Essays on fed cattle production and net return risk using stochastic simulation

by

Kaitlyn Maree Dinges Weber

B.S., Fort Hays State University, 2018

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2022

Abstract

Chapter 1: Cattle Feeding Net Returns Simulation: A Confirmation Exercise

There is great variability in cattle feeding net returns across the industry due to varying economic risk levels dependent on a multitude of cattle characteristics and attributes. There are very few simulation studies that evaluate the deterministic and stochastic influence of performance and price metric relationship between such inputs and the resulting expected net return distribution. One such study is by Dennis et al. (2018), where the authors evaluated the impact of alternative animal health treatment strategies on net returns. The objective of this study is to replicate the results from Dennis et al.'s net return simulation and approximately verify such results utilizing the KSU – Beef Farm Management Guide Spreadsheet. Utilizing the equations, deterministic and stochastic inputs, and simulated distributions in Dennis et al.'s publication, results indicated that the difference between high-risk and metaphylaxis treated cattle averaged $23.77 higher across all weight categories compared to the original publication. One glaring difference between the results for the return simulation duplication and the original results is the shift of distributions rightward along the x-axis, which represents the net returns per head in dollars per head. The KSU Beef Finishing Budget calculated net return differs from the simulation distributional mean value by as little as $11.09 per head, up to the largest difference of $93.40 per head, with three key factors accounting for much of the differences—mortality, feeding cost, and total revenue. We were able to successfully replicate the study by Dennis et al. (2018) and identify what we believe to be the key difference—the feeder cattle purchase price—between the published study and the duplication attempt, while also comparing expected net returns utilizing the KSU Beef Finishing Budget and determine the calculations attributing to the differences.

Chapter 2: Net Return Distributions Across Different Pricing Mechanisms in Fed Cattle Production

The cattle feeding industry has a lengthy history of being one of the most variable agricultural sectors concerning profitability (Tonsor, 2022). Price risk, production risk, and quality risk in the fed cattle industry all contribute to this profit variability of cattle placed on feed. While other studies have estimated cattle feeding net return models, this study explicitly considers the mortality rate, performance, quality, and expected net return difference between low health-risk cattle and high health-risk cattle that have been treated with metaphylaxis placed on feed using a stochastic simulation net returns framework that evaluates both live weight and grid pricing revenue methods. The results demonstrate that pen characteristics, such as entry weight, gender, and risk classification influence the mean and variability of production factors, defined as mortality, average daily gain, average feed conversion, and veterinary cost per head. The better we can predict animal health and quantify the uncertainty between low health-risk and high health-risk cattle, the more informed cattle feeders become regarding the profit variability between the two classifications of cattle given live weight and grid pricing. Due to higher transaction prices associated with healthier animals that generally have lower probabilities of morbidity and mortality, there is an incentive to buy higher health-risk cattle at a lower cost. Results further inform industry stakeholders by quantifying the price discount that high health-risk cattle must be purchased at relative to low health-risk cattle to achieve the same breakeven profit.

Chapter 3: Evaluation of Bovine Respiratory Disease Morbidity in the Feedlot and its Effect on Net Return Distributions

Costs associated with morbidity are one of the most important determinants of profitability in the feedlot (Gardner et al., 1999). Bovine respiratory disease (BRD) is responsible for a large portion, approximately 75%, of feedlot morbidity and 50-80% of feedlot deaths (Edwards, 1996; Kelly & Janzen, 1986). This study models the impact of the percentage of a pen of cattle individually treated one time, two times, or three or more times for BRD on mortality, performance, and overall expected net returns per head by parameterizing production and profitability risks associated with BRD morbidity in the feedlot. This research adapts a fed cattle net returns model (Belasco et al., 2009; Dennis et al., 2018, 2020) to capture varying mortality rates and stochastic performance metrics—average daily gain, average feed conversion, and veterinary cost per head—as a function of BRD morbidity to model overall fed cattle net return risk. Results indicate that mean net returns per pen decrease as the overall percentage of animals treated within the pen increases. This is driven by a combination of things, including but not limited to, decreased animal performance due to BRD-related sickness, increased veterinary cost per head, and increased mean and standard deviation of the mortality distribution as morbidity increases.

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Dedication

To my husband, family, and friends for supporting me alongside every step of this journey, which has challenged me as a scholar and a person. Your encouragement means more than words can describe. To the late Dr. Robert Keener—a mentor, friend, and the true epitome of someone that made a difference through academia; may your memory always live on in students that share your passion for agriculture.

Chapter 1 - Cattle Feeding Net Returns Simulation: A Confirmation Exercise

Introduction

Across the cattle feeding industry, a multitude of performance metrics and prices affect net return distributions, including but not limited to feed efficiency, average daily gain, days on feed, cattle prices, corn prices, and interest rates (Langemeier et al., 1992; Lawrence et al., 1999; Mark, Schroeder, & Jones, 2000; Schroeder, Albright, Langemeier, & Mintert, 1993; Schroeder & Mintert, 1988). This results in great variability in cattle feeding net returns across the industry due to varying economic risk levels dependent on a multitude of cattle characteristics and attributes.

Variability is a vast and complex problem for feedlot decision-makers as they face risk in multiple ways while typically operating under a resource constraint. Few simulation studies evaluate the influence of deterministic and stochastic inputs on feedlot cattle production and performance by comparing expected net return distributions across cattle placement weights. One study by Dennis et al. (2018) evaluated the impact of alternative animal health treatment strategies on net returns across three different cattle placement weight categories. While the net return distribution summary statistics were not published in the study, the comparative measure between cattle that received metaphylaxis treatment versus animals of the same weight category that did not receive such treatment was presented. Metaphylaxis is the process of administering FDA-approved antimicrobials to eliminate or minimize the acute onset of disease (U.S. Department of Agriculture, 2013). Another study by Dennis et al. (2020) was constructed using the same simulation framework as Dennis et al. (2018); the main focus of this study was across different health management options for high health-risk steers—"no metaphylaxis", "Upper Tier" antimicrobial, and "Lower Tier" antimicrobial.

As one of the few cattle feeding net return simulation studies in existence, there are numerous equations that include multiple variables with deterministic and stochastic inputs. While Dennis et al.'s net returns study is novel, there is a great deal of importance in confirmation and duplication for a multitude of reasons. A primary reason to replicate models is to verify potentially fragile results where small changes can affect results in a significant way (Leamer, 1983). This is especially relevant in this study, where an inaccurate value for an input factor could potentially have an impact on the results of the model. As Tomek (1993) discussed, replication and confirmation may be difficult and time-consuming. If a model will be used to make decisions, robust and minimally erroneous results are essential. An attempt to duplicate the results that Dennis et al. (2018) obtained will not only serve as a confirmation for that study and the cattle feeding net returns simulation model, but will also serve as a starting point to build and expand upon to assess subsequent objectives to follow in later chapters of this study. The objective of this study is to not only attempt to replicate the results of Dennis et al.'s net return simulation but also to approximately verify such results utilizing the KSU – Beef Farm Management Guide Spreadsheet on AgManager.info, published by Dr. Tonsor and Robin Reid (2020). One portion of this calculator serves as a decision-aid tool for evaluating feedlot cattle risk management. This two-step procedure will allow a deeper assessment of the net return results than simply evaluating simulated net return distributions.

Data

Simulation

This chapter is dedicated to the attempted duplication of the cattle feeding net return model created by Dennis et al. (2018). The simulation model section of the paper was developed using proprietary feedlot closeout data comprised of over 6 million head from January 1989 to December 2008. Due to the private nature of the data, much of the data for this duplication exercise will be simulated using the methods described in the next section using distributional assumptions and deterministic values determined by the large dataset the study utilized. The exception to the simulated data is a matrix of correlation coefficient values obtained through personal communication with the corresponding author, Elliott Dennis, due to the previously unpublished nature of this matrix.

Beef Finishing Budget

The deterministic values utilized in the simulation framework will also be incorporated as input values for the KSU Beef Finishing Budget. Since distributions cannot be included in this budget calculator as with the simulation, the mean value of the distribution will be utilized as the input factor.

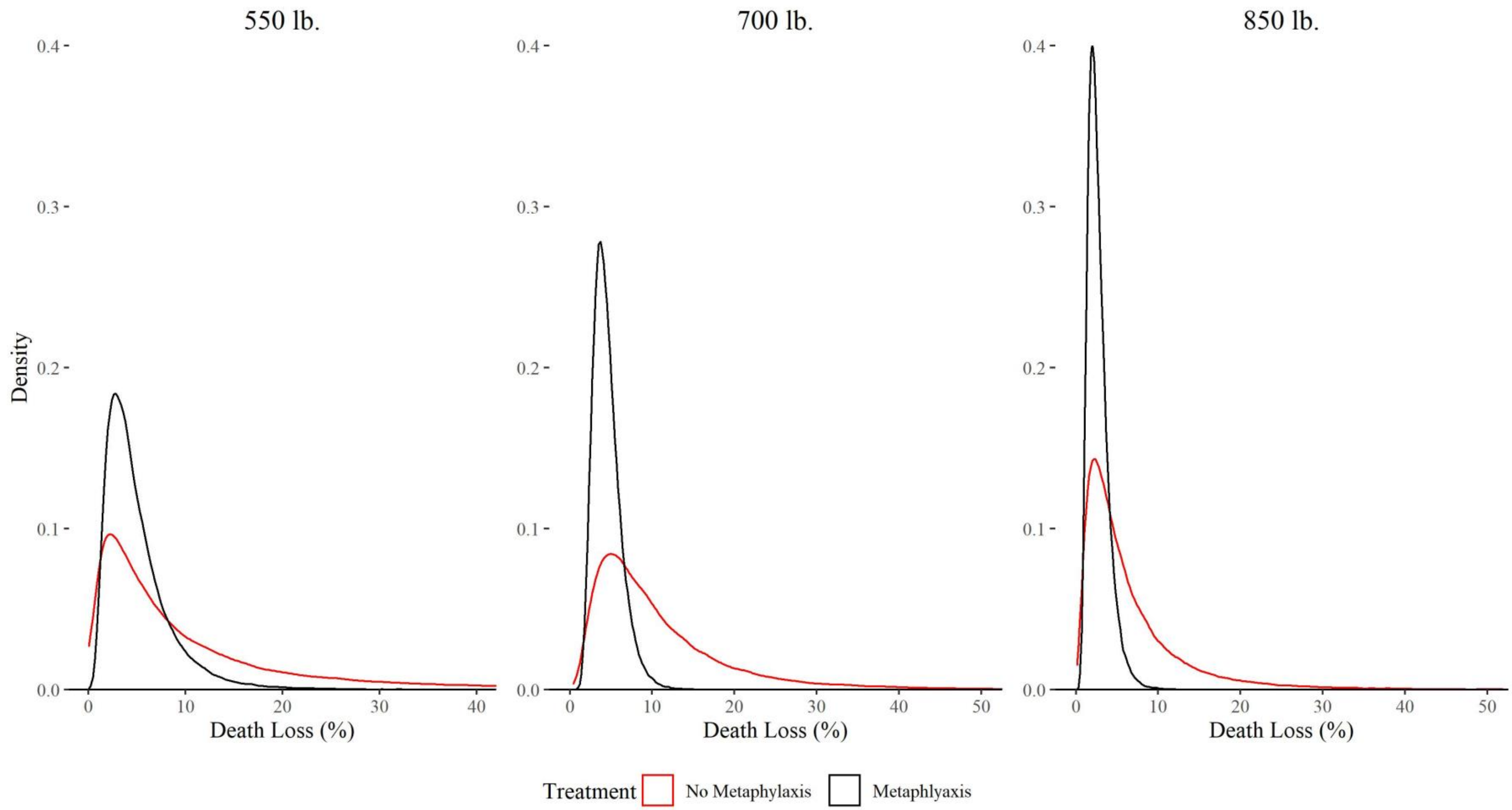
Methods

Simulation Framework

Three different cattle purchase weight categories, CPW_w—550 pounds, 700 pounds, and 850 pounds—were considered. The finished animal weight if the animal reaches maturity, CSW_k, equals 1,350 pounds, or 0 otherwise. The proportion of the chronically ill animals culled from the cohort, $CULL$, is 0.014, or 1.4% of the final cohort; the average weight of the culled animals, *CULLW*, is 861 pounds per head. The fed cattle sale price, *FP*, is \$1.48/lb; culled animals are assumed to sell for 75% of the fed cattle sale price. The original purchase price of the cattle, FRP_w, at weights of 550 pounds, 700 pounds, and 850 pounds is \$1.70/lb., \$1.49/lb., and \$1.39/lb., respectively. The annualized interest rate, *IR*, is 0.05, or 5%, whereas the proportion of live-weight shrink in the live cattle when marketed, *SHRINK*, is 0.04, or 4%.

Mortality distributions in feedlot data are generally observed as rightly-skewed distributions with long tails, but these distributions can also be modeled using log-normal, zero-inflated negative binomial, or zero-inflated Poisson distributions conditional on a vector of observable characteristics—weight, season, gender, location, and breed (Babcock, 2010). Based on Dennis et al. (2018) and Babcock (2010), a log-normal death loss distribution was applied for each weight category. In this study, only high-risk cattle were evaluated. Thus, the non-metaphylaxis cattle were high-risk cattle that did not receive metaphylaxis, whereas the metaphylaxis cattle were high-risk cattle that did receive the animal health intervention treatment. Since metaphylaxis is a well-documented way to reduce mortality, the high-risk non-metaphylaxis death loss distributions have a higher realized mortality rate than the treated cattle. The normal mean (standard deviation) percentage death losses for non-metaphylaxis weight categories—550 pounds, 700 pounds, and 850 pounds—are as follows: 12.3 (19.6), 11.0 (9.3), and 6.7 (7.2); and the normal mean (standard deviation) for metaphylaxis weight categories—550 pounds, 700 pounds, and 850 pounds—are as follows: 5.0 (3.5), 4.5 (1.7), and 2.7 (1.3). These distributions can be seen in Figure 1.1 as we were able to replicate the death loss distributions for each weight category and treatment.

Figure 1.1. Mortality Distributions for High-Risk Cattle by Metaphylaxis Use and Placement Weight Category



Average daily gain in pounds/head/day (*ADG*), average feed conversion in lb. feed/lb. gain (A*FC*), and health cost in $/head (*HC*) are calculated using the linear mixed model equations published by Dennis et al. (2018). The mortality variable, *MORT,* is the percent of animals in a pen that died during the feeding period, *lnPWT* is the log of placement weight, *STEER* is a dummy variable indicating the group's sex, and the season variables—*SPRING*, *SUMMER*, and *FALL*—are dummy variables indicating the placement season. The percentage of data composition for gender and season of placement was used to facilitate the simulation of the performance metrics—*ADG* and *AFC*; this allows for average inference across gender and season. Steers composed 46% of the dataset, whereas heifers totaled 54%. Hence, the value utilized for the *STEER* variable in equation (1.1) would be 0.46. To account for seasonality of placement, the percentage of cattle placed during each season—Spring, Summer, Fall, and Winter—was determined to be 25.1%, 27.4%, 24.3%, and 23.2% of the dataset, respectively. These proportions were used in equations (1.1) and (1.2) as well.

$$ADG = -4.056 - 0.056 \times MORT + 1.086 \times lnPWT + 0.245 \times STEER - 0.021 \times SPRING - 0.102 \times SUMMER - 0.188 \times FALL \quad (1.1)$$

$$AFC = -2.077 + 0.045 \times MORT + 1.262 \times lnPWT - 0.284 \times STEER - 0.073 \times SPRING - 0.302 \times SUMMER + 0.284 \times FALL \quad (1.2)$$

$$HC = 30.515 + 1.606 \times MORT - 2.180 \times lnPWT + 23.811 \times METAPHYLAXIS \quad (1.3)$$

$$DOF_{w,k,\tau} = \frac{CSW_k - CPW_w}{ADG_{w,k,\tau}} \quad (1.4)$$

$$YC_{w,k,\tau} = 0.30 \times DOF_{w,k,\tau} \quad (1.5)$$

$$FDRC_w = FRP_w \times CPW_w \quad (1.6)$$

ADF, *AFC*, and *HC* are correlated, thus requiring the use of Iman and Conover's (1980) algorithm for 10,000 iterations. These variables are simulated distributed as $N_k \sim (\gamma_k, \sigma)$, where γ_k is the estimate of *ADG*, *AFC*, and *HC* estimated from equations (1.1 – 1.3) and σ are the respective standard deviations. The distributional standard deviations (E. Dennis, personal communication, May 25, 2021) and the performance metric correlation matrix was provided by Elliott Dennis (personal communication, September 1, 2021) due to the inaccessibility of the proprietary observational data. Both the variable correlation matrix and the distributional standard deviations can be seen in Appendix A as Table A.1 and Table A.2, respectively.

The additional structural equations for the simulation model include the following[1]: feed cost (\$/head), $FC_{w,k,\tau}$; interest cost (\$/head), $IC_{w,k,\tau}$; cattle sales total revenue (\$/head), $TR_{w,k,\tau}$; yardage cost (\$/head), $YC_{w,k,\tau}$; and net feeding returns (\$/head), $\rho_{w,k}$.

$$FC_{w,k,\tau} = FEED \times \{AFC_{w,k,\tau}\,[CSW_k \times (1 - MORT_{w,k,\tau} - CULL) - CPW_w]\} \tag{1.7}$$

$$IC_{w,k,\tau} = \{0.5 \times [YC_{w,k,\tau} + FC_{w,k,\tau} + HC_{w,\tau}] + FDRC_w\} \times DOF_{w,k,\tau} \times (IR/365) \tag{1.8}$$

$$TR_{w,k,\tau} = FP \times CSW_k \times (1 - SHRINK) \times (1 - MORT_{w,k,\tau} - CULL) + (CULL \times CULLW \times CULLP) \tag{1.9}$$

$$\rho_{w,k,\tau} = TR_{w,k,\tau} - FDRC_w - YC_{w,k,\tau} - FC_{w,k,\tau} - HC_{w,\tau} - IC_{w,k,\tau} \tag{1.10}$$

Given a random value (φ_w) from the log-normal death loss distribution sampled using Halton draws and a representative pen of 120 head, $\varphi_{w,\tau} \times 120$ net returns were selected from the $\rho_{w,k=1350}$ distribution and $(1 - \varphi_{w,\tau}) \times 120$ net returns were chosen from the $\rho_{w,k=0}$ distribution.

---

[1] For the structural equations, *w* denotes the cattle weight and *k* denotes the death loss group.

The mean of each iteration was calculated, and this was repeated 10,000 times to determine the weighted-average net return distribution.

Table 1.1. Net Return Simulation Variables

Variables	Description	Value/Calculation
Simulated		
$\boldsymbol{MORT_{w,k,\tau}}$	Percent of death loss in purchased group	$\varphi_{w,\tau}$
$\boldsymbol{ADG_{w,k,\tau}}$	Average daily gain during feeding (lb./head/day)	See equation (1.1)
$\boldsymbol{AFC_{w,k,\tau}}$	Average pounds of feed consumer per pound of weight gain (lb. feed/lb. gain)	See equation (1.2)
$\boldsymbol{HC_{w,\tau}}$	Animal health care cost including metaphylaxis, pull-and-treat, vaccinations, labor costs, etc. ($/head)	See equation (1.3)
$\boldsymbol{DOF_{w,k,\tau}}$	Number of days on feed (days)	See equation (1.4)
$\boldsymbol{YC_{w,k,\tau}}$	Yardage cost of feeding cattle ($/head)	See equation (1.5)
$\boldsymbol{FC_{w,k,\tau}}$	Feed cost ($/head)	See equation (1.7)
$\boldsymbol{IC_{w,\tau}}$	Interest cost ($/head)	See equation (1.8)
$\boldsymbol{TR_{w,k,\tau}}$	Total revenue from cattle sales ($/head)	See equation (1.9)
$\boldsymbol{\rho_{w,k,\tau}}$	Net feeding returns ($/head) for each weight (*w*), death loss group (*k*), and treatment (τ)	See equation (1.10)
Fixed		
$\boldsymbol{CPW_w}$	Cattle purchase weight (lb./head)	550, 700, 850
$\boldsymbol{CSW_k}$	Finished animal weight (lb./head) if animal reaches maturity (i.e., *k* = *alive*); 0 otherwise (i.e., *k* = *dead*)	1,350
CULL	Proportion chronically ill animals culled from the remaining cohort	0.014
CULLP	Price received for cull animals ($/lb.)	0.75 × ***FP***
CULLW	Average weight of culled animals (lb./head)	861
$\boldsymbol{FDRC_w}$	Feeder cattle purchase cost ($/head)	See equation (1.9)
FEED	Corn price when cattle are placed on feed ($/lb.)	0.0923
FP	Fed cattle sale price ($/lb.)	1.48
$\boldsymbol{FRP_w}$	Purchase price for CPW 550, 700, and 850 ($/lb.)	1.70, 1.49, 1.39
IR	Annualized interest rate	0.05
SHRINK	Proportion shrink in live weight when marketed	0.04

Note: From “Value of Arrival Metaphylaxis in U.S. Cattle Industry” by Dennis et al., 2018, *Journal of Agricultural and Resource Economics* 43(2), p. 241

Beef Finishing Budget

The KSU Beef Finishing Budget is a calculator published on AgManager.info to determine income per head based on production efficiency information—death loss, days on feed, and average daily gain; gross returns—fed animal sale, purchase price, death loss, and other; and variable costs—vet medicine/drugs, feed expense, etc. The decision tool provides calculations for the current production year, in addition to the 5-year average for all prices—corn, soybean mean, distiller's dried grains with solubles (DDGS), silage, prairie hay, alfalfa, and other beef mineral. The fed cattle price, feeder cattle purchase price, days on feed, and average daily gain will be utilized from the simulation structure, as seen in Table 1.2. Additionally, finishing feed requirements in pounds per day per animal are included for a finishing feed ration for the following variables: total harvested forage—prairie/brome hay, silage, and alfalfa; total grain/protein supplements—corn, DDGS, and soybean meal; and salt and mineral. The tables for the finishing feed requirements and finishing price assumptions can be seen in Table A.3 and Table A.4, respectively. To be able to directly compare net return per head values, the feed cost prices were all increased by 21.65%, or the percentage increase from the 2021 corn price in the KSU budget to the corn price specified in the simulation framework, as noted in Table 1.1. The assumed feed requirements per head were not adjusted. The only input factors for the KSU budget dependent on weight and metaphylaxis treatment are death loss, days on feed, average daily gain, and purchase price. ADG is calculated using equation (1.1) of the simulation methods with the mean death loss percentage by placement weight, and then the calculated ADG is used in the *DOF* calculation using equation (1.4). Utilizing inputs from Table 1.2, Table 1.3, Table A.3, and Table A.4 to populate equations for Gross Revenue, $GR_{w,\tau}$ and

Variable Costs, $VC_{w,\tau}$, the overall net returns per head, $\delta_{w,\tau}$, is determined and compared to the net return values calculated in the simulation section of this chapter.

Table 1.2. KSU Beef Finishing Budget Variables based on Treatment Category

Variables	Placement Weight		
	550	700	850
Metaphylaxis Treated Cattle			
Death Loss	5.0%	4.5%	2.7%
Days on Feed	283	211	152
Average Daily Gain	2.83	3.09	3.30
Purchase Price	1.70	1.49	1.39
Non-Metaphylaxis Treated Cattle			
Death Loss	12.3%	11.0%	6.7%
Days on Feed	283	211	152
Average Daily Gain	2.82	3.09	3.30
Purchase Price	1.70	1.49	1.39

Table 1.3. Deterministic KSU Beef Finishing Budget Variables

Variables	Description	Value/Calculation
Production Efficiency Information		
Death Loss %	Percent of Animals lost	See Table (1.2)
Days on Feed	Total number of days at feedlot	See Table (1.2)
Average Daily Gain	Average daily gain during feeding (lb./head/day)	See Table (1.2)
Gross Return		
FP	Fed cattle sale price ($/lb.)	1.48
CSW	Fed cattle finishing weight (lb.)	1,350
FRP_w	Purchase price for each weight category: 550, 700, and 850 ($/lb.)	1.70, 1.49, 1.39
CRP_w	Initial placement weight	550, 700, 850
Death Loss	Percent of Animals Dead	$\boldsymbol{DL_{w,\tau}} \times (\boldsymbol{FRP_w} \times \boldsymbol{CPW_w})$
Variable Costs		
Harvested Forage	Daily Ration of hay, silage, and alfalfa ($/head/day)	Price/ton × total lbs.
Grain/Protein Supplements	Daily Ration of corn, soybean meal, and distiller's grains ($/head/day)	Price/ton × total lbs.
Mineral	Daily Ration of supplemental mineral ($/head/day)	Price/ton × total lbs.
Labor	Determined by KFMA Labor Hired + Unpaid Operator Labor ($/hour)	$30.00
Vet Medicine/Drugs	KFMA Value	$5.00
Marketing Costs	KFMA Value – includes trucking and sale commissions	$10.00
Utilities	KFMA Value	$6.00
Machinery/Repairs	KFMA Value	$6.00
Interest	KFMA Value	$36.00
Other Variable Costs	Approximation of all other KFMA variable costs	$3.00

Note: Adapted from "KSU-Beef Farm Management Guide Spreadsheet" by G. Tonsor and R. Reid, 2020, from KSU Ag Manager (https://www.agmanager.info/farm-mgmt-guides/livestock-budgets/ksu-beef-farm-management-guide-spreadsheet-3).

$$GR_{w,\tau} = \underbrace{(FP \times CSW)}_{Fed\ Animal\ Sale} - \underbrace{(FRP_w \times CPW_w)}_{Purchase\ Price} - \underbrace{\{DL_{w,\tau} \times (FRP_w \times CPW_w)\}}_{Death\ Loss} \tag{1.11}$$

$$VC_{w,\tau} = \underbrace{P \times QTY}_{Forage} + \underbrace{P \times QTY}_{Grain} + \underbrace{P \times QTY}_{Mineral} + \underbrace{P \times QTY}_{Other\ Feed} + \underbrace{P \times QTY}_{Labor} \tag{1.12}$$

+ Vet Expense + Marketing Costs + Utilities +

Machinery/Repairs + Interest + Other Variable Costs

$$\delta_{w,\tau} = GR_{w,\tau} - VC_{w,\tau} \tag{1.13}$$

Results

Simulation

The full summary statistics for each simulated net returns distribution are shown in Table 1.4. Table 1.5 shows the net differences in treated and untreated high-risk cattle returns for both our simulation results and the differences reported in Dennis et al. (2018). Based on our simulated distribution averages, the difference between 550 lb. high-risk non-metaphylaxis cattle versus treated high-risk cattle is \$124.11 per head. The mean net returns per head for treated 700 lb. calves is \$251.49 per head, whereas untreated 700 lb. calves have an average net return of \$116.60 per head for a loss of \$134.89 per head. The loss for 850-pound non-treated high-risk cattle compared to treated high-risk 850-pound cattle is \$79.40 per head.

The difference in our confirmation results for 550-pound cattle is \$19.65 per head greater than the difference Dennis et al. found. The difference between the confirmation results and the originally published results for 700-pound cattle is larger—the duplication results tally in at \$134.89 per head which is a \$35.63 greater loss than Dennis et al. found. Finally, the 850-pound cattle difference is \$16.04 per head when comparing the duplication results to the original. The greatest difference occurs in the 700-pound group when assessing differences across all treatment and weight categories compared to the original results (Dennis et al., 2018).

Beyond the treatment and weight category comparison, we also have an interest in the overall shape and distributional values. While the distributional mean values were not reported by Dennis et al., we can visually assess the overall shape and placement of the distribution. The distributional shapes appear to be similar with minor differences, yet based on the x-axis and overall mean values of the simulated distributions, there is an input factor contributing to the difference in our results and those of Dennis et al. Our distributions are shifted significantly more rightward indicating higher mean net returns per head. The original Metaphylaxis and No Metaphylaxis net return results can be seen in Figure A.1 in Appendix A.

