Evaluations of extended finishing in feedlot cattle and frameworks for economic assessments of controlled trials

by

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B.S., University of Wyoming, 2015
M.S., Kansas State University, 2018

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Diagnostic Medicine and Pathobiology
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Abstract

Outcomes research in animal agriculture provides stakeholders with meaningful insights into health, production, and economics, where decision-makers often rely on well-conducted research to make evidence-based choices. While health and production are top priorities, economic incentive is often the driving factor for producers to implement new interventions or management strategies. Randomized controlled trials (RCTs) provide strong evidence for causal inference, yet economic outcomes from feedlot cattle RCTs are frequently underreported, or lack consistent, well-described methodologies. In recent decades, U.S. feedlot cattle have been fed to heavier endpoints (EPs), which raises health, production, and economic considerations. The primary objectives of this dissertation were: to address knowledge gaps for a lesser, but common revenue source in the feedlot – culled animals; to evaluate performance and carcass characteristics of feedlot heifers when fed to alternative EPs; to assess the economic implications of extending days-on-feed (DOF) for heifers and steers, accounting for economic risk; and to provide guidance on economic analysis of RCT data. In an observational study of feedlot culls (2,992) from four Kansas feedlots, it was found that prices received for culls were most correlated with cull cow prices, and that cull cow prices may be used to estimate revenue for culls by using proportion of the cull cow price, contingent on culled animal weight. This provides a basis for estimating revenue from animals culled from feedlots, or removed from RCTs in future economic assessments. Three RCTs conducted at commercial feedlots in Kansas and Texas were pooled for a more robust assessment of heifer performance and carcass impacts when extending DOF. When feeding heifers to later EPs, live performance metrics such as daily weight gain and feed efficiency decreased as DOF increased. However, the amount of carcass weight gain as a proportion of live weight gain increased with longer feeding. The distributions of Quality and Yield Grades (QG and YG) also shifted towards higher grades with extended DOF, which has economic implications when marketing on a premium and discount-based grid. Economic assessments of extended feeding used a partial budget framework, incorporating differing methodologies to account for economic risk. From the pooled RCT data, a sensitivity analysis evaluated the economic implications of extending heifer DOF under various pricing and market scenarios by varying key economic factors. Overall, extending DOF showed minimal economic benefit for feedlot heifers, with net returns for later-fed EPs being poorest under low fed cattle prices, and high feed and yardage prices. When extending DOF, marketing heifers on a carcass basis was more favorable than live marketing. To evaluate the economic implications of feeding steers to later EPs, a stochastic simulation model was developed to characterize net return distributions and evaluate risk under recent economic conditions with contemporary cattle populations. Industry and RCT data from a commercial trial in Texas were utilized for parameterization. Compared to an industry-standard EP, median net return differences worsened with each later-fed EP, whether marketing live or on a grid. Although later EPs had the potential for higher net returns, they also carried increased risk of greater losses. The most impactful variable in the model was the difference in fed cattle price across EPs, which varied to reflect marketing on different weeks. Other influential variables included corn price, fed cattle price, mortality risk, and the QG grid when grid marketing. This dissertation concludes by discussing various economic analyses, identifying the partial budget as the most pragmatic option for evaluating alternative interventions or management strategies from RCTs in animal agriculture. Recommendations for future economic assessments include explicitly stating the type of analysis, detailing price sources, and clearly describing methodologies. This work provides valuable information and guidance to industry stakeholders on the application and conduct of economic assessments on RCTs, and the considerations and economic risk associated with feeding cattle to later EPs.

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Outcomes research in animal agriculture provides stakeholders with meaningful insights into health, production, and economics, where decision-makers often rely on well-conducted research to make evidence-based choices. While health and production are top priorities, economic incentive is often the driving factor for producers to implement new interventions or management strategies. Randomized controlled trials (RCTs) provide strong evidence for causal inference, yet economic outcomes from feedlot cattle RCTs are frequently underreported, or lack consistent, well-described methodologies. In recent decades, U.S. feedlot cattle have been fed to heavier endpoints (EPs), which raises health, production, and economic considerations. The primary objectives of this dissertation were: to address knowledge gaps for a lesser, but common revenue source in the feedlot – culled animals; to evaluate performance and carcass characteristics of feedlot heifers when fed to alternative EPs; to assess the economic implications of extending days-on-feed (DOF) for heifers and steers, accounting for economic risk; and to provide guidance on economic analysis of RCT data. In an observational study of feedlot culls (2,992) from four Kansas feedlots, it was found that prices received for culls were most correlated with cull cow prices, and that cull cow prices may be used to estimate revenue for culls by using proportion of the cull cow price, contingent on culled animal weight. This provides a basis for estimating revenue from animals culled from feedlots, or removed from RCTs in future economic assessments. Three RCTs conducted at commercial feedlots in Kansas and Texas were pooled for a more robust assessment of heifer performance and carcass impacts when extending DOF. When feeding heifers to later EPs, live performance metrics such as daily weight gain and feed efficiency decreased as DOF increased. However, the amount of carcass weight gain as a proportion of live weight gain increased with longer feeding. The distributions of Quality and Yield Grades (QG and YG) also shifted towards higher grades with extended DOF, which has economic implications when marketing on a premium and discount-based grid. Economic assessments of extended feeding used a partial budget framework, incorporating differing methodologies to account for economic risk. From the pooled RCT data, a sensitivity analysis evaluated the economic implications of extending heifer DOF under various pricing and market scenarios by varying key economic factors. Overall, extending DOF showed minimal economic benefit for feedlot heifers, with net returns for later-fed EPs being poorest under low fed cattle prices, and high feed and yardage prices. When extending DOF, marketing heifers on a carcass basis was more favorable than live marketing. To evaluate the economic implications of feeding steers to later EPs, a stochastic simulation model was developed to characterize net return distributions and evaluate risk under recent economic conditions with contemporary cattle populations. Industry and RCT data from a commercial trial in Texas were utilized for parameterization. Compared to an industry-standard EP, median net return differences worsened with each later-fed EP, whether marketing live or on a grid. Although later EPs had the potential for higher net returns, they also carried increased risk of greater losses. The most impactful variable in the model was the difference in fed cattle price across EPs, which varied to reflect marketing on different weeks. Other influential variables included corn price, fed cattle price, mortality risk, and the QG grid when grid marketing. This dissertation concludes by discussing various economic analyses, identifying the partial budget as the most pragmatic option for evaluating alternative interventions or management strategies from RCTs in animal agriculture. Recommendations for future economic assessments include explicitly stating the type of analysis, detailing price sources, and clearly describing methodologies. This work provides valuable information and guidance to industry stakeholders on the application and conduct of economic assessments on RCTs, and the considerations and economic risk associated with feeding cattle to later EPs.

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Preface

The chapters included in this dissertation are formatted according to the respective journal guidelines in which they were published or intended to be published. Table and Figure numbers were modified to accommodate the designated dissertation chapter, otherwise content is unchanged from the publication.

Chapter 1 - Introduction

The composition of feedlot cattle in the U.S. has changed in recent decades. This introduction provides an overview on the role of outcomes research in animal agriculture, emphasizing the importance of incorporating elements of value – particularly economic considerations – alongside traditional health and production outcomes. The trend of extending days-on-feed (DOF) in feedlot cattle is discussed, describing associated production changes, impacts of technologies, and the potential for late-day health risks. Additionally, the economic implications of these practices are examined, highlighting the necessity for future endpoint management research for feedlot cattle. This chapter also addresses the importance of conducting economic analyses with randomized controlled trials (RCTs), noting inconsistencies in the literature, which underscores the need for standardized methodologies to enhance decision-making for producers and industry stakeholders.

Outcomes research in animal agriculture

Producers and industry stakeholders in animal agriculture often rely on research to make evidence-based decisions, particularly when outcomes from well-conducted, internally valid research are relevant and have tangible, impactful value externally. The distinguishing feature of outcomes research is that an element of value is considered alongside traditional outcomes of interest (Cernicchiaro et al., 2022; Dewsbury et al., 2022). While well established in human medicine, outcomes research is still relatively new in the fields of veterinary medicine and animal agriculture (Cernicchiaro et al., 2022; Dewsbury et al., 2022). Common themes of outcomes research include health, production, economics, and marketing (Dewsbury et al., 2022). While values can be – and commonly are – monetary, they may also be non-monetary and dependent on stakeholder perceptions or roles (e.g., producer vs. consumer). Often, there are trade-offs among values. For example, using antimicrobial metaphylaxis in feedlot calves may improve animal well-being and production traits, but conversely, can result in increased antimicrobial use (Horton et al., 2023). In this case, stakeholders need to weigh the respective values of antimicrobial stewardship – in an effort to mitigate risks of antimicrobial resistance – versus animal health and production.

Guidance exists for developing and evaluating research questions, where specificity is recommended, as attempting to address issues broadly can impact internal validity, leading to questionable relevance and unclear conclusions (Covvey et al., 2024). Along these lines, even if it were possible, it is likely inadvisable to attempt to account for all potential values in a single study. While "comprehensive" studies are valuable (comprehensive meaning well-rounded outcomes relevant to a variety of stakeholders, not all possible outcomes), special considerations must be made when designing such research to ensure that reported outcomes are relevant and unbiased (i.e., only outcomes that can be reasonably and practically measured within the confines of the study should be included). Additionally, researchers must use caution when reporting results from comprehensive studies, as most are generally powered based on a single primary outcome, and secondary outcomes not included in sample size calculations are at greater risk of Type II error (Esposito et al., 2009). Moreover, as the number of reported secondary outcomes – and therefore statistical tests – increases, the risk of Type I error consequently increases. With these caveats in mind, prioritization of economic outcomes (potentially in lieu of other secondary outcomes) is still pragmatic, particularly in production livestock species where economics is often one of, if not the deciding factor for implementation of changes.

Importance of economic outcomes

The common themes evaluated in this dissertation include animal health, production, and economics, specifically in relation to feedlot cattle management strategies. While health and production are frequently priorities at the forefront of a producer's mind, often it is economic incentive that drives decision-making on new interventions or management strategies. In other words, if an intervention is not cost-effective, it is less likely to be adopted by producers, regardless of the potential health or production benefits. As is often the case, these factors are commonly correlated; improving animal health and production may subsequently improve economic outcomes, provided that upfront costs are mitigated (Capper and Hayes, 2012; Valencia et al., 2019; Horton et al., 2023; McAtee et al., 2024). The antithesis of this is also commonly true, where poorer health and performance (e.g., disease impacts) is frequently associated with poor economic outcomes (Griffin, 1997; Snowder et al., 2006; Babcock et al., 2009). Still, cases arise where consumer values are not necessarily associated with economic advantages for producers (Wileman et al., 2009), and producers may require economic incentive (e.g., price premiums for organic or non-hormone treated cattle) to compensate for the reduced production associated with such practices.

No matter how innovative a new intervention or management strategy may be, if it is not cost-effective, adoption by producers may be difficult at best. Therefore, economics plays a significant role in this dissertation, focusing on management strategies impacting feedlot cattle health and production, as well as providing guidance and approaches for future clinical livestock research.

Production changes in the feedlot industry – extending days-on-feed

Cattle feeding horizons

The composition of U.S. feedlot cattle has changed in recent decades. Cattle have been progressively fed to increasingly heavier endpoints (EPs), characterized by greater live and carcass weights (Livestock Marketing Information Center; LMIC). The total population of beef cattle has declined, while beef production has increased due to advancing management strategies, genetics, and technologies (Wileman and Thomson, 2010; Meyer and Gunn, 2015). An interest in the effects on feedlot cattle performance and carcass characteristics when extending DOF and feeding to later EPs has led to numerous publications (Sissom et al., 2007; Rathmann et al., 2012; Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021; Galyean et al., 2023). The body of literature in this area continues to grow as cattle populations evolve, and feedlot standard EPs change. Logically, as DOF increase, more weight is gained. Much of this weight comes from fat deposition, as the distributions of U.S. Department of Agriculture (USDA) Quality Grades (QGs) and Yield Grades (YGs) shift towards higher grades (Sissom et al., 2007; Rathmann et al., 2012; Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021; Galyean et al., 2023). Conversely, it is commonly observed for both steers and heifers that live performance metrics, such as daily gain and feed efficiency, decrease as DOF increase (Sissom et al., 2007; Rathmann et al., 2012; Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021; Galyean et al., 2023). Estimates from these publications are valuable to producers and other industry stakeholders, as they provide evidence-based expectations for changes in cattle growth and carcass characteristics when incrementally adding DOF.

On the surface, it may appear that cattle become less efficient and growth rates slow as DOF are added. However, it is critical to consider where the weight is deposited. As immature cattle grow, a large proportion of weight gain is attributed to the gastrointestinal tract and its contents, other internal organs, blood, bone, the head, and the hide (Berg and Butterfield, 1968; Buckley et al., 1990; Coleman et al., 1995; Owens et al., 1995; Honig et al., 2022). As cattle mature and approach finished weights, the growth of these components becomes minimal, while the proportion of muscle, and to a greater extent, fat deposition relative to these other components, increases. This concept was illustrated by Honig et al. (2022), and is shown in Figure 1.1. Therefore, while overall live weight gain may decrease as the growth of non-carcass components slows, the growth of carcass components [i.e., salable weight when marketing on a carcass (i.e., dressed) basis] may still be stable or increasing.

