 2020).

Antimicrobial metaphylaxis has been implemented in an effort to curb economic losses, as well as improve the animal welfare of cattle entering feedlots (Corbin et al., 2020). Metaphylaxis is the use of a U.S. Food and Drug Administration (FDA)-approved antimicrobial agent to treat an entire cohort of cattle that are at high risk for a disease process that would be modified by treatment at or near the time of arrival to a feedlot (Ives & Richeson, 2015). Decreased risk of BRD-related morbidity and mortality are commonly seen results of implementing metaphylaxis (Coppin et al., 2022; Daniels et al., 2000; Word et al., 2020, 2021).

The impact of BRD is highly variable among cohorts of cattle (Rojas et al., 2022; K. J. Smith et al., 2022). In addition, as an indication of metaphylactic efficacy, odds ratios for BRD morbidity cumulative incidence and BRD mortality cumulative incidence vary greatly between different comparisons of common metaphylactic drugs (Abell et al., 2017). The combination of inconsistent disease impact and variable metaphylactic efficacy makes it difficult to predict which cohorts will benefit from metaphylactic treatment for the control of BRD.

Currently, metaphylaxis decisions are made based on risk classification of the cohort (Coppin et al., 2022; Ives & Richeson, 2015). Risk classification assigned at the feedlot is made based on both subjective and objective measures. While much work has been done to show that metaphylaxis can reduce morbidity and mortality, because of differences in efficacy and cost between metaphylactic options, optimum metaphylaxis decisions must be based on more information than risk classification alone (Dennis et al., 2020; Horton et al., 2023). Looking at the decision strictly from an economic outcome helps remove some subjectivity, and incorporating metaphylactic efficacy and cost brings additional important factors to the decision-making process.

The objective of this study is to identify characteristics of cohorts of cattle that had not received metaphylaxis that would have benefited economically from the use of metaphylaxis. Specifically, three metaphylactic options are evaluated: no metaphylaxis (NOMET), low-cost/low-efficacy metaphylaxis (LCLE), and high-cost/high-efficacy metaphylaxis (HCHE), to discover information to update antimicrobial use decisions leading to improved antimicrobial stewardship and economic success. The development of an economic model to determine the differences in net returns between the three metaphylactic options will be used to identify cohort demographics associated with each optimized metaphylactic option.

Materials and Methods

Ethical Statement

Institutional Animal Care and Use Committee (IACUC) approval was not required as historical operational data were used for the analysis and no procedures were performed on cattle specifically for this research.

Study Design

Retrospective, observational, cohort-level data from 13 feedlots over a 5-year period (2016–2020) were collected under confidentiality agreements with feedlot collaborators. Data were combined with economic and statistical models to assess the potential economic impact of metaphylaxis in cohorts that did not receive metaphylaxis. A cohort was defined as a purchased group of cattle that entered and exited the feedlot together. Bovine respiratory disease morbidity was defined as cattle identified with BRD and treated with antimicrobials. Bovine respiratory disease mortality was defined as cattle that died following treatment for BRD or that were classified as dying of BRD even if not previously treated (i.e., pen deads).

Exclusion Criteria

Exclusion criteria were applied to the feedlot data to remove potential data entry errors and to guarantee that only cohorts with complete data were included. For this analysis, only cohorts that did not receive metaphylaxis upon arrival were included. The average entry weight of cohorts had to be greater than 181 kg and less than 499 kg. Cohorts of mixed sex were excluded, in order to be able to analyze differences in economic benefits between cohorts of steers and cohorts of heifers. Data were filtered to only include records where cohort size was greater than 40 cattle at arrival. Total cohort days on feed was limited to less than 400 days and greater than 70 days. Cohort BRD morbidity risk was required to be greater than or equal to BRD mortality risk, meaning the case fatality risk of the cohorts could not be greater than 1, which would have allowed for more BRD deaths than calves treated for BRD.

Study Variables from Cohort Records

The following data were acquired from cohort records: number of head purchased, whole-cohort entry weight, number treated for BRD, number of deaths attributed to BRD, days on feed, number of head sold, whole-cohort exit weight, and pounds of feed consumed. The subsequent adjusted and calculated variables were computed in order to have a consistent comparison between metaphylactic options. All cohorts were adjusted to a constant entry date of 5 October 2018, with exit dates based on actual days on feed (constant entry date allowed for the comparison of cohort demographic effects on the economic outcomes while holding cattle and feed prices steady). The whole-cohort entry weight was divided by number of head purchased to determine the average entry weight per head.

The average daily weight gain of cattle within a cohort was calculated as the average entry weight per head subtracted from the average exit weight per head divided by days on feed to compute deads-out ADG. Bovine respiratory disease morbidity and mortality risk was provided in the original data from collaborating feedlots. Morbidity attributed to other causes beyond BRD was not included in the model. The case fatality risk as a depiction of treatment success was calculated as number of deaths from BRD divided by number of cattle treated for BRD within each cohort. Deaths not attributed to BRD were designated as "other deaths" and were assumed to be equal proportions regardless of metaphylactic options.

Head days for each cohort were calculated by assuming that BRD deaths occurred at day 50, per expert opinion. Other deaths were assumed to occur at the midpoint for days on feed for that cohort, and cattle that finished the feeding phase had head days equivalent to days on feed. Head days were used to calculate expenses accrued on a daily time-step by the number of cattle in the cohort present at each day, such as yardage and feed cost.

Arrival processing and yardage costs were acquired for each cohort from the cooperating feedlot. The whole-cohort arrival processing cost was divided by the number of cattle upon feedlot arrival and then averaged across all cohorts to determine an average processing cost per head across all yards. The processing cost was assigned as $23.60 per head upon feedlot entry and was based on data provided by cooperating feedlots. The whole-cohort yardage cost was divided by head days and then averaged across all cohorts to determine an average yardage cost per head day across all yards. A yardage cost of $0.35 per head day was used in the model.

Study Variables—Cattle Prices

Feeder cattle purchase prices for 5 October 2018 (Table 2.1) (*CattleFax - 450 LB Steers*, n.d.; *CattleFax - 550 LB Steers*, n.d.; *CattleFax - 650 LB Steers*, n.d.; *CattleFax - 750 LB Steers*, n.d.; *CattleFax - 850 LB Steers*, n.d.) were acquired from an online database. A purchase cost was then calculated based on the average entry weight for each cohort and the purchase price relative to entry weight category. Live cattle sale prices were the weekly prices reported from November 2018 to October 2019 (Table 2.2) (*CattleFax Fed Steer Price*, n.d.). The sale price was assigned based on the cohort exit date from the feedlot, with the exit date being equivalent to 5 October 2018, plus the actual days on feed of the cohort. The sale price and the cohort exit weights were used to determine the income for each original cohort and its two metaphylaxis treatment-generated cohorts.

Study Variables—Metaphylactic Treatment Prices

The pricing of metaphylactic options was based on various antibiotic agents at bulk price from an online veterinary retailer as of June 2022, in combination with expert opinion (*Valley Vet Supply*, n.d.). The costs for the LCLE and HCHE metaphylactic options were set at $0.02 per kg and $0.08 per kg of entry weight, respectively. The cost of metaphylaxis was in addition to the processing costs.

Study Variables—Feed Costs

The feed ration price per kg was determined using historical commodity and feedstuffs prices. Kansas State University's Focus on Feedlots Monthly Report was used for alfalfa hay and corn prices (Waggoner, n.d.). Agriculture Marketing Resource Center's Weekly Ethanol, Distillers Grain, and Corn Prices was used to determine the price of wet distillers grains based on an average of the monthly prices from Illinois, Iowa, Nebraska, South Dakota, and Wisconsin (Johanns, n.d.). A feed ration consisting of 10% alfalfa hay, 60% corn, and 30% wet distillers grains was developed. Prices for alfalfa, corn, and wet distillers grains were determined to be $170.24 per ton ($0.19 per kg), $137.50 per ton ($0.15 per kg), and $46.12 per ton ($0.05 per kg), respectively. Using these values, feed was priced at $0.18 per kg of feed. For NOMET, the total pounds of feed consumed was acquired from data records and used to determine feed costs. When cohort data were modified for LCLE and HCHE metaphylaxis treatment-generated cohorts, the total pounds of feed consumed was modified by a proportion of change in head days to account for increased head days within the cohort due to fewer BRD deaths.

Study Variables Based on Differences in Metaphylactic Efficacy on Odds Ratios for Cumulative BRD Morbidity

A systematic review and mixed treatment meta-analysis of metaphylaxis was used to identify that there are differences in efficacy among metaphylactic antimicrobials which allowed us to create higher-efficacy and lower-efficacy categories (Abell et al., 2017). These higher- and lower-efficacy categories were not intended to indicate specific antimicrobials but were used to inform the metaphylactic efficacy odds ratios of 0.6 and 0.3 for LCLE and HCHE, respectively.

Each cohort was modeled three times: first, the actual performance of the cohort (i.e., no-metaphylaxis NOMET); second, the modeled performance of the cohort if it had received LCLE; and third, the modeled performance of the cohort if it had received HCHE. The metaphylactic efficacy odds ratio was used to modify the morbidity risk of each NOMET cohort to determine a new, reduced morbidity risk within the cohort when either LCLE or HCHE metaphylaxis was modeled. The new morbidity risk was used to determine the number of animals within each metaphylaxis treatment-generated cohort that was treated for BRD. The original case fatality risk of each baseline cohort (NOMET) was then used to determine the number of animals that died from BRD for each metaphylaxis treatment-generated comparison cohort. Other deaths were assumed to not be differentially affected by the use of a metaphylactic antibiotic. A lower morbidity risk and subsequently lower mortality risk increased both income and costs for LCLE- and HCHE-modeled cohorts compared to the income and costs modeled for the associated NOMET cohort.

Using each NOMET cohort's ADG we calculated a healthy-adjusted ADG, as well as a BRD-treated-adjusted ADG, in relation to the number of morbid calves in the NOMET cohort. These were calculated on the basis of a 5% decrease in weight gain of the BRD-treated calves (Schneider et al., 2009). These adjusted ADG values were used to determine the group-level ADG for each metaphylaxis treatment-generated cohort based on the adjusted number of healthy and BRD-morbid cattle for both LCLE and HCHE options. The group-level ADG was then used to calculate the total exit weight for each metaphylaxis treatment-generated cohort.