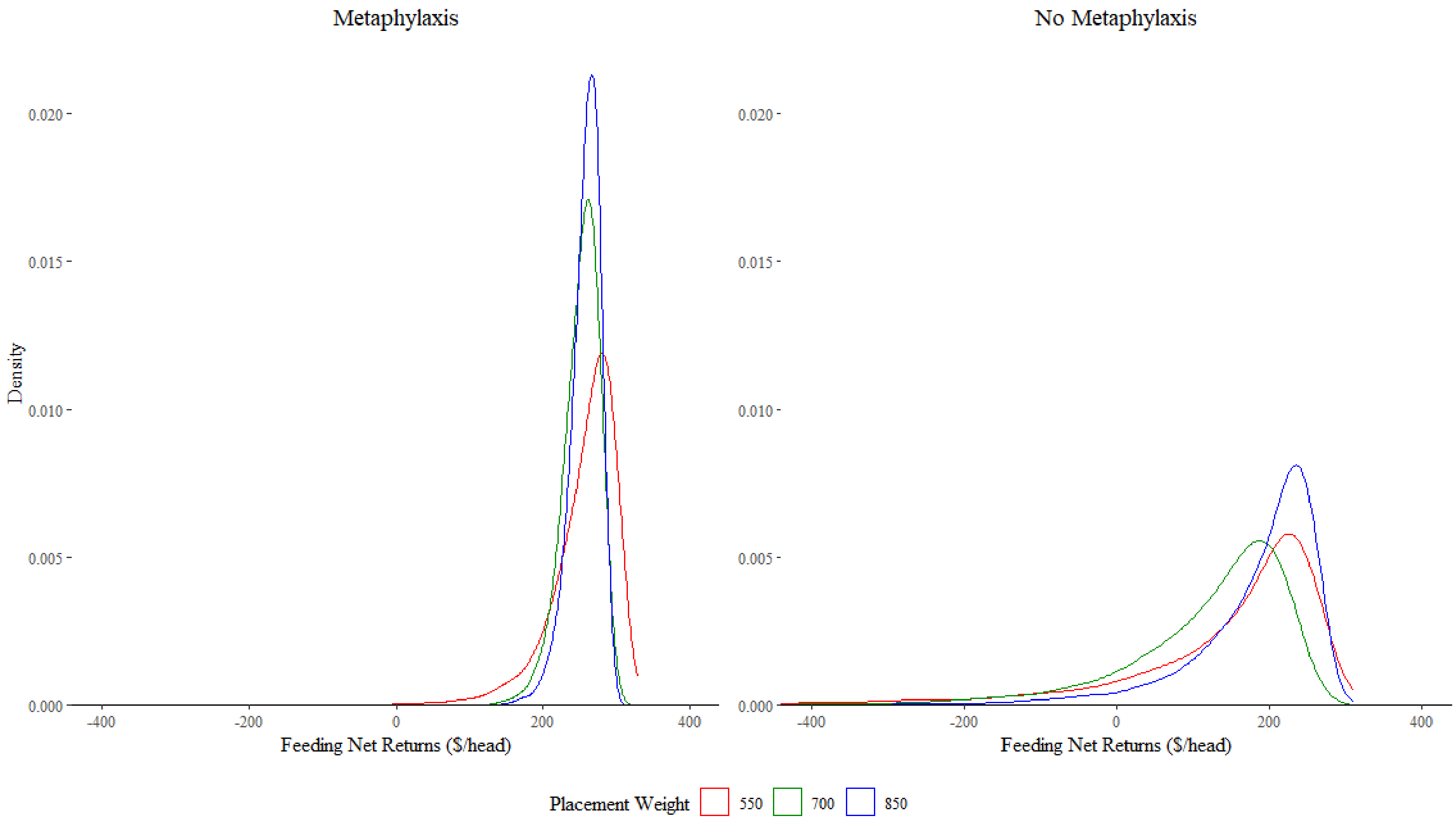
Table 1.4. Simulation Net Return Summary Statistics

Placement Weight	Net Return ($/head)			
	Minimum	Median	Mean	Max
Metaphylaxis Treated Cattle				
550 pounds	-250.40	267.10	255.90	328.20
700 pounds	74.04	255.42	251.49	309.27
850 pounds	88.20	260.20	257.10	297.80
Non-Metaphylaxis Treated Cattle				
550 pounds	-999.97	188.75	131.88	309.04
700 pounds	-1057.40	150.50	116.60	278.70
850 pounds	-1143.40	208.70	177.70	296.8

Table 1.5. Net Differences between Metaphylaxis Treated and Untreated Cattle

Weight	Loss for High-Risk Cattle Relative to Metaphylaxis Treated Cattle ($/head)
Confirmation Results	
550 pounds	124.11
700 pounds	134.89
850 pounds	79.40
Dennis et al. Results	
550 pounds	104.46
700 pounds	99.26
850 pounds	63.35

Figure 1.2. Feeding Net Returns Simulation Confirmation Distributions



Beef Finishing Budget

Results for the Beef Finishing Budget for each treatment and weight category combination can be seen in Table 1.6 with net returns for metaphylaxis treated cattle ranging between $162.50 and $269.94 per head for 550-pound to 850-pound cattle. The overall net return values for non-treated high-risk cattle are lower with the range of $94.25 to $222.68 per head. Also shown in Table 1.6 are the results of the confirmation attempt for a direct comparison. The largest difference between the KSU budget calculator and the study duplication attempt net returns per head occurs in the metaphylaxis treated 550-pound classification of cattle; the other weight categories of metaphylaxis cattle—700-pound and 850-pound—differ minimally between values. The net return values between methods for non-metaphylaxis cattle differ by $56.00 per head or less.

Table 1.6. KSU Beef Finishing Budget Returns based on Treatment Category

Placement Weight	KSU Budget Net Returns per Head	Duplication Attempt Net Returns per Head	Difference from Duplication Attempt
Metaphylaxis Treated			
550 pounds	$162.50	$255.90	(93.40)
700 pounds	$240.40	$251.49	(11.09)
850 pounds	$269.94	$257.10	12.84
Non-Metaphylaxis Treated			
550 pounds	$94.25	$131.88	(37.63)
700 pounds	$172.60	$116.60	56.00
850 pounds	$222.68	$177.70	44.98

Discussion

Simulation

Based on the simulation input equations and fixed factors, there are a multitude of performance metrics and prices that affect net return distributions and increase variability about the expected mean of net returns per head. This variability is a vast and complex problem for feedlot decision-makers as they face risk in multiple ways. Thus, the more we know about expected net return distributions and the sensitivity of input factors changing the shape and expected mean of such distributions, the more informed feedlot decision makers become.

The overall takeaway from the confirmation exercise effort is that given the input information that is published, along with additional key components received through communication with the author, the resulting distribution shape is similar and may vary slightly for a few general unavoidable reasons. One of these differences could simply be the seed number chosen, which signifies the starting point for random number sequence generation. If different starting points are chosen across multiple randomly drawn vectors of numbers, we ultimately hope to produce approximate results, not necessarily achieve the exact value in such a duplication. Results of setting different seeds across the duplication can be seen in Table A.5; minimal differences are seen across the median and mean values, yet the minimum and maximum values for the distribution vary more when the seed value is changed. Setting the seed number when coding in R is important because it ensures the reproducibility of results (Jones et al., 2014). Another potential difference between the two peak values of the distributions is the difference in how R script is written across authors; due to a lack of specific information in the original manuscript, missing information may result in different end values based on interpretation of what was written. Finally, differences in RStudio versions may marginally affect the results, especially for a simulation-heavy project. The duplication effort was built using RStudio Version 1.1.456.

One glaring difference between the results in Figure 1.2—the return simulation duplication results—and Figure A.1—the original results—is the shift of duplication attempt distributions rightward along the x-axis. Through deductive elimination based on input factors and applying a basic spreadsheet calculation where the distributions are simplified to their mean values, either the fed cattle price, *FP*, or the feeder cattle purchase prices, CPW_w, are misprinted in the original published article by Dennis et al. (2018). It is worth noting that this likely does not affect their conclusions because the main focus of the study was the difference between metaphylaxis and non-metaphylaxis returns, not the absolute value of overall net returns.

In another article by Dennis, Schroeder, and Renter (2020) that utilizes this same cattle net returns simulation structure, the feeder cattle purchase price is the same $1.48/lb., or $148/cwt., but the feeder cattle prices differ in relation to the fed cattle price. While we cannot infer the precise feeder prices for the weight categories utilized for this simulation due to different weight classifications, the prices are more in line with what we would expect given $1.48/lb. for the fed cattle price. The adjusted breakeven feeder purchase price for 600-pound spring and winter placements are $2.1461/lb. and $2.1379/lb. respectively, and 800-pound calves placed in the spring and winter are $1.7591/lb. and $1.7436/lb., respectively, given a fed cattle price of $1.48/lb. This leads us to believe that the feeder prices should be higher for non-metaphylaxis breakeven cattle feeding net returns.

Based on breakeven calculations by adjusting the feeder purchase price for the metaphylaxis treated cattle by weight group, we found what we believe would be more accurate feeder cattle purchase prices relative to the fed cattle price of $1.48 per pound for each weight category. The adjusted feeder cattle purchase prices for 550-pound, 700-pound, and 850-pound cattle are $2.15, $1.84, and $1.69, respectively, based on the mean net return per head value using the same methods as the cattle net returns simulation. When these prices are adjusted to breakeven values, or where mean net returns are as close to zero as possible given simulation rounding, the replicated results are then shifted leftward to a very similar representation of the original net return simulation results when visually assessed, as seen in Figure A.2.

To illustrate the sensitivity of the distributional mean, for every $0.01/lb. increase in the purchase price of 850-pound calves, there is a $8.68 decrease in the net return per head on average, holding all else constant. For every $0.01/lb. increase in the purchase price of 700-pound calves, there is a $7.20 decrease in the net return per head on average, holding all else constant. Thirdly, for every $0.01/lb. increase in the purchase price of 550-pound calves, there is a $5.71 decrease in the net return per head on average, holding all else constant.

Beef Finishing Budget

The KSU Beef Finishing Budget calculated net return differs from the simulation distributional mean value by as little as $11.09 per head, up to the largest difference of $93.40 per head. The two key factors that account for much of the differences between the cattle feeding net return simulation distributional mean values and the KSU Beef Finishing Budget are mortality and feeding cost. Mortality is incorporated into the simulation and budget differently. The returns simulation treats mortality as an opportunity cost based on the final sales revenue, as opposed to the budget that includes a lower cost approach to morality by assuming that the cattle die on the truck when en route to the feedlot.

Another diverging factor is feed cost; feed cost in the net returns simulation is based on a singular fixed corn price per bushel. This contrasts with the feed cost calculation as outlined in the KSU Finishing Beef Budget which is a weighted-average feed cost based on Table A.3 and Table A.4 that outline the feed requirements and adjusted feed prices to more accurately compare to the corn price used in the simulation. The feed requirements in pounds per day per animal were not adjusted. Where the KSU budget assumes corn as a portion of the feeding ration at 17 lbs./day/animal, the simulation assumes corn as the sole feed ration at 16.19 lbs./day, 18.63 lbs./day, and 20.69 lbs./day for 550-pound, 700-pound, and 850-pound animals, respectively, given their days on feed and average feed conversion. As the cattle placement weight gets lighter, the feed cost per animal increases at an increasing rate for the KSU Budget as compared to the simulation. There are also additional factors included in the simulation framework that are not considered in the budget, such as shrink and the sale of culled cattle, that are contributing to the difference in total revenue per animal as seen in Table 1.7. The total revenue per animal in the KSU Budget is simply the selling weight multiplied by the fed cattle sale price.

Table 1.7. KSU Beef Finishing Budget Return Calculation Comparison

Placement Weight	Feed Cost		Total Revenue Per Animal	
	KSU Budget	Simulation	KSU Budget	Simulation
Metaphylaxis Treated				
550 pounds	$735.75	$377.59	$1998.00	$1808.70
700 pounds	$563.67	$317.80	$1998.00	$1818.29
850 pounds	$422.66	$257.80	$1998.00	$1852.82
Non-Metaphylaxis Treated				
550 pounds	$735.75	$335.70	$1998.00	$1668.68
700 pounds	$563.67	$270.40	$1998.00	$1693.62
850 pounds	$422.66	$227.70	$1998.00	$1776.00

Conclusion

While this simulation duplication effort was indeed time-consuming and difficult as Tomek discussed (1993), it ultimately served as a starting point to confirm results where minor errors have significant impacts on the absolute value of the results, as one would expect with a structural simulation of this magnitude. In an effort to replicate the study by Dennis et al. (2018), the structural equations, fixed parameters, and distributional assumptions provided in the published article were utilized to simulate net return distributions for high-risk cattle placed at three different weights—550 pounds, 700 pounds, and 850 pounds—and 2 treatments—metaphylaxis and non-metaphylaxis—for a total of six different net return distributions. While the replicated shape of the distributions closely matched the shape of the distributions in the published article, the replicated distributions were shifted rightward along the x-axis which valued the net feeding returns in dollars per head. We concluded that the driving difference between the published distributions and the duplication attempt most likely stems from incorrect feeder cattle purchase prices listed in the *Value of Arrival Metaphylaxis in U.S. Cattle Industry* article. In a similar article by Dennis et al. (2020) that utilizes the same structural approach, the feeder cattle purchase prices are more in line with what we would expect. Based on backward induction if feeder purchase prices are adjusted to equal breakeven prices holding all else constant, the adjusted feeder cattle purchase prices per pound for 550-pound, 700-pound, and 850-pound cattle are closer to $2.15 per pound, $1.84 per pound, and $1.685 per pound, respectively. Critical attention to detail is essential when small changes have an impactful influence on the outcome. For instance, for each $0.01/lb. increase in the feeder purchase price, there is a $8.68 decrease, $7.20 decrease, and a $5.71 decrease in the net return per head on average, holding all else constant, for 850-pound, 700-pound, and 550-pound cattle, respectively

Additionally, comparing the confirmation results to the KSU – Beef Farm Management Guide Spreadsheet on AgManager.info allows for a secondary check of expected net returns per head utilizing the same prices, mortality rates, and performance metrics as in the simulation framework to compare more accurately. While the calculation procedure to determine the final net returns per head differs from the simulation framework, it does provide an approximation in which the duplication efforts can be compared to. Three substantial differences between the simulation framework and the KSU budget are how mortality is accounted for, how feed cost is calculated, and the overall differences in total revenue per animal. Given the differences in the methods, the KSU budget and duplication attempt net returns per head differ by as little as \$11.09 for metaphylaxis treated 700-pound calves to as much as \$93.40 for metaphylaxis treated 550-pound calves. The remaining four treatment-weight combinations differ by ±\$37.68 per head on average.

In conclusion, we did confirm that small changes, or mistakes even, have impactful differences in the net return distributions and the associated summary statistics for each treatment-weight combination. We were able to successfully replicate the study by Dennis et al. (2018) and identify what we believe to be the key difference—the feeder cattle purchase price—between the published study and the duplication attempt.

Chapter 2 - Net Return Distributions Across Different Pricing Mechanisms in Fed Cattle Production

Introduction

The cattle feeding industry has a lengthy history of being one of the most variable agricultural sectors concerning profitability (Tonsor, 2022). Many elements in the fed cattle industry contribute to this profit variability of cattle placed on feed. To manage risk in the feedlot, understanding the risk factors—price risk, production risk, and quality risk—that contribute to profit variability is necessary. Factors that contribute to price risk include the following: feeder cattle price, fed cattle price, and corn price. Production risk stems from the variability in production efficiency regarding average daily gain (ADG), average feed conversion (AFC), and mortality risk. In the feedlot setting, this variability is influenced by placement characteristics, including weight, gender, season, genetic differences, and previous management. Not only is prior management of cattle influential on the likelihood of feeding success, but once cattle are in the feedlot setting, a new set of management decisions also influence the projected net returns distribution. These factors also contribute to the incoming risk classification that a feedlot assigns cattle, which further influences how the cattle are managed at the feedlot. Low health-risk cattle tend to have lower production and mortality risk as compared to their high health-risk counterparts. As a whole, the business of fed cattle is a moderately risky investment (Hampel et al., 1998), so making sound management decisions to reduce uncertainty, while also striving to increase mean returns, is essential to the profitability of cattle feeding operations.

The objective of this chapter is to assess the profit variability of feedlot net returns for low health-risk and high health-risk cattle treated with metaphylaxis given a stochastic simulation of factors affecting cattle performance, price, and quality by comparing live and grid pricing methods. This study extends on earlier work by Belasco et al. (2009) and Dennis et al. (2018) by evaluating profit variability given additional factors and adjustments to the original model specification. The scope of the net returns model is also expanded to adopt grid pricing as another pricing method to evaluate variability due to quality differences amongst cattle on feed.

Literature Review

Cattle Feeding Net Returns

Feed efficiency, ADG, days on feed, cattle prices, corn prices, and interest rates are a limited list of cattle performance metrics and prices that influence net returns (Langemeier et al., 1992; Lawrence et al., 1999; Mark et al., 2000; Schroeder et al., 1993; Schroeder & Mintert, 1988). One of the largest risks producers face is price risk (Belasco et al., 2009). Schroeder and Hayenga (1988, p. 141) comment that “feedlots face significant price risks in feeder-cattle and feed procurement and in fed-cattle marketing”. Based on previous literature, live cattle price and feeder cattle price comprise 50% and 25% of the variability regarding profit, respectively; the price of corn is also influential to profit (Langemeier et al., 1992; Schroeder et al., 1993). Langemeier et al. (1992) assessed the relationship between independent variables and feedlot profits using proprietary data; the model included variables for fed cattle price, feeder cattle price, corn price, interest cost, ADG, and feed conversion. They concluded that fed cattle price had the largest influence on profit per head. In addition, Mark et al. (2000) found that fed and feeder cattle prices had greater impacts than corn prices, interest rates, and animal performance on cattle feeding profitability. On the other hand, when considering production variability, corn price, feed conversion, and ADG account for 65%, 27%, and 2% of the variation, respectively.

When assessing feed grain consumption across U.S. livestock, corn makes up the vast majority by accounting for over 80 percent of all utilization (Ash, 1992). Overall, corn price variability makes up more than 60 percent of the cost of gain variability (Albright et al., 1994). Additionally, 22 percent of cattle feeding variability is due to changes in the price of corn (Langemeier et al., 1992). Previous research also confirms the correlated relationship between the price of corn and feeder-calf price. For example, Fox (1996) found that for a one dollar per bushel increase in the price of corn, there is an associated seven to ten dollar decrease in the overall value of calves and feeder calves. Similarly, Maday (1996) reports a ten-cent per bushel increase in the price of corn results in a feeder price decrease of seventy-five cents per hundredweight.

While most cattle revenue risk comes from price variability, there is another risk—production risk. There is a tradeoff amongst cattle characteristics that play a role in feedlot performance. Factors—sex, breed, placement weight, expected finish weight, and season of feedlot placement—affect performance in the feedlot. Trapp and Cleveland (1989) found that while fed and feeder cattle price risk comprised 65.5% of profit volatility, production risk made up 22.1%. Production risk primarily occurs in the form of disease, mechanical failure, or variability in ADG (Hart et al., 2001). Another facet of profit variability majorly depends on cattle death loss, as cattle deaths across U.S. feedlots account for substantial losses (Smith, 1998). Multiple factors have been found to be associated with feedlot mortality risk—arrival weight, gender, arrival month, weather, and commingling of cattle (Loneragan, 2004; MacVean et al., 1986; Martin et al., 1982; Ribble et al., 1998). Economic losses due to mortality and culling tremendously impact North American feedlot production systems (Smith et al., 2001). When mortality occurs, there are many areas of economic loss: purchase price of the animal, feed cost from the time of placement until death, health costs, disposal costs, labor costs, and interest expense (Babcock et al., 2006; Loneragan, 2004; Loneragan et al., 2001). Additionally, the opportunity cost of not having a fed animal to sell can be substantive. Approximately 45-55% of all feedlot deaths are caused by bovine respiratory disease (BRD) (Edwards, 1996; Vogel & Parrott, 1994).

Grid Pricing

As an effort to increase economic signals sent to producers, value-based or grid pricing evolved and began replacing average pricing. Average pricing was the dominant pricing method before the 1990s where all cattle receive the same price. Alternatively, the grid pricing method undervalues above-average quality cattle and overvalues cattle that are below-average quality (Feuz et al., 1993). This pricing mechanism rewards certain carcass traits with premiums while it discounts undesirable qualities. In 1996, 16% of fed cattle marketed were priced using grid pricing; cattle producer survey respondents indicated they expected this proportion would increase to 45% by 2001 (Schroeder et al., 2002). Due to the adoption of grid pricing, a wider variety of factors may affect profitability at both the pen level and across time (McDonald & Schroeder, 2003). Selling higher quality cattle using grid pricing may result in higher profits as compared to live weight pricing with a fixed fed cattle price.

In a study of fed cattle profit where two different grid structures were evaluated, the largest effect on profit was the feeder cattle purchase price, followed by the base price of the grid. The motivation to evaluate two different grids was that grid pricing mechanisms vary from packer to packer (McDonald & Schroeder, 2003). These findings are supported by similar results across other studies that found fed and feeder cattle prices to be the most critical profit determinants (Langemeier et al., 1992; Mark et al., 2000). Collectively, McDonald and Schroeder (2003) found that although quality grade and yield grade for fed cattle priced using a grid method is important, cattle market fundamentals—grid base and feeder cattle prices—

dominate a majority of the profit variability determinants. Additionally, corn price risk is also an important piece of the profitability puzzle. These results suggest that risk management practices heavily focused on these two prices can greatly influence profitability over time.

Specifically, concerning the animal's yield and quality grade, the grade is highly influenced by genetics and management. Days on feed, or the length of time that an animal is on the feedlot's feeding regime, is the most significant management factor. In addition, the USDA quality grade that a carcass is given primarily depends on carcass marbling and animal maturity. USDA yield grade is determined by hot carcass weight, external fat thickness, ribeye area, and the amount of kidney, pelvic, and heart fat (Hale et al., 2013).

Grid pricing consists of a base price that is adjusted using premiums and discounts based on carcasses above or below the standard quality specification, given an additive structure. While there is a potential for higher prices utilizing this pricing method, there is also more risk for the producer as compared to alternative methods. Given live weight pricing, the carcass characteristic risk of the cattle purchased falls on the packer. As a small step towards mitigating packer risk and putting more pressure on the producer for dressing percentage, dressed weight pricing evolved. Dressed weight pricing is based on the total carcass weight, so packers do not bear the dressing percentage risk. While the dressed weight is known, the quality characteristics—quality grade and yield grade—are still a risk the packer endures. With grid pricing, producers bear the entire burden of cattle characteristics—dressing percentage, quality grade, and yield grade—yet face a higher risk and reward tradeoff (Ward et al., 2002). Results of this study will allow a further exploration of profit variability and expected net return distributions given specific cattle characteristics, management decisions, and simulated performance characteristics utilizing a grid pricing mechanism.

Metaphylaxis

At the time of arrival, feedlots assess the risk level of a cattle cohort to determine if metaphylaxis is advisable. Metaphylaxis is the process of mass medicating a group of high-risk animals using FDA-approved antimicrobials to reduce or eliminate an expected outbreak of disease. Metaphylaxis is used to reduce the risk of bovine respiratory disease (BRD), the most common cause of morbidity and mortality in feedlot cattle. This disease costs the beef industry an estimated $6 billion annually (Abell et al., 2017; Griffin, 1997; O'Connor et al., 2016; U.S. Department of Agriculture, 2013).

While 59.3% of feedlots utilized metaphylaxis for some cattle, only 20.5% of cattle placed on feed across all cattle placement weights were treated (U.S. Department of Agriculture, 2013). When considering metaphylaxis treatment, feedlot decision makers must weigh the perceived benefits of metaphylaxis against the treatment cost, and then choose the type of antimicrobial to administer if metaphylaxis treatment is elected (Nickell & White, 2010). Not only does metaphylaxis reduce mortality and morbidity risk in cattle, but it may also reduce additional medication cost and days on feed, while improving carcass quality (Cernicchiaro et al., 2013; Duff et al., 2000; Encinias et al., 2006; Schumann et al., 1991; Schumann et al., 1990; Tennant et al., 2014; Van Donkersgoed, 1992). When comparing high health-risk cattle that did and did not receive metaphylaxis, 550 lb. high health-risk cattle lose $104.46/head compared to treated cattle; 700 lb. high health-risk untreated cattle lost $99.26/head relative to their treated counterparts; and 850 lb. high health-risk cattle lose $63.36/head when not treated (Dennis et al., 2018). Despite technological advancement and a greater understanding of BRD, mortality associated with BRD has remained relatively unchanged and continues to be a profitability risk (Miles, 2009).

Data

A proprietary Midwestern feedlot dataset is utilized in this study to parameterize the simulation models. The dataset is a culmination of individual treatment information, individual mortality reports, pen-level closeout and performance metrics, pen-level carcass data, and individual and pen-level veterinary expense from 10 large commercial feedlot operations. This dataset includes 1,672 pens comprised of 210,371 head ranging in placement dates from February 2014 through August 2015. Pens were excluded from the study if the average placement weight was less than 300 pounds or greater than 1,110 pounds. Overall pen-level summary statistics for all animals can be seen in Table 2.1, and then animals differentiated by health-risk status can be seen in Table 2.2. In Table 2.2, the summary statistics show an increase in mortality rate and veterinary costs, and a decrease in ADG from low health-risk cattle to high health-risk cattle that received metaphylaxis upon arrival. An additional table, Table 2.3, summarizes the differences between all cattle classified by weight category. As placement weight increases, both mortality and total vet charge per head decrease on average. Two additional tables, Table B.1 and Table B.2, can be seen in the Appendix that further subset the data and provide an overview of the summary statistics by placement weight category and metaphylaxis status. This dataset was also utilized in two other papers that evaluated the use of metaphylaxis in the United States (Dennis et al., 2018, 2020).

Of the available total 1,672 pens, only 1,341 pens included carcass information, including hot carcass weight, yield percent, yield grade, and quality grade. Of those 1,341 pens, 359 pens were deemed high health-risk and received metaphylaxis and 982 pens were low health-risk. The yield grade and quality grade characteristics for the whole sample, and then the sample stratified by health-risk status can be found in Table 2.4. The similarity of our yield and quality joint distribution to yield and quality grade outcomes reported in the 2016 National Beef Quality Quality Audit that sampled 9,106 carcasses across 30 different facilities suggests our sample is representative of the current carcass quality distribution in the U.S. beef industry (Boykin et al., 2017).

In addition to the proprietary feedlot dataset, three additional datasets obtained from the Livestock Marketing Information Center were utilized in the calibration of the net returns model. These datasets were used in determining the fed cattle price, grid base price, and grid premiums and discounts. All prices, premiums, or discounts were determined by a 10-year average from May 2012 to May 2022. The fed cattle price was calculated using the 5-Area Weekly Weighted Average Direct Slaughter Cattle report. The average for live steers and heifers was $1.2629/lb. and $1.2627/lb., respectively. The grid base price was determined by the formula presented in Ward, Feuz, and Schroeder: dressed weight price plus the Choice-Select spread multiplied by the percent of animals that graded Select or lower in the observational dataset (1999). The result is a grid base price of $2.0461 per pound given an average dressed price of $2.0052 per pound, a Choice-Select spread of $0.1189/lb., and 34.41% of the dataset was graded Select or below. The second dataset used to build the grid price model premium and discount schedule was the 5-Area Weekly Weighted Average Direct Slaughter Cattle – Premiums and Discounts. The third and final dataset was the Weekly National Direct Cow and Bull Negotiated Report. This dataset was utilized to parameterize the cull price. In the article by Horton et al. (2021), the authors concluded that cull cow prices were more highly correlated with the feedlot cull prices received than other prices evaluated.