This relates closely to the concept of incremental dressing percentage – also termed carcass transfer – which is the amount of carcass weight gain as a proportion of live weight gain (Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021; Galyean et al., 2023). Incremental dressing percentage has been shown to increase as cattle are fed beyond standard finishing EPs (Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021; Galyean et al., 2023), meaning that while live growth rates slow, the amount of weight gain stored as carcass weight increases. For example, an incremental dressing percentage value of 75% would imply that for every 1 kg of live weight gain, 0.75 kg of the gained weight is deposited in the carcass. In pooled analyses of serial harvest studies evaluating extending DOF, Galyean et al. (2023) reported mean carcass transfer values of 80%, 78%, and 68% for heifers, steers, and Holstein steers, respectively. It has been suggested that these values may approach 100% as DOF lengthen (Wilken et al., 2015).

Impacts of technologies when extending days-on-feed

As previously mentioned, advancements in technologies have enabled the beef industry to produce more product with fewer animals (Wileman et al., 2009; Wileman and Thomson, 2010; Capper and Hayes, 2012; Meyer and Gunn, 2015). Some of these technologies and management strategies include steroidal or hormonal implants, in-feed ionophores, in-feed hormones, in-feed antimicrobials, beta-adrenergic agonists, and antimicrobial metaphylaxis. As it is plausible that some of these technologies may have differential or modified effects when extending feedlot cattle DOF, each of the previously referenced serial harvest studies (Sissom et al., 2007; Rathmann et al., 2012; Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021; Galyean et al., 2023) incorporated one of these technologies or management strategies as part of the experimental design. These publications included beta-adrenergic agonists (Sissom et al., 2007; Rathmann et al., 2012; Streeter et al., 2012; Walter et al., 2018; Galyean et al., 2023), implants (Streeter et al., 2012; Smith et al., 2019; Ohnoutka et al., 2021; Galyean et al., 2023), and metaphylaxis (Word et al., 2021). A technology × DOF interaction for a given outcome would imply that the technology effect is dependent on DOF, or vice versa. However, across these studies, few significant interactions have been observed, suggesting that technology and DOF effects are additive when feeding cattle to later EPs. Still, it may be crucial to continue evaluating technologies when concurrently extending feedlot cattle DOF, particularly as cattle populations evolve and are fed to new extremes.

Late-day health risks when extending days-on-feed

Although most adverse health events generally occur early in the feeding period (Edwards, 1996; Sanderson et al., 2008; Babcock et al., 2009), a growing issue in the beef industry is late-day morbidity and mortality (Engler et al., 2014; Vogel et al., 2015; Smith et al., 2022a; Smith et al., 2022b). This issue may be partly associated with cattle being fed to extremes previously unseen. In the last 30 DOF, Vogel et al. (2015) reported 0.26% and 0.21% mortality for feedlot heifers and steers, respectively; however, these estimates do not reflect cattle being fed beyond industry standards which have since changed. While the risk of an adverse health event presumably increases as DOF lengthen due to having more animal-time at risk, none of the previously referenced serial harvest publications reported health outcomes when extending DOF. Late-day health events are an animal welfare issue with economic implications that needs considered when feeding to later EPs.

Economic implications of extending days-on-feed

Economic incentive is presumably the primary driver behind the trend toward heavier cattle weights in recent decades. There are critical considerations for producers when extending DOF, as this practice has various implications for costs and revenues. However, none of the referenced serial harvest trials evaluated or reported economic outcomes. Some analyses have reported that feeding cattle beyond industry norms can lead to greater profitability (Wilken et al., 2015; Poss et al., 2022) – noting that the methodologies for these studies did not use RCT data with a serial harvest component. It also has been suggested that the cost of overfeeding cattle past an “optimal” EP is greater than underfeeding due to the penalties incurred from discounts in grid pricing systems (Koontz et al., 2008). For feeding cattle to later EPs to be advantageous, the marginal difference between increased revenue and increased cost, must be positive.

Revenue increases from extending DOF are derived from increased saleable weight at the time of marketing. Wilken et al. (2015) found it to be more profitable to market on a dressed basis rather than live when adding DOF. This observation is likely related to incremental dressing percentage, where if marketing live, decreasing feed efficiency and daily gain as DOF increase results in less salable weight gain per unit of input. Conversely, if marketing dressed, a larger proportion of the total weight gain is deposited in the carcass when adding DOF; therefore, salable weight gains may still be cost-efficient (Wilken et al., 2015). Poss et al. (2022) described the importance of accounting for changing carcass characteristics (i.e., QG and YG) when extending DOF. The majority of U.S. fed cattle are marketed on a formula basis with a premium and discount-based grid (LMIC), wherein price adjustments are made depending on carcass grades, as well as other factors such as weight. There are strong implications for cattle fed to later EPs when grid marketing, as the increase in weight and QG premiums may need to outweigh YG 4 and 5 discounts. Adding DOF also may increase the risk of heavyweight carcasses, which incur discounts when grid marketing [commonly those greater than 476 kg (1,050 lb)]. Risk of heavyweight discounts is greater for steers than it is heifers, which have lighter harvest weights.

The primary costs of feeding to later EPs are presumably increased costs of feed and yardage, which account for overhead costs such as utilities, equipment, and labor. Other costs may include health risks, where sick cattle require treatment, mortality cases result in lost revenue, or animals that require culling due to health reasons (i.e., railers) have discounted revenue compared to their pen-mates. The risks of these adverse health events for cattle fed to EPs beyond industry standards are not known to be reported in published literature. An additional cost consideration is the opportunity cost of delaying when revenue is received when extending DOF. Opportunity cost in this context is similar to the concept of discounting, where the value of a current dollar is greater than that of a future dollar because the current dollar can be invested to accumulate value greater than its original worth (Rushton, 2007). Therefore, revenue from cattle fed to later EPs should be discounted to account for the fact that revenue could have been received earlier if not extending DOF, and that revenue could have been invested to grow in value, pay off operating loans, or be used elsewhere. Although this is a common practice applied in budgets by agricultural economists, it is unknown if discounting or the opportunity cost of delaying revenue when extending DOF has been accounted for in published economic assessments on this topic.

Differing from epidemiological risk, which is the risk (e.g., probability) of an event (e.g., disease) occurring, economic risk is the uncertainty of economic outcomes that may be affected by environmental variations (production or yield uncertainty), price variation (market uncertainty), or a lack of information (Rushton, 2007). When marketing cattle at alternative EPs, it is apparent that returns may be heavily influenced by these uncertainties. For example, every pen of cattle may not gain at the same rate or incur identical shifts in carcass grades when extending feeding. Also, market prices fluctuate, so there may be conditions in which it is favorable to delay marketing and others where it is not. Therefore, producers should anticipate receiving different fed cattle prices when marketing on different weeks, further increasing the risk of price uncertainty. Therefore, when evaluating the economic implications of extending feedlot cattle DOF, there may not be a clear-cut answer, and variable conditions accounting for economic risk should be incorporated into economic assessments.

Future endpoint management research

Although endpoint management, particularly the effects of extending feedlot cattle DOF, has been a focal research area in the industry, future research needs remain. A major factor contributing to this is the ever-evolving feedlot cattle population. As cattle are fed to greater extremes, feedlot standard EPs change, leading to historic research becoming outdated with reduced external validity. Additionally, as certain technologies become unavailable (e.g., zilpaterol HCl; Rathmann et al., 2012; Walter et al., 2018) and new technologies emerge on the market (e.g., lubabegron; Kube et al., 2021), updated research is needed. Therefore, there is a benefit to reevaluating questions on feedlot cattle EP management with updated, contemporary cattle populations, along with potentially pooling RCTs for more robust, broader-reaching findings. Randomized controlled trials provide the strongest evidence for causal inference outside of systematic reviews and meta-analyses of RCTs (Sargeant et al., 2014). Consequently, concurrent economic analyses accounting for risk should be performed using data from RCTs on EP management, to better inform industry stakeholders on what is presumably the driving factor behind extending feedlot cattle DOF.

Economic analyses with randomized controlled trials

Although economics plays an integral role in decision-making, there is inconsistency in how economic evaluations are performed and reported in animal health and production research. Saatkamp et al. (2016) underscored the absence of standardized methodologies for categorizing costs associated with outbreaks of highly contagious livestock diseases and noted that this lack of standardization may lead to challenges in comparing studies and may result in misinterpretations. Dixon et al. (2022) further echoed these concerns in a scoping review of feedlot trials, revealing widespread variability in how economic assessments are conducted and reported. Their findings showed that many studies failed to clearly state economic objectives, provided limited details on methodologies, and often lacked the necessary information for reproducing or critically assessing results. Economic assessments are arguably underperformed in applied livestock health and production RCTs. When performed, inconsistent methodologies and reporting limit the usefulness of economic findings for researchers and industry stakeholders, reducing their utility for decision-making.

When evaluating the required elements of a feedlot cattle budget to include in economic assessments of RCT data, a notable gap emerges. Unlike market prices for fed cattle, feed, or pharmaceuticals, there is no publicly available source to obtain reported prices for animals culled from feedlots (i.e., those removed from an RCT for health reasons). Although various methodologies have been used to account for revenue from culls (Tennant et al., 2014; Terrell et al., 2017; Valencia et al., 2019), there is no known evidence-based resource for estimating the value of these animals. While representing a small fraction of feedlot revenue compared to fed cattle sales, reasonable estimation of feedlot cull value may be crucial in many scenarios, particularly when interventions or management strategies impact animal health outcomes.

Given these considerations, there is a need for improved standardization and guidance for both the conduct of economic assessments with RCT data and for estimating feedlot cull revenue. By addressing these issues, researchers can be more confident about the quality and reproducibility of comprehensive economic assessments, ultimately providing more value to stakeholders.

Dissertation outline

This dissertation addresses the issues introduced in this chapter in further detail, using an outcomes research approach to provide meaningful and applicable findings for industry stakeholders. In Chapter 2, populations of feedlot animals culled for slaughter are characterized and described, and correlations between prices received for these animals and U.S. beef market prices are defined. Observations from Chapter 2 are used to inform economic assessments in future chapters, providing a basis for estimating revenue from feedlot culls. In Chapter 3, data from three recent RCTs were pooled to evaluate the health, performance, and carcass characteristics of feedlot heifers fed to alternative EPs when administering different implant programs. Pooled data from Chapter 3 were utilized in Chapter 4 to conduct sensitivity analyses, evaluating the economic implications of feeding heifers to alternative EPs when varying key economic factors. In Chapter 5, data from a recent RCT along with industry data were used to parameterize a stochastic simulation model that evaluates distributions of net returns when feeding beef steers to later EPs under variable conditions, and explores the most influential factors affecting returns. From lessons learned in the previous chapters, evaluations and descriptions of economic assessments for RCT data are provided in Chapter 6, along with a framework and feedlot cattle case study, in order to offer guidance for future conduct of such analyses. Finally, the key findings and implications of the dissertation are summarized and concluded in Chapter 7.

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Figures

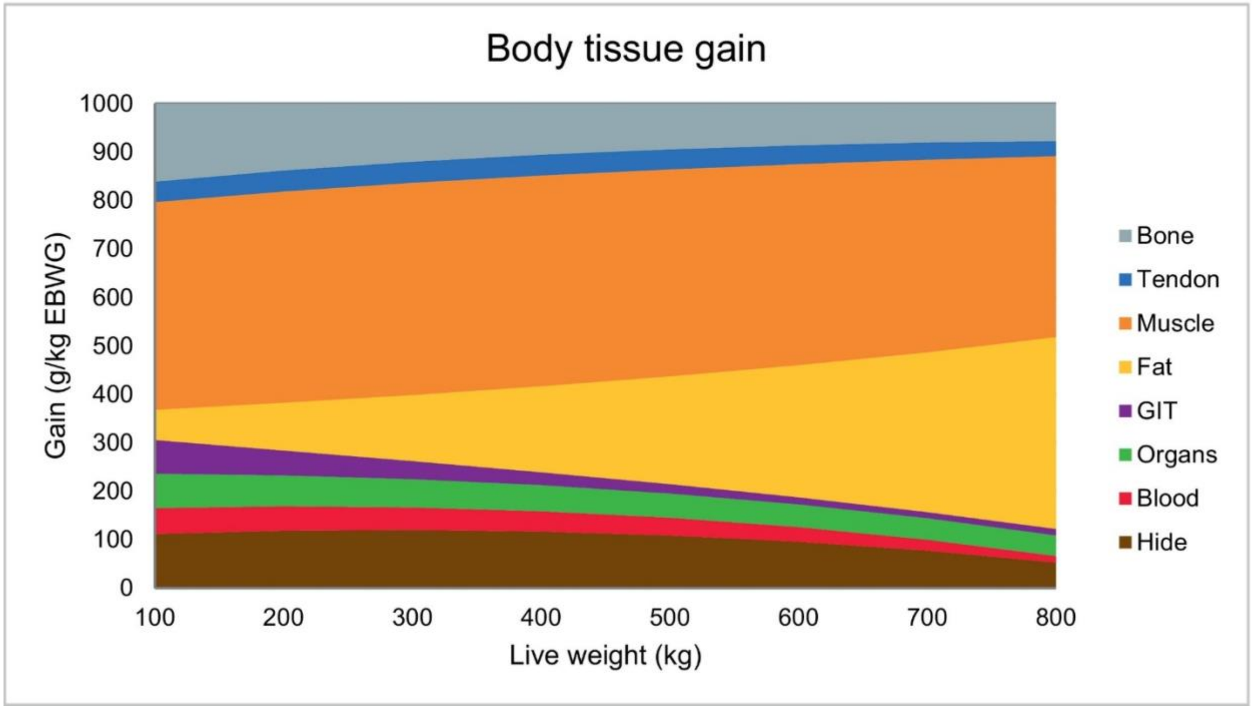

Figure 1.1. Sourced from Honig et al. (2022); calculated body tissue gain per kg empty body weight gain of growing beef bulls.