The number of head days for the LCLE and HCHE cohort models were based on the metaphylaxis treatment-adjusted number of cattle that died from BRD, relative to the designated morbidity and mortality reduction assigned for the LCLE and HCHE, and the number of other deaths provided in the NOMET cohort. Bovine respiratory disease deaths were assumed to die on day 50 while other deaths were assumed to die at the midpoint of days on feed.

Morbid cattle that were pulled and treated for BRD were charged for the high-cost antibiotic priced at $0.08 per kg as well as being charged a $1.50 chute fee per head. For dosing purposes, the weight of morbid cattle was based on the average cohort entry weight into the feedlot.

Model Comparison of Net Return between Metaphylactic Options

A net return economic model using enterprise budgets was developed to assess the optimal metaphylactic option of cohorts of U.S. feedlot cattle that had not received metaphylaxis at arrival based on the highest net return among the three metaphylactic options: NOMET, LCLE, and HCHE. For analysis, a logistic regression model was used to initially compare NOMET to a "yes" metaphylaxis variable (YESMET) which comprised both LCLE and HCHE, followed by a second logistic regression model to analyze LCLE versus HCHE within the YESMET-modeled cohorts.

Net returns were calculated as the difference between total revenue and total expenses. Total expenses included the purchase cost of feeder cattle, processing cost, yardage cost, BRD treatment cost, chute fee cost, and feed cost, as well as the cost of metaphylaxis. Net returns for all cohorts were compared across NOMET, LCLE, and HCHE, and the optimal decision for each cohort was selected based on the highest net return.

Economic calculations and metaphylaxis adjustments were completed using Excel (Microsoft Excel, Microsoft Office Professional Plus 2019, Microsoft Corporation, Redmond, WA, USA). Data analysis was completed using RStudio (R Core Team, 2022). The association of sex, entry weight, cohort size, exit weight, ADG, and days on feed with the probability of benefiting economically from metaphylaxis options was evaluated with a logistic regression model with feedlot as a random effect using the glm() function. Data variables were evaluated for interactions and none were found. Two logistic regression models were completed with the first model comparing NOMET to a "yes" metaphylaxis variable that combined LCLE and HCHE into one outcome, and the second model comparing LCLE to HCHE within the cohorts that were YESMET in the first regression analysis. Among cohorts benefiting economically from metaphylaxis, the association of the same variables with the probability of benefiting from

HCHE metaphylaxis versus LCLE metaphylaxis was evaluated with a logistic regression model with feedlot as a random effect.

Results

Records for 16,809 cohorts were originally acquired from collaborators. The application of the exclusion criteria outlined above resulted in 12,785 cohorts of feedlot cattle in the dataset. The final dataset of 12,785 cohorts encompassed 4038 cohorts of heifers and 8747 cohorts of steers. These cohorts included 2,206,338 head of cattle that originated from 38 states across the United States; 631,521 head were heifers and 1,574,817 head were steers. The analysis of the included cohorts found the median percent morbidity risk was 5.1% with an interquartile range of 2.5% to 10% (Figure 2.1).

Metaphylaxis adjustments (LCLE and HCHE) resulted in a greater sale weight and less BRD treatment costs, as well as an increased arrival processing cost, increased feed cost due to increased feed consumed, increased yardage, and other costs associated with less disease and death compared to NOMET. The optimal metaphylactic choice based on the economic model output varied among cohorts with a distribution of cohorts falling into NOMET (72.0%; 9204/12,785), LCLE (25.4%; 3242/12,785), and HCHE (2.7%; 339/12,785). Statistical analysis included two logistic regressions that first compared NOMET (72%) to YESMET (28%) and then compared LCLE to HCHE within the YESMET cohorts.

When comparing NOMET to YESMET, sex, the entry weight category, number of cattle in the cohort, and the average daily weight gain category were found to be statistically significant. Cohorts of steers had a higher probability (31.2 ± 3.3%) of benefiting economically from metaphylaxis in comparison to cohorts of heifers (19.9 ± 2.5%) ($p < 0.05$). Cohorts within the three lowest average entry weight intervals (37 kg intervals) had a higher probability of benefiting economically from metaphylaxis than the other four weight categories (Figure 2.2). Cohorts of less than 100 head of cattle had a higher probability (30.0 ± 3.3%) of benefiting economically from metaphylaxis in comparison to cohorts with 100 to 200 head of cattle (25.1 ± 2.9%) ($p < 0.05$) and those cohorts with over 200 head of cattle (20.8 ± 2.6%) ($p < 0.05$). Cohorts with an ADG of 0.45–1.36 kg/day had a higher probability (8.3 ± 0.5%) of benefiting economically from metaphylaxis compared to those with ADG greater than 1.36 kg/day (Figure 2.3).

Within the YESMET cohorts, the entry weight category, number of cattle in the cohort, and average daily weight gain were associated with the probability of HCHE versus LCLE metaphylaxis having a higher net return. Of cohorts benefiting economically from metaphylaxis, those within the three lowest entry weight categories had the highest probability of benefiting economically from HCHE metaphylaxis (Figure 2.4). Of cohorts that benefited from metaphylaxis, cohorts of less than 100 head had a higher probability (5.3 ± 1.4%) ($p < 0.05$) of benefiting from HCHE metaphylaxis in comparison to cohorts of 100 to 200 head of cattle (3.3 ± 0.9%) and cohorts of over 200 head of cattle (3.2 ± 0.9%). Of those that benefited from metaphylaxis, cohorts with an ADG of 0.45–1.36 kg/day had the highest probability of benefiting economically from HCHE metaphylaxis and cohorts with an ADG of 1.36–1.54 kg/day and 1.54–1.68 kg/day had a higher probability of benefiting economically from HCHE metaphylaxis compared to cohorts with an ADG of 1.68–2.72 kg/day (Figure 2.5).

Discussion

Modeling the administration of metaphylaxis changed both income and costs resulting in different net returns for the three modeled scenarios for each original cohort. When comparing cohorts of feedlot cattle that had not received metaphylaxis across NOMET, LCLE, and HCHE, most (72%) cohorts in this data set would not economically benefit from metaphylaxis. Our results differ from Dennis et al. (Dennis et al., 2020) who modeled net return distributions for metaphylactic decisions for cattle at high risk for BRD. Because the data set used in our study only included cohorts that did not receive metaphylaxis, we assume that the perceived risk of BRD in our cohorts was lower than for cohorts modeled by Dennis et al. (Dennis et al., 2020).

Based on the cohorts used in this analysis, we found a median cohort percent morbidity of 5.1%. Prior research showed a 12.8% bovine respiratory disease morbidity risk in feeder cattle via surveys of feedlots in Kansas, Nebraska, Texas, North Dakota, and other states, which differs substantially from our results (Woolums, 2005). Because we excluded cohorts that received metaphylaxis at arrival, it is not surprising that morbidity was lower in our study. Cattle chosen to receive metaphylaxis at feedlots typically have an increased risk of developing disease, so exclusion of these animals would lead to decreased morbidity within this data set (Ives & Richeson, 2015).

Steers had a greater probability of benefiting economically from metaphylaxis compared to heifers. Other studies have estimated that steers have a mean ADG of 1.62 kg per day while heifers have a mean ADG of 1.36 kg per day (Zinn et al., 2008). With this in mind, a 5% decrease in ADG seen in cattle affected by BRD would have a greater impact on cohorts of steers because of their greater ADG. Metaphylaxis thus provides more improvement in sale weight within steer cohorts over heifer cohorts.

Upon arrival to the feedlot, lightweight cohorts of cattle are considered to be at greater risk for BRD in comparison to heavier cattle (Ives & Richeson, 2015). The same BRD odds ratio benefit from metaphylaxis applied to high-morbidity-risk cohorts provides a greater reduction in number of cattle affected by BRD compared to low-morbidity-risk cohorts; therefore, metaphylaxis, and specifically, HCHE metaphylaxis, is more likely to provide economic benefits for high-risk cohorts.

Cohorts with less than 100 head of cattle were more likely to benefit economically from metaphylaxis. We do not have a hypothesis for the biological association between smaller cohort size and the economic benefit of metaphylaxis. A smaller cohort size would be associated with a proportionally higher impact of morbidity and mortality. One morbid animal in a pen of 50 head (1/50, 2.0%) would cause a significantly higher morbidity compared to a single morbid animal in a pen of 500 head (1/500, 0.2%). Another possibility for this association is that smaller cohorts of animals may be more likely to be commingled in order to fill a pen. Commingling means that cattle from different sources are put together in order to fill a pen closer to capacity. The commingling of cattle from different sources increases the likelihood of cattle developing BRD (Sanderson et al., 2008). Each smaller cohort will have different levels of immunity to diseases as well as bring in different strains of bacteria and viruses, which helps to contribute to an increased likelihood of developing disease. We were surprised to see that cohorts with lower ADG were more likely to benefit from metaphylaxis and HCHE metaphylaxis.

The limitations within this study include the following: the choice of constant entry dates and pricing; set values for feed costs, chute fees, yardage costs, processing costs, and metaphylactic prices and efficacies. Constant entry dates and pricing allow for a more straight-forward comparison of net returns based solely on metaphylaxis effects. The date of 5 October 2018 was chosen to allow all cohorts to reach slaughter prior to the COVID-19 pandemic, as there were drastic changes in market values during those times. We discern that these values would be a better representation of actual figures if they were allowed to fluctuate, but the additional variation would hinder the comparison of cohort demographics across equivalent economic factors of production. Future research utilizing stochastic prices for cattle purchasing, sales, and various inputs would be useful for determining how prices affect metaphylactic decision making.

Conclusions

By modeling cohorts of feeder cattle for NOMET, LCLE, and HCHE metaphylaxis options, we were able to identify which strategy resulted in the greatest net return, and we were able to analyze key differences and similarities between the populations. We found that most (72%) cohorts in this data set that had not received metaphylaxis at arrival would not economically benefit from metaphylaxis, and we determined that cattle cohort demographics influenced the probability that cohorts would benefit economically from metaphylaxis and the type of metaphylaxis utilized. The results of this study as well as future published studies will provide decision makers with important information to improve the integration of multiple considerations when making metaphylaxis decisions in cohorts of cattle and management systems similar to those modeled in this study. Based on the results of this study, decision makers should recognize that NOMET was the correct decision in 72% of comparisons, and they should consider using metaphylaxis in cohorts currently not receiving the intervention when the arrival weight is low, the cohort consists of a small number of cattle, and the cohort sex is steers. In order to optimize net returns while maintaining antimicrobial stewardship and animal welfare, producers and veterinarians should continue to develop decision tools that incorporate cohort demographic factors when making metaphylaxis choices.