Table 2.1. Feedlot Dataset Summary Statistics

Performance Metric	Mean	St. Dev	Minimum	Maximum
Feed Conversion (lb. feed/lb. gain)	6.13	0.61	4.29	10.68
Average Daily Gain (lb. gain/day)	3.59	0.46	2.18	5.70
Mortality (%)	2.08	2.86	0.00	21.24
Placement Weight (lb.)	710.75	171.76	301.33	1096.00
Cull (%)	1.06	1.66	0.00	0.20
Railer Weight (lb.)	821.23	220.41	260.00	1830.00
Days on Feed (days)	171.80	58.81	78.32	365.97
Finish Weight (lb.)	1314.78	102.28	1009.27	1740.14
Hot Carcass Weight (lb.)	831.37	64.43	650.87	1099.46
Total Vet Charge ($/head)	25.30	17.10	1.26	121.48
Gender	Steers	49.10%	Heifers	50.90%
Season	Spring	29.07%	Summer	18.60%
	Fall	30.74%	Winter	21.59%

Notes: N = 1,672 pens

Source: Proprietary feedlot data

Table 2.2. Feedlot Dataset Summary Statistics by Health-Risk Status

Performance Metric	Mean	St. Dev	Minimum	Maximum
	Low Health-Risk			
Feed Conversion (lb. feed/lb. gain)	6.11	0.60	4.30	10.11
Average Daily Gain (lb. gain/day)	3.70	0.45	2.18	5.70
Mortality (%)	1.01	1.36	0.00	20.00
Placement Weight (lb.)	786.58	111.48	321.19	1096.00
Cull (%)	0.54	0.87	0.00	7.27
Railer Weight (lb.)	911.24	209.18	380.00	1830.00
Days on Feed (days)	144.75	27.11	78.32	347.98
Finish Weight (lb.)	1318.36	98.62	1068.81	1740.14
Hot Carcass Weight (lb.)	839.47	65.53	689.41	1099.46
Total Vet Charge ($/head)	16.09	5.18	2.05	76.73
Gender	Steers	47.01%	Heifers	52.99%
	High Health-Risk			
Feed Conversion (lb. feed/lb. gain)	6.17	0.63	4.61	10.68
Average Daily Gain (lb. gain/day)	3.31	0.35	2.36	4.77
Mortality (%)	4.85	3.73	0.00	21.24
Placement Weight (lb.)	514.51	142.48	301.33	1090.80
Cull (%)	2.41	2.32	0.00	20.00
Railer Weight (lb.)	705.23	175.99	260.00	1342.50
Days on Feed (days)	241.80	60.97	99.40	365.97
Finish Weight (lb.)	1305.51	110.76	1009.27	1551.63
Hot Carcass Weight (lb.)	809.40	55.80	650.87	977.63
Total Vet Charge ($/head)	49.13	13.84	1.26	121.48
Gender	Steers	60.94%	Heifers	39.06%

Notes: N = 1,672 pens total; N = 1,206 pens were low health-risk; N = 466 pens were high health-risk and received metaphylaxis

Source: Proprietary feedlot data

Table 2.3. Dataset I Summary Statistics by Weight Category

Placement Weight: < 625 pounds	Mean	St. Dev	Minimum	Maximum
Feed Conversion (lb. feed/lb. gain)	6.10	0.53	4.30	10.68
Average Daily Gain (lb. gain/day)	3.25	0.30	2.36	4.30
Mortality (%)	4.57	3.73	0	21.24
Placement Weight (lb.)	477.08	103.89	301.33	624.70
Cull (%)	2.26	2.15	0	18.75
Railer Weight (lb.)	700.72	183.11	260.00	1382.00
Days on Feed (days)	251.45	55.13	147.00	365.97
Finish Weight (lb.)	1290.32	111.74	1009.27	1512.39
Hot Carcass Weight (lb.)	800.92	54.60	650.87	977.63
Total Vet Charge ($/head)	44.33	15.53	5.44	121.48
Placement Weight: 625 – 775 pounds				
Feed Conversion (lb. feed/lb. gain)	6.07	0.56	4.61	9.55
Average Daily Gain (lb. gain/day)	3.59	0.41	2.18	4.97
Mortality (%)	1.54	2.09	0.00	15.87
Placement Weight (lb.)	707.85	40.51	625.87	774.96
Cull (%)	0.79	1.47	0.00	20.00
Railer Weight (lb.)	826.83	175.42	380.00	1302.00
Days on Feed (days)	158.86	20.64	116.53	251.00
Finish Weight (lb.)	1276.77	87.44	1068.81	1491.20
Hot Carcass Weight (lb.)	813.10	53.08	694.86	963.17
Total Vet Charge ($/head)	21.49	15.42	1.26	117.34
Placement Weight: > 775 pounds				
Feed Conversion (lb. feed/lb. gain)	6.20	0.68	4.80	10.11
Average Daily Gain (lb. gain/day)	3.81	0.46	2.42	5.70
Mortality (%)	0.91	1.39	0.00	17.95
Placement Weight (lb.)	864.19	71.77	775.07	1096.00
Cull (%)	0.50	0.85	0.00	5.26
Railer Weight (lb.)	984.71	202.18	485.00	1830.00
Days on Feed (days)	130.70	15.65	78.32	201.35
Finish Weight (lb.)	1361.18	87.97	1119.26	1740.14
Hot Carcass Weight (lb.)	867.00	62.40	744.31	1099.464
Total Vet Charge ($/head)	16.06	6.21	5.28	82.69

Notes: N = 441 pens for < 625 pounds; N = 549 pens for 625 – 775 pounds; and N = 682 pens for > 775 pounds

Source: Proprietary feedlot data

Table 2.4. Carcass Characteristics Stratified by Health-Risk Status

Whole Sample	
Quality Grade	
Prime, %	1.23
Choice, %	64.37
Select, %	31.25
Standard, %	0.23
Other, %	2.93
Yield Grade	
YG 1, %	13.12
YG 2, %	42.13
YG 3, %	35.84
YG 4, %	8.15
YG 5, %	0.76

By Health-Risk Status		
Item	Health-Risk Status	
	High Health-Risk	Low Health-Risk
Quality Grade		
Prime, %	1.15	1.37
Choice, %	59.32	67.02
Select, %	35.16	28.98
Standard, %	0.25	0.15
Other, %	4.11	2.47
Yield Grade		
YG 1, %	13.16	12.89
YG 2, %	44.92	41.30
YG 3, %	34.17	36.36
YG 4, %	7.09	8.62
YG 5, %	0.66	0.84

Notes: N = 1,341 pen total; N = 982 pens were classified as low health-risk; N = 359 pens were classified as high health-risk and received metaphylaxis.

Source: Proprietary feedlot data

Simulation Framework

Given the multi-faced nature of this cattle returns simulation, the methods section for this chapter is divided into focused sections for each step of the simulation—estimating necessary equations, parameterizing the simulation, and comparing the net return distributions.

Mortality Rate Model

Mortality in the feedlot is the largest health risk outcome and net return losses due to cattle mortality greatly affect cattle feeding profitability. Final morbidity and mortality are not realized until cattle harvest. The nature of mortality in the feedlot is that not every pen has a realized mortality rate greater than zero where animals die before harvest, so mortality is censored at zero for these pens. For this dataset, 32.65% of the observations are censored at zero, yet the mortality rate can vary widely based on the vector of cattle characteristics being placed on feed. Thus, a mortality model must account for differences in mean and variance of specific cattle characteristics.

An option to model censored data is a simple Tobit model with the following specification:

$$\begin{aligned} y_i^* &= x_i{}'\beta + \varepsilon_i \qquad (2.1) \\ y_i &= 0 \; if \; y_i^* \le 0, \\ y_i &= y_i^* \; if \; y_i^* > 0. \end{aligned}$$

where y_i^* represents the unobserved continuous latent variable, y_i is the observed variable, x' is a vector of independent variables, and β is a vector of coefficients. The error term, ε_i, is independently and normally distributed with mean zero and variance σ^2 (Maddala, 1983, p. 151). Additionally, when estimating a Tobit model, accounting for heteroskedasticity is necessary because the Tobit estimates are biased and inconsistent when heteroskedasticity is not regarded in estimation (Hurd, 1979; Maddala, 1983, p. 179). One of the few articles that model mortality in a stochastic simulation setting is Belasco et al. (2009); the authors utilize a Tobit Multiplicative Heteroskedasticity model to account for the censored nature of the mortality dependent variable.

The conditional mean equation for the Tobit model with multiplicative heteroskedasticity model is the same as equation (2.1). The pen-level characteristic independent variables for the Multiplicative Heteroskedastic Tobit model include $STEER$, a binary variable equal to 1 if the gender of the pen is steers or 0, otherwise; $lnPWT$, log of the placement weight; and $HIGH\_HEALTH\_RISK$, a binary variable equal to 1 if the pen of cattle was deemed high health-risk and received metaphylaxis or 0 otherwise. The pen-level mortality rate, $MORT$, is the percent of the pen that died during the feeding period.

The log-likelihood function from a simple Tobit model can be adjusted for the heteroskedasticity by replacing σ with σ_i and including σ_i^2 in the summations; additionally, $\sigma_i^2 = exp(z_i'\alpha)$. It can be written as

$$\begin{aligned} log\ L \quad = \quad & \sum_{y_i>0} -\frac{1}{2}\left[ln(2\pi) + ln(\sigma^2) + z_i'\alpha + \frac{1}{\sigma^2 \exp(z_i'\alpha)}\right] \\ & + \sum_{y_i=0} ln\left[\Phi\left(\frac{-x'\beta_i}{\sigma^2 \exp(z_i'\alpha)}\right)\right] \end{aligned} \tag{2.2}$$

where Φ is the normal CDF. The conditional variance for the Tobit model with multiplicative heteroskedasticity is specific to each observation and is

$$\sigma_i^2 \quad = \quad \sigma^2[\exp(z_i'\alpha)]^2. \tag{2.3}$$

In the case of no heteroskedasticity, α would be equal to zero. The expected value for the mortality rate is calculated using the following equation:

$$E[y|x] = \Phi\left(\frac{x'\beta}{\sigma}\right)(x'\beta + \sigma\lambda) \tag{2.4}$$

where

$$\lambda = \frac{\phi[(0 - x'\beta/\sigma)]}{1 - \Phi[(0 - x'\beta/\sigma)]} = \frac{\phi(x'\beta/\sigma)}{\Phi(x'\beta/\sigma)} \tag{2.5}$$

(Greene, 2018, pg. 933-946).

When estimating a simple Tobit model with $STEERS$, $lnPWT$, and $HIGH\_HEALTH\_RISK$ as independent variables and the pen-level mortality rate, $MORT,$ as the censored dependent variables, we obtain the following results:

Table 2.5. Mortality Tobit Model Results

Variable	Conditional Mean
Constant	21.2069* (2.478)
High Health-Risk	3.1830* (0.233)
Steers	0.1544 (0.150)
Log Placement Weight	-3.1811* (0.372)
Observations	1,672
Log Likelihood	-3239.52

Notes: * denotes the estimate is statistically significant at the 5% level. Standard errors are in the parentheses.

To further investigate the Tobit model with multiplicative heteroskedasticity, we believe that mortality variances will differ between groups of cattle with different risk classifications—low health-risk cattle and high health-risk cattle that receive metaphylaxis. The estimation results are outlined in Table 2.6.

Table 2.6. Mortality Tobit Multiplicative Heteroskedasticity Model Results

Variable	Conditional Mean	Conditional Variance
Constant	19.5600* (2.265)	1.9621* (0.056)
High Health-Risk	2.9178* (0.247)	0.6863* (0.045)
Steers	0.1902 (0.116)	
Log Placement Weight	-2.8859* (0.341)	
Observations	1,672	
Log Likelihood	-3120.11	

Notes: * denotes the estimate is statistically significant at the 5% level. Standard errors are in the parentheses.

To determine the appropriateness of assuming multiplicative heteroskedasticity, a likelihood ratio test was performed with a restricted model. The restricted model, in this case, is specified such that the conditioning variable has no impact on variability. The likelihood ratio test of the model with 5 degrees of freedom was statistically significant with a P-value less than 0.001; the null hypothesis is rejected for the alternative hypothesis that variability is impacted by the conditioning variable. Thus, a Tobit Multiplicative Heteroskedasticity model is appropriate to account for the censoring of the dependent variable, as well as modeling the mean and variance based on specific placement characteristics.

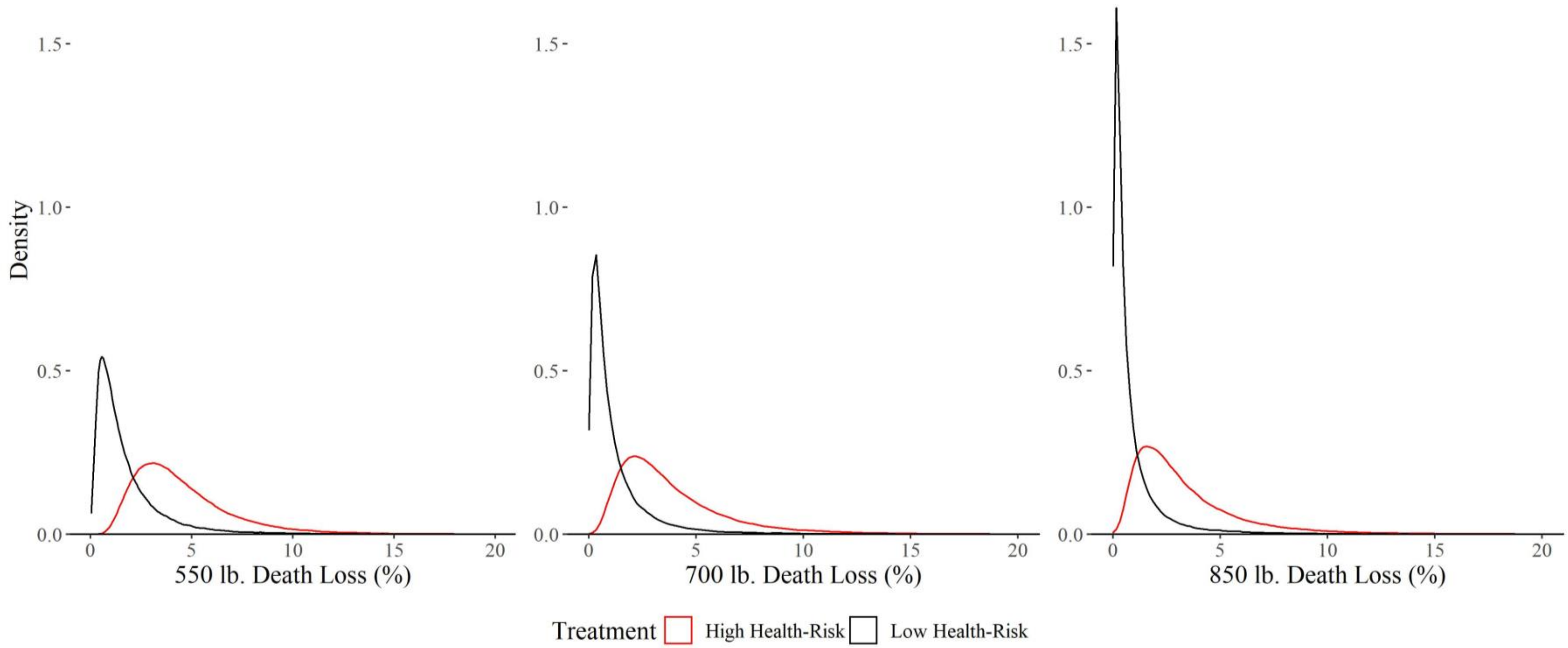
The $HIGH\_HEALTH\_RISK$ binary variable is statistically significant for the conditional mean and variance of mortality. Not only does the mean of the mortality rate increase if cattle are deemed high health-risk and receive metaphylaxis, but the standard deviation of the mortality distribution also increases as well. The coefficient for the $STEER$ binary variable indicated that there is not a statistically significant difference in mortality rates between steers and heifers in the feedlot. A one percentage point increase in the placement weight is associated with a 2.89% decrease in mortality rate. The mortality distributions shown in Figure 2.2 are generated using the results of the Mortality Tobit Multiplicative Heteroskedasticity Model as shown in Table 2.6, and to parameterize equations (2.6) and (2.7), where $MORT_{w,\tau}$ is the pen-level mortality rate as a percentage and σ^2 is the variance. Alternative model specifications were considered with additional variables included in the variance equation, and the model that minimized Akaike information criteria was selected.

$$MORT_{w,\tau} = 19.5600 + 2.9178\, HIGH\_HEALTH\_RISK + 0.1902\, STEER - 2.8859\, lnPWT \quad (2.6)$$

$$\sigma^2 = 1.9621 + 0.6863\, HIGH\_HEALTH\_RISK \quad (2.7)$$

The generated mortality distributions are for low health-risk and high health-risk steers placed at the corresponding weights—550 pounds, 700 pounds, and 850 pounds. Higher health-risk cattle that receive metaphylaxis have mortality distributions with higher means and wider standard deviations across all three placement weights as compared to cattle deemed low health-risk upon placement. The mean of the expected mortality distribution decreases as the placement weight of the cattle increases.

Figure 2.1. Mortality Distributions across Placement Weight and Health-Risk Category



Note: Mean and standard deviation mortality parameters for high health-risk cattle that receive metaphylaxis and low health-risk cattle, respectively, are: i) 850 lb.: 3.37 (2.77), 0.93 (1.96); ii) 700 lb.: 3.87 (2.77), 1.28 (1.96); iii) 550 lb.: 4.52 (2.77), 1.78 (1.96). Standard deviations are in the parentheses.

Performance Metric and Veterinary Expense Models

Multiple model specifications have been used to quantify ADG, AFC, and veterinary cost per head (VCPH) including Multivariate Tobit, ordinary least squares, maximum likelihood, and linear mixed models (Belasco, 2008; Belasco et al., 2009; Dennis et al., 2018, 2020; Irsik et al., 2006). In our study, we utilized linear mixed models (LMM) to parameterize the effects of pen-level characteristics—sex, placement weight, mortality rate, and health-risk status. The linear predictor for the LMM model is

$$y = X\beta + Zu + \varepsilon \tag{2.8}$$

where X is the matrix of fixed effects, β is the vector of fixed effect parameters, Z is the design matrix of random effects, u is the vector of random effects, and ε is the vector of random errors. The expected value of y is

$$E(y) = X\beta. \tag{2.9}$$

ADG, AFC, and VCPH are both individually modeled as a function of the $STEERS$ binary variable, $lnPWT$, and the pen-level mortality rate, $MORT$, as fixed effects. The VCPH model includes an additional $HIGH\_HEALTH\_RISK$ binary variable equal to 1 if the group of cattle was deemed high health-risk upon placement and administered metaphylaxis or 0 otherwise. Additional feedlot-specific characteristics also influence the variation due to differences in geographic location, management practices, and differences across cattle placed on feed at certain locations, thus company and cohort size (i.e., number of head per purchase lot) as random effects in all three models—ADG, AFC, and VCPH. Seasonal effects were not included in these equations due to the short timeframe of the dataset.

Estimation results for *ADG*, *AFC*, and *VCPH* per head are shown in Table 2.7 and are represented by equations (2.10) through (2.12).

$$ADG_{w,k,\tau} = -1.686 + 0.289\, STEER + 0.786\, lnPWT_w - 0.009\, MORT_{w,\tau} \quad (2.10)$$

$$AFC_{w,k,\tau} = 1.486 - 0.239\, STEER + 0.717\, lnPWT_w + 0.087\, MORT_{w,\tau} \quad (2.11)$$

$$VCPH_{w,k,\tau} = 29.702 + 1.141\, STEER - 2.172\, lnPWT_w + 1.392\, MORT_{w,\tau} + 24.684\, HIGH\_HEALTH\_RISK_\tau \quad (2.12)$$

All fixed effect coefficients are statistically significant and similar to the parameter estimates in Dennis et al. (2018). Steer cohorts are associated with an increase in *ADG* and *VCPH*, but a decrease in *AFC* compared to heifer pens. An increase in the log placement weight of cohorts indicates an increase in *ADG* and *AFC*, yet a decrease in the *VCPH* per head. This result is expected due to cattle with heavier placement weights being stepped up to full-feed high-energy feed rations upon feedlot placement as an alternative to a lower energy grower ration. Finally, for *VCPH*, if the group of cattle is deemed high health-risk and prophylactic metaphylaxis is administered, an additional estimated cost of $24.68 per head expense is incurred.

Table 2.7. Linear Mixed Models for Performance Metrics

Variables	ADG	AFC	VCPH
Fixed Effects			
Constant	-1.686* (0.267)	1.468* (0.380)	29.702* (6.434)
Steers	0.289* (0.019)	-0.239* (0.026)	1.141* (0.354)
Log Placement Weight	0.786* (0.040)	0.717* (0.056)	-2.172* (0.935)
Mortality	-0.009* (0.004)	0.087* (0.006)	1.392* (0.079)
High Health-Risk			24.684* (0.628)
Random Effects[a]			
Company	0.006	0.026	17.767
Cohort Size	0.017	0.030	0.663
Observations	1,672	1,672	1,672
Log Likelihood	-717.854	-1304.22	-5654.32

Notes: [a] Variances are reported for each random effect. * denotes the estimate is statistically significant at the 5% level.

Net Returns Models

Live Weight Net Returns Model

The remaining core of the simulation framework for this study is adapted from Belasco et al. (2009) and Dennis et al. (2018). Adjustments to these similar models are made through changing some previously deterministic variables to stochastic distributions, as well as adjusting inputs given previous literature and data calibration. The model will be modified and extended to incorporate grid pricing as well.

This simulation exercise considers three different purchase weight categories[2], CPW_w — 550 pounds, 700 pounds, and 850 pounds. In addition to animals that reach maturity and those that die, an assumed fixed proportion of the lot, conditional on placement weight, is marketed prematurely represented by $CULL_w$ in the simulation. These culled animals, often called realizers or railers, are typically lame or chronically sick animals that are sold at sizably discounted market prices. As noted in Feuz, Feuz, and Johnson (2020), managers are generally willing to accept discounted prices for culled animals as this revenue is preferred over the alternative possibility of premature death. One change to the structural models from Belasco et al. (2009) and Dennis et al. (2018) is how cull cattle are priced. Horton et al. (2021) concluded that for all prices evaluated, feedlot cull prices were most highly correlated with national dressed cull cow prices, specifically Breaker [75% lean]; over 500 lb. HCW. For all hot carcass weights ranging from below 400 pounds to over 600 pounds, the mean price received for culled animals was 74.63% of the mean cull cow price. Subsequently, the 10-year average national cull cow price used in the calculation is \$1.4070 per dressed pound, resulting in a cull price, $CULLP$, of \$1.05

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[2] For the simulation equations, the subscript w denotes the cattle placement weight of 550, 700, or 850 pounds.

per dressed pound. The average live weight of culled animals is 701 pounds, 827 pounds, and 985 pounds for each placement weight group of 550 pounds, 700 pounds, and 850 pounds, respectively. When multiplied by the average sample dressing percentage of 63.32%, the culled animal hot carcass weights, $CULLW_w$, are equal to 444 pounds, 524 pounds, and 624 pounds.

The cattle purchase price, FRP_w, is stratified by placement weight—550 pounds, 700 pounds, and 850 pounds—equal to $1.7526/lb., $1.5614/lb., and $1.4650/lb., respectively. These feeder cattle purchase prices are determined by the breakeven for low health-risk cattle where the profit per head is approximately equal to zero. The model incorporates a 5% annualized interest rate—*IR*, as well as a 4% pencil shrink, *SHRINK*, to account for weight lost during shipping. The corn price, *FEED*, is the price of corn per pound. We expect animals that were placed at a heavier weight to finish at a heavier weight so the mean and standard deviation values depend on placement weight and health-risk status. The finished animal weight[3], $CSW_{w,k,\tau}$, determined at maturity for animals that are alive is simulated through a normal distribution with a mean $(\boldsymbol{\gamma_k})$ and standard deviation $(\boldsymbol{\sigma})$ dependent on placement weight and health-risk status. The model uses the finish weight means and standard deviations found in Table B.1 and Table B.2. For low health-risk animals not treated with metaphylaxis, the mean (standard deviation) finish weights are 1,248 pounds (75 pounds), 1,269 pounds (84 pounds), and 1,360 pounds (88 pounds) for placement weights of 550, 700, and 850 pounds, respectively. For high-risk animals treated with metaphylaxis, the mean (standard deviation) finish weights by CPW_w are 1,299 pounds (114 pounds), 1,315 pounds (93 pounds), and 1,406 pounds (59 pounds), sequentially. The finished animal weight is equal to zero for animals that died $(i.e., k = dead)$. The fed cattle price, *FP*, used to calculate total revenue is set to $1.2628/lb.

[3] The subscript *k* denotes the death loss group of either *k* = *alive* or *k* = *dead*.

The expected mean values for pen-level average daily gain in pounds per head per day (*ADG*), average feed conversion in pounds fed to one pound gained (A*FC*), and health cost in $/head (*VCPH*) are calculated using the coefficient estimates of the linear mixed models. Due to the correlated nature of *ADF*, *AFC*, and *VCPH*, the simulation necessitates the use of Iman and Conover's (1980) algorithm. This algorithm allows for the simulation of multivariate data where each variable has a given univariate distribution and is correlated with the other performance metrics according to the specified correlation matrix. This correlation matrix is included in Table B.3 for reproducibility. For the simulation, these variables are normally distributed, $N_k \sim (\mu_k, \sigma)$, where μ_k is the vector of expected values representing *ADG*, *AFC*, and *VCPH* estimated from equations (2.10) through (2.12) and σ is a vector containing the standard deviation of the residuals for each estimated equation.

Additional calculated or simulated inputs for the live weight returns model include the following: days on feed, $DOF_{w,k,\tau}$; feed cost, $FC_{w,k,\tau}$; feeder cattle purchase cost, $FDRC_w$; interest cost, $IC_{w,k,\tau}$; cattle sales total revenue, $TR_{w,k,\tau}$; yardage cost, $YC_{w,k,\tau}$; and net feeding returns, $\rho_{w,k,\tau}$. These inputs are depicted by equations (2.13) through (2.19). Days on feed for animals that die are fixed at 106 days, 73 days, and 68 days based on the average days from placement to death by CPW_w, respectively; these DOF for dead animals are calculated from observational data.

To determine the weighted-average net return distribution, a random mortality rate ($MORT_{w,\tau}$) is sampled from the corresponding log-normal death loss distribution using Halton draws. Halton draws allow for intelligent sampling across the domain of a distribution, which dramatically increases the estimation speed without sacrificing simulation performance. This allows for a smaller number of draws while also reducing the simulation error (Train, 1999).

Utilizing a representative pen size of 120 head, $\varphi_{w,\tau} \times 120$ net returns are calculated for *k* = *dead* animals, $CULL_w \times 120$ net returns are calculated for the animals that are culled, and $\left(1 - \varphi_{w,\tau} - CULL_w\right) \times 120$ net returns are calculated for *k* = *alive* animals. The mean of each pen is then computed, and this process is repeated 10,000 times to determine the weighted-average net return distribution.