Chapter 2 - Description of feedlot animals culled for slaughter, revenue received, and associations with reported US beef market prices

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Abstract

Our objectives were to describe revenue received for feedlot cattle culled for slaughter and associations with reported weekly prices from US beef markets. Observational data on feedlot culls (N = 2,992) were collected from 4 Kansas feedlots over 2 years (2018 to 2020). Weekly prices from various US beef markets were used to evaluate correlations with prices received for culled animals. Descriptive statistics, and linear and generalized linear mixed models, were used to evaluate characteristics of feedlot culls. Musculoskeletal/trauma (49.7%) and respiratory disease (40.9%) were the most common reasons for culling. Culls returned revenue 98.1% of the time; those culled for respiratory disease or "other" reasons returned revenue significantly less frequently (96.7 or 96.3%, respectively) than those culled for musculoskeletal/trauma (99.1%). Mean revenue received [± 95% CI] was 434.81 [427.22 to 442.40] $/animal (culls returning no revenue included); and mean carcass price was 87.40 [86.70 to 88.10] $/hundredweight. Revenue was significantly correlated with several market indices, but most correlations were relatively weak. In this population, national cull cow (Breaker [75% lean]; over 500 lb [227 kg]) prices appeared to be the overall best indicator of feedlot cull prices, with feedlot cull carcasses averaging 74.6% of the weekly cull cow carcass price.

Key words: beef markets, cattle, cull, feedlot, revenue

Introduction

Cattle are culled from feedlots when they are no longer able to perform along with pen-mates, and it is expected that they will be unable to be harvested at a reasonable endpoint. Common ailments that may lead to culling a feedlot animal include respiratory disease, lameness/injury, digestive, and metabolic disorders.[14,6] This decision is made when producers feel the risk of death, or costs associated with feeding, housing, and treating, outweigh the potential benefits of feeding an animal until it reaches an ideal harvest weight. It is assumed that some amount of economic loss (e.g., purchase price, feed, processing costs) will be recovered, or "salvaged," by culling these types of animals. Verbiage of feedlot culls varies, but common terms include "railer" (referring to a light carcass hanging on a packing plant rail), "realizer" (i.e., one can "realize" some revenue returned), or "chronic" (an animal treated multiple times that has failed to recover).[6] There are a few common market pathways used for feedlot culls; animals can be slaughtered (generally at a small scale abattoir), sold at an auction market (with buyers aware of additional risk), sold to a "railer buyer" (a person who purchases the animal at a reduced price [typically 0.15 to 0.35 $/lb live weight[6]] and attempts to rehabilitate the animal), or placed in a "re-start" program, where the animal would be allotted to pasture or a grass-trap for recovery.[6]

There are limited publicly available data or literature on feedlot animals culled for slaughter and the associated revenues (or costs). While on a much smaller scale compared to fat cattle sales, feedlot culls still represent a proportion of feedlot revenue. A comprehensive assessment of costs and revenues associated with culls may not be fully quantified for management decisions. In addition, economic assessments can be an important component of feedlot research trials, but there is a lack of methodological consistency with how revenue from feedlot culls is estimated. United States Department of Agriculture (USDA) Agricultural Marketing Service (AMS) reports live cattle and beef carcass price indices, but none for culled feedlot animals. Tennant et al used USDA AMS weekly cow and boneless beef summary for 80 to 95% lean, 600 to 900 lb (272 to 408 kg) cows from four states to estimate revenue for feedlot culls in a randomized controlled finishing trial.[18] An observational study on feedlot lameness assumed prices received for culls to be 54% of fat cattle market value.[19] Valencia et al estimated revenue from removed animals in a growing calf study as 70% of the standardized purchase price of feeder calves,[25] and referenced an observational study of feeder cattle prices.[2] The last example was a study evaluating stocker calves whereas the previous examples were for finishing cattle. Without a standardized reporting system or published research on methods for price evaluation, there remains a lack of an evidence-based resource for estimating revenue of culled feedlot cattle.

The primary objective of our retrospective observational study was to describe revenue received for feedlot cattle culled for slaughter from Central Kansas commercial feedlots, and evaluate associations with US beef cattle markets. Our secondary objective was to describe factors that characterize this population of feedlot culls.

Materials and methods

Data Sources

Four commercial feedlots in Central Kansas were used to collect data on culled feedlot cattle. Feedlot data were from 2 sources; 1) manual entry of "receipts," which contained individual animal level data, and 2) operational database records, which contained lot level (where "lot" is defined as a group of cattle purchased, received, housed, and marketed together) and animal level data. Culled animals were harvested for "salvage" value (i.e., an attempt to recover some revenue and mitigate risk of a total loss), and each of the 4 feedlots shipped culls to a small, specialized abattoir, which provided the feedlots with hot carcass weight (HCW), $/lb HCW, and total $/animal. Data were collected on animals culled between the weeks of December 24, 2018 and November 23, 2020.

Data entered manually from culled animal receipts included: feedlot name, lot number, animal-ID (unique identification ear-tag), date culled, sale weight (HCW), price received ($/cwt), total value/animal, and reason for culling (variable by feedlot if reported here or in operational database). Lot level data from the operational database included: in-date(s) for lot, number of animals, average in-weight, sex, and processing charges. Animal level data from the operational database consisted of reasons for culling, and treatment history records which included: reason for each pull, date of each pull, product(s) administered at each pull, and cost/product ($).

Pricing data from US beef markets (fed cattle, feeder cattle, cull cow, and boxed beef) were sourced to compare possible associations with revenue from feedlot culls. Historic fat cattle prices in KS were sourced from the USDA AMS as a weekly report (LM_CT140[22] and LM_CT157[20]). The sale/purchase bases of fat cattle were both live or dressed, and included: formula net, forward contract net, negotiated grid net, negotiated grid base (delivered or "free on board"; FOB), and negotiated cash (delivered or FOB). Historic national cull cow prices were also obtained from USDA AMS as a weekly report (LM_CT168).[23] Sale/purchase of cull cows on a dressed basis are classified as "Breaker" (75% lean; above or below 500 lb [227 kg]), "Boner" (85% lean; above or below 500 lb [227 kg]), "Cutter" (90% lean; under 400 lb [181 kg], 400 to 500 lb [181 to 227 kg], or above 500 lb [227 kg]), and "Premium White" (all weights). If sold live, cull cows are categorized the same as above, but are not categorized into weight groups (only "all weights" reported). Feeder cattle sale/purchase prices were sourced from the Livestock Marketing Information Center (LMIC)[9] which uses USDA AMS data. An average sale price per week was calculated from 100 lb [45 kg] weight ranges for medium and large frame #1 steers and heifers by averaging price across all ranges. Additionally, weekly averages of boneless cow and beef trimmings in the Central US were sourced from USDA AMS (report LM_XB460)[24] to compare possible associations.

Inclusion Criteria

Feedlot culls included in the final dataset were of beef lineage (i.e., dairy-bred cattle excluded), classified as steers or heifers (cattle from "mixed" lots excluded), met conditions of being normal feedlot inhabitants (e.g., culls from pasture excluded), and were harvested for salvage (i.e., animals re-sold live at auction market excluded). Cull data that did not link with a lot number within the feedlot operational database were excluded from the final dataset.

Data Management

Data were managed and formatted for analyses using a combination of R[a], Access 2016[b], and Excel 2016[b]. Manual entry data from Excel were uploaded in R. Two operational database spreadsheets were then uploaded in R, one of which contained lot level data, and the other contained animal level data for each cull. Manual entry and operational lot level data were linked using lot (within feedlot) as a unique identifier; variables linked from lot level data included: number of animals received, initial weight, first in-date, last in-date, and sex. Manual entry and operational animal level data were linked using animal-ID (within lot and feedlot) as a unique identifier; and the variable linked from operational data was reason for culling. Days-on-feed at culling (DOF) for each cull was calculated as the number of days between the date culled and first in-date for its respective lot. Sex could only be determined for individual culls using the sex assigned to each lot in operational lot level data; culls from a lot classified as "mixed" or "dairy-bred" were then removed so only steers and heifers remained.

To assess animal health history, pulls and antimicrobial treatments were separated into 2 categories; a "pull" was any time an animal was removed from its home pen for further evaluation of health concerns, and includes any/all products administered and procedures performed; an "antimicrobial treatment" was any time an animal was pulled and administered an injectable antimicrobial compound (i.e., all antimicrobial treatments are pulls, but not all pulls are antimicrobial treatments). Pull and treatment history were animal level data, and were linked with individual culls using animal-ID (within lot and feedlot). If a cull did not link with any pull/treatment data, it was assumed that the animal was never pulled or treated. Variables linked from pull/treatment data included: date, reason, products used, and total cost of products used. Processing costs were lot level, and included the cost of products used and operational charges. Estimated processing cost per culled animal was calculated as the total lot processing cost divided by the number of animals received in the lot. Average processing cost per animal was then linked with individual culls using lot (within feedlot) as a unique identifier.

Reasons for culling were categorized into musculoskeletal/trauma, respiratory, or "other." Common culling reasons classified as "other" included: bloat, hardware, unknown, poor performance, and abscess. Depending on the feedlot, culling reasons were either listed on receipts (and entered manually), or in the operational database. To determine a consensus for each cull, these two sources were merged into a single column. In cases where reasons were non-specific (i.e., not clear which culling category to use) or unknown, the pull/treatment history of individual culls was used to determine the final category (reason for culling). Cases that were still unclear or unknown were classified as "other."

There were two reasons in which culls that were shipped for harvest did not return revenue to the feedlot; 1) cattle were either not harvested (e.g., died between shipping and harvest or were non-ambulatory) or were condemned post-harvest, or 2) the packer was instructed to harvest the animal and return product (meat) back to the owner. In both cases, no values for HCW or revenue were provided, although, other data from the animals were still used in other analyses (e.g., DOF, cause of cull, times pulled). For case 1), revenue received for each animal was included as $0.00 and still used in descriptive and inferential statistical analyses. For case 2), no value for revenue was included in any analyses (i.e., observations for price/revenue received excluded).

Historic beef market data were linked with individual feedlot cull receipts to assess possible associations between beef market prices and prices received for culls. These were week-level data, and were matched with the week culled for each animal. Weekly average fat cattle and feeder cattle prices in KS were linked with individual feedlot culls based on week and sex. Weekly average national cull cow and Central US boneless cow and beef trimmings prices were linked with individual culls based on week.

As cattle market prices are largely driven by weight, feedlot culls were categorized into weight groups to describe and characterize potential differences by weight. These categories were culls with HCW over 600 lb (272 kg), between 400 and 599 lb (181 to 271 kg), and below 400 lb (181 kg). Categories were chosen relative to weight-based discounts as reported by the USDA AMS for fat cattle, where: carcasses over 600 lb (272 kg) receive no discounted price, carcasses between 400 and 599 lb (181 to 271 kg) are discounted, and carcasses below 400 lb (181 kg) are not reported.[21] As HCW of individual culls could only be obtained from those that received revenue, those that did not return revenue and those that were harvested and returned meat to the owner were excluded (n = 66) from this categorization and statistical analyses.

Statistical Analyses

Descriptive statistics including means, standard errors of the means (SEM), medians, interquartile ranges (IQR), ranges, and 95% confidence intervals (CI) were calculated in Excel. Spearman's correlation coefficients between prices received for feedlot culls and US beef markets were determined using Proc CORR in SAS[c]. Only feedlot culls that returned revenue were included in correlation analyses. While many beef markets were used for correlations (see "*Data Sources*"), only the most relevant results are provided. Interpretation of correlation coefficients varies, is not always consistent across disciplines, and may change based on research objectives and precision/accuracy of measurements.[10,13] We considered (in absolute value) $r <$

0.20 as a negligible/very weak relationship; $0.20 \leq r < 0.40$ as a small/weak relationship; $0.40 \leq r < 0.70$ as a moderate relationship; $0.70 \leq r < 0.90$ as a strong relationship; and $r \geq 0.90$ as a very strong/highly correlated relationship. R^2 values, which indicate the percentage of the variation explained by the correlation, are also reported.

We used general and generalized linear mixed models (LMM and GLMM, respectively; Proc GLIMMIX, SAS[c]) for all analyses with significance declared at $\alpha \leq 0.05$. Individual feedlot culls were the unit of analysis. All models included "feedlot" as a random intercept to account for lack of independence between culls within a feedlot.

Continuous outcomes (e.g., DOF, HCW, metrics of price/cost) were modeled using LMM assuming a normal distribution. For variables with a price ($) component, a random residual term for "month culled" with a first-order autoregressive covariance structure was used to account for correlations of prices over time. Generalized linear mixed models were used to fit revenue returned (yes or no) using a binomial distribution, and count distributions for times pulled and antimicrobial treatments were specified with a Poisson distribution. A Tukey-Kramer adjustment was used for pairwise comparisons of fixed effects in all LMM and GLMM models, and model adjusted means and SEM are reported.

Multinomial variables (e.g., culling reason category), when fit as a response, were fit with a generalized logit link function for non-ordered categories. A likelihood ratio test was used to assess whether the distribution of nominal outcomes differed significantly between independent variables, and the resulting *P*-value is reported along with frequency statistics (percent and count).

Results

The initial population contained 4,135 observations (culled animals). Observations excluded from final dataset included: n = 135 from dairy-bred lots, n = 332 from "mixed" lots, n = 608 marketed at auction, and n = 6 for failure to link with a lot within feedlot from the operational database. Additionally, n = 62 animals were removed as they could not be classified as a feedlot cull. Thus, the final population of feedlot culls meeting inclusion criteria contained 2,992 total animals, with 1,322 steers (44.2%), and 1,670 heifers (55.8%). Of all animals culled and shipped from feedlots for salvage value, 98.1% returned revenue while 1.9% did not.