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Figures

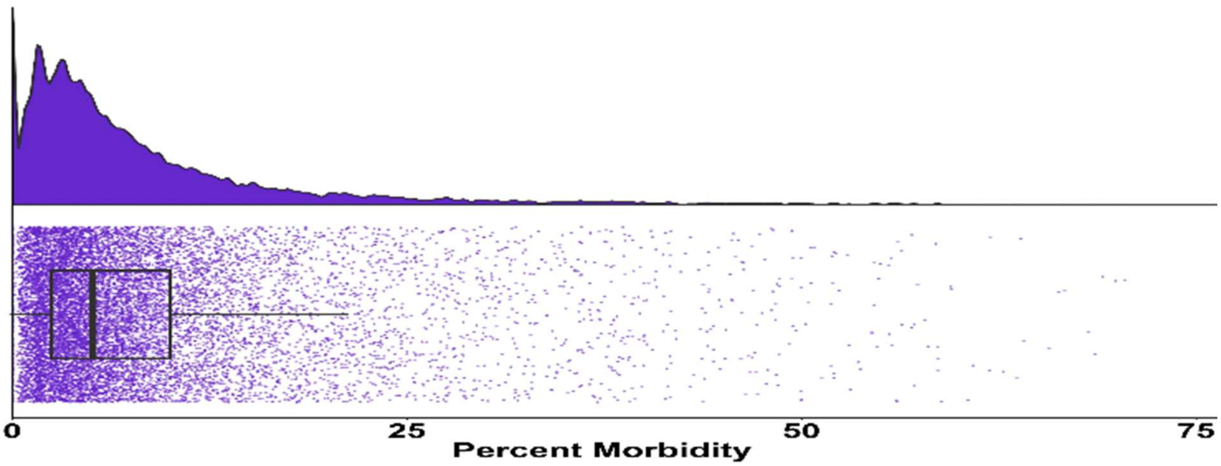

Figure 2.1. Distribution of cohort morbidity risk displayed in a raincloud plot.

The upper section shows density of morbidity percentage due to bovine respiratory disease for each cohort. The lower portion shows a scatter plot of each cohort by morbidity percentage with a box-and-whisker plot overlay.

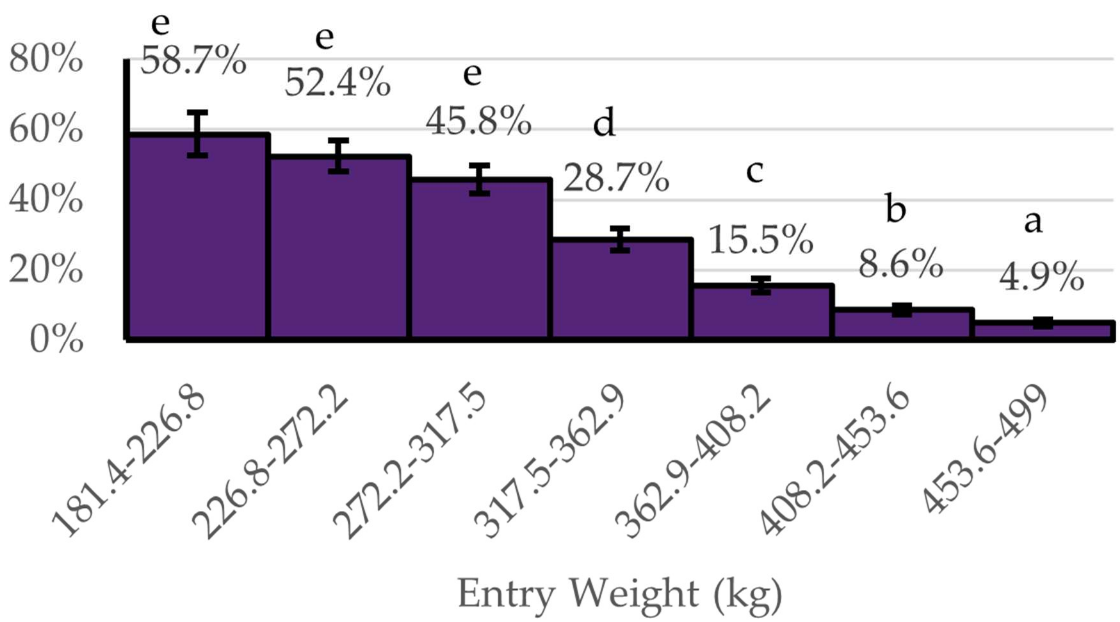

Figure 2.2. Probability of benefiting economically from metaphylaxis (YESMET) by entry weight.

[abcde] Bars without a common superscript letter differ at $p \leq 0.05$.

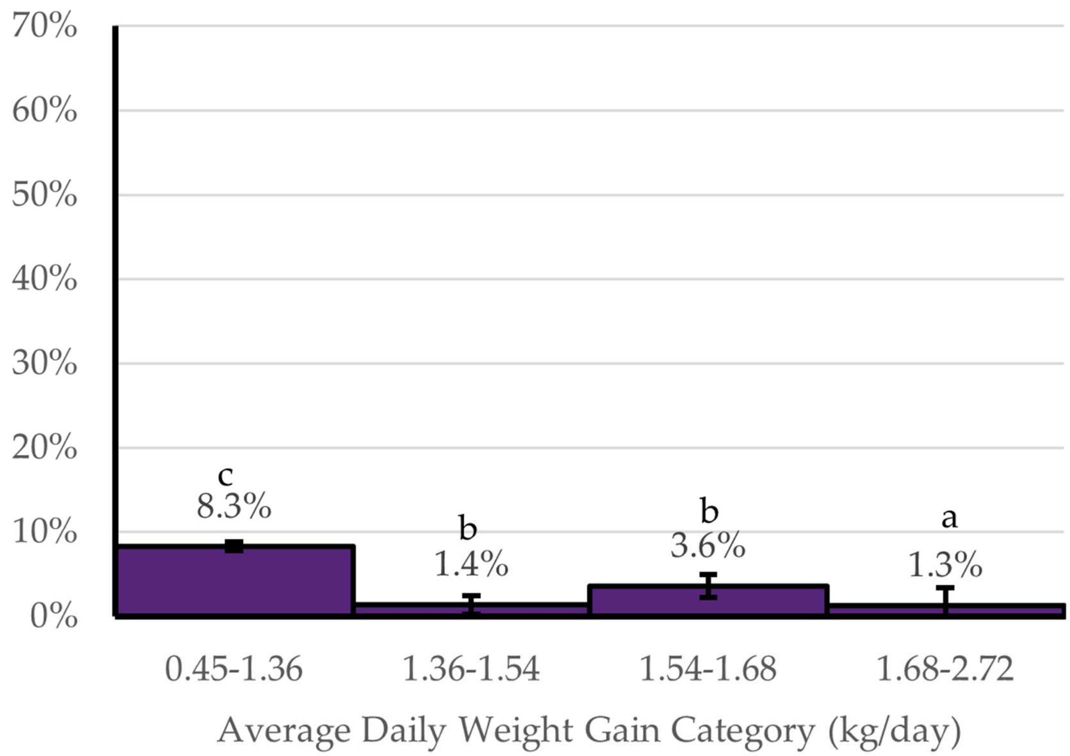

Figure 2.3. Probability of benefiting economically from metaphylaxis (YESMET) by average daily weight gain categories.

[abc] Bars without a common superscript letter differ at $p \leq 0.05$.

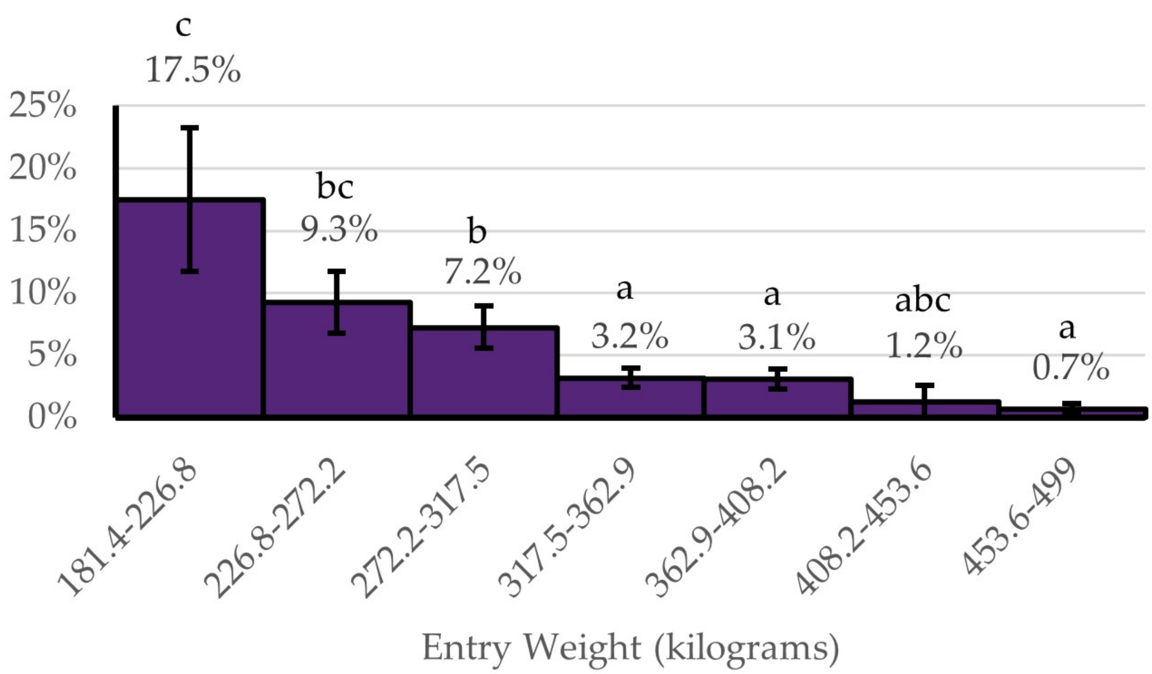

Figure 2.4. Among cohorts benefiting economically from metaphylaxis (YESMET), the probability of benefiting economically from HCHE by entry weight.

[abc] Bars without a common superscript letter differ at $p \leq 0.05$.