Table 2.8. Live Weight Net Returns Model Variables

Fixed		
$\boldsymbol{CPW_w}$	Cattle purchase weight (lb./head)	550, 700, 850
$\boldsymbol{CULL_w}$	Proportion of chronically ill animals culled from the remaining cohort based on CPW—550, 700, and 850	0.0226, 0.0079, 0.0050
$\boldsymbol{CULLP}$	Dressed price received for cull animals ($/dressed lb.)	1.05
$\boldsymbol{CULLW_w}$	Average dressed weight of culled animals by CPW_w (dressed lb./head)	444, 524, 624
$\boldsymbol{FEED}$	Corn price when cattle are placed on feed ($/lb.)	0.0923
$\boldsymbol{FP}$	Fed cattle sale price ($/lb.)	1.2628
$\boldsymbol{FRP_w}$	Purchase price for 550-, 700-, and 850-pound calves ($/lb.)	1.7526, 1.5614, 1.4650
$\boldsymbol{IR}$	Annualized interest rate	0.05
$\boldsymbol{SHRINK}$	Percentage shrink in live weight when marketed	4%
Simulated/Calculated		
$\boldsymbol{\varphi_{w,k,\tau}}$	Proportion of death loss in pen	$(\boldsymbol{MORT_{w,\tau}/100})$
$\boldsymbol{CSW_{w,k,\tau}}$	Finished animal weight (lb./head) if animal reaches maturity (i.e., $k = alive$); 0 otherwise (i.e., $k = dead$)	$N_k \sim (\gamma_k, \sigma)$
$\boldsymbol{ADG_{w,k,\tau}}$	Average daily gain during feeding (lb./head/day)	See equation (2.10)
$\boldsymbol{AFC_{w,k,\tau}}$	Average pounds of feed consumer per pound of weight gain (lb. feed/lb. gain)	See equation (2.11)
$\boldsymbol{VCPH_{w,\tau}}$	Animal health care cost including metaphylaxis, pull-and-treat, vaccinations, labor costs, etc. ($/head)	See equation (2.12)
$\boldsymbol{DOF_{w,k,\tau}}$	Number of days on feed (days)	See equation (2.13)
$\boldsymbol{YC_{w,k,\tau}}$	Yardage cost of feeding cattle ($/head)	See equation (2.14)
$\boldsymbol{FC_{w,k,\tau}}$	Feed cost ($/head)	See equation (2.15)
$\boldsymbol{FDRC_w}$	Feeder cattle purchase cost ($/head)	See equation (2.16)
$\boldsymbol{IC_{w,k,\tau}}$	Interest cost ($/head)	See equation (2.17)
$\boldsymbol{TR_{w,k,\tau}}$	Total revenue from cattle sales ($/head)	See equation (2.18)
$\boldsymbol{\rho_{w,k,\tau}}$	Net feeding returns ($/head) for each weight ($w$), death loss group ($k$), and health-risk classification (τ)	See equation (2.19)

Note: Adapted from “Value of Arrival Metaphylaxis in U.S. Cattle Industry” by Dennis et al., 2018, *Journal of Agricultural and Resource Economics* 43(2), p. 241

$$DOF_{w,k,\tau} = \frac{CSW_{w,k,\tau} - CPW_w}{ADG_{w,k,\tau}} \tag{2.13}$$

$$YC_{w,k,\tau} = 0.40 \times DOF_{w,k,\tau} \tag{2.14}$$

$$FC_{w,k,\tau} = FEED\{AFC_{w,\tau}[CSW_{w,k,\tau} \times \left(1 - \varphi_{w,k,\tau} - CULL_w\right) - CPW_w]\} \tag{2.15}$$

$$FDRC_w = FRP_w \times CPW_w \tag{2.16}$$

$$IC_{w,k,\tau} = \left\{0.5 \times \left[YC_{w,k,\tau} + FC_{w,k,\tau} + VCPH_{w,\tau}\right] + FDRC_w\right\} \times DOF_{w,k,\tau} \times (IR/365) \tag{2.17}$$

$$TR_{w,k,\tau} = FP \times CSW_{w,k,\tau} \times (1 - SHRINK) \times \left(1 - \varphi_{w,k,\tau} - CULL_w\right) + (CULL_w \times CULLW_w \times CULLP) \tag{2.18}$$

$$\rho_{w,k,\tau} = TR_{w,k,\tau} - FDRC_w - YC_{w,k,\tau} - FC_{w,k} - VCPH_{w,\tau} - IC_{w,k,\tau} \tag{2.19}$$

Grid Pricing Net Returns Model

An essential element of the grid pricing model is the yield grade and quality grade a carcass receives so that proper premiums or discounts can be tabulated. The joint observational distribution from the whole dataset observational data is shown in Table 2.10, and then each distribution by health-risk status in Table 2.11 and Table 2.12. The intersection of the yield grade and quality grade is the probability of that animal receiving that specific yield and quality grade. For example, based on the observational data, the probability of an animal grading Yield Grade 2, Choice is 27.12%, whereas the chance of being a Yield Grade 1, Prime is only 0.16%.

The grid price model simulation is similar to the live weight pricing model and the only difference arises from how the total revenue is calculated. The equations utilized for the grid price model are outlined in Table 2.9. The hot carcass weight, $HCW_{w,k,\tau}$ for each animal is found by multiplying the dressing percentage divided by 100 for each health-risk treatment status, $(DP_{\tau}/100)$, and the randomly drawn finished animal weight, $CSW_{w,k,\tau}$. The grid price per animal, $GP_{w,k,\tau}$, is calculated by adding any premiums or subtracting any discounts for yield grade, quality grade, or hot carcass weight from the base price for that specific animal. Given an average dressed price of $2.0052 per pound, a Choice-Select spread of $0.1189/lb., and the proportion of the dataset that graded Select or below, the average grid base price is set to $2.0461. This is the formula proposed by Ward, Feuz, and Schroeder to determine the grid base price (1999).

As in Thompson et al.'s 2016 article, two additional grids are also evaluated for sensitivity. The grid base price for Alternate Grids 1 and 2 are calculated from the 25th and 75th percentile of the Choice-Select spread, respectively, for the same 10-year time frame utilized for all other average price calculations. The corresponding weeks chosen for the Alternate Grids 1 and 2 were September 26th, 2016 and August 24th, 2020. The yield grade, quality grade, and carcass weight premiums and discounts are utilized from those same weeks. The grid premiums and discounts for all three options—average price, alternate grid 1, and alternate grid 2—are in Table 2.13. The final grid price total revenue per head, $GPTR_{w,k}$, and the grid price net returns per head, $\pi_{w,k,\tau}$, are denoted by equations (2.22) and (2.23). The grid price model follows the same procedures as the live weight model in determining the weighted-average net return distribution.

A random mortality rate ($MORT_{w,\tau}$) is sampled from the corresponding log-normal death loss distribution using Halton draws. Utilizing a representative pen size of 120 head, $\varphi_{w,k,\tau} \times 120$ net returns are calculated for k = *dead* animals, $CULL_w \times 120$ net returns are calculated for the animals that are culled, and $\left(1 - \varphi_{w,k,\tau} - CULL_w\right) \times 120$ net returns are calculated for k = *dead* animals. The mean of each pen is then computed, and this process is repeated 10,000 times to determine the weighted-average net return distribution.

$$HCW_{w,k,\tau} = (DP_\tau/100) \times CSW_{w,k,\tau} \tag{2.20}$$

$$GP_{w,k,\tau} = BASE\ PRICE\ +\ PREMIUMS\left(YG_k, QG_k, HCW_{w,k,\tau}\right) - DISCOUNTS(YG_k,\ QG_k, HCW_{w,k,\tau}) \tag{2.21}$$

$$GPTR_{w,k,\tau} = HCW_{w,k,\tau} \times GP_{w,k,\tau} \times \left(1\ -\ \varphi_{w,k,\tau}\ - CULL_w\right) + (CULL_w \times CULLW_w \times CULLP) \tag{2.22}$$

$$\pi_{w,k,\tau} = GPTR_{w,k,\tau} - FDRC_{w,k,\tau} - YC_{w,k,\tau} -\ FC_{w,k,\tau} - VCPH_{w,\tau} - IC_{w,k,\tau} \tag{2.23}$$

Table 2.9. Grid Pricing Net Returns Model Variables

Fixed		
CPW_w	Cattle purchase weight (lb./head)	550, 700, 850
$CULL_w$	Proportion of chronically ill animals culled from the remaining cohort based on CPW—550, 700, and 850	0.0226, 0.0079, 0.0050
$CULLP$	Dressed price received for cull animals ($/dressed lb.)	1.05
$CULLW_w$	Average dressed weight of culled animals by CPW_w (dressed lb./head)	444, 524, 624
DP_τ	Dressing percentage by health-risk status: low-risk and high-risk treated with metaphylaxis	63.74%, 62.56%
$FEED$	Corn price when cattle are placed on feed ($/lb.)	0.0923
FP	Fed cattle sale price ($/lb.)	1.2628
FRP_w	Purchase price for 550-, 700-, and 850-pound calves ($/lb.)	1.7526, 1.5614, 1.4650
IR	Annualized interest rate	0.05
Simulated		
$\varphi_{w,k,\tau}$	Proportion of death loss in pen	$(MORT_{w,\tau}/100)$
$CSW_{w,k,\tau}$	Finished animal weight (lb./head) if animal reaches maturity (i.e., k = *alive*); 0 otherwise (i.e., k = *dead*)	$N_k \sim (\gamma_k, \sigma)$
$ADG_{w,k,\tau}$	Average daily gain during feeding (lb./head/day)	See equation (2.10)
$AFC_{w,k,\tau}$	Average pounds of feed consumer per pound of weight gain (lb. feed/lb. gain)	See equation (2.11)
$VCPH_{w,\tau}$	Animal health care cost including metaphylaxis, pull-and-treat, vaccinations, labor costs, etc. ($/head)	See equation (2.12)
$DOF_{w,k,\tau}$	Number of days on feed (days)	See equation (2.13)
$YC_{w,k,\tau}$	Yardage cost of feeding cattle ($/head)	See equation (2.14)
$FC_{w,k,\tau}$	Feed cost ($/head)	See equation (2.15)
$FDRC_w$	Feeder cattle purchase cost ($/head)	See equation (2.16)
$IC_{w,k,\tau}$	Interest cost ($/head)	See equation (2.17)
$HCW_{w,k}$	Hot carcass weight (lbs.)	See equation (2.20)
$GP_{w,k}$	Grid price per animal	See equation (2.21)
$GPTR_{w,k}$	Grid pricing total revenue	See equation (2.22)
$\pi_{w,k,\tau}$	Net feeding returns ($/head) for each weight ($w$), death loss group ($k$), and health-risk classification (τ)	See equation (2.23)

Note: Adapted from "Value of Arrival Metaphylaxis in U.S. Cattle Industry" by Dennis et al., 2018, *Journal of Agricultural and Resource Economics* 43(2), p. 241

Table 2.10. Joint Distribution 1 – Yield and Quality Grade Outcomes for All Cattle

Quality Grade	Yield Grades					Total
	1	2	3	4	5	
Prime	0.0016	0.0845	0.0410	0.0003	0.0038	0.1312
Choice	0.0052	0.2712	0.1317	0.0010	0.0123	0.4213
Select	0.0044	0.2307	0.1120	0.0008	0.0105	0.3584
Standard	0.0010	0.0525	0.0255	0.0002	0.0024	0.0815
Other[4]	0.0001	0.0049	0.0024	0.0000	0.0002	0.0076
Total	0.0123	0.6437	0.3125	0.0023	0.0293	1.0000

Note: Values in the table are the probability of each quality grade and yield grade combination

Table 2.11. Joint Distribution 2 – Yield and Quality Grade Outcomes for High Health-Risk Cattle that Received Metaphylaxis

Quality Grade	Yield Grades					Total
	1	2	3	4	5	
Prime	0.0016	0.0847	0.0411	0.0003	0.0039	0.1316
Choice	0.0055	0.2892	0.1404	0.0010	0.0132	0.4492
Select	0.0042	0.2200	0.1068	0.0008	0.0100	0.3417
Standard	0.0009	0.0456	0.0222	0.0002	0.0021	0.0709
Other[4]	0.0001	0.0042	0.0021	0.0000	0.0002	0.0066
Total	0.0115	0.5932	0.3516	0.0025	0.0411	1.0000

Note: Values in the table are the probability of each quality grade and yield grade combination

Table 2.12. Joint Distribution 3 –Yield and Quality Grade Outcomes for Low Health-Risk Cattle

Quality Grade	Yield Grades					Total
	1	2	3	4	5	
Prime	0.0016	0.0830	0.0403	0.0003	0.0038	0.1289
Choice	0.0051	0.2658	0.1291	0.0009	0.0121	0.4130
Select	0.0045	0.2340	0.1136	0.0008	0.0107	0.3636
Standard	0.0011	0.0555	0.0269	0.0002	0.0025	0.0862
Other[4]	0.0001	0.0054	0.0026	0.0000	0.0002	0.0084
Total	0.0137	0.6702	0.2898	0.0015	0.0247	1.0000

Note: Values in the table are the probability of each quality grade and yield grade combination

[4] Other includes miscellaneous quality grades not captured in Prime, Choice, Select, or Standard quality grades.

Table 2.13. Grid Premium and Discounts

Category	10-Year Average	Alternate Grid 1[1]	Alternate Grid 2[1]
Base Price ($/lb.)	$2.0461	$2.0309	$2.0588
Quality Grade (QG) Adjustment			
Prime	0.1621	0.1832	0.1114
Choice	0.0000	0.0000	0.0000
Select	(0.1189)	(0.0748)	(0.1557)
Standard	(0.2577)	(0.2042)	(0.3039)
Other[2]	(0.3759)	(0.3742)	(0.3799)
Yield Grade (YG) Adjustment			
1	0.0520	0.0571	0.0572
2	0.0253	0.0298	0.0300
3	0.0000	0.0000	0.0000
4	(0.0954)	(0.0977)	(0.0980)
5	(0.1453)	(0.1480)	(0.1000)
Carcass Weight (CW) Adjustment			
400-500	(0.2637)	(0.2578)	(0.2558)
500-550	(0.2203)	(0.2312)	(0.2283)
550-600	(0.0307)	(0.0280)	(0.0298)
600-900	0.0000	0.0000	0.0000
900-1000	(0.0030)	(0.0019)	(0.0023)
1000-1050	(0.0239)	(0.0236)	(0.0225)
>1050	(0.2132)	(0.2321)	(0.1686)

[1] Alternate Grids 1 and 2 are selected from the weeks at the 25th and 75th percentile of the Choice-Select spread, respectively.

[2] Quality Grade – Other discount is the average of Bullock/Stag, Hardbone, and Dark Cutter.

Comparison of Net Return Distributions

Multiple techniques can be utilized to determine the distributional differences for the various combinations of weight categories, sex, and management treatments. For simple measures of the distributional characteristics, we can utilize simple summary statistics of the distribution for the center and the spread or variability about the mean. The expected mean and median of the distribution provide information regarding the center; mean absolute deviation and standard deviation are more telling of the variability.

Additional methods to account for higher order moment distributional differences include a Kolmogorov-Smirnov (K.S.) two-sample test, a non-parametric test to assess the statistical significance of distributional differences across different distributions. A paired t-test is not appropriate in this scenario because it only reports statistically different mean differences instead of assessing real distributional differences. This is one method to determine if two samples come from the same distribution. The two-sample test is an extension of the one-sample K.S. test, but instead of comparison to a theoretical distribution, the two empirical distributional functions are compared. The following equation determines the KS two-sample test statistic:

$$D = |E_1(i) - E_2(i)| \tag{2.24}$$

where E_1 and E_2 are the empirical distribution functions for the respective data samples computed over each point in both samples. The null hypothesis is that two samples come from a common distribution, whereas the alternative hypothesis is that the two samples do not come from a common distribution (Conover, 1999).

Another consideration is to employ tests of stochastic dominance, which are Kolmogorov-Smirnov type tests. As a way of determining distributional superiority, these tests compare multiple partial integrals of the underlying distribution. First-order stochastic dominance does not require any restrictions beyond a nondecreasing utility function, i.e., feedlot decision makers prefer higher net returns over lower net returns. For first-order stochastic dominance, when comparing two different distributions denoted at distributions A and B, we consider the cumulative distribution functions, $f_A(x)$ and $f_B(x)$, with the objective to maximize x, or the value of net returns. If

$$f_A(x) \leq f_B(x) \; \forall \; x \tag{2.25}$$

then distribution A is superior to distribution B, or the cumulative distribution function (CDF) for distribution A is to the right of the CDF for distribution B. In terms of net returns, option A would give an overall higher net return value than the vector of inputs used to simulate distribution B. If one CDF line does not lie entirely above the other, higher-order stochastic dominance tests are available if needed (Hadar & Russell, 1969; Hanoch & Levy, 1969; Hardaker et al., 2004; Kaur et al., 1994). Table 2.14 provides a review of stochastic simulation studies that use distributional comparison methods associated with beef cattle production simulations.

Table 2.14. Similar Beef Cattle Stochastic Simulation Applications and Methods

Authors	Application	Methods
Pacheco et al. (2014)	Estimating the risk of feedlot finishing young versus older steers	Stochastic dominance; Kolmogorov-Smirnov test
Pacheco et al. (2017)	Stochastic simulation of feedlot finishing steers finished at different weights in Brazil	Stochastic dominance; Kolmogorov-Smirnov test
Khakbazan et al. (2014)	Stochastic simulation of various beef calving and feeding systems in Canada	Stochastic dominance; Stochastic efficiency with respect to a function

Results

Simulation

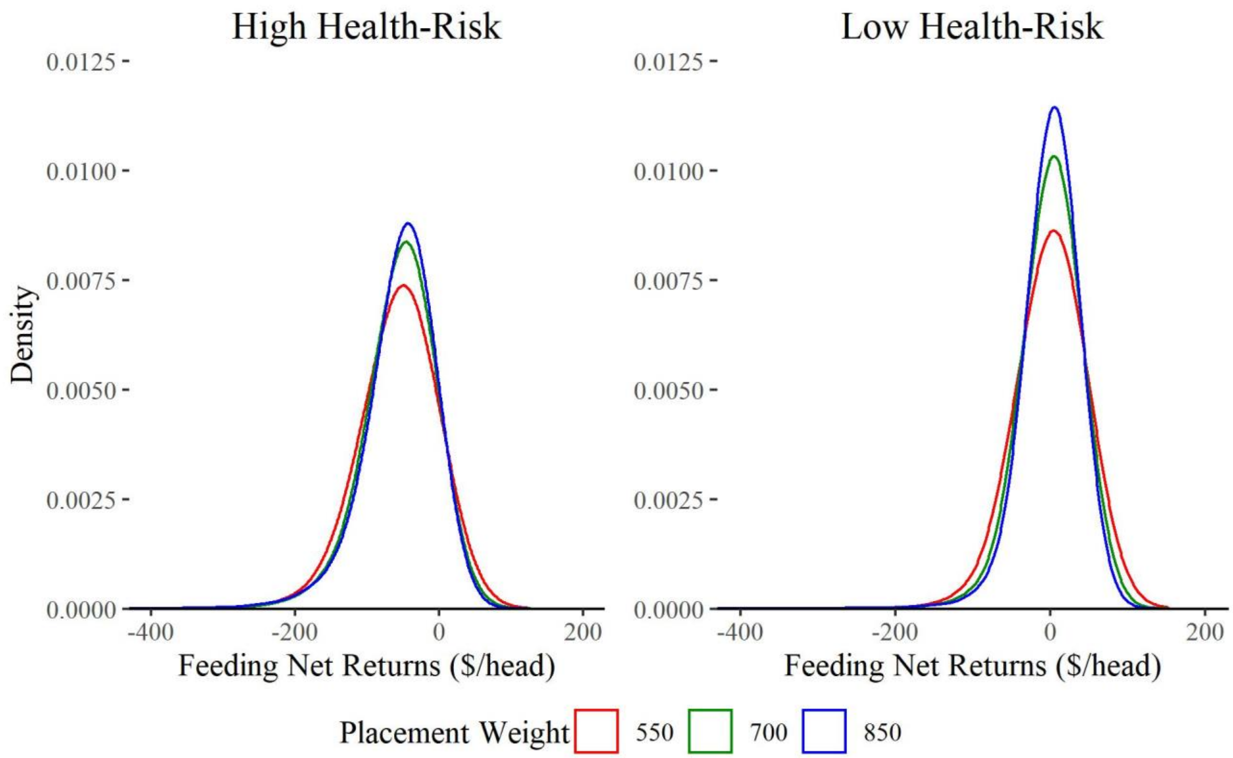
Live Weight Model

Based on the simulated weighted-average net returns for the live weight model, the difference between 550 lb. low-risk and high-risk cattle that receive metaphylaxis is $56.50 per head which implies that high-risk cattle lose $56.50 on average compared to their low-risk counterparts if purchased at the same price per pound. For cattle placed at 700 pounds, the average loss on high-risk cattle compared to low-risk cattle is $54.79. For 850-pound high-risk cattle compared to low-risk 850-pound cattle, high-risk cattle face a loss of $54.54 per head. Full distributional summary statistics for each weight and treatment status category are in Table 2.15, along with the plotted distributions of mean net returns per head in Figure 2.2. As illustrated in Figure 2.2, the net return distributions for all high health-risk cattle are much more broadly dispersed than the distributions of the lower-risk cattle. At the same purchase and fed cattle price, not only are higher-risk cattle associated with more variable returns based on the distributional standard deviations, but their returns are also much lower than for lower-risk cattle. Due to this realized loss on high-risk cattle, there are generally higher transaction costs associated with healthier cattle that have fewer risk factors for morbidity and mortality (Dennis et al., 2018). Thus, there is an incentive to purchase high health-risk cattle at a reduced price given their reduced performance and higher cost per head (Ives & Richeson, 2015).

Table 2.15. Live Weight Simulation Net Return Summary Statistics

Placement Weight	Net Return ($/head)				
	Minimum	Median	Mean	Max	St. Dev.
High Health-Risk Cattle					
550 pounds	-408.44	-53.29	-56.50	126.67	53.34
700 pounds	-455.85	-50.54	-54.75	103.61	49.36
850 pounds	-541.02	-48.99	-54.53	98.83	50.22
Low Health-Risk Cattle					
550 pounds	-396.52	2.09	0.00	151.42	44.96
700 pounds	-497.19	2.48	0.04	138.42	39.96
850 pounds	-650.14	2.68	0.01	106.70	38.48

Figure 2.2. Live Weight Simulated Net Return Distributions



Grid Price Model

A breakdown of summary statistics for the grid pricing model for each weight and health-risk status given the Average Price Grid Premiums and Discounts and Joint Distribution 1 is in Table 2.16. The differences across lower health-risk and higher health-risk cattle are larger when evaluated on a grid pricing structure. The difference between 550 lb. low health-risk and high health-risk cattle that receive metaphylaxis is $84.71 which implies that high health-risk cattle lose $84.71 on average compared to their low health-risk counterparts given the same purchase price and grid structure. For cattle placed at 700 pounds, the average loss on high health-risk cattle compared to low health-risk cattle is $83.95. For 850-pound high health-risk cattle compared to low health-risk 850-pound cattle, high health-risk cattle face a loss of $85.54 per head. As illustrated in Figure 2.3, the net return distributions for high health-risk cattle receiving metaphylaxis are more broadly dispersed than the distributions of the lower health-risk cattle given the same joint yield and quality grade distribution.

Table 2.16. Grid Price Simulation Net Return Summary Statistics

Placement Weight	Net Return ($/head)				
	Minimum	Median	Mean	Max	St. Dev.
High Health-Risk Cattle					
550 pounds	-364.37	3.25	0.04	185.84	55.24
700 pounds	-415.23	8.66	4.15	115.11	51.46
850 pounds	-500.43	14.62	8.30	158.53	52.53
Low Health-Risk Cattle					
550 pounds	-338.04	87.49	84.75	254.42	46.78
700 pounds	-446.03	90.67	88.10	217.17	42.03
850 pounds	-606.36	96.79	93.84	204.90	40.85

Figure 2.3. Simulated Grid Price Net Return Distributions

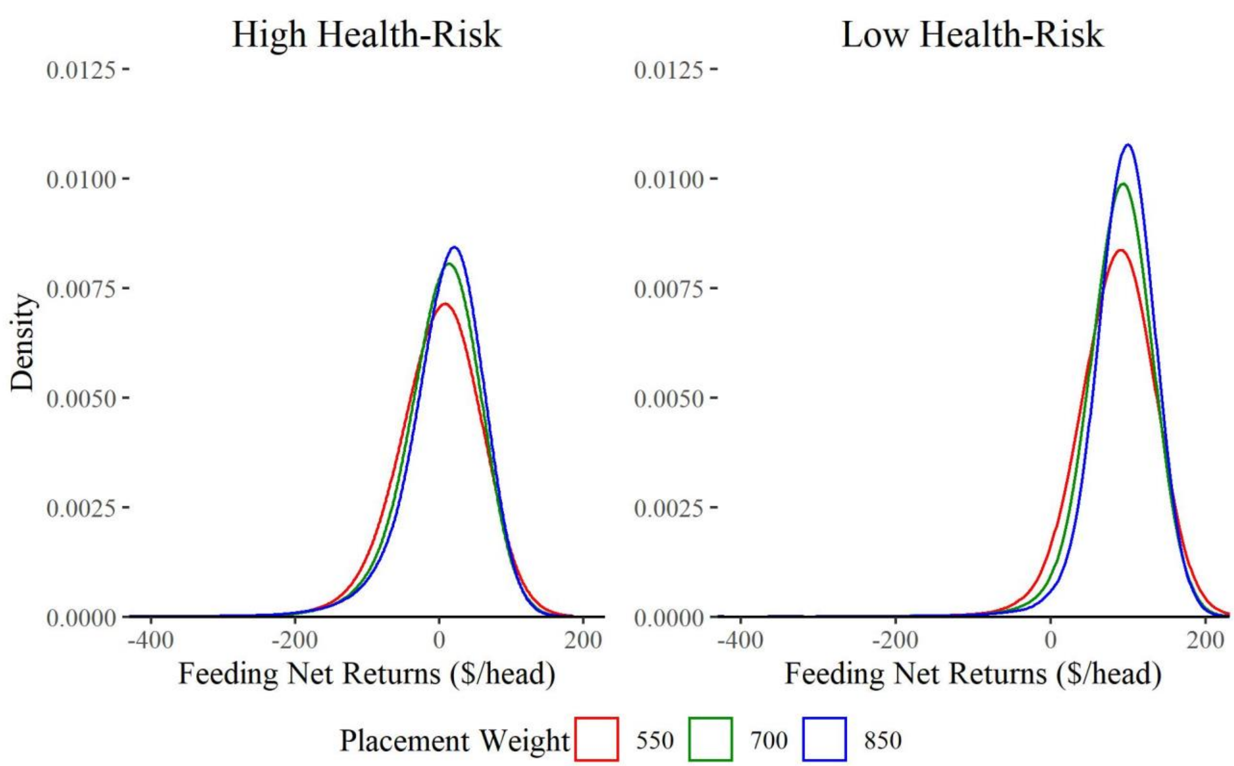


Table 2.17 contains the mean value of each net return distribution for all possibilities evaluated in the grid pricing sensitivity analysis. For all YG/QG distributions and placement weights, the highest net returns occurred under Alternate Grid 1 Pricing. Although Alternate

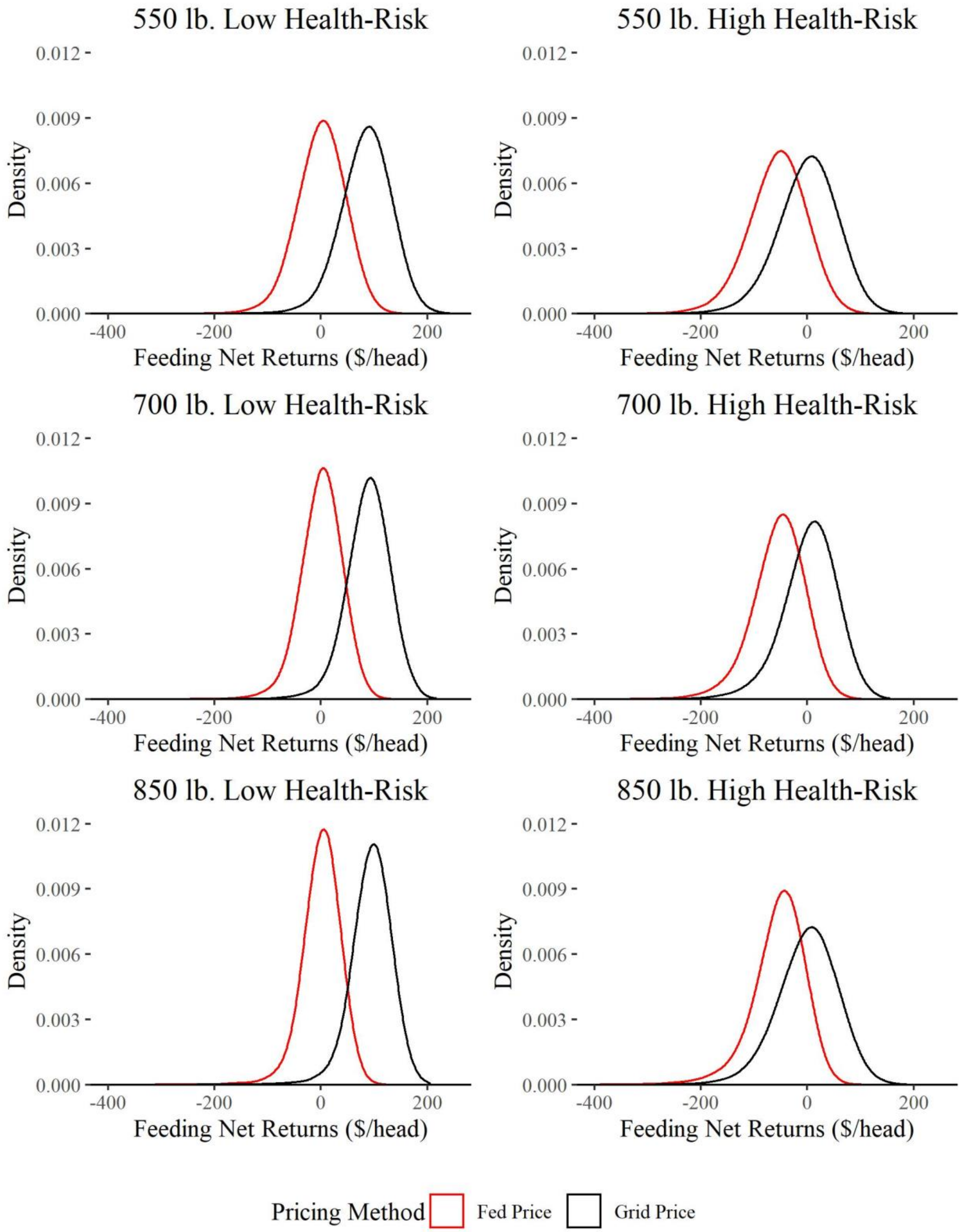
Grid 1 had the lowest base price, the quality grade premium for prime was the highest, and lower quality grades were not discounted as heavily. Alternate Grid 1 did have larger premiums for yield grades above YG 3, yet heavily discounted YG 5 carcasses. Additionally, Alternate Grid 1 had the highest carcass weight discounts for carcasses over 1,050 pounds. The least profitable pricing distribution was for Alternate Grid 2 across all placement weights, health-risk classification, and carcass YG/QQ distributions. Alternatively, for lower health-risk cattle, grid pricing under all distributions and alternate grid pricing options assessed was more profitable than under the live weight model.