Descriptive Statistics

Descriptive statistics of continuous variables of feedlot culls, overall and by reason for cull are in Table 2.1. Descriptive statistics of continuous variables grouped by HCW ranges are in Table 2.2. In the entire population, the number of animals received in lots with feedlot culls had a median of 150 animals/lot, and a mean [± 95% CI] of 153 [151 to 155] animals/lot. Average arrival weight of all cattle per lot had a median of 743 lb (337 kg), and a mean [± 95% CI] of 745 lb [741 to 749 lb] (338 kg [336 to 340 kg]). Days-on-feed at culling (measured as difference in days between the date culled and initial lot in-date) for the entire population had a median of 111 days, and a mean [± 95% CI] of 111 [109 to 113] days. Hot carcass weight had a median of 473 lb (215 kg), and a mean [± 95% CI] of 483 lb [478 to 488 lb] (219 kg [217 to 221 kg]). For the entire population, prices received on a HCW basis had a median of 87.00 $/cwt, and a mean [± 95% CI] of 87.40 [86.70 to 88.10] $/cwt. Hot carcass weight, and HCW price excluded culls that returned no revenue (n = 57) and those harvested which returned meat to the owner (n = 9). Total revenue received resulted in a median of 405.02 $/animal, and a mean [± 95% CI] of 434.81 [427.22 to 442.40] $/animal. Total revenue received includes culls that returned no revenue ($0.00; n = 57), but excludes those that were harvested and returned meat to the owner (n = 9). The number of times animals were pulled from home pens for further evaluation of health concerns ranged from 0 to 10 pulls/animal, with a median of 2 pulls/animal, and a mean [± 95% CI] of 2.39 [2.34 to 2.44] pulls/animal. The number of antimicrobial treatments ranged from 0 to 8 treatments/animal, with a median of 2 treatments/animal, and a mean [± 95% CI] of 1.73 [1.69 to 1.77] treatments/animal. Total treatment costs (all pulls/treatments) had a median of 42.88 $/animal, and a mean [± 95% CI] of 45.09 [43.91 to 46.27] $/animal. Costs associated with processing lots with feedlot culls had a median of 15.73 $/animal, and a mean [± 95% CI] of 18.72 [18.37 to 19.07] $/animal.

Sex Comparisons

Table 2.3 depicts outcomes from statistical models testing for potential differences between steers and heifers. There was no difference between steers and heifers for the proportion of culls that returned revenue ($P = 0.86$). Frequencies of removal reasons did not appear to be impacted by sex as there was no evidence for a difference when comparing their distributions ($P = 0.55$). Weight ranges were used to examine if prices received for culls differed between sexes when HCW was similar. There was a sex by HCW range interaction ($P < 0.01$), thus, comparisons between sexes were only made within HCW ranges. Evidence for a difference between sexes occurred only for culls with carcasses weighing over 800 lb (363 kg), where heifers received higher prices on average compared to steers ($P < 0.01$).

Removal Reason Comparisons

Results of analyses of factors associated with categories for removal reasons are in Table 2.4. Animals culled for musculoskeletal/trauma reasons were from larger lots than respiratory culls ($P < 0.01$), but mean lot size for musculoskeletal/trauma culls was not significantly different ($P = 0.07$) than for “other” culls. Average arrival weight (per animal) was approximately 30 lb (14 kg) greater for musculoskeletal/trauma culls when compared to both respiratory and “other” culls (P-values < 0.01). Days-on-feed at culling was smallest for respiratory culls, which differed from both musculoskeletal/trauma and “other” culls (P-values < 0.01). The proportion of animals that returned revenue was greatest for musculoskeletal/trauma culls, differing significantly from respiratory and “other” culls (P-values < 0.01). There were heavier HCW for musculoskeletal/trauma culls, versus for respiratory and “other” culls; respiratory culls had the smallest mean HCW, which also differed from “other” culls (P-values < 0.05). With price partially being a function of HCW, musculoskeletal/trauma culls on average received the greatest $/cwt, and the greatest total revenue per animal compared to respiratory and “other” culls (P-values < 0.01). Respiratory culls were pulled from their home pen, and administered injectable antimicrobial treatments, significantly more often than musculoskeletal/trauma or “other” culls (P-values < 0.01). Musculoskeletal/trauma culls received antimicrobial treatments more often than “other” culls ($P < 0.01$). Total costs associated with pulling and treating were highest for respiratory culls, approximately twice as much as costs associated with “other” and musculoskeletal/trauma culls (P-values < 0.01). Processing costs were significantly greater for lots with respiratory culls when compared to musculoskeletal/trauma culls ($P < 0.01$). There was no evidence for a difference in processing costs for “other” culls compared to respiratory or musculoskeletal/trauma culls (Table 2.4).

Weight Range Comparisons

Table 2.5 contains results from statistical models evaluating effects of HCW, grouped by ranges (under 400 lb [light; 181 kg], 400 to 599 lb [middle; 181 to 271 kg], and over 600 lb [heavy; 272 kg]). Distributions of animals in the removal reasons categories differed between the three weight categories ($P < 0.01$); in particular, the number of respiratory culls decreased and musculoskeletal/trauma increased with increasing weight categories. Mean number of animals received per lot was smallest for the light HCW group, which differed from middle and heavy groups (P-values < 0.01). Average lot arrival weight, DOF, $/cwt, and total revenue per animal were all smallest for light culls, and greatest for heavy culls (with middleweight culls intermediate). The mean number of times pulled and antimicrobial treatments, were both greatest for light culls, and smallest for heavy culls; thus, total treatment costs were greatest for light culls, and smallest for heavy culls (Table 2.5). Processing costs were also highest for light culls and lowest for heavy culls.

Beef Market Associations

Spearman's correlation coefficients between prices received for individual feedlot culls and weekly beef market averages are in Table 2.6. Generally speaking, price correlations tended to be significant, but were weak to negligible ($r < 0.40$) when culls were grouped by all weights, 400 to 599 lb (181 to 271 kg) HCW, or below 400 lb (181 kg) HCW. Evidence of strong correlations was observed when comparing feedlot culls weighing over 600 lb (272 kg) HCW with cull cow (Breaker [75% lean]) and boneless beef trimmings (85% lean) markets. The strongest correlation was observed between prices received for feedlot culls over 600 lb (272 kg) when compared with prices of dressed cull cows over 500 lb (227 kg) HCW ($r = 0.77$). Cull cows sold on a live basis (all weights) compared to actual prices for feedlot culls over 600 lb (272 kg) indicated a moderate relationship ($r = 0.55$). Additionally, a moderate relationship was observed between actual price of feedlot culls over 600 lb (272 kg) and boneless beef trimmings ($r = 0.49$). Prices received for feedlot culls over 600 lb (272 kg) HCW were significantly correlated with feeder cattle prices, but the correlation was weak and negative ($r = -0.16$), and the feedlot cull prices received were not correlated with fat cattle markets (Table 2.6).

Prices received for feedlot culls expressed as a percent of dressed cull cow (Breaker [75% lean]) pricing for each weight category are in Figure 2.1. On average [with 95% CI], prices received for feedlot culls of all weights were 74.6% [74.1 to 75.2%] of weekly dressed cull cow (over 500 lb [227 kg] HCW) prices; and when categorized by weight, culls weighing below 400 lb (181 kg) HCW, between 400 and 599 lb (181 to 271 kg) HCW, and over 600 lb (272 kg) HCW received 59.5% [58.7 to 60.3%], 76.3% [75.8 to 76.9%], and 92.0% [91.5 to 92.5%] of cull cow prices, respectively.

Discussion

This is the first known published paper reporting the actual revenue returned from feedlot animals culled for slaughter and evaluating relationships between revenue received and reported US beef market prices. While the majority of price relationships were weak to negligible, the correlations were stronger when cattle were categorized by weight groups. The vast majority of culls returned at least some revenue (98.1% of total population). However, it is important to consider that this only accounts for animals that were actually shipped as culls; there was likely a population of animals that were intended to be culled from the feedlot, but were unable to ship (e.g., death at feedlot) and thus were not measured herein. Since there was no evidence that populations of culls that returned revenue differed compared to those that did not return revenue with respect to any of the characteristics reported in descriptive statistics, those results were not provided.

Overall, comparisons of data between culled steers and heifers were not meaningfully different (Table 2.3). Proportions of culls between sex that returned revenue were similar, and there was no evidence for a difference in reasons for culling between sexes. Hot carcass weight could be considered a potential confounder when comparing carcass price/value as steers on average weigh more than heifers. However, when HCW is controlled for by categorizing steers and heifers into weight groups, prices received between sexes were similar (within weight groups), with the lone exception being when HCW was greater than 800 lb (363 kg). While this indicated heifers received 7.76 $/cwt more than steers when carcasses were over 800 lb (363 kg), there were few carcasses in this weight group category with only 5 heifers and 39 steers with HCW over 800 lb. Although this mean price difference could be due to heifers and steers having differences in carcass composition (fat/meat/yield), those data were not available. Generally speaking, the results indicate that steers and heifers of the same weight receive a similar price when culled, and since the proportion of animals that return revenue and reasons for culling were not significantly different, both sexes were combined for subsequent analyses.

Historically, respiratory disease has accounted for the greatest proportions of morbidity (70 to 80%) and mortality (40 to 50%) in US beef feedlots.[14] More recently, evidence of respiratory disease contributing to 65 to 75% of feedlot deaths has been reported.[5] However, in the population of feedlot culls used in this study, there was a greater proportion of animals culled due to musculoskeletal/trauma reasons (approximately 50%), followed by respiratory (approximately 41%). Although literature on feedlot culls is limited, a past report attributed 70% of non-performing cattle sales to those with lameness.[7] Our results demonstrating differences in culled cattle populations when grouped by removal reason categories (Table 2.4) tend to agree with previous literature. It is generally well accepted that risk of respiratory disease in feedlot cattle is associated with arrival weight, and risk decreases in heavier cattle;[12,3,15] this is similar to our observations comparing mean lot arrival weight between animals culled for respiratory vs musculoskeletal/trauma reasons. The greatest proportion of respiratory disease incidence typically occurs early in the feeding period,[12,4,17,14] and in this population, animals culled for respiratory reasons had the smallest mean DOF compared to other reasons for culling. Feedlot cattle treated for respiratory disease multiple times (0, 1, 2, or over 3 times) have decreased total value ($/animal) as the number of treatments increase;[16] notably, growth performance indicators like average daily gain as well as carcass quality measurements (quality grade, marbling score) also have been shown to decrease as the number of respiratory treatments increased.[8,16] Cattle culled for respiratory reasons in our study were pulled and administered antimicrobial treatments more often, and had reduced carcass value compared to musculoskeletal/trauma culls. Additionally, respiratory culls originated from lots with higher processing costs compared to musculoskeletal/trauma culls, possibly due to increased use of antimicrobial metaphylaxis in lots presumably at greater risk of respiratory disease.

When feedlot culls were categorized by weight groups, changes in the distributions of animals by removal reasons were observed (Table 2.5). Light weight cattle were primarily culled for respiratory reasons, and as weight increased to middle and heavy weight groups, the distribution shifted in a likewise manner towards a greater proportion of musculoskeletal/trauma culls. A majority of observed differences between weight groups may be explained by the shift of respiratory to musculoskeletal/trauma culls as weight increased.

As this is the first known published paper describing actual revenue returned from feedlot culls and relationships with reported US beef market prices, available literature for comparison is minimal. As noted previously, the strength of correlations increased with weight group categorizations. Some important observations to note were that prices received for the heaviest culls were not significantly correlated with fat cattle prices (Table 2.6); and that prices received for heavy culls had the strongest correlation with 85% lean boneless cow and beef trimmings. Overall, cull cow prices had the highest correlation coefficients with received feedlot cull prices;

thus, it appears that use of cull cow prices may provide the best estimate of feedlot cull prices. We described this relationship for each weight group of feedlot culls using dressed cull cow (Breaker [75% lean]) prices from cows weighing over 500 lb (227 kg) HCW in Figure 2.1. If estimating feedlot cull prices for individual animals, estimating the animals HCW would enable a more accurate approximation of potential revenue. If not, the percent of dressed cull cow price received for all weights of feedlot culls may still provide an adequate estimate for economic analyses.

This study was limited to four commercial feedlots, all located in a similar geographic region, and studied during a limited time frame. Additionally, all feedlots used the same specialized abattoir to harvest feedlot culls. This scope may be an adequate representation for Central KS, but broadening inference to other states, or other regions of the US would rely on the tenuous assumptions that our data are representative. In addition, US beef markets are prone to volatility, especially over multiple years.[1,11] This must be taken into consideration when making conclusions, or using these outcomes to estimate feedlot cull revenue. Future research in a greater variety of regions and larger populations of cattle would be beneficial to improve the validity of using US beef market pricing to estimate revenue generated from feedlot culls.

Conclusions

In this study of commercial feedlot animals culled for slaughter, the vast majority returned revenue to the feedlot, but the amount of revenue varied significantly depending on the reason for culling and carcass weight. Cattle culled for musculoskeletal/trauma reasons were heaviest, and returned the most revenue compared to respiratory and "other" culls. While respiratory disease typically has the greatest health impact in beef feedlots, we observed a greater proportion of feedlot animals that were culled for slaughter, were culled for musculoskeletal/trauma reasons. Prices received for feedlot culls were significantly correlated with several reported US beef market price indices; most were weak to negligible, but improved when categorizing culls by carcass weight. Overall, the strongest relationships occurred when correlating received feedlot cull prices with dressed cull cow prices. Reported dressed cull cow prices may provide an adequate estimation of revenue from harvested feedlot culls in economic assessments.