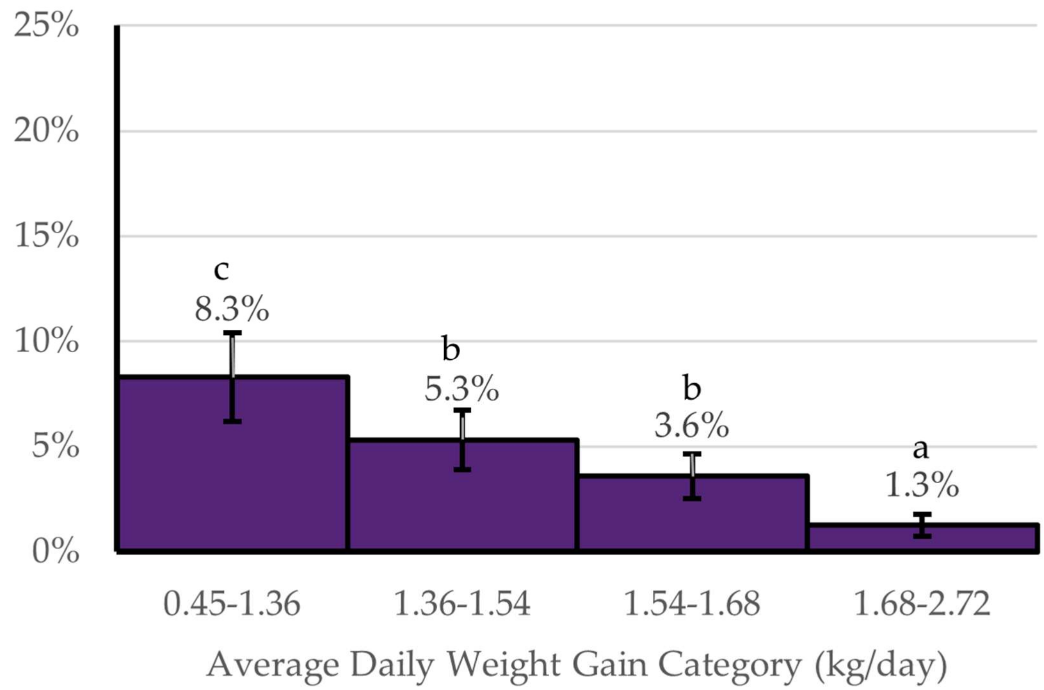

Figure 2.5. Among cohorts benefiting economically from metaphylaxis (YESMET), the probability of benefiting economically from HCHE by average daily weight gain categories.

[abc] Bars without a common superscript letter differ at $p \leq 0.05$.

Tables

Table 2.1. Feeder cattle purchase prices as of 5 October 2018

(CattleFax - 450 LB Steers, n.d.; CattleFax - 550 LB Steers, n.d.; CattleFax - 650 LB Steers, n.d.; CattleFax - 750 LB Steers, n.d.; CattleFax - 850 LB Steers, n.d.)

Entry Weight Category	Price (USD/kg)	Price (USD/cwt)
181.4–226.8 kg:	4.11	186.36
226.8–272.2 kg:	3.83	173.65
272.2–317.5 kg:	3.60	163.28
317.5–362.9 kg:	3.50	158.73
362.9–499.0 kg:	3.39	153.67

Table 2.2. Fed cattle prices, monthly range of weekly sale prices (CattleFax Fed Steer Price, n.d.)

Sale Month	Price (USD/kg)	Price (USD/cwt)
November 2018:	2.5–2.59	113.53–117.54
December 2018:	2.61–2.7	118.40–122.65
January 2019:	2.7–2.74	122.63–124.06
February 2019:	2.73–2.78	123.73–126.15
March 2019:	2.77–2.83	125.83–128.50
April 2019:	2.76–2.82	125.19–127.75
May 2019:	2.54–2.92	115.28–132.27
June 2019:	2.43–2.5	110.29–113.48
July 2019:	2.43–2.5	110.41–113.37

Chapter 3 - Use of Monte Carlo Simulation to determine cohort-level economic and health outcomes of metaphylaxis decisions in feedyard cattle with varied demographics and market conditions

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Abstract

Metaphylactic antimicrobial administration at feedyard arrival is commonly used to control bovine respiratory disease (BRD), but its justification varies across cattle cohorts and market conditions. The objective of this study was to quantify relationships and directionality between predictor variables and differences in net returns of cattle cohorts when metaphylactic antimicrobials, cyclical pricing, and stochastic variation are considered. Cohort-level data (n=16,368 lots; 2,823,584 head) from 20 U.S. feedyards were analyzed using a Monte Carlo-based stochastic economic model to estimate net returns under two scenarios: receiving or not receiving metaphylaxis. Each cohort was simulated across 120 month-year pricing combinations from a 10-year dataset to produce 1200 cohort-month scenarios. Metaphylactic efficacy odds ratios and average daily weight gain (ADG) adjustment factors were randomly sampled from defined distributions over 10 iterations per scenario, resulting in 19,641,600 paired comparisons. The economically optimum metaphylactic strategy based on variability in cohort-level health metrics was identified for each paired comparison. A linear regression model incorporating independent variables of cohort size, entry weight, ADG, purchase price, feed prices, sale price, ADG adjustment factor, metaphylactic efficacy odds ratio, exit weight, and BRD morbidity and mortality percentages was used to calculate standardized beta coefficient of differences in net returns. Standardized beta coefficients were visualized in a tornado diagram to assess relative influence of independent variables. A majority of modeled cohort-months (80.0%) demonstrated higher net return without metaphylaxis. Mortality attributed to BRD exhibited the greatest influence on metaphylactic decisions (standardized β = 0.7627), followed by entry weight (standardized β = -0.1838) and metaphylactic efficacy odds ratio (standardized β = -0.1710). These findings demonstrate cohort-level mortality risk is a critical determinant of metaphylaxis economic value and results provide quantitative support for risk-based antimicrobial use in feedyard cattle.

Keywords: Bovine respiratory disease; economics; metaphylactic antimicrobials; net returns; stochastic simulation

Introduction

Bovine respiratory disease (BRD) remains one of the most economically significant health challenges within the cattle industry, particularly in feedyard systems (Edwards, 1996). As of 2010, death due to respiratory disease in cattle equates to over $640 million economic loss to the United States (U.S.) cattle industry (USDA NASS, 2011). Cost to the industry is not solely captured by cattle mortality, as producers experience decreased productivity of morbid animals, increased expense of antimicrobial treatment and increased labor. Decreased productivity of morbid feedyard cattle encompasses reduced average daily weight gain (ADG), reduced feed efficiency, and smaller, leaner carcasses (Blakebrough-Hall et al., 2020; Gardner et al., 1999; Irsik et al., 2006; Schneider et al., 2009; Smith, 1998; Thompson et al., 2006; Wittum et al., 1996). Bovine respiratory disease is characterized by a complex interplay of viral and bacterial pathogens, environmental stressors, and management practices (Nickell & White, 2010). Due to the complexity of the disease occurrence, effective prevention and control strategies require an integrated approach that encompasses multiple variables in the beef production system.

One of the most widely adopted control strategies in feedyard systems in the U.S. is the use of metaphylactic antimicrobials to mitigate the impacts of BRD. Metaphylaxis is the administration of antimicrobials to a population of animals to reduce the severity and incidence of disease in a group that has evidence of disease or infection (American Veterinary Medical Association, 2025; Nickell & White, 2010). Metaphylactic antimicrobials are used in 22.4% of cattle placed in all feedyards across the U.S. and 39.9% of cattle placed in feedyards with greater 5,000 head (USDA-APHIS-VS-CEAH-NAHMS, 2024). Currently, the decision to use metaphylactic antimicrobials is based on risk classification of a cohort of feedyard cattle. High risk cattle are generally defined as meeting any of the following criteria: lightweight, extended duration of transport, recently weaned, commingled, originated at an auction market, unknown vaccination history, or bull calves that are castrated on arrival to the feedyard (Ives & Richeson, 2015). However, risk classification alone is an imperfect predictor of the impact that BRD and metaphylaxis can have on a cohort of feedyard cattle. Beyond the impact of metaphylaxis to control BRD, this intervention has been increasingly scrutinized in the context of antimicrobial stewardship, prompting the need to better quantify the economic impact of metaphylaxis on net returns of a cohort of feedyard cattle under a variety of production scenarios.

Economic outcomes in livestock production systems are sensitive to fluctuations in input and output prices. Cattle purchase and sale price are subject to significant cyclical volatility associated with supply and demand within the market. The cattle cycle typically lasts 8 to 14 years, with the average considered to be 10 years in length (Bennett, 1955; Franzmann, 1971).

Prices of feedstuffs, including corn, alfalfa hay, and wet distillers grain, vary across time. Variability in feed prices can alter cost of gain of cattle in feedyards and feeding strategy decisions. Volatility in input and output prices contribute to the uncertainty of predicting cattle cohort profitability. These dynamic prices can amplify or offset the benefits of disease management interventions, whether that be vaccination protocols, cattle acclimation protocols, or metaphylactic strategies.

Traditional deterministic models fail to capture the uncertainty and volatility in cattle health and marketing conditions. Monte Carlo simulation is useful in this context, as it allows for random sampling of a variable within a defined probability distribution. This results in the generation of a range of potential variable outcomes rather than a single point-estimate as used in previous economic metaphylaxis modeling. Monte Carlo simulation has been widely applied in the human health field (Velikova et al., 2024). By simulating thousands of potential scenarios, Monte Carlo models provide a more realistic assessment of the distribution of economic returns under market circumstances. In the case of metaphylactic antimicrobials, this methodology enables a rigorous evaluation of whether administration improves net returns across diverse feedyard cattle cohorts and cyclical pricing environments.

The objective of this study is to quantify relationships and directionality between predictor variables and differences in net returns of cattle cohorts when metaphylactic antimicrobials, cyclical pricing, and stochastic variation are considered. By understanding these relationships, decision-makers have valuable insight when making metaphylaxis decisions.

Materials and Methods

Ethical Statement

Institutional Animal Care and Use Committee approval was not required because all data used for analysis were obtained from historical operational databases and no procedures were performed on cattle.

Study Design

Retrospective, observational, cohort-level data were collected from 20 feedyards over an eight-year period (2015-2023) under confidentiality agreements with feedyard collaborators. Data were integrated into stochastic models to assess the potential economic impact of differences in health metrics due to metaphylactic antimicrobials on net returns. Cohorts were defined as purchased groups of cattle that entered and exited the feedyard together, though they were not necessarily housed together for the entire feeding period.