Table 2.17. Grid Price Simulation Net Return Sensitivity Analysis Summary Statistics

Joint Distribution by Health-Risk Status and Placement Weight	Pricing Scheme		
	10-year Average	Alternate Grid 1	Alternate Grid 2
Joint YG/QG Distribution 1			
High Health-Risk			
550 pounds	0.04 (55.24)	8.19 (55.29)	-4.81 (55.17)
700 pounds	4.15 (51.46)	12.58 (51.48)	-0.91 (51.43)
850 pounds	8.30 (52.53)	17.54 (52.58)	2.97 (52.50)
Low Health-Risk			
550 pounds	84.75 (46.77)	92.83 (46.74)	79.76 (46.78)
700 pounds	88.10 (42.03)	96.57 (41.96)	82.95 (42.06)
850 pounds	93.84 (40.85)	103.17 (40.75)	88.48 (40.88)
Joint YG/QG Distribution 2 – High Health-Risk Cattle			
High Health-Risk			
550 pounds	3.99 (55.07)	11.16 (55.23)	-0.03 (55.11)
700 pounds	8.26 (51.59)	15.67 (51.60)	4.05 (51.57)
850 pounds	12.71 (52.69)	20.86 (52.72)	8.30 (52.67)
Joint YG/QG Distribution 3 – Low Health-Risk Cattle			
Low Health-Risk			
550 pounds	82.92 (46.82)	91.36 (46.77)	77.73 (46.80)
700 pounds	86.22 (42.04)	95.04 (41.96)	80.84 (42.07)
850 pounds	91.83 (40.85)	101.53 (40.76)	86.21 (40.90)

Mean values in the table are net returns in $/head.
Values in the parentheses are the standard deviations for the distribution.

Figure 2.4. Simulated Fed Price and Grid Price Net Return Distributions by Weight and Health-Risk Status



Note: Grid price distribution for each weight and health-risk status is for average prices and joint distribution 1.

Comparison of Net Return Distributions

When comparing net return distributions between the live weight model and the average grid price model results in Table 2.16, the standard deviation increases for all placement weight and health-risk status combinations. This can be visualized in Figure 2.4. The mean net return for the grid price model is greater than for the live weight, or fixed fed price, model. The increase in net returns from the live weight model to grid pricing for 550 lb., 700 lb., and 850 lb. low health-risk cattle is \$84.75 per head, \$88.06 per head, and \$93.83 per head, respectively. The difference between the live weight and grid pricing model is not as pronounced for high health-risk cattle. For 550 lb., 700 lb., and 850 lb. high health-risk cattle that receive metaphylaxis, the difference in net returns is \$56.54 per head, \$58.90 per head, and \$62.83 per head for each placement weight, respectively.

Using the K.S. test we can evaluate if two sampled net returns come from the same distribution. The null hypothesis is that two samples come from a common distribution, whereas the alternative hypothesis is that the two samples do not come from a common distribution (Conover, 1999). For all possible combinations of two-sample K.S. tests given our simulated distributions, we reject the null hypothesis for the alternative hypothesis indicating that the samples do not come from a common distribution.

The alternative K.S. test is a way of determining distributional superiority. To test distributional superiority for an (x, y) two-sample pair, the null hypothesis is that x is greater than y. Distribution superiority was tested for each pair of samples (i.e. if the CDF of x is to the right of the CDF of y). Results by placement weight can be seen in Table 2.18, Table 2.19, and Table 2.20. In cases where we reject the null hypothesis for the alternative, y lies to the left of x. Furthermore, the empirical cumulative distribution functions (ECDF) for each placement weight by health-risk status are in Figure 2.5, Figure 2.6, and Figure 2.7. These ECDF plots provide another visualization of the net return distributions where the distribution furthest right has the highest net return per head.

Table 2.18. Kolmogorov-Smirnov Test Results for 550-pound cattle

Null Hypothesis	K.S. Statistic	P-Value
550 Pound Placement Weight		
High Health-Risk		
Live Weight > Avg. Grid, Joint Dist. 1	0.4247	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 1	0.4756	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 1	0.3916	<0.001
Live Weight > Avg. Grid, Joint Dist. 2	0.4512	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 2	0.4947	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 2	0.4261	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 1	0.0672	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	<0.001
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Avg. Grid, Joint Dist. 2 > Alt. Grid 1, Joint Dist. 2	0.0582	<0.001
Avg. Grid, Joint Dist. 2 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Alt. Grid 1, Joint Dist. 2 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Low Health-Risk		
Live Weight > Avg. Grid, Joint Dist. 1	0.6718	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 1	0.7153	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 1	0.6431	<0.001
Live Weight > Avg. Grid, Joint Dist. 3	0.6598	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 3	0.7075	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 3	0.6287	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 1	0.0773	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0002	1.000
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Avg. Grid, Joint Dist. 3 > Alt. Grid 1, Joint Dist. 3	0.0806	<0.001
Avg. Grid, Joint Dist. 3 > Alt. Grid 2, Joint Dist. 3	0.0000	1.000
Alt. Grid 1, Joint Dist. 3 > Alt. Grid 2, Joint Dist. 3	0.0000	1.000

Table 2.19. Kolmogorov-Smirnov Test Results for 700-pound cattle

Null Hypothesis	K.S. Statistic	P-Value
700 Pound Placement Weight		
High Health-Risk		
Live Weight > Avg. Grid, Joint Dist. 1	0.4883	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 1	0.5445	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 1	0.4522	<0.001
Live Weight > Avg. Grid, Joint Dist. 2	0.5146	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 2	0.5625	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 2	0.4882	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 1	0.0781	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	<0.001
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Avg. Grid, Joint Dist. 2 > Alt. Grid 1, Joint Dist. 2	0.0661	<0.001
Avg. Grid, Joint Dist. 2 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Alt. Grid 1, Joint Dist. 2 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Low Health-Risk		
Live Weight > Avg. Grid, Joint Dist. 1	0.7695	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 1	0.8099	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 1	0.7418	<0.001
Live Weight > Avg. Grid, Joint Dist. 3	0.7600	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 3	0.8013	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 3	0.7298	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 1	0.0970	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Avg. Grid, Joint Dist. 3 > Alt. Grid 1, Joint Dist. 3	0.1014	<0.001
Avg. Grid, Joint Dist. 3 > Alt. Grid 2, Joint Dist. 3	0.0000	1.000
Alt. Grid 1, Joint Dist. 3 > Alt. Grid 2, Joint Dist. 3	0.0000	1.000

Table 2.20. Kolmogorov-Smirnov Test Results for 850-pound cattle

Null Hypothesis	K.S. Statistic	P-Value
850 Pound Placement Weight		
High Health-Risk		
Live Weight > Avg. Grid, Joint Dist. 1	0.4247	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 1	0.4756	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 1	0.3916	<0.001
Live Weight > Avg. Grid, Joint Dist. 2	0.4512	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 2	0.4947	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 2	0.4261	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 1	0.0672	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	<0.001
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 2	0.0582	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Low Health-Risk		
Live Weight > Avg. Grid, Joint Dist. 1	0.5391	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 1	0.5993	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 1	0.5015	<0.001
Live Weight > Avg. Grid, Joint Dist. 2	0.5683	<0.001
Live Weight > Alt. Grid 1, Joint Dist. 2	0.6174	<0.001
Live Weight > Alt. Grid 2, Joint Dist. 2	0.5382	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 1	0.0892	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 1	0.0000	1.000
Avg. Grid, Joint Dist. 1 > Alt. Grid 1, Joint Dist. 2	0.0781	<0.001
Avg. Grid, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000
Alt. Grid 1, Joint Dist. 1 > Alt. Grid 2, Joint Dist. 2	0.0000	1.000

Figure 2.5. Empirical Cumulative Distribution Function for 550-pound High Health-Risk and Low Health-Risk Cattle

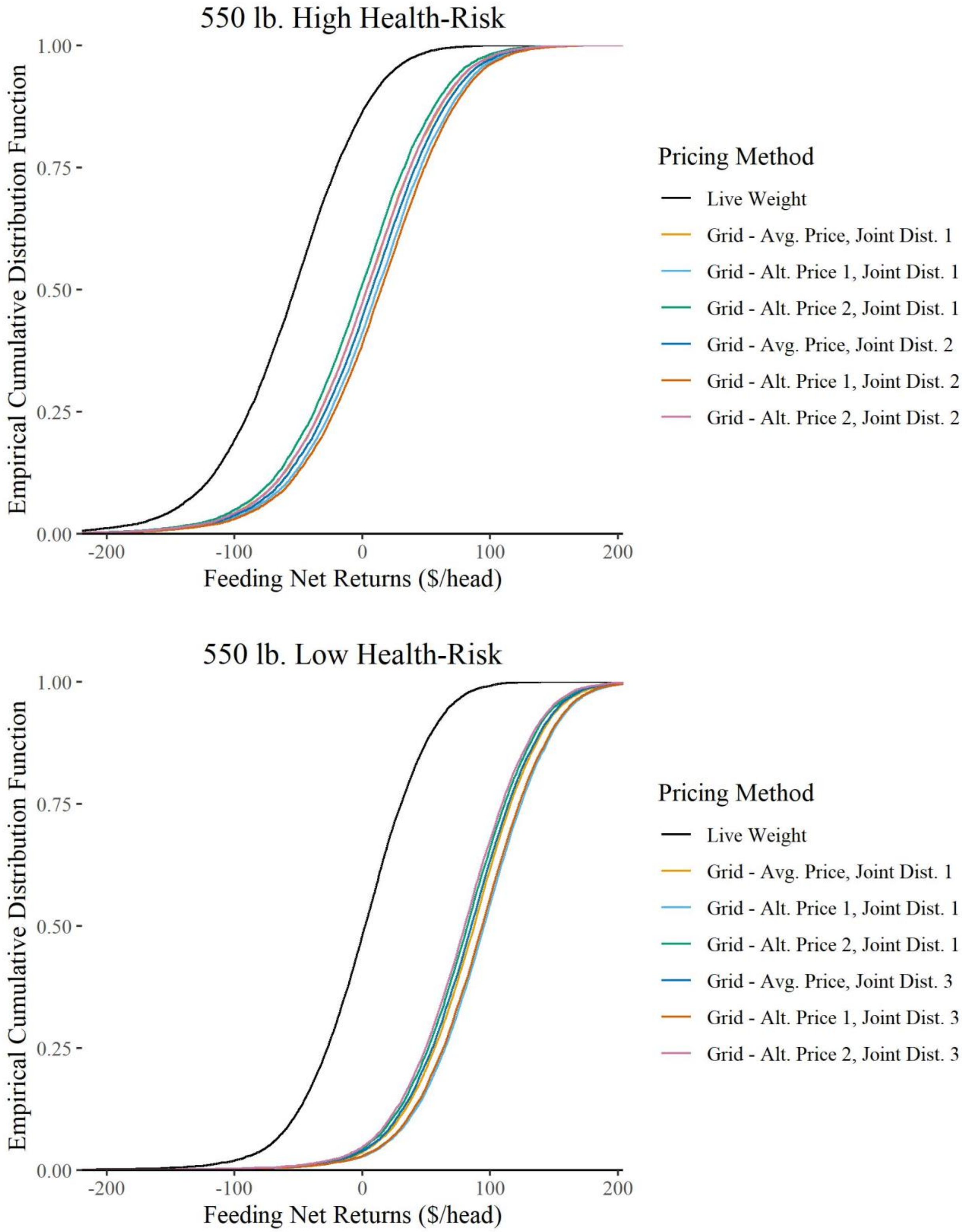
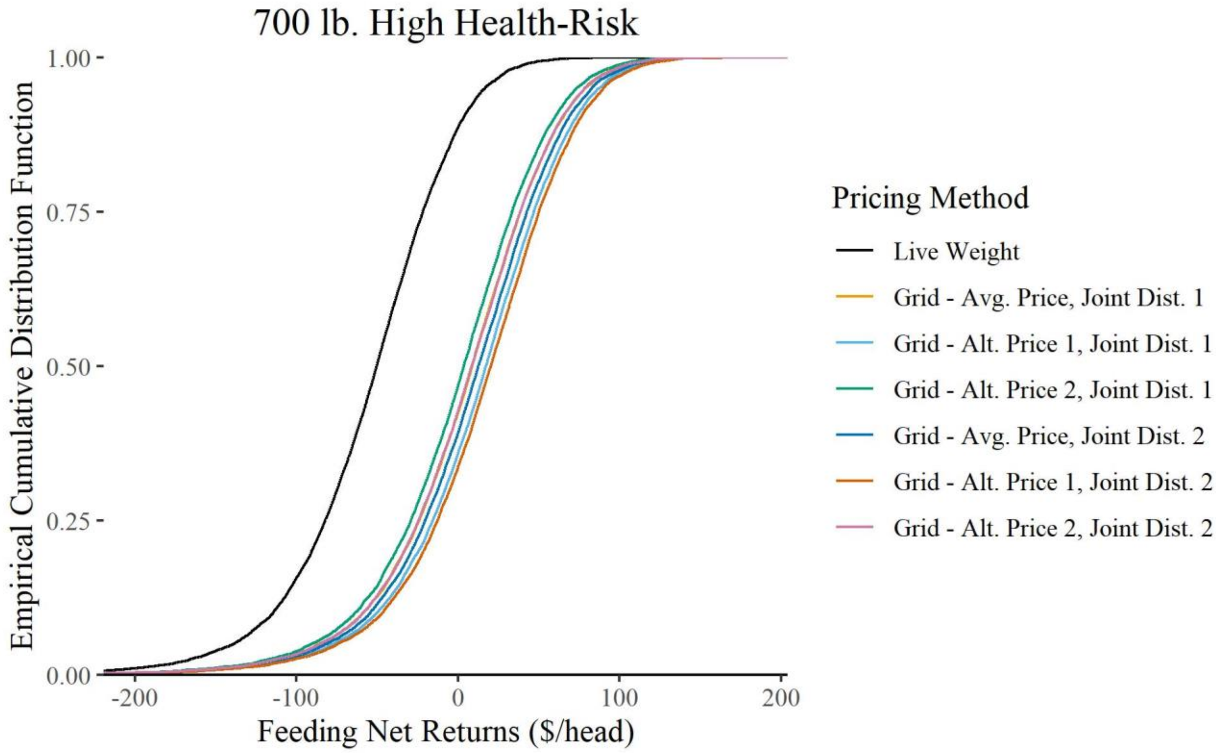


Figure 2.6. Empirical Cumulative Distribution Function for 700-pound High Health-Risk and Low Health-Risk Cattle



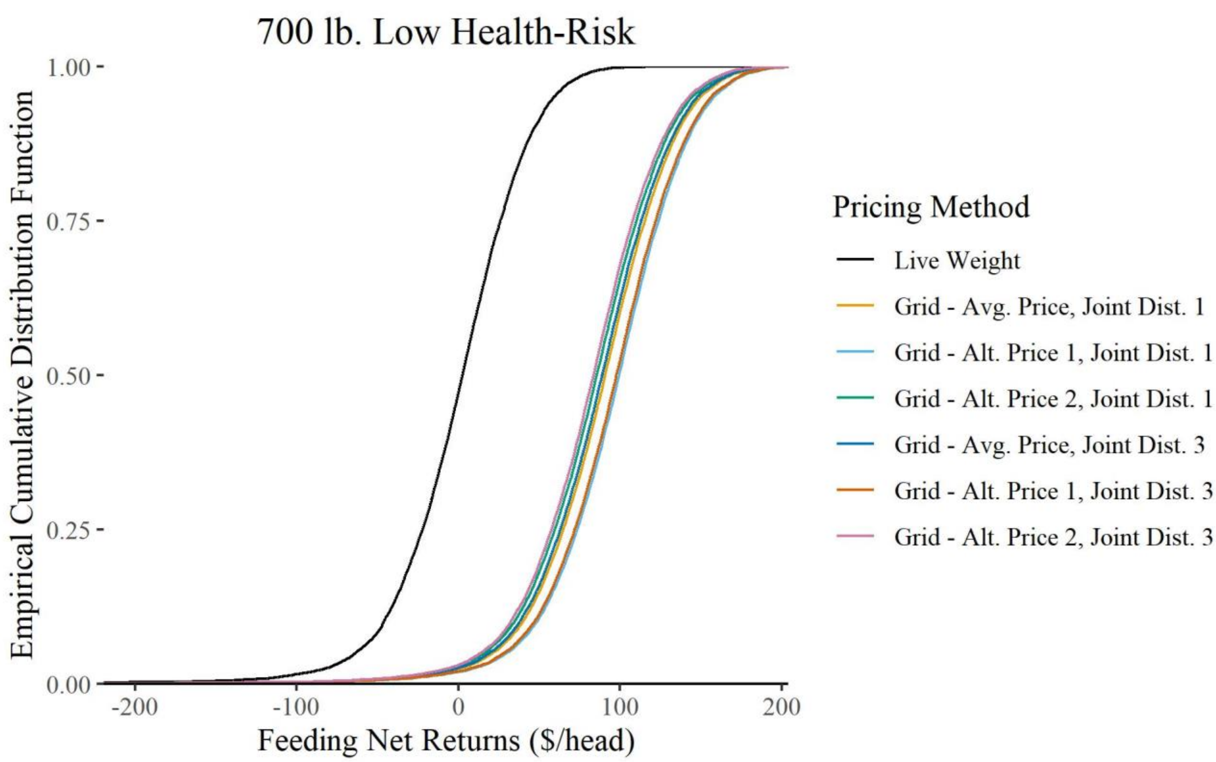
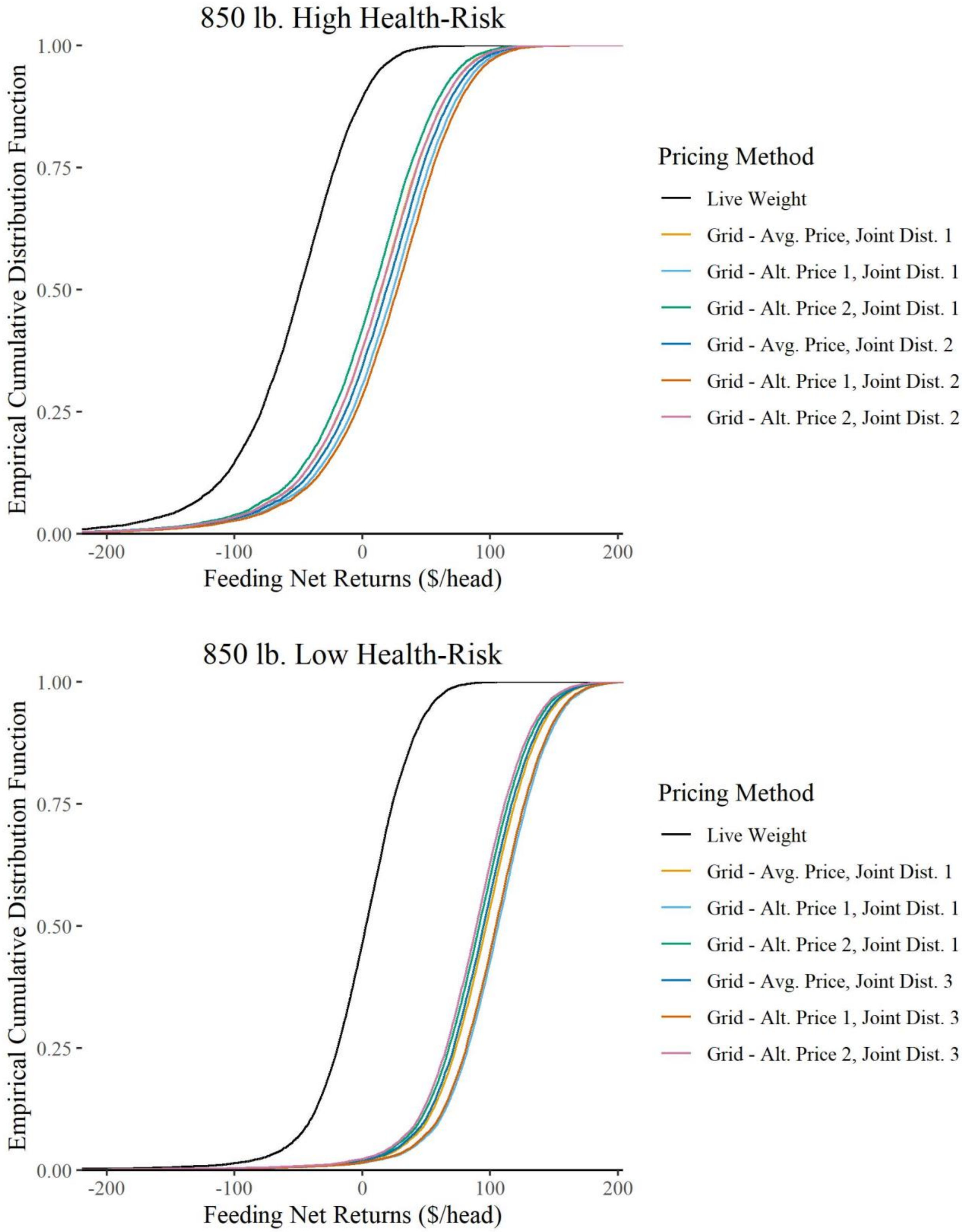


Figure 2.7. Empirical Cumulative Distribution Function for 850-pound High Health-Risk and Low Health-Risk Cattle



Discussion

Mortality Rate Model

Prior literature assessing mortality across gender has mixed results. When assessing risk factors associated with mortality for 121 feedlots in the late 1990s, Loneragan et al. (2001) found that when comparing heifer and steer cohorts, heifer cohorts have a higher mortality risk. In contrast, Cusack et al. (2007) found a higher mortality rate in steers as compared to heifers. In our mortality model, *Steers* have a higher mean mortality rate than heifers.

Additionally, one of the few papers that estimated a feedlot mortality model in previous literature is Belasco et al. (2009). The authors first estimated a mortality model, then utilized the results in a cattle feeding net returns simulation. The Tobit Multiplicative Heteroskedasticity model specification for mortality that the authors used was quite different than the specification we used here as they utilized pens consisting of either all steers, all heifers, or a mixture of both; a Kansas binary variable; log of the placement weight; and binary seasonal variables for winter, fall, and spring. Comparing the mortality model results in Table 2.6 to their estimated coefficients, a pen of steers have a higher mean mortality rate than a pen of heifers; this is a common result between the parameter we estimate and Belasco et al. (2009). The other comparable parameter between our model and Belasco et al. (2009) is the conditional mean for the natural log of the placement weight. Again, the sign and magnitude for the conditional mean estimates are similar between our model and Belasco et al. The major contrast is that we only include health-risk status in the conditional variance equation.

Utilizing the mortality equation from Belasco et al. (2009) to compare expected mortality, we obtained mortality percentage rate estimates of 550-pound, 700-pound, and 850-pound steers placed in the fall with mean mortality rates (standard deviation) of 2.18 (2.59), 1.45

(2.16), and 0.94 (1.87). These estimates do not account for the expected mortality rate difference between low health-risk cattle and high health-risk cattle treated with metaphylaxis; the mean values estimated by Belasco et al. fall between our estimated low health-risk and high health-risk mortality distribution means. Our mortality rate model would benefit from the inclusion of additional data over multiple years to be able to include monthly or seasonal dummy variables to capture the additional seasonality component involved with cattle mortality. Multiple studies show that cattle placed in the fall are at a higher risk for BRD-associated mortality than cattle placed in the spring and summer (Ribble et al., 1998; Vogel et al., 2015; Vogel & Parrott, 1994). An additional limitation to this study is the lack of data for low health-risk cattle that receive metaphylaxis and high health-risk cattle that do not receive metaphylaxis treatment upon placement at the feedlot. Due to the inherent differences across these groups of cattle, an ideal study would include all four classifications of cattle, as opposed to the two groups we were able to include in our study based on data availability. This is ultimately a real-world data issue that is difficult to overcome with observational data in the feedlot setting.

Performance Metric and Veterinary Expense Models

When comparing the results of the performance metric models to other similar models, we find comparable parameter signs and magnitudes in two of Dennis et al.'s (2020, 2018) papers that utilize LMM to model ADG, AFC, and VCPH. These coefficient signs for *steers* and *log placement weight* are also consistent with the Harvey Model results for ADG, AFC, and VCPH in Belasco et al. (2009). Results for the ADG, AFC, and VCPH models indicate statistically significant differences between gender. Despite an increase in feed conversion as log placement weight increases, heavier weight placed pens gain more weight per day. Also, as placement weight increases, pens tend to have fewer health problems and medication costs than lighter-weight pens. To compare the expense to treat a high health-risk animal with metaphylaxis, the National Animal Health Monitoring Survey (NAHMS) (U.S. Department of Agriculture, 2013) reported estimated an expense of $23.50 per head. While marginally higher at $24.68, our results are consistent with the NAHMS findings and the $23.81 estimated value of administering metaphylaxis from Dennis et al. (2018).

Net Returns Simulation

When cattle producers are buying cattle to place on feed, there are generally higher transaction prices associated with healthier animals with lower probabilities of morbidity and mortality (Dennis et al., 2018). This serves as an incentive to buy higher-risk cattle at a lower cost to offset the additional risk. A major driver of this is also influenced by the efficacy and availability of antimicrobial metaphylaxis (Ives & Richeson, 2015). To determine the difference in purchase prices needed for high health-risk cattle that receive metaphylaxis to offset higher expected morbidity and mortality risk, we determine the purchase price necessary for the simulation mean to be at the breakeven where profit is zero. This price for 550-pound cattle is $1.6527 per pound, or a 5.70% decrease in the purchase price of low health-risk cattle. For 700-pound cattle, the necessary purchase price to achieve breakeven is $1.4849 per pound or a 4.90% discount compared to the low health-risk cattle breakeven. Thirdly, for 850-pound cattle, the required discount for breakeven is a 4.29% decrease for a purchase price of $1.4021 per pound.

For the grid pricing model, transportation cost was not included in the grid price simulation. This could slightly inflate the difference between live pricing and grid basis, yet the trucking cost only represents approximately $0.25/cwt or less (Schroeder & Graff, 2000). The increase in mean net returns per head are consistent with higher profits for cattle priced using a grid as opposed to live weight pricing (Feuz, 1999; Feuz et al., 1993).