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Endnotes

[a] R Core Team, Vienna, Austria; Version 4.0.2

[b] Microsoft, Redmond, WA

[c] SAS Institute Inc., Cary, NC; Version 9.4

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Tables and Figures

Table 2.1. Descriptive statistics of continuous variables for feedlot culls that were harvested for salvage overall and by reason for culling category

Item	n*	Mean	95% CI†	Median	IQR‡	Range
Animals received per lot, n						
All cattle	2,992	153	151 to 155	150	101 to 192	28 to 506
Musculoskeletal/trauma	1,488	159	155 to 163	154	109 to 201	40 to 448
Respiratory	1,223	148	144 to 152	146	92 to 186	28 to 506
Other	281	146	139 to 153	150	102 to 179	31 to 353
Average lot arrival weight, lb/animal						
All cattle	2,992	745	741 to 749	743	677 to 810	339 to 1,203
Musculoskeletal/trauma	1,488	762	757 to 767	763	701 to 824	411 to 1,203
Respiratory	1,223	727	721 to 733	724	663 to 789	399 to 1,182
Other	281	730	716 to 744	726	652 to 803	339 to 1,096
Days-on-feed at culling						
All cattle	2,992	111	109 to 113	111	69 to 146	1 to 331
Musculoskeletal/trauma	1,488	113	111 to 116	116	68 to 147	1 to 331
Respiratory	1,223	107	105 to 110	102	68 to 139	30 to 317
Other	281	118	112 to 124	118	75 to 153	7 to 315
Hot carcass weight§, lb						
All cattle	2,926	483	478 to 488	473	380 to 583	129 to 919
Musculoskeletal/trauma	1,468	516	509 to 523	520	410 to 618	169 to 899
Respiratory	1,187	445	438 to 453	429	349 to 526	163 to 919
Other	271	472	455 to 489	462	381 to 553	129 to 898
Carcass weight price§, $/cwt						
All cattle	2,926	87.40	86.70 to 88.10	87.00	74.00 to 101.00	21.00 to 155.00
Musculoskeletal/trauma	1,468	91.12	90.19 to 92.05	93.00	79.00 to 105.00	32.00 to 155.00
Respiratory	1,187	83.20	82.08 to 84.32	82.00	69.00 to 98.00	25.00 to 155.00
Other	271	85.61	83.28 to 87.94	85.00	73.00 to 100.00	21.00 to 125.00
Total revenue‖, $/animal						
All cattle	2,983	434.81	427.22 to 442.40	405.02	280.96 to 585.96	0.00 to 1,378.50
Musculoskeletal/trauma	1,480	485.22	474.70 to 495.74	480.69	326.26 to 640.04	0.00 to 1,278.75
Respiratory	1,223	379.30	367.88 to 390.72	343.50	242.00 to 497.20	0.00 to 1,378.50
Other	280	410.79	386.34 to 435.24	393.69	277.41 to 552.86	0.00 to 942.90

* n = number of observations (animals) used for descriptive statistics
† 95% confidence interval of the mean
‡ IQR (interquartile range: quartiles 1 to 3)
§ Animals that returned no revenue had no carcass weight or price recorded and were excluded (n = 57 total [n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other]), those which returned harvested meat back to the owner were excluded (n = 9 total [n = 8 musculoskeletal/trauma, n = 1 other])
‖ Animals that returned no revenue ($0.00) were included in total revenue (n = 57 total [n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other]), but those that returned harvested meat back to the owner were excluded (n = 9 total [n = 8 musculoskeletal/trauma, n = 1 other])

Table 2.1. Continued

Item	n*	Mean	95% CI†	Median	IQR‡	Range
Times pulled, n/animal						
All cattle	2,992	2.39	2.34 to 2.44	2	1 to 3	0 to 10
Musculoskeletal/trauma	1,488	2.11	2.05 to 2.17	2	1 to 3	0 to 10
Respiratory	1,223	2.82	2.75 to 2.89	3	2 to 3	0 to 10
Other	281	1.96	1.78 to 2.14	2	1 to 3	0 to 10
Antimicrobial treatments, n/animal						
All cattle	2,992	1.73	1.69 to 1.77	2	1 to 3	0 to 8
Musculoskeletal/trauma	1,488	1.42	1.36 to 1.48	1	0 to 2	0 to 6
Respiratory	1,223	2.26	2.20 to 2.32	2	1 to 3	0 to 7
Other	281	1.13	0.98 to 1.28	1	0 to 2	0 to 8
Total treatment costs, $/animal						
All cattle	2,992	45.09	43.91 to 46.27	42.88	18.94 to 68.05	0.00 to 185.43
Musculoskeletal/trauma	1,488	32.51	31.00 to 34.02	26.98	4.54 to 50.11	0.00 to 185.43
Respiratory	1,223	63.34	61.78 to 64.90	58.50	43.54 to 81.80	0.00 to 185.43
Other	281	32.30	28.34 to 36.26	27.10	2.10 to 56.09	0.00 to 150.96
Processing cost, $/animal						
All cattle	2,992	18.72	18.37 to 19.07	15.73	14.04 to 18.43	4.98 to 71.36
Musculoskeletal/trauma	1,488	17.32	16.93 to 17.71	15.42	13.93 to 17.67	7.56 to 64.09
Respiratory	1,223	20.21	19.56 to 20.86	16.06	14.23 to 19.68	4.98 to 71.36
Other	281	19.68	18.41 to 20.95	15.75	13.97 to 18.99	9.03 to 69.60

* n = number of observations (animals) used for descriptive statistics
† 95% confidence interval of the mean
‡ IQR (interquartile range: quartiles 1 to 3)

Table 2.2. Descriptive statistics of continuous variables for feedlot culls that were harvested for salvage by carcass weight categories

Item	n*	Mean	95% CI†	Median	IQR‡	Range
Animals received per lot, n						
Over 600 lb	639	159	154 to 164	156	115 to 200	45 to 488
400 to 599 lb	1,394	154	150 to 158	149	102 to 194	28 to 470
Under 400 lb	893	148	144 to 152	147	90 to 180	31 to 506
Average lot arrival weight, lb/animal						
Over 600 lb	639	795	786 to 804	789	728 to 874	399 to 1,203
400 to 599 lb	1,394	751	746 to 757	753	691 to 813	406 to 1,182
Under 400 lb	893	699	693 to 705	701	630 to 760	339 to 1,096
Days-on-feed at culling						
Over 600 lb	639	143	140 to 146	144	123 to 165	39 to 331
400 to 599 lb	1,394	114	112 to 117	113	75 to 146	1 to 317
Under 400 lb	893	82	79 to 85	70	55 to 101	1 to 315
Hot carcass weight, lb						
Over 600 lb	639	684	679 to 689	668	630 to 725	600 to 919
400 to 599 lb	1,394	493	490 to 496	489	446 to 539	400 to 599
Under 400 lb	893	324	320 to 328	335	287 to 371	129 to 399
Carcass weight price, $/cwt						
Over 600 lb	639	107.18	106.30 to 108.06	105.00	100.00 to 115.00	65.00 to 155.00
400 to 599 lb	1,394	89.74	89.02 to 90.46	87.00	79.00 to 100.00	55.00 to 122.00
Under 400 lb	893	69.58	68.59 to 70.57	69.00	59.00 to 81.00	21.00 to 110.00
Total revenue, $/animal						
Over 600 lb	639	734.23	725.16 to 743.30	718.30	657.30 to 787.20	419.25 to 1,378.50
400 to 599 lb	1,394	446.10	440.79 to 451.41	439.13	365.75 to 521.53	237.60 to 701.50
Under 400 lb	893	230.69	225.79 to 235.59	231.88	180.96 to 283.91	43.25 to 392.70
Times pulled, n/animal						
Over 600 lb	639	1.74	1.66 to 1.82	2	1 to 2	0 to 8
400 to 599 lb	1,394	2.35	2.28 to 2.42	2	1 to 3	0 to 10
Under 400 lb	893	2.91	2.83 to 2.99	3	2 to 4	0 to 8
Antimicrobial treatments, n/animal						
Over 600 lb	639	1.05	0.98 to 1.12	1	0 to 2	0 to 5
400 to 599 lb	1,394	1.69	1.63 to 1.75	2	1 to 3	0 to 8
Under 400 lb	893	2.29	2.22 to 2.36	2	2 to 3	0 to 7
Total treatment costs, $/animal						
Over 600 lb	639	36.24	33.61 to 38.87	35.56	2.53 to 55.47	0.00 to 168.30
400 to 599 lb	1,394	46.43	44.64 to 48.22	41.28	19.06 to 71.11	0.00 to 185.43
Under 400 lb	893	49.54	47.61 to 51.48	48.68	28.15 to 69.07	0.00 to 185.43
Processing cost, $/animal						
Over 600 lb	639	16.63	16.15 to 17.11	15.36	14.00 to 16.79	8.53 to 62.72
400 to 599 lb	1,394	18.31	17.84 to 18.78	15.73	14.03 to 18.31	4.98 to 69.60
Under 400 lb	893	20.84	20.03 to 21.65	15.90	14.11 to 20.12	6.34 to 71.36

* n = number of observations (animals) used for descriptive statistics; only animals that had a recorded carcass weight were included (57 excluded that returned no revenue [n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other], and 9 excluded that returned harvested meat back to the owner [n = 8 musculoskeletal/trauma, n = 1 other])

† 95% confidence interval of the mean

‡ IQR (interquartile range: quartiles 1 to 3)

Table 2.3. Results from analyses of potential differences between culled steers and culled heifers

Item	Steers	Heifers	*P*-value
Revenue returned[*], % (SEM)	97.80 (0.733)	97.90 (0.662)	0.86
Culling reason category[†], % of sex (n)			0.55
Musculoskeletal/trauma	50.08 (662)	49.46 (826)	
Respiratory	41.15 (544)	40.66 (679)	
Other	8.77 (116)	9.88 (165)	
Price received[‡], $/cwt HCW (SEM)			
Sex*HCW range	--	--	< 0.01
100 to 199 lb	47.06 (2.193)	44.44 (1.409)	0.26
200 to 299 lb	56.01 (0.977)	55.09 (0.878)	0.17
300 to 399 lb	74.38 (0.859)	74.09 (0.836)	0.46
400 to 499 lb	83.98 (0.841)	83.46 (0.830)	0.13
500 to 599 lb	97.56 (0.850)	97.49 (0.838)	0.85
600 to 699 lb	107.22 (0.866)	106.42 (0.872)	0.08
700 to 799 lb	109.47 (0.906)	110.12 (1.019)	0.39
Over 800 lb	114.83 (1.107)	122.59 (2.182)	< 0.01

[*] Percent of feedlot culls that returned revenue; values are model mean percentages

[†] Comparison of the distribution steers or heifers across categories; values are frequency statistics

[‡] Price received ($/cwt [hundredweight] HCW [hot carcass weight]); 57 animals that returned no revenue and thus had no price were excluded (n = 25 steers, n = 32 heifers) and 9 animals that returned harvested meat back to the owner were excluded (n = 2 steers, n = 7 heifers); values are model adjusted means for sex within HCW range and used an adjustment for multiple comparisons for determination of *P*-values

Table 2.4. Model adjusted means and standard errors of the means (SEM) from analyses of factors associated with reasons for culling

Item[*], (SEM)	Reason for culling: Musculoskeletal/trauma	Respiratory	Other	Overall P-value
Animals received per lot, n	162 (8.1)[a]	152 (8.2)[b]	152 (8.9)[ab]	< 0.01
Average lot arrival weight, lb/animal	752 (9.1)[a]	720 (9.2)[b]	721 (10.8)[b]	< 0.01
Days-on-feed at culling, mean	115 (9.0)[a]	110 (9.0)[b]	120 (9.3)[a]	< 0.01
Revenue returned[†,‡], %	99.14 (0.359)[a]	96.73 (1.081)[b]	96.30 (1.612)[b]	< 0.01
Hot carcass weight[‡,§], lb	505 (17.0)[a]	435 (17.0)[b]	457 (18.5)[c]	< 0.01
Carcass weight price[‡,§], $/cwt	89.10 (2.635)[a]	82.73 (2.638)[b]	83.49 (2.762)[b]	< 0.01
Total revenue[ǀ], $/animal	463.85 (26.098)[a]	369.68 (26.142)[b]	385.83 (27.955)[b]	< 0.01
Times pulled, mean	2.26 (0.209)[a]	3.03 (0.278)[b]	2.15 (0.214)[a]	< 0.01
Antimicrobial treatments, mean	1.51 (0.119)[a]	2.40 (0.185)[b]	1.20 (0.112)[c]	< 0.01
Total treatment costs, $/animal	33.99 (5.204)[a]	62.68 (5.210)[b]	30.61 (5.421)[a]	< 0.01
Processing cost, $/animal	17.74 (2.292)[a]	19.49 (2.293)[b]	18.60 (2.339)[ab]	< 0.01

[a,b] Different superscripts within a row indicate a difference between culling reason categories ($P < 0.05$) after adjustment for multiple comparisons

[*] N = 2,992 total animals unless otherwise specified (n = 1,488 musculoskeletal/trauma, n = 1,223 respiratory, n = 281 other)

[†] Percent of feedlot culls that returned revenue; values are model adjusted mean percentages

[‡] N = 9 animals excluded that returned harvested meat back to the owner (n = 8 musculoskeletal/trauma, n = 1 other)

[§] N = 57 animals that returned no revenue had no carcass weight or price recorded and were excluded (n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other)

[ǀ] Animals that returned no revenue ($0.00) were included in total revenue (n = 57 total [n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other]), but those that returned harvested meat back to the owner were excluded (n = 9 total [n = 8 musculoskeletal/trauma, n = 1 other])