Exclusion Criteria

Records of feedyard cattle cohorts were obtained from collaborators for analysis. Exclusion and inclusion criteria were applied to ensure the use of cohorts with complete and accurate data. Cohorts with incomplete data were removed. Mixed sex cohorts were excluded in order to provide comparison between steers and heifers. Cohorts had to include greater than 50 head of feedyard cattle at arrival. Days on feed between arrival at the feedyard and departure to harvest had to be greater than 50 days and less than 250 days. Average cohort entry weight had to be between 181.4 and 453.6 kilograms. Sale weight had to be greater than or equal to 453.6 kilograms and less than or equal to 816.5 kilograms. The number of cattle treated for BRD could not exceed the number of cattle purchased at arrival. The number of cattle died due to BRD could not exceed the number of cattle that were treated for BRD. The BRD percent morbidity had to be less than 100%. These criteria align closely to those used in comparable studies (Heinen et al., 2023, 2024, 2025; Kopp et al., 2024).

Overall Project Methodology

All included cohorts were modeled over 120 different price scenarios based on monthly prices from the ten-year period of January 2012 to December 2021 to determine net returns for cohort-month scenarios. Each cohort-month scenario was modeled under both observed (actual) metaphylactic status and a counterfactual opposite metaphylactic status with the use of Monte Carlo simulation. The observed metaphylactic status of 'yes administered metaphylaxis' or 'no metaphylaxis administered' was determined for each cohort from feedyard operational data. For each cohort-month scenario, 10 stochastic iterations were generated from sampling from two distributions: (1) an ADG adjustment factor distribution for cattle classified as having BRD, and (2) a metaphylaxis efficacy odds ratio distribution for antimicrobial metaphylaxis in reducing BRD morbidity risk within a cohort. This resulted in paired net returns allowing testing for potential effects of cohort demographics and prices on difference in net returns for the same cohort that received or did not receive metaphylaxis.

Study Variables from Cohort Records

The following information was acquired from cohort records: number of head purchased at arrival, arrival and exit dates, days on feed, cohort average entry and exit weights, sex, BRD morbidity and BRD mortality counts, count of all other causes of death, cull count, number of head sold, and cohort metaphylaxis information. Bovine respiratory disease morbidity count included only those animals that were diagnosed with BRD at the time of treatment, with diagnosis made by trained personnel at each feedyard and based on industry accepted clinical signs. Bovine respiratory disease mortality counts included only those that were assigned a cause of death of BRD; necropsy to confirm cause of death was not routinely performed at all feedyards. Culled cattle are defined as those that are sold prior to their pen mates, typically at lower than market price. Metaphylaxis information described whether a cohort received or did not receive metaphylaxis. A cohort was considered to have received metaphylaxis if more than 50% of the cohort was administered an antimicrobial at arrival.

The following adjusted and calculated variables were derived to allow consistent comparison between metaphylaxis and no-metaphylaxis scenarios. These variables and economic analysis are computed similarly to a study by Kopp et al. (Kopp et al., 2024).

Bovine respiratory disease morbidity and mortality risks were calculated as morbidity or mortality count divided by number of head purchased at arrival for each cohort. The case fatality risk as a depiction of treatment success was calculated as BRD mortality count divided by BRD morbidity count within each cohort. Deaths not attributed to BRD were calculated as the sum of other death count and culled count. Deaths not attributed to BRD were assumed to be an equal proportion for each metaphylaxis classification per cohort.

Average daily weight gain of cattle within a cohort was calculated as average entry weight per head subtracted from average exit weight per head divided by days on feed to compute ADG. Head days for each cohort were calculated by assuming that BRD mortality occurred on day 50, per expert opinion, other deaths were assumed to occur at the midpoint of days on feed of that cohort, and cattle that finished the feeding period had head days equivalent to days on feed.

Cohort feed consumption data was not provided by collaborators. Dry matter intake (DMI) per head was estimated using an equation detailed in Heinen et al. (Heinen et al., 2025).

The DMI equation utilizes the cohort's calculated ADG and the average entry weight per head to estimate the DMI for each cohort (Equation 1).

Each cohort was then replicated 120 times, with the entry date of the cohort being modified to represent each month from January 2012 through December 2021. Exit date of the cohort was assigned based on the cohort's days on feed. All other cohort variables detailed above remained constant.

Study Variables—Pricing Variables

Feeder cattle purchase prices for steers and heifers for January 2012 through December 2021 were acquired from United States Department of Agriculture's Agriculture Marketing Service (USDA-AMS) (USDA AMS Livestock, Poultry & Grain Market News, n.d.-a) (Table 3.3). Purchase prices were arranged by sex, hundredweight category, month, and year. Data were provided in USD per hundredweight and then converted to USD per kilogram. Purchase price was assigned to each cohort based on assigned entry date, sex, and entry weight category (Figures 3.1 and 3.2). Purchase cost was calculated based on cohort average entry weight and purchase price. Live cattle sale prices from January 2012 through April 2023 were acquired from the same database (USDA AMS Livestock, Poultry & Grain Market News, n.d.-a) (Table 3.3). Sale price was assigned to each cohort based on assigned exit date (Figure 3.3). Exit date was determined as assigned entry date plus the observed DOF. The sale price and cohort average exit weight were used to determine the revenue for each original cohort.

Processing cost (i.e., vaccines, growth implants, anthelminthics, labor, animal processing fee at time of arrival) was assessed to be $28.60 per head and was based on the median value of processing costs provided by cooperating feedyards. The pricing of metaphylaxis was based on the price of generic tulathromycin from an online veterinary retailer at the time of economic analysis and was set at $0.067 per kilogram of entry weight. Metaphylaxis cost was calculated as price of metaphylaxis multiplied by the average entry weight per head multiplied by the number of head at arrival. Treatment price for animals diagnosed with BRD was set to the same cost as metaphylaxis. For dosing purposes, the weight of morbid cattle was based on the average entry weight for the cohort. Total treatment cost for a cohort was equivalent to price of treatment multiplied by the weight per head and the morbidity count. An animal processing at time of treatment fee was also assessed at $1.50 per head of cattle treated.

Head days were used to calculate expenses accrued on a daily time-step by the number of cattle in the cohort present each day, such as yardage and feed costs. Yardage was set as $0.35 per head day (Buckner et al., 2008).

A hypothetical diet was created based on a survey of consulting feedyard nutritionists which included 67% corn, 20% wet distillers' grain, 10% alfalfa hay, and 3% supplement (Heinen et al., 2025; Samuelson et al., 2016). Feed price per kilogram was calculated using historic prices corresponding to the 2012-2021 cattle prices obtained above and assigned by month of feedyard entry for each cohort. Average monthly alfalfa hay prices were obtained from Kansas State University's Focus on Feedlots Monthly Report (Waggoner, n.d.) (Table 3.3). Average monthly corn and wet distillers' grain prices were acquired from USDA-AMS (USDA AMS Livestock, Poultry & Grain Market News, n.d.-b) (Table 3.3). All feedstuff prices are based on Kansas pricing as a majority of feedyards in the study are in the High Plains region. Cyclical commodity prices over time are included in Figure 3.3. Price for each commodity was assigned to the cohort based on month and year of entry into the feedyard. The price of supplement was set at 0.77 USD per kilogram. Dry matter percentage for feedstuffs were set at 0.88, 0.35, 0.85, and 0.93 for corn, wet distillers' grain, alfalfa hay, and supplement, respectively. The ration percentage, individual commodity prices, and dry matter were used to calculate feed price. Total feed expense for each cohort was calculated from the feed price and DMI.

Study Variables—Calculation of Original Net Returns

Total expenses and revenues were calculated for each cohort-month scenario to approximate net returns based on the existing metaphylactic status assigned at the feedyard. Revenue encompassed each cohort's sale price and exit weights, as detailed in the *Pricing data* section. Total expense included purchase cost of feeder cattle, processing cost, yardage cost, BRD treatment cost including an animal processing fee at the time of treatment, feed cost, and cost of metaphylaxis treatment for each cohort when modeled under that metaphylactic scenario. Net returns for the original feedyard decision were then calculated as revenue minus total expense.

Study Variables—Calculation of Opposite Scenario Net Returns

For each cohort-month scenario, the opposite metaphylactic scenario was calculated. For reference, the opposite scenario for a cohort-month that did not receive metaphylaxis at arrival according to feedyard operational data would be modeled to receive metaphylaxis at arrival and vice versa. The model randomly drew from a distribution of metaphylaxis efficacy odds ratios to change morbidity risk and a distribution of the ADG adjustment of BRD-affected cattle for 10 iterations for each cohort-month scenario to generate paired-comparisons. Metaphylactic efficacy odds ratio (MEOR) distribution for tulathromycin was derived from a systematic review and mixed treatment meta-analysis (Abell et al., 2017). The efficacy odds ratio was modeled using a PERT distribution (minimum= 0.1, mode= 0.35, maximum= 0.9, shape= 5) generated with the *rpert* function in R (version 4.5.0; R Core Team, 2025). ADG adjustment was drawn from a truncated normal distribution (minimum= 0.0, mean= 0.05, standard deviation= 0.02, maximum=0.1) using the *rtruncnorm* function in R.

Cohort-month scenarios that did not receive metaphylaxis at feedyard arrival according to feedyard operational data would have a reduced morbidity risk for the simulated opposite scenario using the metaphylactic efficacy odds ratio. And, cohort-month scenarios that did receive metaphylaxis according to feedyard operational data would have an increased morbidity risk when simulated for the opposite scenario using the metaphylactic efficacy odds ratio. The original case fatality risk for each cohort was held constant across simulations and was used to determine the number of animals that died from BRD in each opposite metaphylactic scenario. Deaths not attributed to BRD, including culled animals, were held constant between metaphylactic scenarios.

The following adjustments were made to the opposite metaphylactic scenario cohort. Head days were adjusted based on newly generated morbidity and mortality counts and were used to change feed consumption of the cohort on the basis of percentage change in head days. Income was adjusted to include the difference in mortality count, resulting in either increased or decreased head sold at slaughter. Expenses for each were adjusted to include the cost of metaphylaxis, changes to BRD treatment cost, yardage cost, and feed expense.

After modeling the opposite scenario, net returns were calculated. Difference between the two net returns for each cohort-month was calculated on a per head basis, with the equation being metaphylaxis scenario net returns minus no-metaphylaxis scenario net returns. A positive difference in net returns was indicative of higher net returns when metaphylaxis was used while a negative difference showed higher net returns without metaphylaxis. Cohorts were assigned a label of Meta or NoMeta based on which scenario was the most profitable. Output was exported into an RDS file for subsequent analysis, interpretation, and visualization.