Comparison of Net Return Distributions

Given the results of the K.S. test to determine if two samples come from the same distribution, we know that no two of the samples we tested come from a common distribution. Alternatively, the distributional superiority K.S. test allows us to compare the net return simulation results beyond comparing the means and plotted net return distributions. The use of stochastic dominance criteria complements the risk analysis of the simulation by showing which investment, given the all the fixed and stochastic inputs, alternative joint distributions, and pricing methods, is preferable. This allows us to conclude which pricing alternative is most profitable for each placement weight and health-risk status combination based on the input values utilized for this study. For all low health-risk cattle, the option with the highest net return per head is the Alternate Grid 1, Joint Distribution 1, whereas, for high health-risk cattle that receive metaphylaxis, the highest net returns are seen under the Alternate Grid 1, Joint Distribution 2. Additionally, the ECDF plots illustrate an alternative visualization of each net return distribution.

Conclusion

In an industry with a long history of profit variability (Tonsor, 2022), developing a risk management strategy suited to each pen of cattle based on placement weight and risk classification requires careful consideration of the effects of price risk, production risk, and quality risk on profitability. While other studies have estimated cattle feeding net return models, this study explicitly considers the mortality rate, performance, quality, and expected net return difference between low health-risk cattle and high health-risk metaphylaxis treated cattle placed on feed. We compared live weight and grid pricing methods for three different placement weight categories across three different yield grade and quality grade joint distributions using three different grid pricing structures. To do so, we estimated a multiplicative heteroskedasticity model for expected mortality and LMM models for ADG, AFC, and VCPH. The mortality model was constructed using conditioning variables based on information known to a cattle feeder upon time of placement. This model provides insight into the relative impact of cattle characteristics on the expected mean of the mortality distribution and accompanying variance. The high health-risk variable has a statistically significant effect on variance, so the standard deviation of the mortality distribution differs based on the qualities inherently associated with the risk classification of cattle upon placement. The performance metric LMM models provide insight into how ADG, AFC, and VCPH change as the sex of the pen, placement weight, mortality rate, and health-risk status change. The results of these models are incorporated into the stochastic cattle feeding returns model structure to determine the variability of expected net returns given cattle characteristics upon placement.

The better we can predict animal health and quantify the uncertainty between low health-risk and high health-risk cattle, the more informed cattle feeders become regarding the profit variability between the two classifications of cattle. This profit variability becomes even more pronounced when animals are priced using a grid method due to more factors influencing the price per pound received per animal, as well as the yield and quality grade differences between cattle within the same pen. Additionally, due to higher transaction prices associated with healthier animals that generally have lower probabilities of morbidity and mortality, there is an incentive to buy higher-risk cattle at a lower cost. Results of this study inform industry stakeholders by quantifying the price discount that high health-risk cattle must be purchased at to achieve the same breakeven profit as low health-risk cattle.

Chapter 3 - Evaluation of Bovine Respiratory Disease Morbidity in the Feedlot and its Effect on Net Return Distributions

Introduction

One of the most important determinants of profitability in feedlot cattle is the cost associated with morbidity (Gardner et al., 1996). Bovine respiratory disease (BRD) is responsible for a large portion, approximately 75%, of feedlot morbidity and 50-80% of feedlot deaths (Edwards, 1996; Kelly & Janzen, 1986). This disease costs the beef industry an estimated $6 billion annually (Abell et al., 2017; Griffin, 1997; O'Connor et al., 2016; U.S. Department of Agriculture, 2013). This economic impact is comprised of expenses related to prevention, treatment, reduced performance, culling, and death (Gardner et al., 1999; Smith, 1998).

Risk factors for BRD are well documented across epidemiological literature. Mixed gender groups, intermingled calves from multiple sources, and increased shipping distance are all associated with a higher risk of respiratory morbidity. Cattle that arrive at heavier weights are at a decreased risk for BRD morbidity (Hay et al., 2016; Sanderson et al., 2008). Cattle deemed low-risk upon placement have lower production and mortality risks, are never prescribed metaphylaxis, and are individually treated upon the presentation of clinical signs of morbidity (i.e., pull-and-treat) (Dennis, 2019).

Given low-risk cattle, the objective of this study is to evaluate the impact of the percentage of a pen of cattle individually treated one time, two times, or three or more times for BRD on mortality, performance, and overall expected net returns per head. We do this through parameterizing production and profitability risks associated with BRD morbidity in the feedlot. This research utilizes and adapts a fed cattle net returns model to capture varying mortality rates and stochastic performance metrics—ADG, AFC, and VCPH—as a function of BRD morbidity to model overall fed cattle profit risk. While it can be difficult to estimate disease costs for calves entering the feedlot, this study evaluates the net return sensitivity given BRD morbidity to provide more information regarding expected net return distributions as BRD morbidity in a pen increases.

Literature Review

Multiple studies have evaluated the performance of cattle affected by BRD in the feedlot. BRD is associated with poor productive performance, impaired carcass quality, lower average daily gain, and suppressed net returns (Babcock et al., 2009; Cernicchiaro et al., 2013; Wittum et al., 1996). Additional knowledge of factors that contribute to net return variability improves management and marketing decisions for specific cattle (White et al., 2007).

Several studies have reported a significant reduction in average daily gain (ADG) when comparing healthy animals to animals treated at least once for BRD (Bateman et al., 1990; Cusack et al., 2007; Gardner et al., 1999; Morck et al., 1993; Reinhardt et al., 2009; Schneider et al., 2009; Seeger et al., 2008; Snowder et al., 2006; Wittum et al., 1996). Others report no significant differences in ADG across treated and untreated calves (Brooks, 2008; Jim et al., 1993; Snowder et al., 2007; Wittum et al., 1996). One study by Roeber et al. (2001) found that treated animals had a higher ADG than untreated cattle.

Final body weight is another performance measure associated with a difference after BRD treatments. A 1999 study (Gardner et al.) concludes that steers treated for BRD had lower final body weights than untreated steers, although animals treated 2 times did not have significantly different finish weights. Results of two additional studies concluded similar differences between treated and healthy animal finish weight (Reinhardt et al., 2009; Schneider et al., 2009).

One of the most comprehensive economic assessments of BRD is the Ranch to Rail Program in Texas. Over the program's duration, BRD was associated with increased production costs, poorer feedlot performance, and lower USDA quality grades. The resulting difference between healthy animals and animals that were treated once was a $92.26 more per head return. One study found that treating animals once, twice, or three or more times decreases carcass value by $23.23, $30.15, and $54.01, respectively, compared to animals that were never treated. While individual carcass valuation was assessed, overall net returns were not estimated for this study. There were a total of 488 cattle in this study treated for BRD, 53% of which were treated once, 34% were treated twice, and 13% were treated three or more times (Schneider et al., 2009). Another study found that increased BRD treatments decreased net returns, yet the magnitude of the difference depended on placement season. The least squares mean net returns for animals not treated for BRD is $30.37; animals treated once, twice, and three or more times had least squares mean net returns of $17.79, $1.93, and -$45.52 per head, respectively (Cernicchiaro et al., 2013). While previous studies have evaluated the net return per animal using a simple profit function, we further the evaluation of BRD treatments on expected net returns by utilizing stochastic simulation and introducing additional variation into the net returns model.

Data

Dataset I is a proprietary feedlot dataset consisting of 1,157 pens of cattle. Information regarding individual treatment, mortality reports, and veterinary expense, as well as pen-level closeout information, performance metrics, and veterinary expense are included in the data. The dataset was refined to only include treatments for BRD after arrival at the feedlot. Treatments for causes other than BRD are not considered and if individual animal or pen-level records had incomplete information, they were removed from the sample. Pens of cattle that received arrival metaphylaxis were also excluded from the dataset due to confounding treatment effects. Other studies that utilize this dataset are *Value of arrival metaphylaxis in U.S. cattle industry* and *Net return distributions when metaphylaxis is used to control bovine respiratory disease in high health-risk cattle* (Dennis et al., 2018, 2020).

Dataset II is a Midwestern feedlot dataset that is more limited in scope with respect to certain variables due to the data collection procedure. The advantage of this dataset as compared to Dataset I is that it provides a more granular view of the effects of BRD on the animals by including individual animal ADG, BRD treatment information, and individual animal carcass characteristics. There are 206,918 head in Dataset II for a total of 2,592 cohorts. Animals that died and treatment cost information are not available for this dataset, along with feed conversion due to the individual nature of the data collection. This dataset is the same data utilized by Cernicchiaro et al. (2013) to evaluate BRD and net returns in feeder cattle.

Summary statistics for both Dataset I and II can be found in Table 3.1. Dataset I ranges in placement dates from February 2014 through August 2015. Dataset II has pens of cattle with a placement date beginning in February 2001 through February 2006. Table 3.2 further breaks down the summary statistics for Dataset I by placement weight category. In Table 3.3, individual animal summary statistics are recorded for Dataset II based on the number of treatments the animal received stratified by placement weight. One performance metric of note is that across all placement weight categories, as the number of treatments increases, ADG decreases. The finished weight is estimated given the placement weight plus the animal-specific ADG multiplied by the total days on feed. Table 3.4 details the mean, standard deviation, minimum, and maximum percentage of animals per pen treated zero times (0X), once (1X), twice (2X), and three or more times (3X) for Dataset I, stratified by placement weight category. Animals treated three or more times are grouped together as they are deemed chronically ill as in Holland et al. (2010). As the placement weight increased, the percentage of animals that received an individual diagnosis and treatment for BRD decreased.

Table 3.1. Dataset Summary Statistics

	Dataset I			
Performance Metric	Mean	St. Dev	Minimum	Maximum
Average Daily Gain (lb. gain/day)	3.70	0.45	2.18	5.70
Feed Conversion (lb. feed/lb. gain)	6.12	0.60	4.77	10.11
Mortality (%)	1.05	1.38	0.00	20.00
Placement Weight (lb.)	784.88	111.74	321.19	1096.00
Railer Weight (lb.)	910.40	208.87	380	1830.00
Days on Feed (days)	145.21	27.38	78.32	347.98
Finish Weight (lb.)	1317.95	97.75	1068.81	1740.14
Total Vet Charge ($/head)	16.36	5.42	2.20	83.21
Gender	Steers	49.10%	Heifers	50.90%
Season	Spring	34.31%	Summer	14.00%
	Fall	25.32%	Winter	26.36%
	Dataset II			
Average Daily Gain (lb. gain/day)	3.20	0.42	1.94	4.81
Placement Weight (lb.)	663.55	107.47	369.62	994.00
Days on Feed (days)	163.81	35.80	84.55	283.13
Finish Weight (lb.)	1175.62	80.58	1000.67	1437.77
Gender	Steers	58.76%	Heifers	41.24%
Season	Spring	13.70%	Summer	29.36%
	Fall	40.51%	Winter	16.44%

Notes: N = 1,157 for Dataset I; N = 2,592 pens for Dataset II.

Table 3.2. Dataset I Summary Statistics by Placement Weight

Dataset I				
Performance Metric	Mean	St. Dev	Min.	Max.
Placement Weight: < 625 pounds				
Average Daily Gain (lb. gain/day)	3.42	0.34	2.71	4.30
Feed Conversion (lb. feed/lb. gain)	5.91	0.49	4.78	7.26
Mortality (%)	2.14	2.51	0.00	20.00
Placement Weight (lb.)	556.83	75.14	321.19	624.70
Days on Feed (days)	204.41	38.06	147.00	347.98
Finish Weight (lb.)	1249.75	86.28	1098.51	1440.96
Total Vet Charge ($/head)	21.74	9.74	5.44	83.21
Placement Weight: 625 – 775 pounds				
Average Daily Gain (lb. gain/day)	3.59	0.41	2.18	4.97
Feed Conversion (lb. feed/lb. gain)	6.04	0.49	4.80	7.95
Mortality (%)	1.08	1.24	0.00	8.47
Placement Weight (lb.)	713.31	38.67	625.96	774.96
Days on Feed (days)	155.58	18.56	117.00	227.70
Finish Weight (lb.)	1270.52	84.37	1068.81	1491.20
Total Vet Charge ($/head)	16.25	5.01	2.20	40.81
Placement Weight: > 775 pounds				
Average Daily Gain (lb. gain/day)	3.80	0.45	2.42	5.70
Feed Conversion (lb. feed/lb. gain)	6.19	0.66	4.93	10.11
Mortality (%)	0.89	1.21	0	9.52
Placement Weight (lb.)	863.15	71.40	775.07	1096.00
Days on Feed (days)	130.73	15.76	78.32	201.35
Finish Weight (lb.)	1359.85	87.45	1119.26	1740.14
Total Vet Charge ($/head)	15.80	4.61	5.28	43.68

Notes: N = 76 pens for < 625 pounds, N = 449 for 625 – 775 pounds, and N = 632 for > 775 pounds

Table 3.3. Dataset II Performance Metrics by Number of Individual BRD Treatments

Performance Metric	Number of BRD Treatments			
	0X	1X	2X	3X or more
< 625 lbs.				
Sample Size	67,724	13,623	4,039	1,977
ADG	3.07 (0.53)	2.95 (0.48)	2.85 (0.46)	2.73 (0.48)
Days on Feed	190.88 (39.84)	201.72 (36.97)	209.42 (35.93)	216.55 (36.32)
Placement Weight, lb.	551.42 (67.96)	542.66 (68.71)	540.12 (68.94)	538.85 (69.21)
Finished Weight[1]	1127.22 (112.14)	1132.02 (115.78)	1133.63 (117.94)	1125.17 (121.94)
Hot Carcass Weight	718.01 (80.06)	723.40 (82.41)	726.27 (84.03)	716.38 (87.26)
Backfat	0.45 (0.17)	0.44 (0.16)	0.43 (0.15)	0.40 (0.16)
Ribeye Area	12.64 (1.62)	12.76 (1.66)	12.81 (1.65)	12.84 (1.77)
KPH	2.29 (0.69)	2.24 (0.76)	2.20 (0.81)	2.20 (0.81)
625 − 775 lbs.				
Sample Size	72,560	6,051	1,363	674
ADG	3.33 (0.61)	3.11 (0.54)	2.95 (0.55)	2.80 (0.60)
Days on Feed	145.24 (31.89)	166.20 (34.10)	174.96 (35.24)	178.42 (41.34)
Placement Weight, lb.	714.19 (45.23)	792.26 (44.01)	699.96 (43.09)	701.07 (43.11)
Finished Weight[1]	1191.48 (109.20)	1214.32 (114.71)	1213.79 (121.99)	1195.70 (131.44)
Hot Carcass Weight	756.31 (77.03)	776.77 (82.45)	778.06 (85.65)	755.91 (97.21)
Backfat	0.46 (0.16)	0.44 (0.16)	0.42 (0.16)	0.39 (0.15)
Ribeye Area	12.95 (1.63)	13.18 (1.64)	13.22 (1.74)	13.19 (1.82)
KPH	2.32 (0.65)	2.28 (0.70)	2.31 (0.66)	2.32 (0.64)
> 775 lbs.				
Sample Size	37,384	1,188	214	121
ADG	3.46 (0.68)	3.15 (0.65)	2.93 (0.72)	2.84 (0.78)
Days on Feed	121.64 (23.41)	137.23 (27.54)	142.04 (30.74)	138.40 (30.03)
Placement Weight, lb.	856.43 (58.60)	850.37 (55.55)	851.72 (55.97)	851.39 (51.52)
Finished Weight[1]	1271.81 (94.63)	1277.98 (100.37)	1263.07 (115.58)	1240.46 (114.83)
Hot Carcass Weight	809.56 (67.34)	818.30 (72.99)	805.49 (82.09)	777.45 (86.47)
Backfat	0.47 (0.18)	0.43 (0.16)	0.42 (0.15)	0.41 (0.19)
Ribeye Area	13.21 (1.61)	13.46 (1.66)	13.32 (1.68)	13.38 (1.81)
KPH	2.20 (0.82)	2.25 (0.75)	2.23 (0.77)	2.22 (0.77)

[1]Estimated live weight based on ADG and total DOF. Values in the parenthesis are standard deviations. Dataset II has 2,592 total pens.

Table 3.4. Treatment Percentage Summary Statistics for Cattle from Dataset I

Category	Mean	Standard Deviation	Minimum	Maximum
		Placement Weight – 550 lb.		
TRT 0X	84.98%	14.11%	12.73%	100%
TRT 1X	10.36%	8.76%	0.00%	51.92%
TRT 2X	2.86%	3.95%	0.00%	20.00%
TRT 3X	1.80%	4.26%	0.00%	34.55%
		Placement Weight – 700 lb.		
TRT 0X	93.47%	7.41%	50.67%	100%
TRT 1X	4.88%	5.40%	0.00%	33.33%
TRT 2X	1.06%	1.85%	0.00%	13.33%
TRT 3X	0.59%	1.29%	0.00%	13.85%
		Placement Weight – 850 lb.		
TRT 0X	95.58%	5.35%	60.00%	100%
TRT 1X	3.49%	4.21%	0.00%	32.76%
TRT 2X	0.66%	1.32%	0.00%	17.78%
TRT 3X	0.27%	0.65%	0.00%	6.78%

Methods

In this chapter, we utilize the foundation of the net returns model presented in Belasco et al. (2009), and then modified in Dennis et al. (2018), to incorporate overall BRD morbidity and treatments in a pen. We modify this net returns model to shift the main driver of feedlot profitability from mortality to BRD morbidity captured through the percent of a pen treated once, twice, or three or more times for clinically diagnosed BRD.

Mortality Rate Model

Similar to Chapter 2, a mortality rate model is estimated to predict the mortality rate mean and standard deviation based on a vector of cattle characteristics. The change from the previous mortality model is through how BRD morbidity impacts mortality as the percentage of cattle in a pen treated for BRD increases. An important consideration of morality is that each pen of feedlot cattle does not have a realized mortality rate, so there is clustering at zero. Conventional regression methods do not account for the differences in the observations censored at zero and the continuous observations (Greene, 2018, pg. 931). While one paper, Belasco et al. (2009), does utilize a Tobit Multiplicative Heteroskedasticity model to model mortality, the authors only consider sex, state of the feedlot, placement weight, and placement season as variables in the conditional mean and conditional variance equations. In addition to considering the key conditioning mean variables, assessing the presence of heteroskedasticity, if any, is important as estimates of the Tobit model are biased and inconsistent if heteroskedasticity is not accounted for (Hurd, 1979).

To evaluate the appropriateness of assuming multiplicative heteroskedasticity, a likelihood ratio test was conducted. The log-likelihood of the model with 7 degrees of freedom is statistically significant with a P-value of less than 0.001. In the restricted model, the conditional variables have no impact on variability. Thus, given a statistically significant likelihood ratio test, a Tobit Multiplicative Heteroskedasticity model is appropriate to account for the censoring of the dependent variable. The conditional mean equation for the Tobit model with multiplicative heteroskedasticity model is specified as followed,

$$\begin{aligned} y_i^* &= x_i{}'\beta + \varepsilon_i \\ y_i &= 0 \; if \; y_i^* \le 0, \\ y_i &= y_i^* \; if \; y_i^* > 0. \end{aligned} \tag{3.1}$$

where y_i^* represents the unobserved continuous latent variable, y_i represents the observed pen-level mortality rate ($MORT$) and x' is a vector of pen-level characteristics: a constant term, a binary variable for steers, $STEER$; log of the placement weight, $lnPWT$; and variables for the percentage of animals treated once ($TRT\ 1X$), twice ($TRT\ 2X$), and three or more times

($TRT\ 3X$). The log-likelihood from a Tobit model can be adjusted for the heteroskedasticity by replacing σ with σ_i and including σ_i^2 in the summations; additionally, $\sigma_i^2 = exp(z_i'\alpha)$. It can be written as

$$\begin{aligned} log\ L \quad = \quad & \sum_{y_i>0} -\frac{1}{2}\left[ln(2\pi) + ln(\sigma^2) + z_i'\alpha + \frac{1}{\sigma^2 \exp(z_i'\alpha)}\right] \\ & + \sum_{y_i=0} ln\left[\Phi\left(\frac{-x'\beta_i}{\sigma^2 \exp(z_i'\alpha)}\right)\right] \end{aligned} \tag{3.2}$$

where Φ is the normal CDF. The conditional variance is specific to each observation and is

$$\sigma_i^2 = \sigma^2[\exp(z_i'\alpha)]^2 \tag{3.3}$$

In the case of no heteroskedasticity, α would be equal to zero. The expected value for the mortality rate is calculated using the following equation:

$$E[y|x] \quad = \quad \Phi\left(\frac{x'\beta}{\sigma}\right)(x'\beta + \sigma\lambda) \tag{3.4}$$

where

$$\lambda \quad = \quad \frac{\phi[(0\ -\ x'\beta/\sigma)]}{1 -\ \Phi[(0\ -\ x'\beta/\sigma)]} = \frac{\phi(x'\beta/\sigma)}{\Phi(x'\beta/\sigma)} \tag{3.5}$$

(Greene, 2018, pg. 933-946).

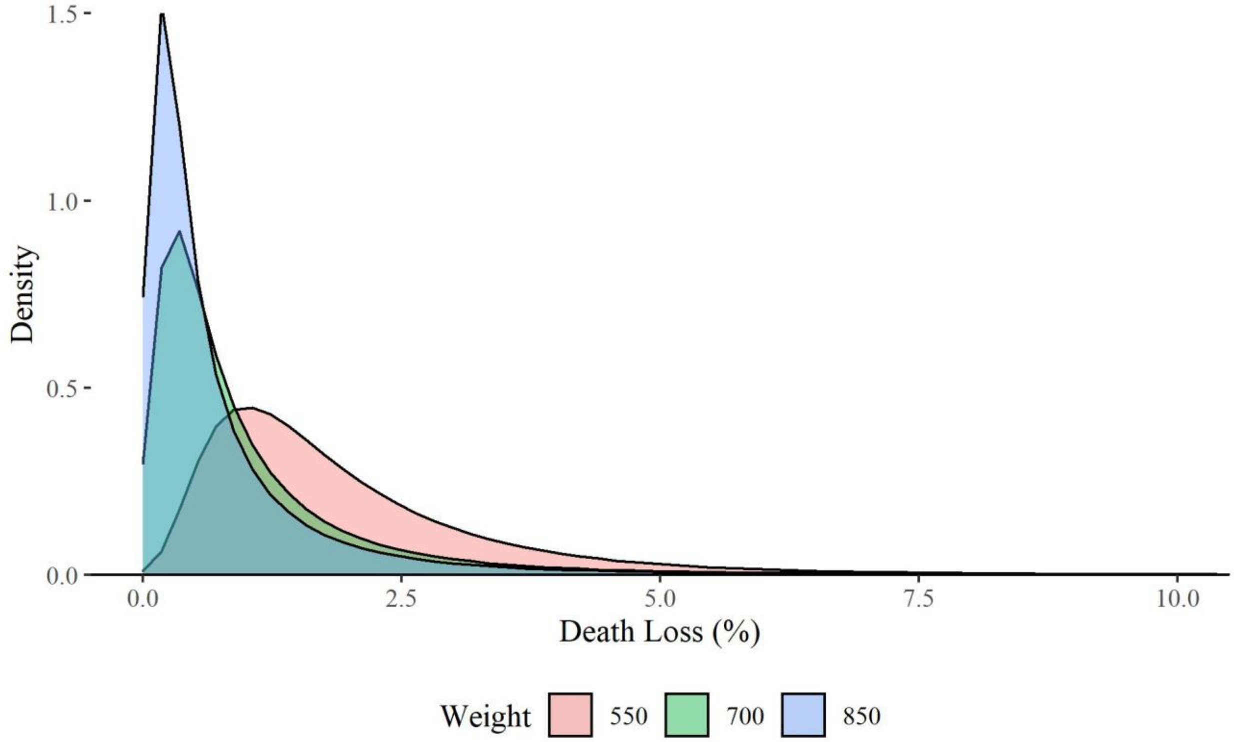
Table 3.5 contains the results for the Tobit model with multiplicative heteroskedasticity. Increases in the percent of animals treated 1X, 2X, and 3X or more increase the conditional mean of the mortality distribution, while a 1% increase in the placement weight is associated with a 0.71% decrease in mortality rate. The percent of animals treated 1X is the only statistically significant conditioning variable. These parameter estimates are utilized in developing mortality distributions depending on the gender of the pen, placement weight, and BRD morbidity. The mortality distributions shown in Figure 3.1 are generated using the results of the Mortality Tobit Multiplicative Heteroskedasticity Model as shown in Table 3.5.

Table 3.5. Mortality Tobit Multiplicative Heteroskedasticity Model Results

Variable	Conditional Mean	Conditional Variance
Constant	4.8691* (2.330)	1.2959* (0.054)
Treated 1X[a]	0.0484* (0.016)	0.0303* (0.006)
Treated 2X[a]	0.1554* (0.049)	0.0193 (0.018)
Treated 3X or more[a]	0.3205* (0.068)	0.0278 (0.025)
Log Placement Weight	-0.7088* (0.348)	
Observations	1,157	
Log-likelihood	-1701.77	

Notes: [a] denotes percent of pen (%) that has been treated 1 time (1X), 2 times (2X), or 3 or more times (3X). * denotes the estimate is statistically significant at the 5% level. Standard errors are in the parentheses.

Figure 3.1. Mortality Distributions using Average Percent of Animals Treated by Placement Weight



Note: Mean and standard deviation mortality parameters for given pen-average treatment values found in Table 3.4 by placement weight are: i) 850 lb.: 0.80 (1.38); ii) 700 lb.: 1.07 (1.42); iii) 550 lb.: 2.01 (1.60). Standard deviations are in the parentheses.

Performance Metric and Veterinary Expense Models

Linear mixed models (LMM) are estimated to parameterize the effects of pen-level characteristics and BRD morbidity on performance and overall veterinary expense per head. The linear predictor for the LMM model is

$$y = X\beta + Zu + \varepsilon \tag{3.6}$$

where X is the matrix of fixed effects, β is the vector of fixed effect parameters, Z is the design matrix of random effects, u is the vector of random effects, and ε is the vector of random errors. The expected value of y is

$$E(y) \quad = \quad X\beta. \tag{3.7}$$

ADG, *AFC*, and veterinary cost per head (*VCPH*) are all individually modeled as a function of $STEER$, $lnPWT$, $TRT\ 1X$, $TRT\ 2X$, and $TRT\ 3X$ as fixed effects. For *AFC* and *VCPH*, the feedlot company and cohort size also influence variation through feedlot-specific differences in geographic location and management practices. The cohort size (i.e., number of head per purchase lot) also captures within-cohort characteristics. Dataset II is used to model *ADG*, and the only random effect considered in the *ADG* model is cohort size because the dataset is from a single feedlot, thus there is no intra-feedlot variation.

The model estimation results for *ADG*, *AFC*, and *VCPH* are shown in Table 3.6. *ADG* is modeled using a linear regression shown by equation (3.8); a linear mixed model was evaluated for *ADG* with cohort size as a random effect, but the likelihood ratio test rejected the LMM in favor of a linear model. The fixed effects for *AFC* and *VCPH* are captured by equations (3.9) and (3.10), with the additional inclusion of two random effects to capture pen-level and feedlot-specific characteristics. Steer cohorts are associated with an increase in *ADG*, a decrease in *AFC,* and an increase in *VCPH*.

Table 3.6. Model Results for Performance Metrics and Veterinary Expense

Variables	ADG	AFC	Veterinary Expense
Fixed Effects			
Constant	-1.2175* (0.299)	-0.3272 (0.769)	20.2466* (4.911)
Steers	0.2881* (0.014)	-0.3206* (0.033)	0.3886 (0.209)
Log Placement Weight	0.6703* (0.045)	1.0199* (0.114)	-0.8346 (0.728)
Treated 1x[a]	-0.0062* (0.001)	-0.0139* (0.004)	0.3421* (0.028)
Treated 2x[a]	-0.0017 (0.002)	0.0280* (0.012)	0.5113* (0.077)
Treated 3x or more[a]	-0.0059* (0.003)	0.0309* (0.013)	1.0126* (0.084)
Random Effects[b]			
Company		0.0513	3.6882
Cohort Size		0.0262	1.7458
Observations	2,592	1,157	1,157
Log-Likelihood	-964.11	-960.96	-3061.52

Notes: [a] denotes proportion of pen (% × 100) that has been treated 1 time (1x), 2 times (2x), or 3 or more times (3x). [b] Variances are reported for each random effect. * denotes the estimate is statistically significant at the 5% level. Standard errors are in the parentheses.