Table 2.5. Model adjusted means and standard errors of the means (SEM) from analyses of factors associated with carcass weight categories of feedlot culls

Item*	Weight group, lb hot carcass weight			Overall *P*-value
	Under 400	400 to 599	Over 600	
Culling reason category†, % of column total (n)				< 0.01
Musculoskeletal/trauma	37.51 (335)	50.22 (700)	67.76 (433)	
Respiratory	53.08 (474)	39.60 (552)	25.20 (161)	
Other	9.41 (84)	10.19 (142)	7.04 (45)	
Animals received per lot, n (SEM)	151 (8.9)[a]	158 (8.8)[b]	165 (9.0)[b]	< 0.01
Average lot arrival weight, lb/animal (SEM)	693 (8.3)[a]	745 (8.1)[b]	788 (8.7)[c]	< 0.01
Days-on-feed at culling, mean (SEM)	87 (8.0)[a]	118 (8.0)[b]	147 (8.1)[c]	< 0.01
Carcass weight price, $/cwt	69.14 (1.169)[a]	89.18 (1.151)[b]	106.37 (1.191)[c]	< 0.01
Total revenue, $/animal	232.68 (7.748)[a]	440.91 (7.528)[b]	721.61 (8.087)[c]	< 0.01
Times pulled, mean (SEM)	3.05 (0.263)[a]	2.53 (0.217)[b]	1.92 (0.172)[c]	< 0.01
Antimicrobial treatments, mean (SEM)	2.41 (0.185)[a]	1.79 (0.137)[b]	1.12 (0.094)[c]	< 0.01
Total treatment costs, $/animal (SEM)	50.71 (6.402)[a]	46.73 (6.373)[b]	36.27 (6.449)[c]	< 0.01
Processing cost, $/animal (SEM)	20.30 (2.294)[a]	18.11 (2.287)[b]	16.46 (2.304)[c]	< 0.01

[abc] Different superscripts within a row indicate a difference between weight groups ($P < 0.05$) after adjustment for multiple comparisons

* N = 2,926 total animals (n = 893 under 400 lb, n = 1,394 between 400 and 599 lb, and n = 639 over 600 lb carcass weight); only animals that had a recorded carcass weight were included (57 excluded that returned no revenue [n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other], and 9 excluded that returned harvested meat back to the owner [n = 8 musculoskeletal/trauma, n = 1 other])

† Comparison of the distribution of animals across culling reason categories; values are frequency statistics

Table 2.6. Correlation coefficients comparing price received for individual feedlot culls to weekly average reported prices of different U.S. beef markets

Feedlot cull weight group, HCW[*]	Spearman's correlation[†]		
Beef market, $/cwt	*r*-value	R^2	*P*-value
All weights, n = 2,926			
Fat cattle[‡], formula net (dressed)	0.07	< 0.01	< 0.01
Fat cattle[‡], formula net (live)	0.05	< 0.01	< 0.01
Cull cow[§], (Breaker, over 500 lb; dressed)	0.26	0.07	< 0.01
Cull cow[§], (Breaker, all weights; live)	0.26	0.07	< 0.01
Feeder cattle[ǀ]	0.06	< 0.01	< 0.01
Boneless beef trimmings (85% lean)[¶]	0.15	0.02	< 0.01
Over 600 lb, n = 639			
Fat cattle[‡], formula net (dressed)	0.02	< 0.01	0.56
Fat cattle[‡], formula net (live)	0.03	< 0.01	0.48
Cull cow[§], (Breaker, over 500 lb; dressed)	0.77	0.59	< 0.01
Cull cow[§], (Breaker, all weights; live)	0.55	0.30	< 0.01
Feeder cattle[ǀ]	-0.16	0.03	< 0.01
Boneless beef trimmings (85% lean)[¶]	0.49	0.24	< 0.01
400 to 599 lb, n = 1,394			
Fat cattle[‡], formula net (dressed)	0.30	0.09	< 0.01
Fat cattle[‡], formula net (live)	0.30	0.09	< 0.01
Cull cow[§], (Breaker, over 500 lb; dressed)	0.34	0.12	< 0.01
Cull cow[§], (Breaker, all weights; live)	0.39	0.15	< 0.01
Feeder cattle[ǀ]	0.03	< 0.01	0.21
Boneless beef trimmings (85% lean)[¶]	0.19	0.04	< 0.01
Under 400 lb, n = 893			
Fat cattle[‡], formula net (dressed)	0.31	0.10	< 0.01
Fat cattle[‡], formula net (live)	0.25	0.06	< 0.01
Cull cow[§], (Breaker, over 500 lb; dressed)	0.23	0.05	< 0.01
Cull cow[§], (Breaker, all weights; live)	0.39	0.15	< 0.01
Feeder cattle[ǀ]	0.08	0.01	0.02
Boneless beef trimmings (85% lean)[¶]	0.13	0.02	< 0.01

[*] HCW (hot carcass weight); only animals that had a recorded HCW and price were included (57 excluded that returned no revenue [n = 12 musculoskeletal/trauma, n = 36 respiratory, n = 9 other], and 9 excluded that returned harvested meat back to the owner [n = 8 musculoskeletal/trauma, n = 1 other])

[†] Spearman's R^2 is the squared correlation coefficient (*r*-value) and indicates the proportion of variation for which received feedlot cull prices can be explained by beef market indices; *P*-value is a measure of significance for the correlation

[‡] Weekly average of historical fat cattle pricing in KS using formula net pricing (dressed or live) for all quality grades[22]

[§] Weekly average of historical U.S. national cull cow (Breaker [75% lean]) pricing (dressed or live)[23]

[ǀ] Weekly average of historical 85% lean boneless cow and beef trimmings (Central U.S. region)[24]

[¶] A mean price per week was calculated for heifers and steers (separately) by averaging across all 100 lb weight ranges for medium and large frame #1 cattle; reported values are for combined KS auctions[9]

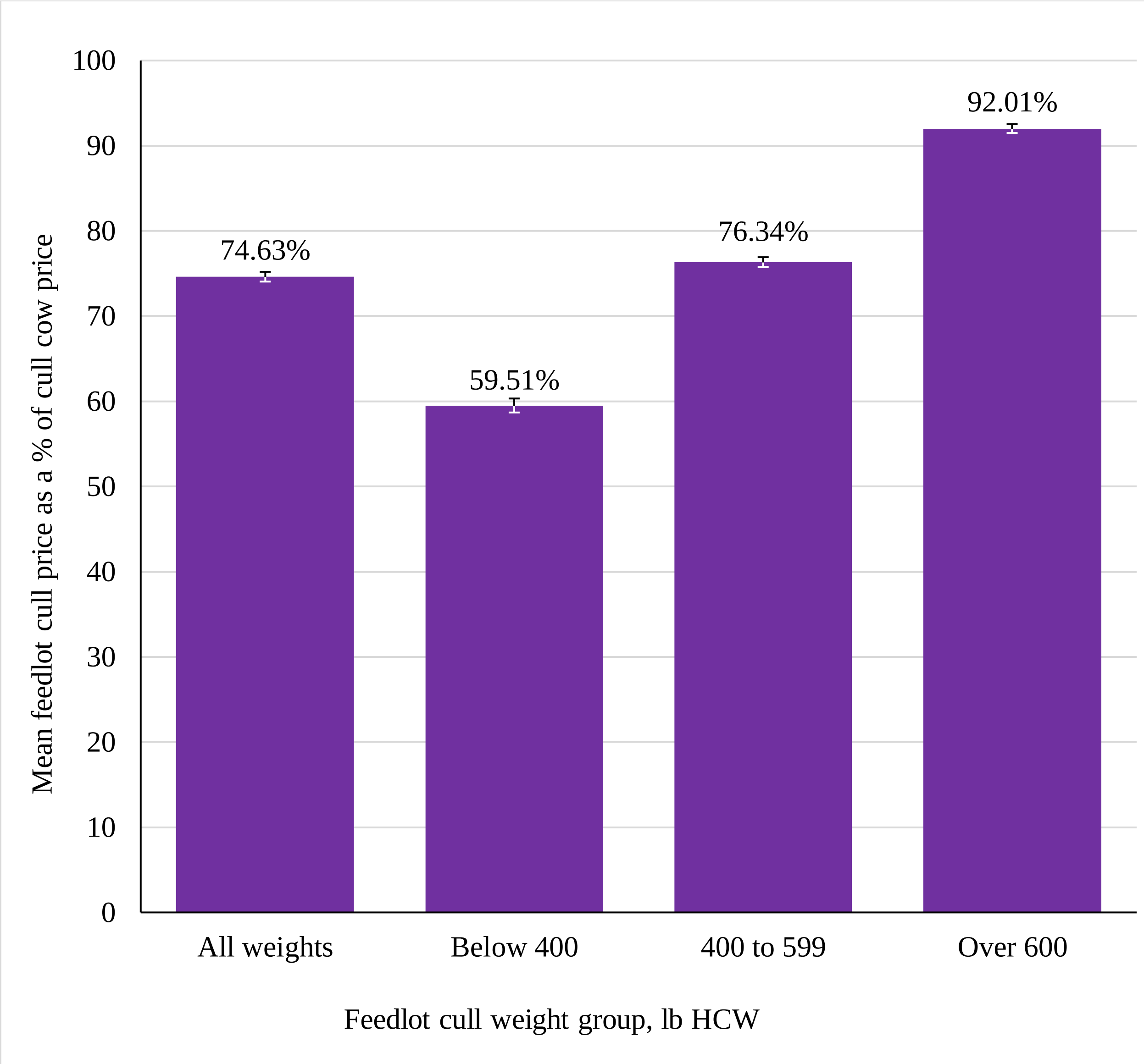


Figure 2.1. Mean price received for feedlot culls by weight group (HCW; hot carcass weight) as a percent of national dressed cull cow prices (Breaker [75% lean]; over 500 lb HCW)[23]. Error bars represent 95% confidence intervals for estimates of mean feedlot cull price received (as a percent of mean cull cow price).

Appendix

Appendix Table 2.A. Descriptive statistics of continuous variables for feedlot culls that were harvested for salvage overall and categorized by sex

Item	n*	Mean	95% CI†	Median	IQR‡	Range
Animals received per lot, n						
All cattle	2,992	153	151 to 155	150	101 to 192	28 to 506
Steers	1,322	148	144 to 152	146	87 to 190	31 to 448
Heifers	1,670	157	154 to 160	152	111 to 195	28 to 506
Average lot arrival weight, lb/animal						
All cattle	2,992	745	741 to 749	743	677 to 810	339 to 1203
Steers	1,322	777	771 to 783	777	107 to 858	339 to 1203
Heifers	1,670	719	714 to 724	726	657 to 779	399 to 1182
Days-on-feed at culling						
All cattle	2,992	111	109 to 113	111	69 to 146	1 to 331
Steers	1,322	111	108 to 114	109	68 to 146	5 to 331
Heifers	1,670	111	109 to 113	111	69 to 145	1 to 317
Carcass weight§, lb						
All cattle	2,926	483	478 to 488	473	380 to 583	129 to 919
Steers	1,295	513	505 to 521	500	399 to 618	129 to 919
Heifers	1,631	460	454 to 466	455	363 to 553	163 to 869
Carcass weight price§, $/cwt						
All cattle	2,926	87.40	86.7 to 88.1	87.00	74.00 to 101.00	21.00 to 155.00
Steers	1,295	90.14	89.11 to 91.17	92.00	76.00 to 105.00	21.00 to 150.00
Heifers	1,631	85.21	84.28 to 86.14	85.00	72.00 to 100.00	25.00 to 155.00
Value returned‖, $/animal						
All cattle	2,983	434.81	427.22 to 442.4	405.02	280.96 to 585.96	0.00 to 1378.50
Steers	1,320	474.81	462.71 to 486.91	454.19	303.59 to 641.30	0.00 to 1378.50
Heifers	1,663	403.06	393.67 to 412.45	380.78	266.22 to 543.15	0.00 to 1278.75
Times pulled, n/animal						
All cattle	2,992	2.39	2.34 to 2.44	2	1 to 3	0 to 10
Steers	1,322	2.36	2.29 to 2.43	2	1 to 3	0 to 10
Heifers	1,670	2.41	2.35 to 2.47	2	1 to 3	0 to 10
Antimicrobial treatments, n/animal						
All cattle	2,992	1.73	1.69 to 1.77	2	1 to 3	0 to 8
Steers	1,322	1.69	1.63 to 1.75	2	1 to 3	0 to 7
Heifers	1,670	1.77	1.71 to 1.83	2	1 to 3	0 to 8
Total treatment costs, $/animal						
All cattle	2,992	45.09	43.91 to 46.27	42.88	18.94 to 68.05	0.00 to 185.43
Steers	1,322	46.00	44.17 to 47.83	44.90	15.83 to 70.08	0.00 to 168.30
Heifers	1,670	44.37	42.82 to 45.92	41.33	20.13 to 66.12	0.00 to 185.43
Processing cost, $/animal						
All cattle	2,992	18.72	18.37 to 19.07	15.73	14.04 to 18.43	4.98 to 71.36
Steers	1,322	18.24	17.75 to 18.73	15.49	14.11 to 17.28	7.56 to 65.15
Heifers	1,670	19.10	18.61 to 19.59	15.95	14.00 to 19.32	4.98 to 71.36

* n = number of observations (animals) used for descriptive statistics

† 95% confidence interval of the mean

‡ IQR (interquartile range: quartiles 1 to 3)

§ Carcass weight and price excludes 57 animals that returned no revenue (n = 25 steers, n = 32 heifers) and 9 animals returned harvested meat back to the owner (n = 2 steers, n = 7 heifers)