Analysis of Difference in Net Returns

Candidate predictor variables for difference in net returns were evaluated for multicollinearity using pairwise Pearson correlation coefficients among all variables. When two variables exhibited a high correlation, one variable was removed to avoid redundancy and inflation of variance estimates, while the retained variable was chosen based on biological relevance and economic importance.

A sensitivity analysis was completed using the *lm* function in R to generate a multivariable linear regression to evaluate the relationship between difference in net returns and key biological and economic variables. The following predictors were included: number of cattle received at arrival, average entry weight per head, average exit weight per head, ADG, feedyard cattle purchase price, finished cattle sale price, corn price, hay price, BRD morbidity risk, BRD mortality risk, ADG adjustment factor, and the metaphylactic efficacy odds ratio. To assess the relative influence of each predictor on the model outcome, standardized beta coefficients were calculated using the *lm.beta* package in R in order to quantify the strength and direction of the relationship between the predictor variables and the difference between metaphylactic scenarios in net returns per head.

Results

Records of 22,789 cohorts of feedyard cattle were obtained from collaborators for analysis. Inclusion and exclusion criteria defined above were applied, resulting in 16,368 cohorts used in the model (Table 3.1). Descriptive statistics of the included cohorts are displayed in Table 3.2. These cohorts were comprised of 7,264 (44.4%) heifer cohorts and 9,104 (55.6%)

steer cohorts. In total, the final dataset included 2,823,584 head of feedyard cattle, including 1,219,979 (43.2%) heifers and 1,603,605 (56.8%) steers. The cattle originated from thirty-seven states in the United States, as well as Canada and Mexico. There were 2,594 (15.8%) cohorts that received metaphylaxis at arrival. Initial analysis of included cohorts showed median percent mortality risk was 0.44% with an interquartile range of 0.00% to 1.47% (Figure 3.4).

Following stochastic modeling and simulation, 19,641,600 paired cohort comparisons were generated from 1,200 cohort-month replicates of each of the original cohorts. Paired cohort comparisons that received metaphylaxis at arrival were the same proportion as the original dataset (15.8%, 3,112,800 cohort comparisons). There were 3,928,589 (20.0%) cohort comparisons that benefited economically from metaphylaxis when modeled for a variety of prices and metaphylactic efficacy scenarios. A two-by-two table of original feedyard decision and economically optimum decision was generated (Table 3.4). Only 34.8% (1,369,010 / 3,928,589, left column of two-by-two table) of the model-predicted cohort-months that would have benefited from metaphylaxis were actually administered metaphylaxis at feed yard arrival. In contrast, 88.9% (13,969,221 / 15,713,011, right column of two-by-two table) of cohort-months that the model-predicted would not benefit from metaphylaxis did not receive metaphylaxis. Of cohorts that received metaphylaxis at the feedyard, 44.0% (1,369,010 / 3,112,800, top row of two-by-two table) needed metaphylaxis to be economically optimal according to the model. In respect to those cohorts that did not receive metaphylaxis at the feedyard, 84.5% (13,969,221 / 16,528,800, bottom row of two-by-two table) did not need metaphylaxis to be economically optimal according to the model.

A sensitivity analysis using standardized beta coefficients of difference between metaphylactic scenarios in net returns per head was used to generate a tornado graph that ranked predictor variables by order of magnitude (Figure 3.5). The sensitivity analysis regression model explained a substantial portion of the variation in net returns (R^2=0.6876). Bovine respiratory disease mortality risk was identified as the most influential predictor of economic difference when using metaphylactic antimicrobials with a standardized beta coefficient of 0.7448. Average entry weight per head and the metaphylactic efficacy odds ratio were of the next highest influence but both had a negative effect, with standardized beta coefficients of -0.1838 and -0.1710, respectively. As per traditional odds ratio interpretation, a smaller metaphylactic efficacy odds ratio is indicative of greater effect, thus, the negative standardized beta coefficient. The only pricing variable of influence was sale price (β=0.0694), while the prices of corn, alfalfa hay, and feeder cattle were less influential.

Discussion

Modeling the overall financial impacts of the observed metaphylactic scenario compared to the opposite metaphylactic scenario in cohorts of feedyard cattle changed both the associated income and costs and resulted in a difference in net returns per head for each paired cohort-month scenario. When looking at the difference in net returns for each paired cohort-month scenario, 80.0% of all cohort-month scenarios did not benefit economically from metaphylaxis. While this percentage may seem to align with the fact that only 15% of actual cohorts received metaphylaxis at arrival, those cohorts selected by the model to receive metaphylaxis are not the same as cohorts actually receiving metaphylaxis.

Baseline cohorts utilized in this study had a median percent mortality of 0.44%. Prior research showed 0.41-0.83% BRD mortality risk for feedyards from 1991-2008 (Miles, 2009). Data from a single Oklahoma feedyard in 2002-2003 has a BRD mortality risk of 0.7% (Fulton et al., 2009). While our median mortality risk falls within the previously reported range, it is towards the lower end of the range. This could be explained by the fact that 84.2% of the baseline cohorts utilized in this study were not given metaphylaxis on arrival at the feedyard, indicating that they were not classified as having an increased risk of developing BRD.

Our study does not support that, from an economic perspective, decision makers at feedyards are over-utilizing metaphylaxis. In fact, from economic and potentially animal welfare perspectives, more cohorts may benefit from metaphylaxis as only 34.8% of the model-predicted cohort-months that would have benefited from metaphylaxis were administered metaphylaxis at feed yard arrival. This means that 65.2% of cohorts that would benefit economically from metaphylaxis did not receive metaphylaxis at the feedyard, leaving unrealized financial opportunity for the feedyard. Feedyards are therefore not effectively identifying cattle cohorts that are most likely to benefit economically from metaphylaxis. Of cohorts that were model-predicted to not benefit economically from metaphylaxis, nearly 90% were correctly not administered metaphylaxis at the feedyard. Our study identified that 56% of cohorts that were given metaphylaxis by the feedyard did not benefit economically from that administration, creating opportunities for more judicious metaphylactic antibiotic decisions. Feedyards are relatively good at selecting those cohorts that do not need metaphylaxis, but 15.5% of cohorts that were not given metaphylaxis on arrival would have benefited economically from administration of antibiotics at arrival.

Bovine respiratory disease mortality was the most influential variable when looking at the difference in net returns of a cohort comparing metaphylaxis to no-metaphylaxis scenarios. In this study, mortality was by far more important from an economic standpoint than morbidity when evaluating the decision of whether or not to intervene with metaphylactic antimicrobial at feedyard arrival. While case-definitions for high-risk cattle that may benefit from metaphylaxis often are based on high morbidity risk, this outcome raises the distinction that metaphylaxis may be more economically beneficial when administered based on anticipated mortality risk. The positive relationship shown describes the fact that cohorts with high levels of mortality have significantly higher net returns when metaphylaxis is given. From an economic standpoint, mortality rises to the top as cattle death loss significantly impacts the net returns of a cohort. While morbidity is still important from an animal health and welfare standpoint, it has less financial impact on a feedyard's profitability than mortality.

Entry weight was the second most influential variable. It has a negative association with difference in net returns, indicating that lightweight cattle entering the feedyard have more economic benefit from metaphylaxis compared to heavier cattle. This agrees with previous research demonstrating that metaphylaxis is most profitable in high-risk, lightweight cattle (Dennis et al., 2018). Our finding is not surprising as lightweight cattle cohorts are considered to be at higher risk of developing BRD in a feedyard environment (Ives & Richeson, 2015). In addition, recent literature on high-risk and lightweight calves show that case fatality risk is higher in lightweight calves (Blakebrough-Hall et al., 2022; Neal et al., 2024). A higher case fatality risk would mean that producers are more likely to experience negative returns due to death in lightweight calves. This supports the ability for metaphylaxis to provide an increased benefit with lower entry weight animals.

Metaphylactic efficacy, represented by an odds ratio of antimicrobial effectiveness, emerged as third most influential predictor of the difference in net returns between metaphylaxis and no-metaphylaxis scenarios with a value of -0.171. The odds ratio was one of the stochastic variables included in the model and was allowed to range from 0.1-0.9 with a mode of 0.35 (Abell et al., 2017). A lower odds ratio is indicative of higher metaphylactic efficacy. The negative relationship between the odds ratio and the difference in net returns shows that a lower odds ratio results in greater difference in net returns.

Sale price for feedyard cattle was the fourth most influential predictor variable. As the primary variable influencing cohort revenue, changes in sale price have significant impact on a cohort's ability to generate profit. While input prices were expected to be influential in the economic metaphylactic decision, corn price, cattle purchase price, and hay price fell to 9th, 10th, and 12th most influential, with beta coefficients of -0.011, 0.01, and -0.005, respectively. Cattle purchase prices and those variables that contribute to cost of gain have tremendous impact on profitability on cohorts but explained only a small proportion of the difference in net returns between metaphylaxis and no-metaphylaxis scenarios.

Several limitations should be acknowledged in this economic modeling framework. First, the full economic value of metaphylaxis may have been underestimated or overestimated due to assumptions regarding constant prices for the treatment fee for animal processing, yardage, processing, and metaphylactic treatment. Second, case fatality risk was held constant at the value observed in each cohort, across simulations. Although metaphylaxis could reasonably be expected to influence case fatality, keeping the variable fixed avoided introducing subjective bias from expert opinion and preserved comparability across simulated scenarios. Third, data included from cooperating feedyards lacked cattle sourcing information, limiting the ability to include analysis of sale barn purchase, commingling, long haul transport, etc. Lastly, economic input and output variables were modeled as point estimates or distributions based on historical market data (2012-2021). While these values capture the typical conditions during the study period, they may not fully represent contemporary or future volatility in cattle, feedstuff, or antimicrobial markets.

In conclusion, metaphylaxis is intended for use in cohorts of cattle considered to be at high risk for bovine respiratory disease. Our analysis implies that high-risk cohorts should be identified on predicted mortality risk rather than predicted morbidity risk. In order to improve metaphylactic antimicrobial stewardship, improving our ability to predict mortality is key. Research into the distinction between high mortality risk and high morbidity risk is warranted.

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Equations

$$\boldsymbol{DMI, kg\ per\ head\ per\ day} \\ = \mathbf{4.0993} + \left(\mathbf{2.5944} * \boldsymbol{ADG, \frac{kg}{d}}\right) + (\mathbf{0.0101} * \boldsymbol{avg.entry\ weight, kg})$$

Equation 3.1. The formula used to compute dry matter intake (DMI) per head derived by Heinen et al.