Simulation

The simulation framework for this chapter is similar to Chapter 2 with the inclusion and adaptation of equations to account for morbidity in the feedlot. This simulation utilizes the same three purchase weight categories, CPW_w—550 pounds, 700 pounds, and 850 pounds. A small proportion of the lot is marketed prematurely represented by $CULL_w$ in the simulation; the average weight of these culled animals is specific to each placement weight category denoted by $CULLW_w$. These prematurely marketed animals, also called realizers or railers, are sold at a sizeable discount due to lameness or chronic sickness. The salvage value of these culled animals is preferred over the economic loss endured by premature death (Feuz, Feuz, & Johnson, 2020). Horton et al. (2021) concluded that the price received for culls in the feedlot was most highly correlated with national dressed cull cow prices, specifically Breaker [75% lean]; over 500 lb.

HCW. We use the cull price, *CULLP*, of \$1.05 per dressed pound and culled hot carcass weights, $CULLW_w$, of 444 pounds, 524 pounds, and 624 pounds calculated in Chapter 2.

The cattle purchase price, FRP_w, is equal to \$1.7397/lb., \$1.5570/lb., and \$1.4558/lb. for animals that weigh 550 pounds, 700 pounds, and 850 pounds at placement, respectively. These prices were determined to result in breakeven net returns ($\pi = 0$) given the average of each treatment category—1X, 2X, and 3X—by placement weight. A 5% annualized interest rate, *IR*, as well as a 4% pencil shrink, *SHRINK*, are also accounted for in the simulation. The corn price, *FEED*, is on a per-pound basis. A normal distribution with a mean ($\boldsymbol{\gamma_k}$) and a standard deviation ($\boldsymbol{\sigma}$) is randomly sampled for the finished animal weight, $CSW_{w,k}$, determined at maturity for animals that survive until slaughter. We expect animals that were placed at a heavier weight to finish at a heavier weight so the mean (standard deviation) values depend on placement weight: i) 550 pounds have a $CSW_{w,k}$ of 1250 pounds (86 pounds); ii) 700 pounds have a $CSW_{w,k}$ of 1271 pounds (84 pounds); iii) 850 pounds have a $CSW_{w,k}$ of 1360 pounds (87 pounds). For animals that died during the finishing phase, the finished animal weight is equal to zero ($i.e., k = 0$). The fed cattle price, FP, used to calculate total revenue is set to \$1.2628/lb.

Iman and Conover's (1980) algorithm is utilized to simulate the individually stochastic yet correlated variables—ADG, AFC, and VCPH. For the simulation, these variables are normally distributed, $N_k \sim (\mu_k, \sigma)$, where μ_k is the vector of means representing ADG, AFC, and VCPH estimated from equations (3.8) through (3.10) and σ is the vector of standard deviations of the residuals from the estimated equations. Days on feed, $DOF_{w,k}$; feed cost, $FC_{w,k}$; feeder cattle purchase cost, $FDRC_w$; interest cost, $IC_{w,k}$; cattle sales total revenue, $TR_{w,k}$; yardage cost, $YC_{w,k}$; and net feeding returns, $\rho_{w,k}$ are additional calculated or simulated inputs for the model. These inputs are depicted by equations (3.11) through (3.17).

The key simulation output of interest that combines all elements outlined above is the weighted-average net return distribution. Using the expected mean and standard deviation of the mortality distribution based on using the Tobit Multiplicative Heteroskedasticity mortality model, a random mortality rate, $MORT_w$, is sampled from the log-normal death loss distribution using Halton draws. Halton draws dramatically increase estimation speed by allowing for intelligent sampling across the domain of a distribution without sacrificing simulation performance (Train, 1999). Then, using a pen size of 120 head, $\varphi_{w,k} \times 120$ net returns are calculated for k = *dead* animals, $CULL_w \times 120$ net returns are calculated for the animals that are culled, and $\left(1 - \varphi_{w,k} - CULL_w\right) \times 120$ net returns are calculated for k = *alive* animals. The mean of each pen is then computed, and this process is repeated 10,000 times to determine the weighted-average net return distribution.

Table 3.7. Simulation Model Variables

Fixed		
CPW_w	Cattle purchase weight (lb./head)	550, 700, 850
$CULL_w$	Proportion of chronically ill animals culled from the remaining cohort based on CPW—550, 700, and 850	0.0226, 0.0079, 0.0050
CULLP	Dressed price received for cull animals ($/dressed lb.)	1.05
$CULLW_w$	Average dressed weight of culled animals by CPW_w (dressed lb./head)	444, 524, 624
FEED	Corn price when cattle are placed on feed ($/lb.)	0.0923
FP	Fed cattle sale price ($/lb.)	1.2628
FRP_w	Purchase price for 550-, 700-, and 850-pound calves ($/lb.)	1.7397, 1.5570, 1.4558
IR	Annualized interest rate	0.05
SHRINK	Percentage shrink in live weight when marketed	4%
Simulated/Calculated		
$\varphi_{w,k}$	Proportion of death loss in pen	$MORT_w/100$
$CSW_{w,k}$	Finished animal weight (lb./head) if animal reaches maturity (i.e., k = alive); 0 otherwise (i.e., k = dead)	$N_k \sim (\gamma_k, \sigma)$
$ADG_{w,k}$	Average daily gain during feeding (lb./head/day)	See equation (3.8)
$AFC_{w,k}$	Average pounds of feed consumer per pound of weight gain (lb. feed/lb. gain)	See equation (3.9)
$VCPH_w$	Animal health care cost including pull-and-treat, vaccinations, labor costs, etc. ($/head)	See equation (3.10)
$DOF_{w,k}$	Number of days on feed (days)	See equation (3.11)
$YC_{w,k}$	Yardage cost of feeding cattle ($/head)	See equation (3.12)
$FC_{w,k}$	Feed cost ($/head)	See equation (3.13)
$FDRC_w$	Feeder cattle purchase cost ($/head)	See equation (3.14)
$IC_{w,k}$	Interest cost ($/head)	See equation (3.15)
$TR_{w,k}$	Total revenue from cattle sales ($/head)	See equation (3.16)
$\rho_{w,k}$	Net feeding returns ($/head) for each weight (w) and death loss group (k)	See equation (3.17)

Note: Adapted from "Value of Arrival Metaphylaxis in U.S. Cattle Industry" by Dennis et al., 2018, *Journal of Agricultural and Resource Economics* 43(2), p. 241

$$ADG_{w,k} = \beta_0 + \beta_1 STEER + \beta_2 lnPWT_w + \beta_3 TRT\ 1X + \beta_4 TRT\ 2X + \beta_5 TRT\ 3X \quad (3.8)$$

$$AFC_{w,k} = \beta_0 + \beta_1 STEER + \beta_2 lnPWT_w + \beta_3 TRT\ 1X + \beta_4 TRT\ 2X + \beta_5 TRT\ 3X \quad (3.9)$$

$$VCPH_{w,k} = \beta_0 + \beta_1 STEER + \beta_2 lnPWT_w + \beta_3 TRT\ 1X + \beta_4 TRT\ 2X + \beta_6 TRT\ 3X \quad (3.10)$$

$$DOF_{w,k} = \frac{CSW_{w,k} - CPW_w}{ADG_{w,k}} \quad (3.11)$$

$$YC_{w,k} = 0.40 \times DOF_{w,k} \quad (3.12)$$

$$FC_{w,k} = \{AFC_{w,k}[CSW_k \times (1 - \varphi_{w,k} - CULL_w) - CPW_w]\} \quad (3.13)$$

$$FDRC_w = FRP_w \times CPW_w \quad (3.14)$$

$$IC_{w,k} = \{0.5 \times [YC_{w,k} + FC_{w,k} + VCPH_w] + FDRC_w\} \times DOF_{w,k} \times (IR/365) \quad (3.15)$$

$$TR_{w,k} = FP \times CSW_k \times (1 - SHRINK) \times (1 - \varphi_{w,k} - CULL_w) + (CULL_w \times CULLW_w \times CULLP) \quad (3.16)$$

$$\rho_{w,k,} = TR_{w,k} - FDRC_w - YC_{w,k} - FC_{w,k} - VCPH_w - IC_{w,k} \quad (3.17)$$

Sensitivity Analysis

To evaluate the sensitivity of increasing the percentage of animals per pen treated once, twice, or three or more times, a linear regression was estimated for each weight category for a total of nine regressions. The reason this process is necessary is due to the lack of observational data as the percent of animals not treated for BRD falls to zero. These regressions aid in approximating the percent of the pen treated 1X, 2X, and 3X given a fixed percentage of animals not treated for BRD during the finishing phase. The independent variable of each of the nine regressions is the percent of animals treated for BRD 0X; the dependent variable for each regression is the percent treated 1X, 2X, or 3X or more times. Parameter estimates for these regressions are seen in Table 3.8. These coefficients were utilized to generate Table 3.9, where the percentage of animals treated 1X, 2X, and 3X or more times by placement weight category is determined using the linear regression results and a fixed percentage of the pen treated 0X.

Table 3.8. Linear Regression Results to Approximate Sensitivity Table

Weight Category	Model Parameter	Dependent Variable		
		Treated 1X	Treated 2X	Treated 3X Times
550 lbs.	Intercept	57.3774	23.2821	19.3405
	TRT 0X Coefficient	-0.5533	-0.2403	-0.20640
	Adj. R^2	0.7906	0.7646	0.4606
700 lbs.	Intercept	69.8423	19.9722	10.1856
	TRT 0X Coefficient	-0.6950	-0.2023	-0.1027
	Adj. R^2	0.9100	0.6543	0.3482
850 lbs.	Intercept	76.0654	17.5625	6.3721
	TRT 0X Coefficient	-0.7593	-0.1768	-0.0639
	Adj. R^2	0.9310	0.5123	0.2725

Notes: N = 76 pens for the 550 lb. weight category; N = 449 pens for the 700 lb. weight category; N = 632 pens for the 850 lb. weight category

Table 3.9. Percentage Treated Sensitivity Values by Placement Weight

TRT 0X	550 lb. Placement Weight			700 lb. Placement Weight			850 lb. Placement Weight		
	TRT 1X	TRT 2X	TRT 3X	TRT 1X	TRT 2X	TRT 3X	TRT 1X	TRT 2X	TRT 3X
100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95.00	3.34[a]	1.04[a]	0.62[a]	3.82	0.75	0.43	3.93	0.76	0.31
90.00	7.58	1.66	0.76	7.29	1.76	0.94	7.73	1.65	0.62
85.00	10.35	2.86	1.80	10.77	2.77	1.46	11.52	2.53	0.94
80.00	13.11	4.06	2.83	14.24	3.79	1.97	15.32	3.42	1.26
75.00	15.88	5.26	3.86	17.72	4.80	2.48	19.12	4.30	1.58
70.00	18.65	6.46	4.89	21.19	5.81	3.00	22.91	5.18	1.90
65.00	21.41	7.66	5.92	24.67	6.82	3.51	26.71	6.07	2.22
60.00	24.18	8.87	6.96	28.14	7.83	4.03	30.51	6.95	2.54
55.00	26.95	10.07	7.99	31.62	8.84	4.54	34.30	7.84	2.86
50.00	29.71	11.27	9.02	35.09	9.86	5.05	38.10	8.72	3.18
45.00	32.48	12.47	10.05	38.57	10.87	5.57	41.90	9.61	3.50
40.00	35.24	13.67	11.08	42.04	11.88	6.08	45.69	10.49	3.82
35.00	38.01	14.87	12.12	45.52	12.89	6.59	49.49	11.37	4.14
30.00	40.78	16.07	13.15	48.99	13.90	7.11	53.29	12.26	4.46
25.00	43.54	17.27	14.18	52.47	14.91	7.62	57.08	13.14	4.78
20.00	46.31	18.48	15.21	55.94	15.93	8.13	60.88	14.03	5.09
15.00	49.08	19.68	16.24	59.42	16.94	8.65	64.68	14.91	5.41
10.00	51.84	20.88	17.28	62.89	17.95	9.16	68.47	15.79	5.73
5.00	54.61	22.08	18.31	66.37	18.96	9.67	72.27	16.68	6.05
0.00	57.38	23.28	19.34	69.84	19.97	10.19	76.07	17.56	6.37

Note: All values in the table are in percentages, %; [a] due to negative percentages estimated using the linear regression results, the values for 550 lb. placement weight given 95% of cattle were treated 0X are approximated from observational data.

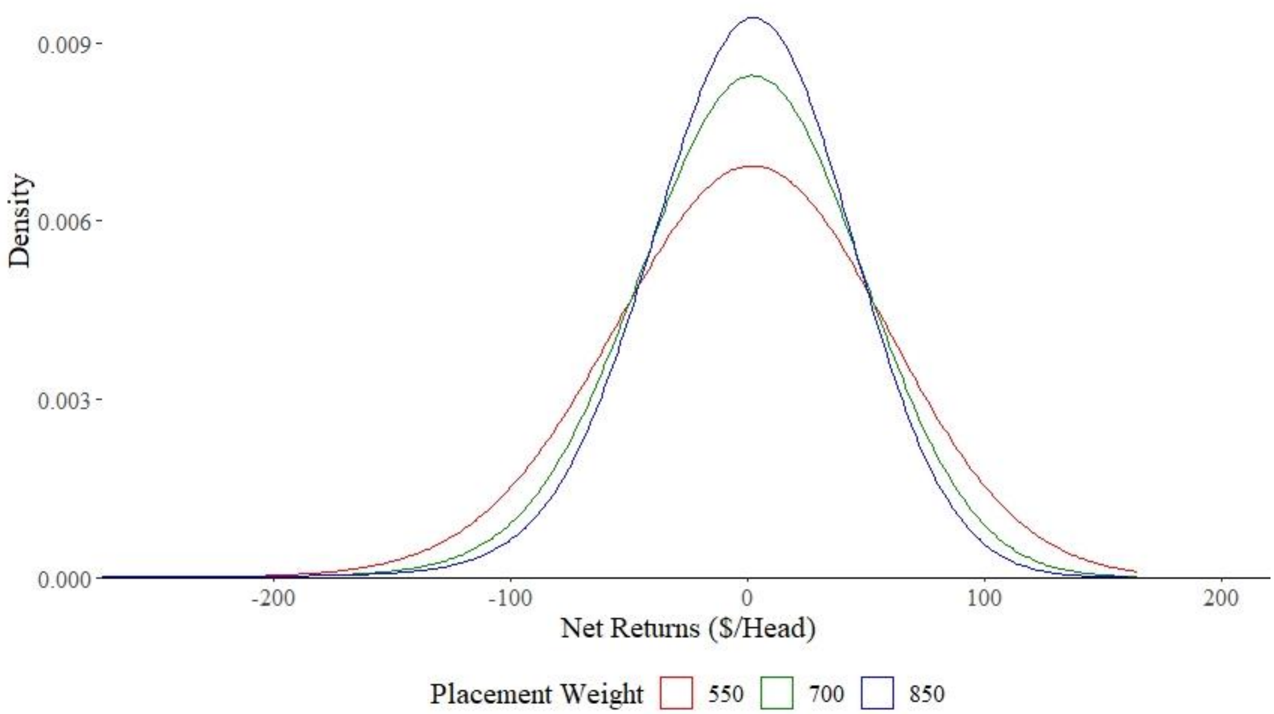
Results

Table 3.10 includes the summary statistics for each net return distribution given the pen-level average of animals treated 1X, 2X, and 3X. The breakeven net returns are determined at the pen-level treatment averages. As the placement weight increases, the standard deviation of the net returns distribution decreases. These distributions are illustrated in Figure 3.2.

Table 3.10. Net Returns by Placement Weight given Pen-level Treatment Averages

Placement Weight	Net Returns ($/head)				
	Minimum	Median	Mean	Max	St. Dev.
550 pounds	-250.40	1.56	0.00	163.92	44.22
700 pounds	-343.20	1.90	0.00	126.10	37.39
850 pounds	-427.37	2.07	0.01	123.16	34.75

Figure 3.2. Net Returns Distributions given Pen Average Percent of Animals Treated by Placement Weight



Note: Net return distributions are for pen-average treatment values found in Table 3.4.

For the sensitivity analysis portion of this chapter, Table 3.11, Table 3.12, and Table 3.13 contain the summary statistics for the sensitivity analysis by placement weight. These tables illustrate the effect of decreasing the percent of cattle in a pen that has been treated for BRD zero times. For 550-pound calves, if no animals get treated for BRD (i.e., TRT 0X = 100), the mean expected net return is $25.80 a head given a purchase price of $1.7397 and a fed cattle price of $1.2628 a pound. Conversely, if all cattle in a pen have received at least one BRD treatment (i.e., TRT 0X = 0.00), the mean net return decreases to a loss of $221.03 per head for cattle with a 550 lb. placement weight. For 700 lb. cattle, when no animals are treated for BRD, the expected net return mean is $8.96 per head. For pens where all cattle have been treated at least once, the mean of the net returns distribution is -$169.95 per head. When pens of cattle with a placement weight of 850 pounds have zero animals treated for BRD, the expected net return per head is $5.11. Then all animals have been treated at least once, the mean net return per head is -$151.78. As the placement weight of the animals increase and the number of animals treated for BRD begins to increase, the risk of retreat decreases for heavier placement weights. This is indicated by the higher percentage of animals treated 3X or more, which contributes to 550-pound cattle having the lowest expected net returns per head when all cattle have had at least one BRD treatment (i.e., TRT 0X = 0).

Additionally, these net return distributions can be visualized using Ridgeline plots, where multiple distributions are all aligned on the same horizontal scale. The vertical line through each distribution represents the mean. The percent of the pen that does not receive any BRD treatments is labeled on the y-axis and on the x-axis is the weighted-average net return in $/head. All Ridgeline plots are in Figure 3.3, Figure 3.4, and Figure 3.5 by placement weight. As the morbidity in the pen increases, this model may slightly underestimate the effect on net returns per head; the underestimation is due to the lack of data to calibrate the effect of morbidity on finish weights of individual animals. It is well documented that as the number of treatments an animal receives increases, the finish weight declines.

Table 3.11. 550 lb. Placement Weight Net Returns Sensitivity

TRT 0X	TRT 1X	TRT 2X	TRT 3X	Minimum	Median	Mean	Maximum	St. Dev.
100.00	0.00	0.00	0.00	-326.18	27.50	25.80	181.70	42.65
95.00	3.34	1.04	0.62	-286.02	18.39	17.06	176.24	43.21
90.00	7.58	1.66	0.76	-273.68	14.14	12.51	164.75	43.78
85.00	10.35	2.86	1.80	-251.82	1.41	-0.02	159.57	44.24
80.00	13.11	4.06	2.83	-245.69	-11.06	-12.73	152.32	44.91
75.00	15.88	5.26	3.86	-255.40	-24.11	-25.74	150.81	45.55
70.00	18.65	6.46	4.89	-256.98	-37.34	-38.83	134.35	46.25
65.00	21.41	7.66	5.92	-274.00	-50.48	-51.96	133.41	47.08
60.00	24.18	8.87	6.96	-289.08	-63.52	-65.15	114.25	47.90
55.00	26.95	10.07	7.99	-309.39	-76.05	-78.26	104.24	48.95
50.00	29.71	11.27	9.02	-336.27	-89.18	-91.37	106.88	50.06
45.00	32.48	12.47	10.05	-356.52	-102.15	-104.44	87.35	51.28
40.00	35.24	13.67	11.08	-384.10	-115.20	-117.49	78.48	52.66
35.00	38.01	14.87	12.12	-406.63	-127.79	-130.56	64.87	54.30
30.00	40.78	16.07	13.15	-441.45	-140.47	-143.56	53.74	56.04
25.00	43.54	17.27	14.18	-461.20	-153.46	-156.53	48.37	57.96
20.00	46.31	18.48	15.21	-501.54	-165.58	-169.50	45.22	60.08
15.00	49.08	19.68	16.24	-535.44	-178.07	-182.43	28.30	62.39
10.00	51.84	20.88	17.28	-564.20	-190.32	-195.34	30.56	64.92
5.00	54.61	22.08	18.31	-606.89	-202.96	-208.22	14.05	67.68
0.00	57.38	23.28	19.34	-646.70	-215.24	-221.03	10.44	70.72

Figure 3.3. Ridgeline Plot for 550 Pound Placement Weight Net Return Densities based on Percent of Pen Treated 0 Times

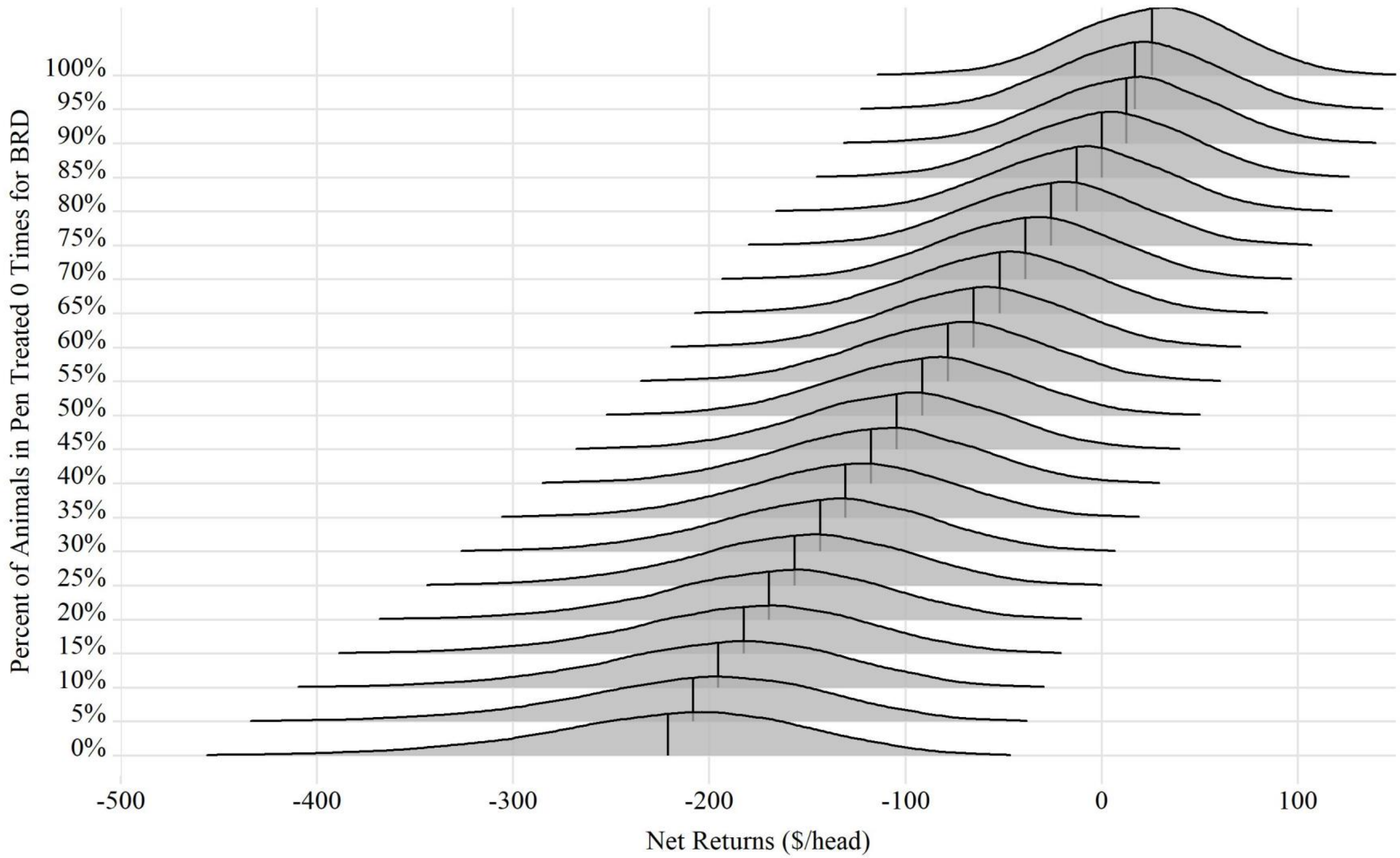


Table 3.12. 700 lb. Placement Weight Net Returns Sensitivity

TRT 0X	TRT 1X	TRT 2X	TRT 3X	Minimum	Median	Mean	Maximum	St. Dev.
100.00	0.00	0.00	0.00	-391.45	10.43	8.96	134.98	36.19
95.00	3.82	0.75	0.43	-347.98	4.12	2.55	131.09	37.13
90.00	7.29	1.76	0.94	-319.11	-4.283	-5.91	127.08	37.99
85.00	10.77	2.77	1.46	-298.24	-12.50	-14.52	132.39	38.55
80.00	14.24	3.79	1.97	-293.37	-21.18	-23.23	114.24	39.52
75.00	17.72	4.80	2.48	-296.40	-29.93	-21.10	111.06	40.48
70.00	21.19	5.81	3.00	-312.81	-38.91	-41.15	116.08	41.44
65.00	24.67	6.82	3.51	-325.52	-47.61	-50.22	109.63	42.71
60.00	28.14	7.83	4.03	-330.50	-56.89	-59.39	82.69	43.99
55.00	31.62	8.84	4.54	-346.80	-65.37	-68.52	94.11	45.48
50.00	35.09	9.86	5.05	-373.62	-74.40	-77.74	81.54	46.92
45.00	38.57	10.87	5.57	-399.21	-83.26	-86.94	80.81	48.65
40.00	42.04	11.88	6.08	-417.37	-92.02	-96.11	70.93	50.61
35.00	45.52	12.89	6.59	-452.67	-100.66	-105.32	65.15	52.76
30.00	48.99	13.90	7.11	-489.02	-109.76	-114.54	75.60	55.10
25.00	52.47	14.91	7.62	-521.23	-117.78	-123.73	66.61	57.62
20.00	55.94	15.93	8.13	-558.29	-126.59	-132.97	52.30	60.39
15.00	59.42	16.94	8.65	-589.74	-135.15	-142.20	43.75	63.47
10.00	62.89	17.95	9.16	-633.25	-142.96	-151.43	40.83	66.73
5.00	66.37	18.96	9.67	-678.09	-151.62	-160.66	40.58	70.28
0.00	69.84	19.97	10.19	-730.08	-159.65	-169.95	36.20	74.25

Figure 3.4. Ridgeline Plot for 700 Pound Placement Weight Net Return Densities based on Percent of Pen Treated 0 Times