‖ Animals that returned no revenue ($0.00) were included in total revenue (n = 57 total [n = 25 steers, n = 32 heifers]), but those that returned harvested meat back to the owner were excluded (n = 9 total [n = 2 steers, n = 7 heifers])

Appendix Table 2.B. Model adjusted means and standard errors of the means (SEM) from analyses of factors comparing feedlot culls that did or did not return revenue

Item[*]	Revenue returned Yes	No	*P*-value
Animals received per lot, n (SEM)	157 (8.6)	149 (12.1)	0.40
Average lot arrival weight, lb/animal (SEM)	735 (9.9)	725 (17.4)	0.49
Days-on-feed at culling, mean (SEM)	113 (9.0)	116 (10.8)	0.68
Times pulled, mean (SEM)	2.59 (0.240)	2.33 (0.294)	0.23
Antimicrobial treatments, mean (SEM)	1.87 (0.158)	1.79 (0.233)	0.66
Total treatment costs, $/animal (SEM)	46.00 (6.468)	49.38 (7.676)	0.43
Processing cost, $/animal (SEM)	18.53 (2.392)	20.38 (2.647)	0.11

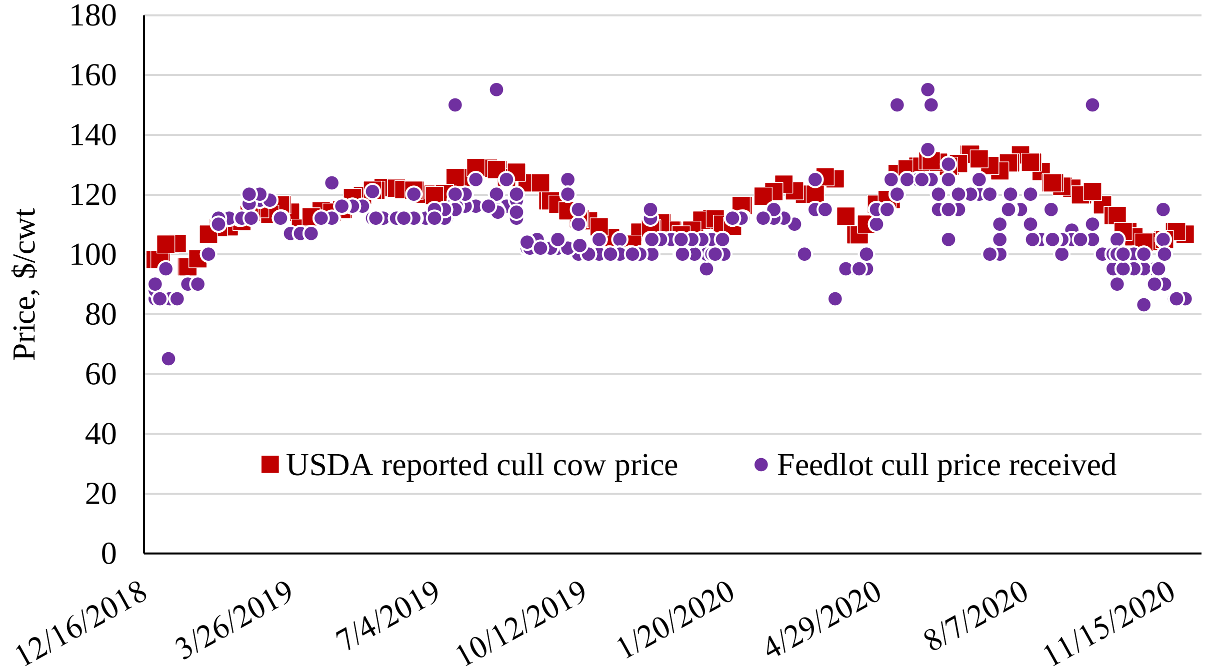
[*] N = 2,926 animals that returned revenue, n = 57 animals that did not return revenue, n = 9 animals excluded that that returned harvested meat back to the owner

Appendix Table 2.C. Description of feedlot culls separated by hot carcass weight (HCW) group

Weight group, lb HCW	n	Percent	Estimated live weight[*], lb	Estimated dressing percent[†]
Over 600	639	21.84	Over 995	Over 60.33
400 to 599	1394	47.64	696 to 993	57.44 to 60.32
Under 400	893	30.52	Under 696	Under 57.42

[*] Live weight of harvested culls was estimated from individual HCW using the inverse of regression equation described by Tatum et al (2012); live weight = $(HCW/0.2598)^{(1/1.1378)}$

[†] Hot carcass weight group / estimated live weight



Appendix Figure 2.1. Description of changes in sale prices over time between individual feedlot culls weighing over 600 lb (272 kg) HCW and weekly average U.S. national dressed cull cow (Breaker [75% lean]) price for carcasses greater than 500 lb (227 kg).

Chapter 3 - A randomized trial and multi-site pooled trial analyses comparing effects of two hormonal implant programs and differing days-on-feed on carcass characteristics and feedlot performance of beef heifers

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Abstract

Research objectives were to evaluate effects of two implant programs for beef heifers fed three different durations (days-on-feed; DOF) on carcass weight and composition (primary outcomes) and feedlot performance (secondary outcomes) at commercial feedlots. Data from a randomized trial in Kansas were analyzed separately and also pooled with data from two previously published trials conducted in Texas. Heifers were randomly allocated to pens within a block, and pens were randomized to treatments in a 2 × 3 factorial randomized complete block design. Implant programs were IH + 200 – an initial Revalor-IH implant [80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2)] and a re-implant after a mean of 98-d (± 10.8 SD) with Revalor-200 (200 mg TBA and 20 mg E_2), or XH – Revalor-XH, a single extended-release implant (200 mg TBA and 20 mg E_2). Heifers were fed to a baseline endpoint (BASE; pooled mean 166-d ± 11.9 SD), +21, or +42 additional DOF. A total of 10,583 crossbred heifers with mean initial body weight (BW) 315 kg (± 20.1 SD) were enrolled in 144 pens in 24 blocks (treatment replications) across the three trials. General and generalized linear mixed models accounting for clustering of trials, blocks, and pens were used to test for effects of treatments, with significance set at $\alpha = 0.05$. The only implant program × DOF interaction in pooled analyses was for dry matter intake (DMI; $P < 0.01$); IH + 200 heifers had lower mean DMI than XH when fed +42 DOF. Gain:feed was higher for IH + 200 compared to XH with dead and removed animals excluded ($P < 0.01$) or included ($P = 0.03$). For IH + 200, hot carcass weight (HCW) increased ($P < 0.01$), USDA Yield Grade (YG) distributions shifted towards lower numerical categories ($P < 0.01$), and Prime carcasses decreased while Select increased compared to XH ($P < 0.01$). For each incremental increase in DOF, final BW ($P < 0.01$) and HCW increased ($P < 0.01$), while daily gain ($P < 0.01$) and gain:feed ($P < 0.01$) decreased. Categories of YG were affected by DOF ($P < 0.01$); there were fewer YG 1 and 2 and more YG 4 and 5 carcasses for +42 compared to BASE and +21. USDA Quality Grade (QG) distributions differed by DOF ($P < 0.01$); each incremental increase in DOF resulted in more Prime and fewer Select carcasses. Without meaningful interactions, tested implant programs likely have a consistent effect when heifers are fed to similar DOF, while changes in HCW, QG, and YG may influence marketing decisions when extending DOF.

Key words: days-on-feed, estradiol, feedlot, heifers, implant, trenbolone acetate

Introduction

Use of hormonal implants in heifers dates back to 1947, with first federal approval for commercial application in 1957 (Montgomery et al., 2001). This technology is now a standard in the US beef industry, for the primary purposes of improving weight gain and feed efficiency (Reinhardt and Wagner, 2014; Smith and Johnson, 2020). A survey of US feedlots in 2011 indicated that 92.3% of cattle weighing less than 317.5 kg at feedlot arrival received at least one implant, with 79.9% receiving two or more; 94.3% of cattle weighing greater than or equal to 317.5 kg at feedlot arrival received at least one implant, with 29.8% receiving two or more (USDA-NAHMS, 2013). For some producers, the practice of re-implanting cattle may impose labor constraints, and may cause cattle stress from handling and processing. Additionally, upcoming guidance regarding the practice of re-implanting cattle will impact its use beginning in June 2023 (FDA, 2021). Newer technologies aim to provide an alternative to re-implanting, allowing cattle to be implanted only once at feedlot arrival but still receive constant delivery from hormonal implants throughout a longer feeding period. One such long-lasting implant for use in heifers is Revalor-XH (Merck Animal Health, De Soto, KS), which contains a combination of four uncoated [80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2) total] and six coated (120 mg TBA and 12 mg E_2 total) implant pellets (FOIS, 2017). The uncoated component allows TBA and E_2 to discharge and have bioavailability immediately after application, while the polymer coated portion breaks-down and does not discharge these compounds until approximately 70 d after initial application.

As changes in carcass composition may be expected when comparing Revalor-XH to a more traditional re-implant program (Smith et al., 2020), it may also be important to evaluate optimal days-on-feed (DOF) when using differing implant programs. Including a serial harvest treatment factor is a method for estimation of incremental dressing percentage (incremental carcass gain/incremental live gain), the estimated proportion of live weight gain that results in carcass weight gain (Streeter et al., 2012). Multiple research trials have been performed to address these questions in beef heifers, and have been summarized independently (Smith et al., 2019; Ohnoutka et al., 2021). The importance of reproducible research in the animal sciences has been discussed by Bello and Renter (2018), and is also a critical aspect of post-licensure evaluation of pharmaceutical products. By conducting similar randomized controlled trials at multiple study locations, scope of inference and external validity of results can increase (Tempelman, 2009; Bello and Renter, 2018). For these reasons, an additional commercial feedlot trial with similar treatment and design structures as the Smith et al. (2019) trials was performed in Kansas. This also allows for pooling of data across multiple trials and location, yielding more robust analyses with broader generalizability. These data could be highly valuable to producers as they consider implant programs and optimal DOF for marketing finishing heifers.

Thus, the primary objective of this research was to evaluate effects of two implant programs and three varying DOF on carcass composition (weight, quality, and yield). The secondary objective was to evaluate how these factors may affect other production components including live performance and health.

Materials and methods

The primary randomized controlled trial (Kansas trial) described herein was performed at a commercial feedlot in central Kansas. Methodology and results from this trial are detailed independently, but also are combined in a pooled analysis with two previously published trials (Smith et al., 2019) in a second facet of this publication. Like the trials reported by Smith et al. (2019), Institutional Animal Care and Use Committee approval was not acquired as the research was conducted at a commercial research feedlot, which followed practices described in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2020).

Kansas trial

Study population

Crossbred beef heifers (*N* = 3,125) were received at a commercial feedlot in central Kansas between November 25, 2018 and December 21, 2018, with heifers enrolled in the study between December 5 and December 27, 2018. The specific feedlot used was not chosen randomly but out of convenience, due to willingness to participate, and history of conducting randomized controlled trials. Heifers were purchased from sale barns located in Kansas, Oklahoma, Nebraska, Missouri, and Iowa. Heifers ineligible for inclusion were those recognizably lame, ill, pregnant, or of extreme heavy or light body weight (BW) at the time of initial processing, resulting in the exclusion of 41 animals. The final population used for trial enrollment included 3,084 heifers which had an initial BW of 309 kg [± 6.4 kg (1 SD)].

Treatment structure and experimental design

A 2 × 3 factorial treatment arrangement was used in a randomized complete block design. Factor 1 was implant program, which had two treatments, Revalor-IH + Revalor-200 (IH + 200) or Revalor-XH (XH). Heifers in the IH + 200 treatment were implanted at trial enrollment with Revalor-IH (Merck Animal Health), which is an uncoated implant containing 80 mg TBA and 8 mg E_2, and re-implanted with approximately 94 DOF remaining with Revalor-200 (Merck Animal Health), which is an uncoated implant containing 200 mg TBA and 20 mg E_2. Heifers in the XH treatment were implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 (uncoated), and a coated component containing an additional 120 mg TBA and 12 mg E_2. Pens of heifers administered XH were implanted only once, and were not removed from their home pens to be reprocessed partway through the feeding period.

Factor 2 was DOF, which had three treatments, baseline (BASE), +21, or +42; mean DOF for each treatment was 179, 200, and 221, respectively, with an SD of 4.7 d. Within a block, heifers in the BASE treatment were harvested based on predictions made by the company marketing group for when the pen would reach an ideal finish weight and fat deposition targeting approximately 15 to 20% USDA Yield Grade (YG) 4 carcasses (i.e., a "normal" harvest endpoint for heifers typically fed in the feedlot). Heifers in the +21 treatment were fed an additional 21-d, and heifers in the +42 treatment were fed an additional 42-d compared to the BASE treatment in each block.

Heifers were blocked by arrival date and source, and a block consisted of six adjacent pens of similar size with all treatment combinations represented. Once enough animals were received to fill all pens within a block, heifers were systematically allocated into pens by moving a group to the processing area, and sorting three-animals at a time into each of six pens within a block, until the desired count per pen was achieved (mean of 86 animals/pen, range 74 to 115 depending on block); this process was performed by feedlot personnel. Within a block, pens were randomly assigned to treatment by use of a random number generating function within an Excel spreadsheet (Microsoft, Redmond, WA). Thus, pen was the experimental unit for all outcomes. Treatments assigned to pens were concealed from feedlot personnel who allocated heifers to pens. All pens in a block were managed identically aside from treatment interventions (implant program and DOF). Heifers were enrolled in the trial from December 5 to December 27, 2018. There was a total of 6 blocks and 36 pens. While no formal calculations of sample size were performed, this study population was assumed to adequately measure and reproduce anticipated effect magnitudes based on results from previous studies that were later published by Smith et al. (2019).