(Heinen et al., 2025).

Figures

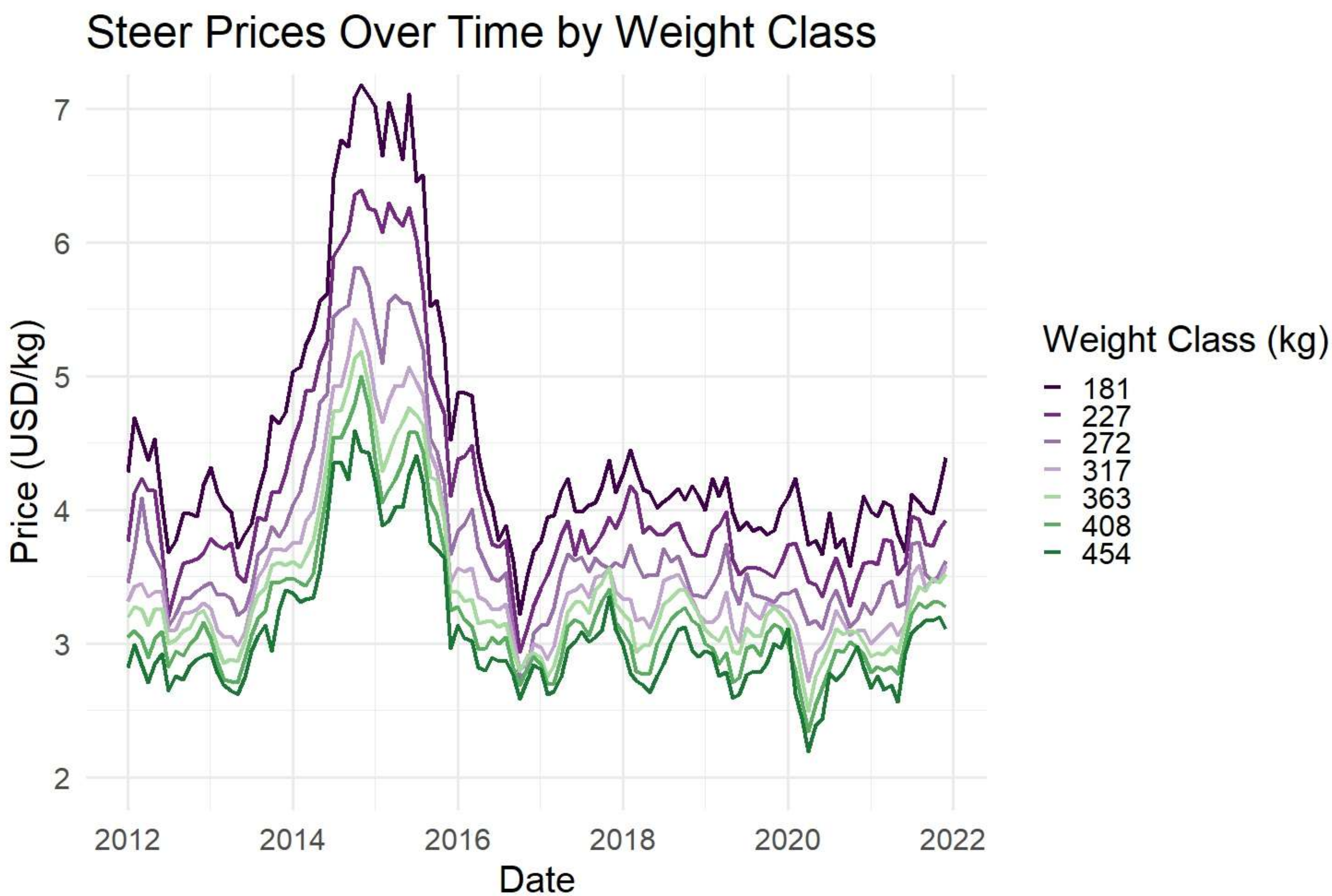

Figure 3.1. Steer purchase prices for weight classes 181 kilograms to 454 kilograms for January 2012 through December 2022.

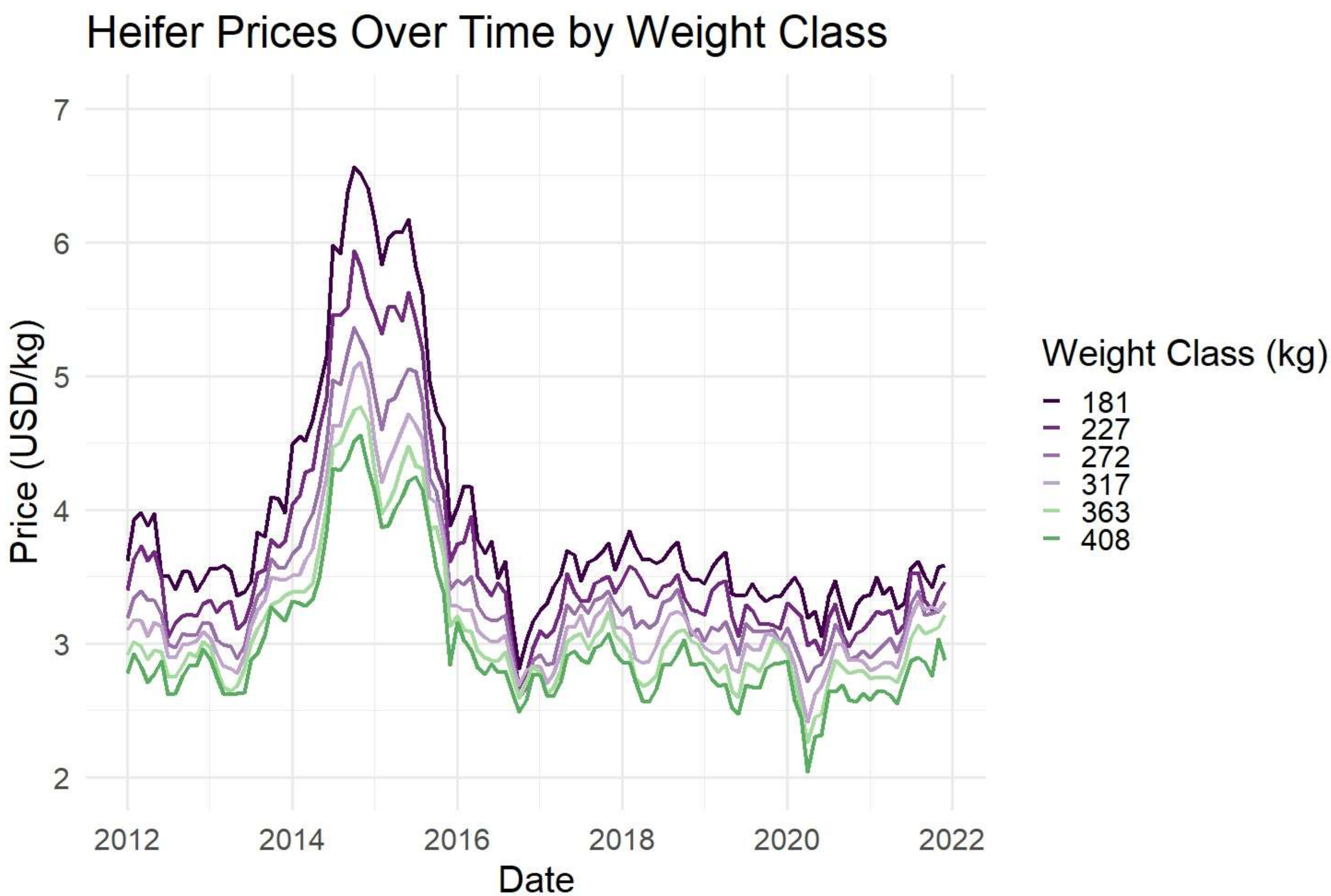

Figure 3.2. Heifer purchase prices for weight classes 181 kilograms to 408 kilograms for January 2012 through December 2022.