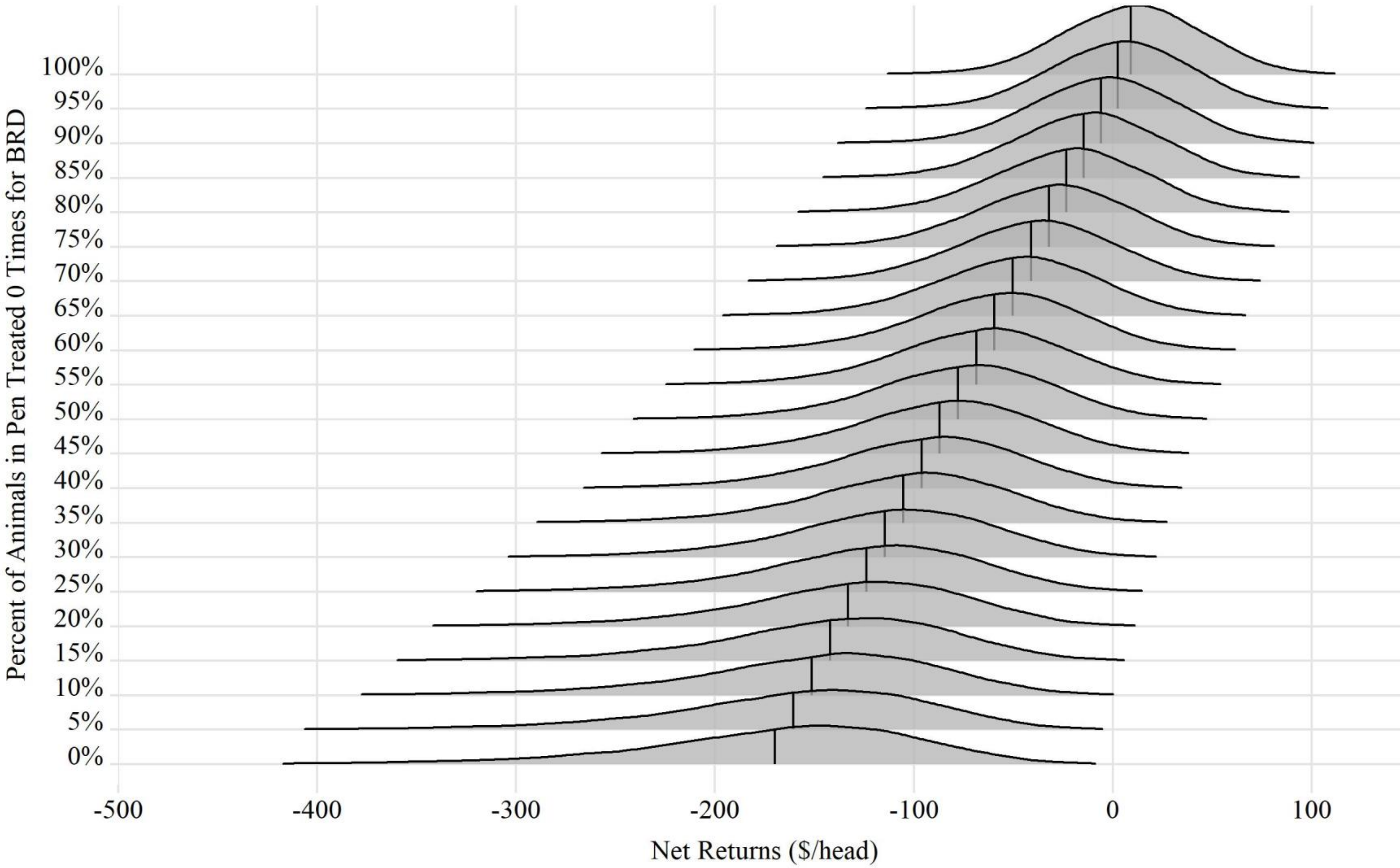
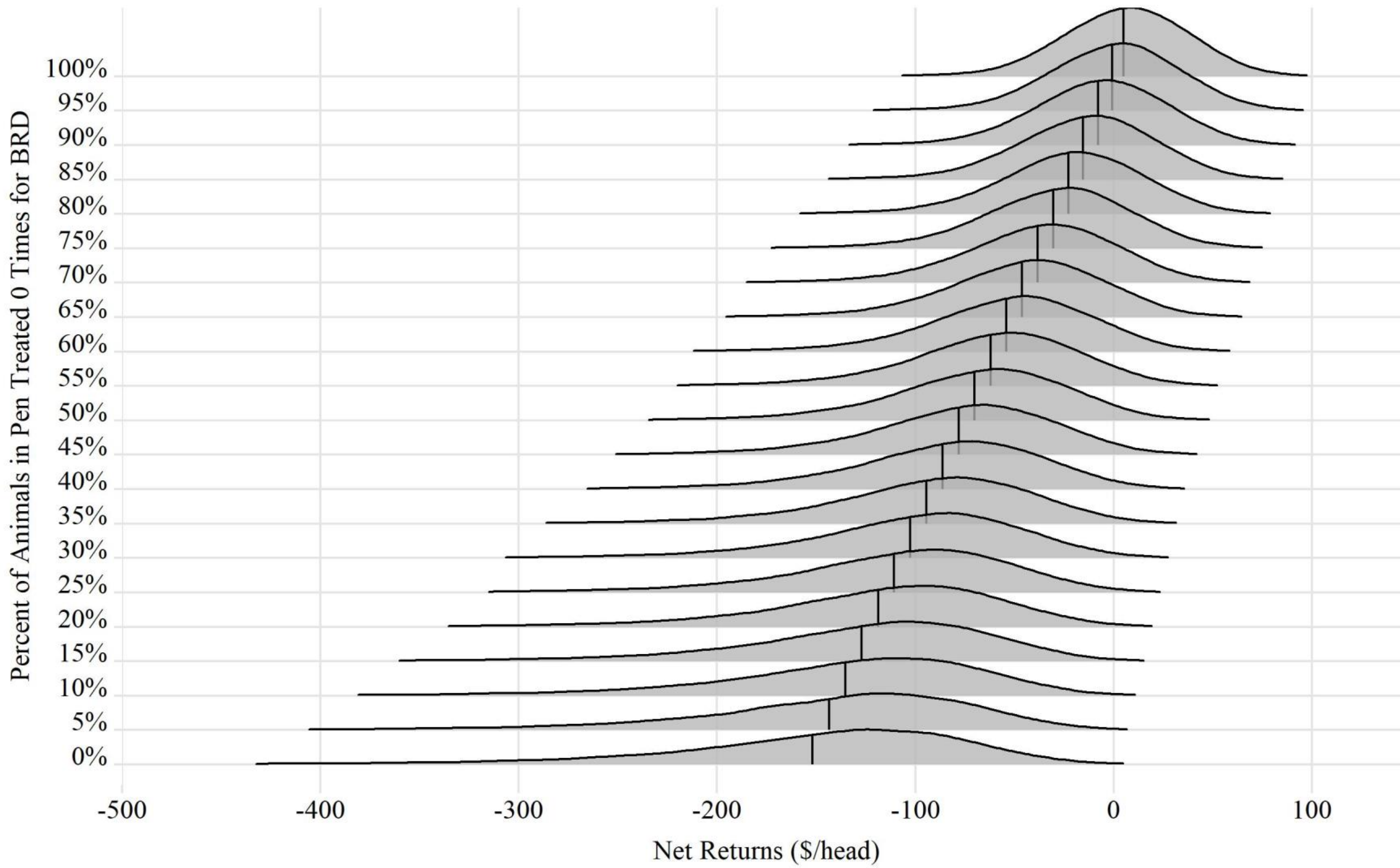


Table 3.13. 850 lb. Placement Weight Net Returns Sensitivity

TRT 0X	TRT 1X	TRT 2X	TRT 3X	Minimum	Median	Mean	Maximum	St. Dev.
100.00	0.00	0.00	0.00	-469.22	6.70	5.11	130.25	33.59
95.00	3.93	0.76	0.31	-426.78	1.36	-0.76	120.09	34.95
90.00	7.73	1.65	0.62	-389.89	-5.86	-7.86	118.84	35.95
85.00	11.52	2.53	0.94	-367.60	-12.97	-15.34	123.54	36.85
80.00	15.32	3.42	1.26	-354.35	-50.56	-22.89	103.34	38.05
75.00	19.12	4.30	1.58	-357.82	-27.44	-30.51	97.95	39.27
70.00	22.91	5.18	1.90	-361.99	-34.93	-38.25	99.99	40.74
65.00	26.71	6.07	2.22	-373.05	-42.88	-46.15	95.28	42.11
60.00	30.51	6.95	2.54	-385.48	-49.93	-54.09	87.57	43.87
55.00	34.30	7.84	2.86	-413.49	-57.77	-62.10	85.86	45.63
50.00	38.10	8.72	3.18	-439.72	-65.12	-70.15	77.20	47.72
45.00	41.90	9.61	3.50	-461.33	-72.88	-78.17	82.12	49.87
40.00	45.69	10.49	3.82	-487.50	-80.25	-86.27	69.39	52.26
35.00	49.49	11.37	4.14	-525.27	-87.85	-94.36	66.18	54.88
30.00	53.29	12.26	4.46	-557.69	-94.99	-102.47	65.84	57.79
25.00	57.08	13.14	4.78	-598.74	-102.21	-110.65	67.33	60.89
20.00	60.88	14.03	5.09	-647.60	-109.40	-127.00	54.59	64.33
15.00	64.68	14.91	5.41	-687.41	-116.46	-127.00	54.59	67.92
10.00	68.47	15.79	5.73	-745.88	-123.84	-135.19	45.88	71.91
5.00	72.27	16.68	6.05	-797.80	-130.36	-143.47	50.91	76.32
0.00	76.07	17.56	6.37	-869.45	-137.48	-151.78	42.45	80.96

Figure 3.5. Ridgeline Plot for 850 Pound Placement Weight Net Return Densities based on Percent of Pen Treated 0 Times



Discussion

Comparing the mortality model specification that we estimated to the mortality linear regression estimated in Irsik et al. (2006), both models are driven by feedlot morbidity but in slightly different capacities. Our mortality model focuses on BRD morbidity and the number of times a percentage of the pen of cattle have been treated. On the other hand, the linear model specification of Irsik et al. (2006) models the percent mortality rate as a function of the percent of animals pulled and treated in the pen as an independent variable. Their primary conclusion from the mortality model is the expected mortality rate of a pen of cattle is the percent treated multiplied by 0.14. For a pen of cattle with 5% of animals treated, this result implies a mortality rate of 0.70%. Alternatively, given steers with a 700-pound placement weight, for our mortality model with 5% of animals having received at least one treatment, is a mean mortality rate of 0.70% with a standard deviation of 0.29. Irsik et al. (2006) is one of the only published mortality rate models modeling death that includes morbidity. Another published mortality model is Belasco et al. (2009) but their model specification does not account for morbidity, only variables known about the cattle at the time of placement—sex of the pens, feedlot location, log of the placement weight, and placement season. The use of a Tobit model with multiplicative heteroskedasticity estimates the conditional mean and variance of mortality, which provides more information regarding the expected mortality distribution. By utilizing the Tobit model with multiplicative heteroskedasticity to model BRD morbidity, we learn more about how treatments for clinically diagnosed BRD within a pen of cattle affect both the conditional mean and dispersion of mortality distributions.

Furthermore, the performance metric and VCPH equations estimated in this chapter are quite unique. Multiple studies have reported associations between BRD and poorer productive performance, impaired carcass quality, lower average daily gain, and suppressed net returns (Babcock et al., 2009; Cernicchiaro et al., 2013; Wittum et al., 1996) and we obtain parameter estimates for ADG, AFC, and VCPH that are mostly in line with previous literature. As the percentage of animals treated 1X, 2X, or 3X or more times within a pen increases, expected mortality increases, ADG decreases, AFC increases for percentage of animals treated 2X and 3X or more, VCPH increases, and overall net returns per head decrease.

Conclusion

Costs associated with morbidity are one of the most important determinants of profitability in the feedlot (Gardner et al., 1999). BRD is responsible for approximately 75% of morbidity and 50-80% of mortality (Edwards, 1996; Kelly & Janzen, 1986). The overall scope of this chapter is unique based on the assessment of both BRD morbidity and total mortality in a pen of cattle placed on feed. Other papers (Cernicchiaro et al., 2013) have assessed the influence of the number of treatments an animal received within the first 100 days on feed on net returns, yet do not model mortality or performance metrics as a function of morbidity that ultimately influence the weighted-average net return given a complex net returns simulation framework.

Evaluating the net return models for each percentage treated combination indicated that as the percentage of animals treated within the pen increases, the mean net return per head decreases for all placement weights. This is driven by a combination of things, including but not limited to, decreased animal performance due to BRD-related sickness, increased veterinary cost per head, and increased mean and standard deviation of mortality distributions. It is worth noting that as Cernicchiaro et al. (2013, p. 307) stated, “we cannot differentiate whether the increasing number of treatments after an initial diagnosis of BRD caused the decreased performance (ADG, hot carcass weight, calculated yield grade, and quality grade) or whether cattle with decreased performance were more prone to develop disease."

Ultimately, the scope of this chapter is unique given the specification of the mortality models, performance metric models, VCPH model, and overall net returns stochastic simulation to include BRD morbidity modeled as the percentage of the pen treated for BRD 1X, 2X, and 3X or more times. Multiple studies have reported associations between BRD and poorer productive performance, impaired carcass quality, lower average daily gain, and suppressed net returns (Babcock et al., 2009; Cernicchiaro et al., 2013; Wittum et al., 1996) and we obtain parameter estimates for ADG, AFC, and VCPH that are mostly in line with previous literature. As the percentage of animals treated 1X, 2X, or 3X or more times within a pen increases, expected mortality increases, ADG decreases, AFC increases for percentage of animals treated 2X and 3X or more, VCPH increases, and overall net returns per head decrease. No other studies that we are aware of model mortality, finishing performance, and net returns as pen-level BRD morbidity changes in this manner.

Further research is needed with the inclusion of high-risk cattle to evaluate the difference between expected treatment distributions and subsequent net returns. Additionally, evaluating other treatments (i.e., digestive, etc.) would provide a more well-rounded approach to modeling feedlot morbidity. Other possible avenues of future research include assessing the effects of preconditioning in reducing the number of treatments an animal receives during the finishing phase compared to animals with unknown health history, similar to the dataset that we utilized in this study.

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Appendix A - Chapter 1 Appendix

Table A.1. Performance Metric Variable Correlation Matrix

	ADG	*AFC*	*HC*
ADG	1.0000000	-0.4400490	-0.4987218
AFC	-0.4400490	1.0000000	0.0481448
HC	-0.4987218	0.0481448	1.0000000

Note: Obtained from personal communication (Dennis, May 25, 2021)

Table A.2. Performance Metric Standard Deviations

Performance Metric	Standard Deviation
ADG	0.3699815
AFC	0.5269904
HC	8.020503

Note: Obtained from personal communication (Dennis, September 1, 2021)

Table A.3. KSU Beef Finishing Feed Requirement per Animal

	Quantity	**Unit**
Prairie/Brome Hay	1.50	lbs./day
Silage	0.00	lbs./day
Alfalfa	1.50	lbs./day
Total Harvested Forage	3.00	lbs./day
Corn	17.00	lbs./day
DDG's	5.00	lbs./day
Soybean Meal	0.00	lbs./day
Total Grain/Protein Supplements	22.00	lbs./day
Salt and Mineral	0.500	lbs./day

Note: Adapted from "KSU-Beef Farm Management Guide Spreadsheet" by G. Tonsor and R. Reid, 2020, from KSU Ag Manager (https://www.agmanager.info/farm-mgmt-guides/livestock-budgets/ksu-beef-farm-management-guide-spreadsheet-3).

Table A.4. KSU Beef Finishing Default Prices

Default Beef Finishing Prices			
	2021 Production Year	Adjusted to Simulation	Five Years Out
Corn ($/bu)	$4.25	$5.17	$3.55
Soybean Meal ($/ton)	$380.00	$462.15	$341.00
DDGS ($/ton)	$210.00	$255.40	$175.41
Silage ($/ton)	$34.00	$41.35	$28.40
Prairie Hay ($/ton)	$70.00	$85.13	$58.47
Alfalfa ($/ton)	$160.00	$194.59	$133.65
Other Beef Mineral ($/ton)	$600.00	$729.71	$660.00

Note: * are predicted prices; Adapted from "KSU-Beef Farm Management Guide Spreadsheet" by G. Tonsor and R. Reid, 2020, from KSU Ag Manager (https://www.agmanager.info/farm-mgmt-guides/livestock-budgets/ksu-beef-farm-management-guide-spreadsheet-3).

Table A.5. Seed Differences for 700-pound Non-metaphylaxis Cattle Simulation

Seed	Net Return ($/head)			
	Minimum	Median	Mean	Max
Simulation Results	-1057.40	150.50	116.60	278.70
50	-1125.26	145.84	113.57	268.59
500	-1070.88	149.97	115.45	309.27
5000	-1078.12	147.52	114.07	272.53
50,000	-974.88	148.29	112.87	273.04
500,000	-1112.10	149.40	113.40	270.80

Table A.6. Simulation Net Return Summary Statistics with Adjusted Feeder Purchase Price

Placement Weight	Net Return ($/head)			
	Minimum	Median	Mean	Max
Metaphylaxis Treated Cattle				
550 pounds	-503.96	10.19	-0.95	71.17
700 pounds	-177.15	3.51	-0.41	57.32
850 pounds	-167.29	4.31	1.15	42.01
Non-Metaphylaxis Treated Cattle				
550 pounds	-1248.56	-67.99	-124.46	51.87
700 pounds	-1303.77	-101.08	-134.93	26.61
850 pounds	-1395.54	-47.17	-78.01	40.81

Table A.7. Net Differences between Metaphylaxis Treated and Untreated Cattle with Adjusted Feeder Purchase Price

Weight	Loss for High-Risk Cattle Relative to Metaphylaxis Treated Cattle ($/head)
Adjusted Duplication Attempt Results	
550 pounds	123.51
700 pounds	134.52
850 pounds	76.86
Dennis et al. Results	
550 pounds	104.46
700 pounds	99.26
850 pounds	63.35

Figure A.1. Original Dennis et al. Return Simulation Results

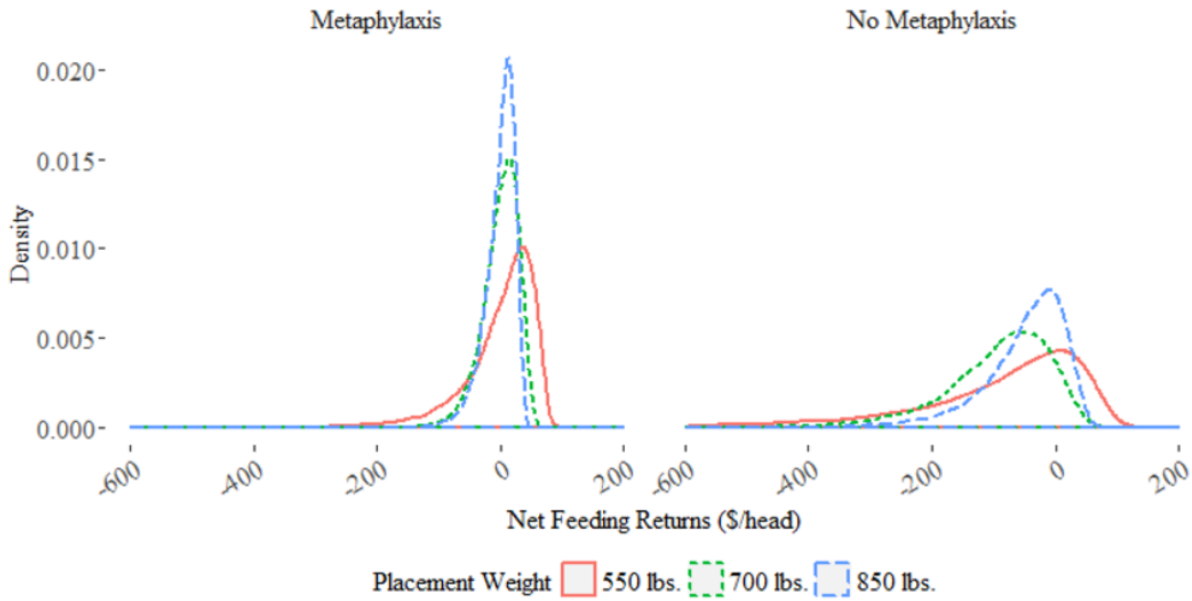
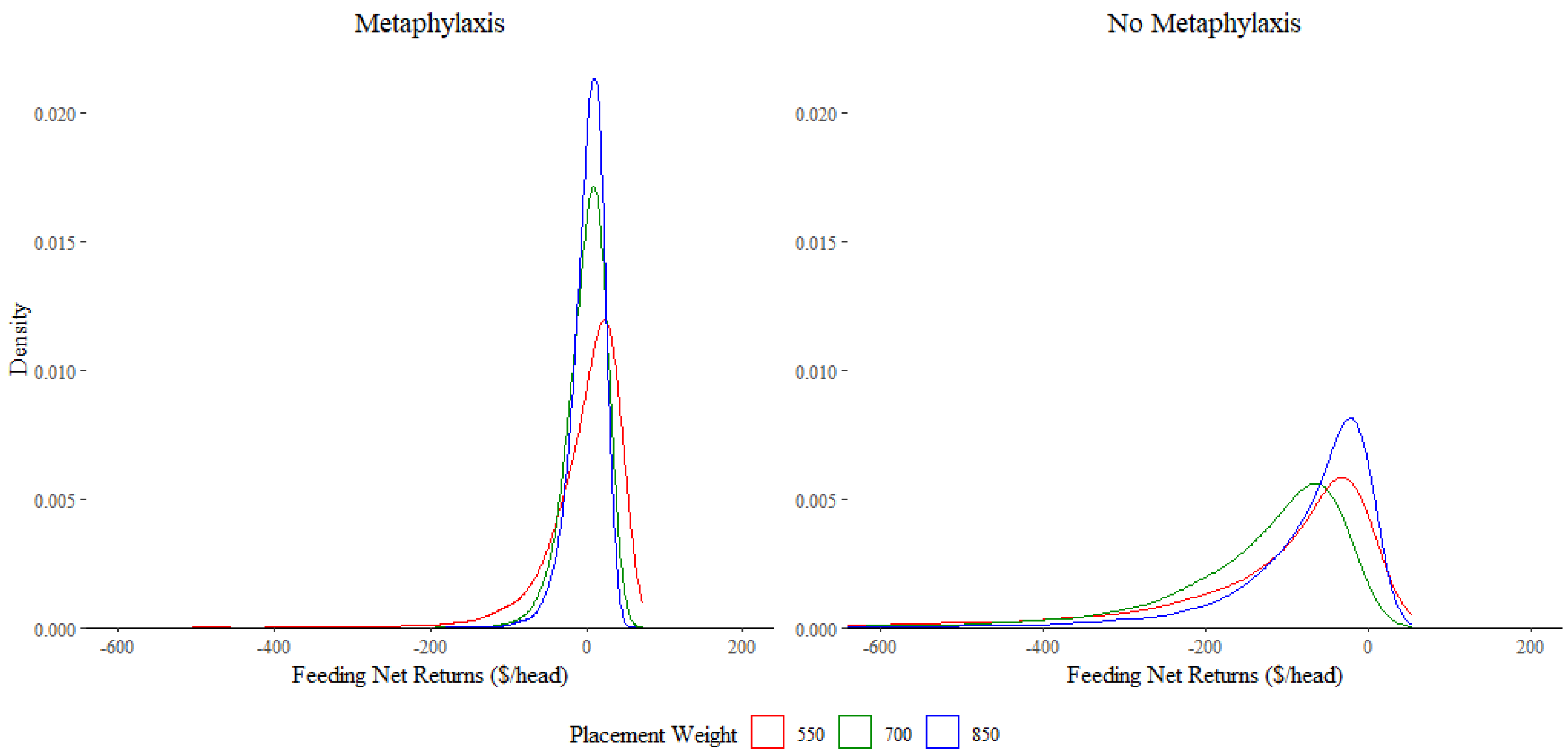


Figure 2.2: Simulated Net Return Distributions by Cattle Health Risk and Placement Weight

Note: 550 lb. high-risk cattle lose $104.46/head relative to treated cattle, 700 lb. high-risk cattle lose $99.26/head, and 850 lb. high-risk cattle lose $63.36/head when not treated with metaphylaxis. Typical cattle feeding returns over a comparable period across all placement weights were -$43.39/head (Focus on Feedlots, 2015).

Note: Reprinted "Economics impacts of metaphylaxis use in U.S. feedlots: Producer decisions, policy, and insurance" by Dennis, E., 2019, p. 38.

Figure A.2. Adjusted Duplication Attempt Results



Appendix B - Chapter 2 Appendix

Table B.1 Summary Statistics for Low Health-Risk Cattle by Weight Category

Placement Weight: < 625 pounds	Mean	St. Dev	Min.	Max.
Feed Conversion (lb. feed/lb. gain)	5.89	0.52	4.30	7.26
Average Daily Gain (lb. gain/day)	3.41	0.34	2.71	4.30
Mortality (%)	2.11	2.51	0.00	20.00
Placement Weight (lb.)	556.76	74.65	321.19	624.70
Days on Feed (days)	203.97	38.01	147.00	347.98
Finish Weight (lb.)	1247.73	74.65	1094.89	1440.96
Hot Carcass Weight (lb.)[a]	788.13	53.31	689.41	921.17
Total Vet Charge ($/head)	21.41	9.30	5.44	76.73
Placement Weight: 625 – 775 pounds				
Feed Conversion (lb. feed/lb. gain)	6.04	0.48	4.80	7.95
Average Daily Gain (lb. gain/day)	3.59	0.41	2.18	4.97
Mortality (%)	1.05	1.23	0.00	8.47
Placement Weight (lb.)	713.45	38.52	625.96	774.96
Days on Feed (days)	155.30	18.55	117.00	227.70
Finish Weight (lb.)	1269.44	84.46	1068.81	1491.20
Hot Carcass Weight (lb.)[a]	810.04	52.16	694.86	963.17
Total Vet Charge ($/head)	15.95	4.78	2.05	40.22
Placement Weight: > 775 pounds				
Feed Conversion (lb. feed/lb. gain)	6.19	0.66	4.80	10.11
Average Daily Gain (lb. gain/day)	3.81	0.46	2.42	5.70
Mortality (%)	0.85	1.19	0.00	9.52
Placement Weight (lb.)	863.54	71.20	775.07	1096.00
Days on Feed (days)	130.64	15.63	78.32	201.35
Finish Weight (lb.)	1360.25	88.27	1119.26	1740.14
Hot Carcass Weight (lb.)[a]	867.22	62.57	744.31	1099.46
Total Vet Charge ($/head)	15.57	4.40	5.28	41.70

Notes: N = 77 for < 625 pounds, N = 461 for 625 – 775 pounds, and N = 668 for > 775 pounds

[a] Hot Carcass Weight only reported for pens with carcass information.

Table B.2 Summary Statistics for High Health-Risk Cattle Given Metaphylaxis by Weight Category

Placement Weight: < 625 pounds	Mean	St. Dev	Min.	Max.
Feed Conversion (lb. feed/lb. gain)	6.14	0.53	4.86	10.68
Average Daily Gain (lb. gain/day)	3.22	0.28	2.36	4.24
Mortality (%)	5.09	3.75	0.00	21.24
Placement Weight (lb.)	460.23	101.42	301.33	623.38
Days on Feed (days)	261.50	52.93	153.00	365.97
Finish Weight (lb.)	1299.32	114.30	1009.27	1512.39
Hot Carcass Weight (lb.)[a]	803.63	54.57	650.87	977.63
Total Vet Charge ($/head)	49.18	11.79	14.86	121.48
Placement Weight: 625 – 775 pounds				
Feed Conversion (lb. feed/lb. gain)	6.23	0.84	4.61	9.55
Average Daily Gain (lb. gain/day)	3.60	0.41	2.49	4.77
Mortality (%)	4.08	3.42	0.00	15.87
Placement Weight (lb.)	678.52	38.18	625.87	755.00
Days on Feed (days)	177.55	21.06	116.53	251.00
Finish Weight (lb.)	1315.16	93.14	1133.18	1486.24
Hot Carcass Weight (lb.)[a]	833.19	55.17	706.25	940.28
Total Vet Charge ($/head)	50.47	19.08	1.26	117.34
Placement Weight: > 775 pounds				
Feed Conversion (lb. feed/lb. gain)	6.73	1.15	5.23	9.65
Average Daily Gain (lb. gain/day)	3.81	0.34	3.05	4.29
Mortality (%)	3.53	4.50	0.00	17.95
Placement Weight (lb.)	895.00	93.12	788.88	1090.80
Days on Feed (days)	133.33	17.11	99.40	152.19
Finish Weight (lb.)	1405.60	58.82	1314.00	1551.63
Hot Carcass Weight (lb.)[a]	850.19	47.98	785.23	919.34
Total Vet Charge ($/head)	39.48	20.58	18.90	82.69

Notes: N = 364 for < 625 pounds, N = 88 for 625 – 775 pounds, and N = 14 for > 775 pounds

[a] Hot Carcass Weight only reported for pens with carcass information.

Table B.3 Performance Metric Variable Correlation Matrix

	ADG	*AFC*	*VCPH*
ADG	1.0000	-0.4799	-0.3262
AFC	-0.4799	1.0000	0.0348
VCPH	-0.3262	0.0348	1.0000

Note: Calculated from proprietary data