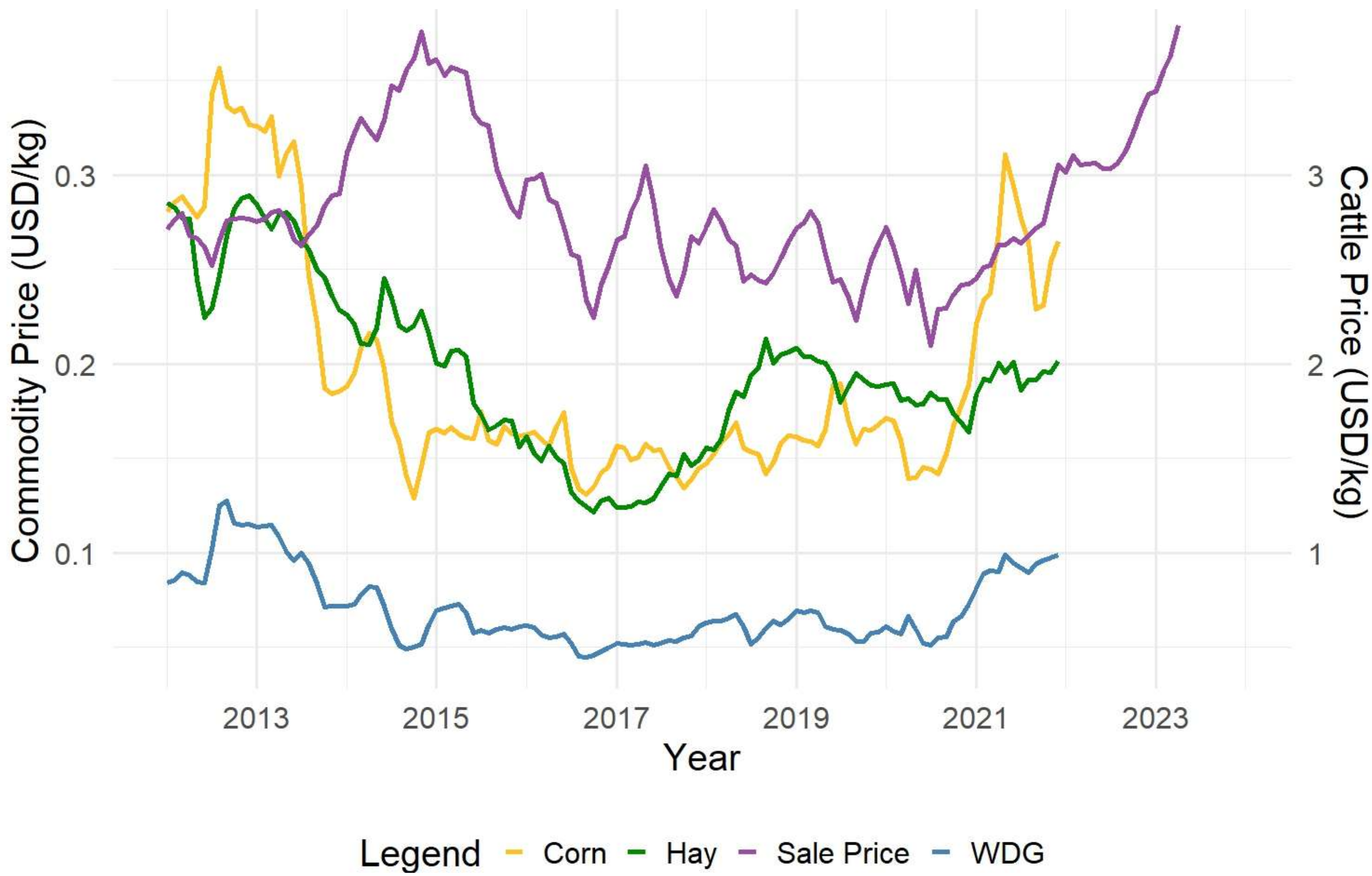

Figure 3.3. Purchase price for corn, alfalfa hay, and wet distillers (left axis) from January 2012 through December 2022 and finished cattle sale price (right axis) from January 2012 through April 2023.

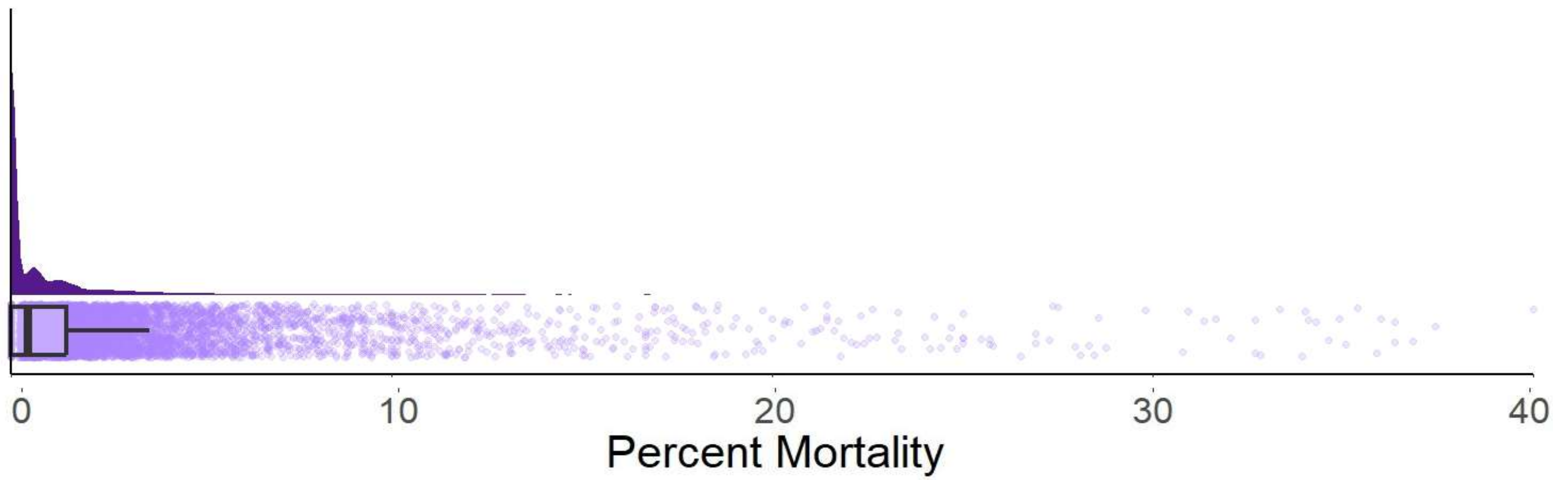

Figure 3.4. Distribution of original cohort mortality risk displayed in a raincloud plot.

The upper portion shows the density of mortality percentage due to bovine respiratory disease while the lower portion shows a scatter plot of mortality percentage for each cohort with a box-and-whisker overlay

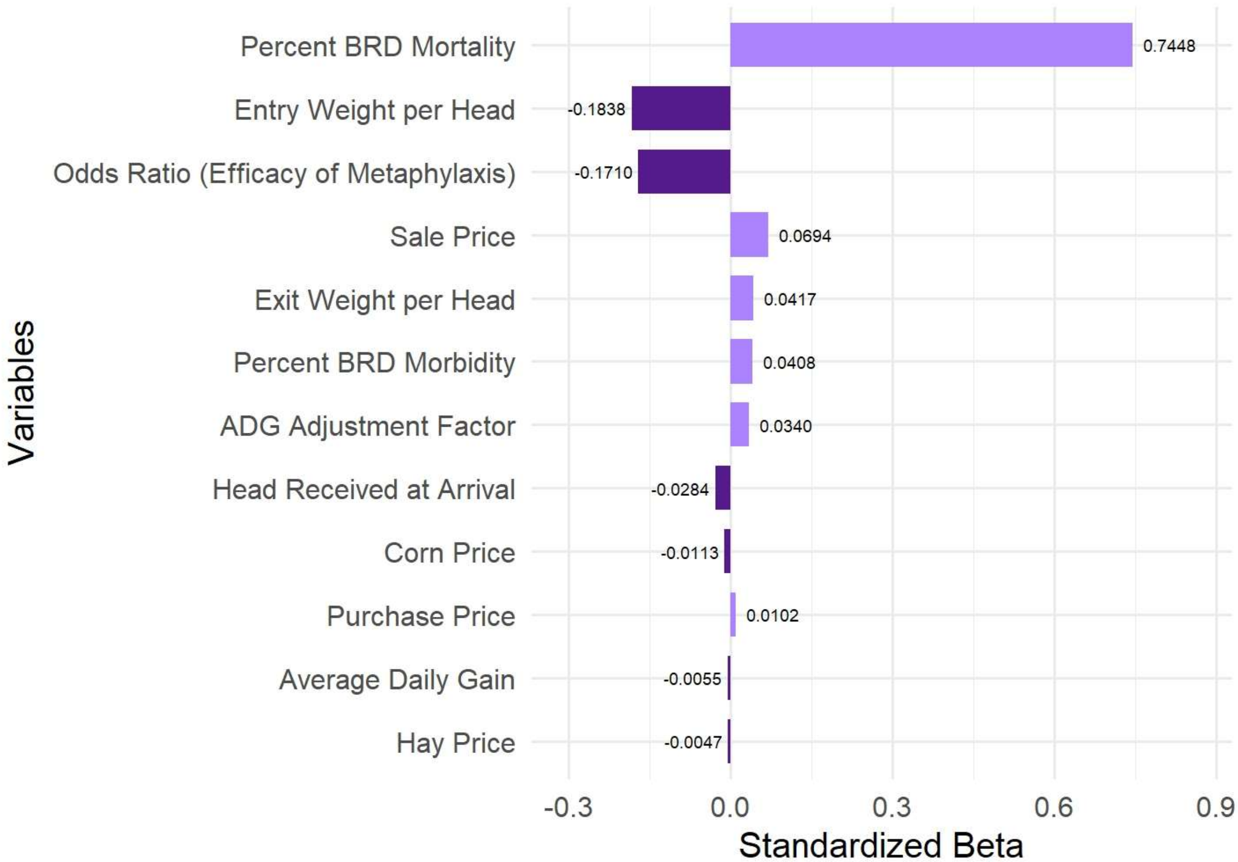

Figure 3.5. Standardized beta values, ranked by magnitude, show strength and directional relationships of predictor variables to difference in net returns between metaphylactic scenarios. Overall model R^2 of 0.6876

Tables

Table 3.1. Criteria for cohort data cleaning and number of cohorts removed for each criterion.

Criteria to remove data	**Cohorts removed**
Incomplete records	1,210
Mixed sex cohorts	437
Days on feed ≥250 or ≤50	1,074
<50 head received on arrival	275
Average cohort entry weight ≥453.6 kilograms or ≤181.4 kilograms	485
Average cohort sale weight ≥816.5 kilograms or ≤453.6 kilograms	862
Number of BRD deaths > Number of BRD treatments	1,974
Number of BRD treatments > Head received on arrival	101
Cohorts with 100% morbidity rate	3
Total cohorts removed	**6,421**

Table 3.2. Descriptive statistics of baseline 16,368 cohorts of feedyard cattle used in the analysis

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Average Daily Gain (kg/day)	0.62	1.41	1.54	1.54	1.67	2.70
Entry Weight (kg)	188.24	311.98	346.00	345.60	378.75	453.14
Exit Weight (kg)	456.31	563.36	603.20	599.70	633.21	814.20
BRD Morbidity (%)	0.00	3.11	7.78	12.62	16.25	98.78
BRD Mortality (%)	0.00	0.00	0.44	1.45	1.47	81.25
Head Received	50.00	95.00	154.50	172.50	224.00	700.00
Days on Feed	62.00	143.00	163.00	165.60	186.00	249.00

Table 3.3. Summary statistics for price variables used for economic modeling.

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Steer Purchase Price (USD/kg)	2.34	3.17	3.52	3.75	4.05	7.18
Heifer Purchase Price (USD/kg)	2.04	2.91	3.21	3.40	3.56	6.56
Sale Price (USD/kg)	2.10	2.52	2.72	2.77	2.89	3.76
Corn Price (USD/kg)	0.12	0.14	0.15	0.18	0.21	0.32
Hay Price (USD/kg)	0.12	0.17	0.19	0.20	0.22	0.29
Wet Distillers Grain Price (USD/kg)	0.04	0.06	0.06	0.07	0.08	0.13

Table 3.4. Two-by-two table of model decision for each paired cohort comparison based on optimal economic returns compared to feedyard metaphylactic decision.

		Model Decision (cohort)		
		Meta	**No Meta**	
Feedyard Decision (cohort)	**Meta**	1,369,010	1,743,790	**3,112,800**
	No Meta	2,559,579	13,969,221	**16,528,800**
		3,928,589	**15,713,011**	