Cattle management

Upon arrival heifers were given *ad libitum* access to fresh water and long-stemmed hay, and were later fed a common growing ration for approximately 10 d prior to trial initiation. Heifers were processed according to standard feedlot procedures, which included: identification with color-coordinated dual ear-tags containing a lot number and unique animal number, a four-way (containing modified live virus components for bovine viral diarrhea type 1, infectious bovine rhinotracheitis, parainfluenza 3, and bovine respiratory syncytial virus; Pyramid-4; Boehringer Ingelheim, St. Joseph, MO) or five-way (containing modified live viral components for bovine viral diarrhea types 1 and 2, infectious bovine rhinotracheitis, parainfluenza 3, bovine respiratory syncytial virus, as well as avirulent live cultures of *Mannheimia haemolytica* and *Pasteurella multocida*; Vista Once; Merck Animal Health) antiviral vaccine (consistent within block), an autogenous bacterin vaccine specific for foot-rot (Newport Laboratories, Inc., Worthington, MN), an internal parasiticide injection (Dectomax; Zoetis Animal Health, Parsippany, NJ), an oral anthelmintic (Safeguard; Merck Animal Health), a topical insecticide (Clean-Up; Bayer HealthCare LLC, Animal Health Division, Shawnee Mission, KS), and a metaphylactic injection of tildipirosin (Zuprevo; Merck Animal Health). All pharmaceutical products were administered according to manufacturer labels. In addition, depending on implant program treatment, heifers were administered Revalor-IH or Revalor-XH under the skin of the posterior aspect of the ear. Pens were weighed on a large platform scale to measure initial pen weight, which was divided by the number of animals enrolled in the pen for pen-level mean initial BW. As previously mentioned, at approximately 94 d prior to harvest, heifers in the IH + 200 treatment were removed from their home pens, and re-implanted with Revalor-200. As typical in many commercial production systems the re-implant program included additional procedures; heifers in the IH + 200 treatment also were revaccinated with a five-way viral vaccine and five-strain *Leptospira* bacterin (Vista 5 L5; Merck Animal Health), and were re-administered a topical insecticide (Clean-Up; Bayer HealthCare LLC, Animal Health Division) at the time of re-implant. Heifers in XH groups were not reprocessed and remained in their home pens.

Heifers were housed in 36 dirt-surfaced pens providing approximately 34.5-cm bunk space and 21-m^2 pen space per animal. Each pen had an automatic waterer which supplied well water *ad libitum*. After initial processing and at the time of trial initiation, pens were fed a starter diet (Table 3.1), and were gradually transitioned to the steam-flaked corn (SFC) finishing diet using a series of “steps” that blended the two diets in different proportions over 23-d for ruminal adaptation to a high-concentrate diet. Finishing diets were formulated to meet the nutritional requirements of beef cattle (NASEM, 2016). Heifers were fed thrice daily at approximately 0700, 1000, and 1350 h. Feed bunks were managed to encourage *ad libitum* consumption, in that only trace residual feed remained at the time of 0700 h feed deliveries. A tornado damaged the feed mill during the trial, which no longer allowed the steam-flaking of grains. This required the primary finishing diet to be reformulated, which resulted in the dry-rolled corn (DRC) finishing diet to be fed starting on May 11, 2019, until the end of the trial; implications of this change are discussed in greater detail in the results and discussion sections. Daily feed deliveries were recorded and summed for the total amount of dry-feed delivered to each pen over the trial period, and mean dry matter intake (DMI) per animal per day was then estimated at the pen-level by dividing total dry-feed delivered by animal days (where animal days includes days for trial fallouts up until their day of removal or death).

Animals in each pen were observed daily by a trained animal care taker. Heifers were observed for lameness, anorexia, dull eyes, labored breathing, low-hanging ears, coughing, diarrhea, nasal discharge, and general well-being. Heifers experiencing any of these clinical signs were removed from the pen and evaluated further. Once restrained at the hospital site, BW, rectal temperature, and lung-score via stethoscope were measured. Heifers were treated based on the combination of clinical signs observed in the pen and results from chute side diagnostics. Treatment regimens for specific diagnoses were identical for all trial cattle and followed protocols established by the feedlots veterinary consultant, with all products administered followed manufacturer labels and guidelines. In general, heifers were treated and returned to their home pen the same day. However, in some cases, the heifer was kept in a hospital recovery pen until well enough to be returned to the home pen. Heifers that were treated three times or that would not respond to therapy were removed from the trial and documented with a removal reason and BW. Pens were monitored for mortalities on a daily basis, and upon occurrence, identification number, pen number, date, and cause of death were recorded. A necropsy was performed on all animals when the cause of death was not apparent. Animal-level records of morbidity and mortality data were collapsed at the pen-level for binomial data structure.

Shipping and harvest

When pens reached their ship-date, determined by DOF treatment within block, pens were weighed as a group on a large platform scale for determination of final BW. A 4% pencil shrink was applied to total pen weights, and thus final calculations of pen-level average final BW, average daily gain (ADG), and gain:feed were adjusted for shrink. Live performance metrics were calculated on a dead and removed animals excluded or included basis. The difference between these calculations was for final BW and ADG (and thus subsequent calculations for gain:feed). On a dead and removed animals excluded basis final BW was: total pen weight / *N* heifers completing the live trial phase; while on a dead and removed animals included basis final BW was: total pen weight / *N* heifers initially enrolled in the trial. On a dead and removed animals excluded basis ADG was: (mean final BW – mean initial BW) / DOF; while on a dead and removed animals included basis ADG was: (total final pen weight – total initial pen weight) / animal days.

Heifers were loaded on trucks and transported approximately 233 km to a commercial abattoir. Heifers were shipped for harvest between June 7, 2019 and August 2, 2019, as determined by DOF treatment within block. When at the abattoir, trained personnel from the Beef Carcass Research Center (West Texas A&M University, Canyon, TX) identified and tracked carcasses through the facility, to correctly match animal and pen identification numbers with carcass identification tags used by the abattoir for the collection of carcass data. Hot carcass weight (HCW) was measured on the day of harvest for each carcass, which was averaged to create a pen-level mean. A dichotomous variable was created for heavyweight carcasses (HCW > 476 kg) based on individual carcass HCW, and was collapsed at the pen-level for binomial data structure. Percent dressed yield was calculated at the pen-level by dividing the mean pen HCW by the mean pen final BW (with dead and removed animals excluded). After a minimum 24-h chill period, carcasses were graded with a camera system wherein carcass-level ribeye area (REA), 12^{th}-rib fat thickness, marbling score, and calculated yield grade were measured; these continuous outcomes were then averaged at the pen-level. Percent empty body fat (EBF) was estimated at the pen-level using calculations described by Guiroy et al. 2001. United States Department of Agriculture (USDA) Yield and Quality Grades (YG and QG, respectively) also were determined at this time, with these outcomes kept at the carcass-level.

Blinding statement

Blinding was not specifically implemented in the trial, as treatments were within the bounds of normal feedlot operation, and no subjective measurements were taken other than standard health monitoring. A custom processing crew administered implants at trial initiation, and were directed which implant to use for each pen as it was processed. Additionally, it would not be possible to blind processors when heifers in the IH + 200 treatment were re-implanted, as those in the XH treatment were never removed from their home pens to be re-processed. Daily caregivers such as pen-riders or cattle feeders were not made aware of study treatments or objectives. Assessment of primary objective outcomes (carcass characteristics) at the abattoir was technically a blinded activity, as this was performed by packing plant employees unaware of treatments given (or even that cattle were part of a trial). Blinding was not used in the data analysis stage.

Statistical analyses

For all analyses pen was the experimental unit; fixed effects were implant program, DOF, and their two-way interaction; and block was included as a random intercept. General and generalized linear mixed models (LMM and GLMM, respectively; Proc GLIMMIX SAS 9.4; SAS Institute Inc., Cary, NC) were fit to evaluate treatment effects on outcomes of interest. Continuous outcomes (e.g., BW, ADG, HCW) were modeled using LMM assuming a Gaussian distribution with an identity link function using restricted maximum likelihood estimation, and a Kenward-Roger degrees of freedom adjustment. Bounded variables (e.g., dressed yield, calculated yield grade) were also modeled this way as their values displayed central tendency and reasonably met LMM model assumptions. Conditional and marginal plots of studentized residuals were produced to assess assumptions of normality and homoscedasticity. Variables fitting a binomial distribution (e.g., morbidity, % heavyweight carcasses) were modeled using GLMM with a logit link function. These models were first run with a Laplace approximation to assess overdispersion, and then re-run with pseudo-likelihood estimation technique and Kenward-Roger's degrees of freedom method. Estimates were back-transformed to probabilities for interpretation. For both Gaussian and binomial variables, model adjusted means and corresponding SEM are reported, and a Tukey-Kramer adjustment to account for multiplicity was used for all pairwise comparisons. Ordinal variables with a multinomial distribution (QG and YG) were fit with a cumulative logit link function, used residual pseudo-likelihood estimation, a Kenward-Roger degrees of freedom adjustment, and had a proportional odds assumption on the ordinal nature of the data. As these data were structured at the carcass-level, an additional random intercept of pen within block was included to account for the lack of independence between carcasses within a pen. A likelihood ratio test was used to assess if distributions of ordinal outcomes differed for fixed effects. If significant, preplanned contrasts were performed for pairwise comparisons of DOF treatments. Values reported for multinomial models are raw frequency statistics (% and *n*). Statistical significance for all outcomes was set *a priori* at $\alpha = 0.05$. Instances of marginal significance ($0.05 < P \leq 0.10$) were noted but not interpreted due to the inflated risk of Type I error.

Pooled trial analyses

Additional analyses were performed on combined data from the Kansas trial and two similar trials performed at a commercial research feedlot in Texas. Results from the Texas trials were summarized independently as exp. 1 and exp. 2 by Smith et al. (2019). The three trials were deemed suitable for pooling because of identical treatment and design structure, as well as similar research conduct and cattle populations (type). A descriptive comparison of the three trials is in Table 3.2. For greater detail on the two separate Texas trials, the reader is referred to Smith et al. (2019).

Statistical analyses of the pooled data were performed as described above for the Kansas trial analyses, with a few exceptions. Only variables that were measured in all three trials were included in the pooled analyses (e.g., camera data of carcass measurements were not available for Smith et al. (2019) exp. 1, so those outcomes were excluded). Linear and quadratic orthogonal polynomial contrasts were performed for main effects of DOF (in the absence of a significant two-way interaction) on final BW (with dead and removed animals excluded) and HCW. Random intercepts used in the pooled analyses accounted for trial, and block within trial for Gaussian and binomial outcomes. For ordinal outcomes (QG and YG), an additional random intercept for pen was included to account for carcass-level data structure. Statistical significance for all outcomes was again set *a priori* at $\alpha = 0.05$, with marginal significance ($0.05 < P \leq 0.10$) noted.

Results

Kansas trial results

The number of pens analyzed for feedlot performance and health outcomes for the Kansas trial was consistent with the number of pens enrolled ($N = 36$; Table 3.3). For BASE, +21, and +42, the DRC finishing diet was fed for the final 28 or 42, 49 or 63, and 70 or 84 d, respectively. This is because within each DOF treatment, heifers were harvested on 1 of 2 dates. As a percent of the total feeding period, the DRC diet was fed for a mean (± 1 SD) of 20% (4.0), 28% (3.3), or 35% (3.6) for BASE, +21, and +42, respectively. Differences in the number of heifers enrolled versus the number completing the live animal phase of the trial affected calculations of feedlot performance on the basis of dead and removed animals included or excluded (Table 3.3). There were no significant two-way interactions (*P*-values ≥ 0.10), therefore, only main effects for implant program and DOF are reported.

For the implant program treatment, there was no evidence of differences in initial BW ($P = 0.94$) or mean daily DMI ($P = 0.47$) between treatments. On a dead and removed animals excluded basis, mean final BW per heifer was 7 kg greater for IH + 200 heifers compared to XH ($P < 0.01$). While DMI was similar, increased final BW resulted in both ADG ($P < 0.01$) and gain:feed ($P < 0.01$) to be greater for the IH + 200 group compared to XH. On the basis of dead and removed animals included, significant differences were not observed between implant programs for final BW ($P = 0.45$), ADG ($P = 0.36$), or gain:feed ($P = 0.20$). There was no evidence of differences between implant programs for morbidity ($P = 0.98$), mortality ($P = 0.70$), animals removed from the trial ($P = 0.30$), or total fallouts (heifer mortalities plus removals; $P = 0.26$).

There were not significant differences in initial BW ($P = 0.83$) or DMI ($P = 0.70$) between different DOF groups (Table 3.3). Calculated on the basis of dead and removed animals excluded, there was a DOF effect on final BW ($P < 0.01$), where for each increase of 21 DOF, final BW increased by approximately 18 kg. Both ADG ($P < 0.01$) and gain:feed ($P < 0.01$) were affected by DOF with both outcomes decreasing as DOF increased. On a dead and removed animals included basis, final BW increased with each incremental increase in DOF ($P < 0.01$). However, there was no evidence for an impact of DOF on ADG ($P = 0.14$), and gain:feed differences were only marginally significant ($P = 0.06$). There was no evidence of a difference in morbidity between DOF treatments ($P = 0.32$). There was an effect of DOF on mortality ($P = 0.02$), where a greater proportion of heifers died in the BASE group compared to +21. There was marginal significance for an effect of DOF on the probability of heifers being removed from the trial ($P = 0.08$). The main effect of DOF was associated with the total number of trial fallouts ($P = 0.05$), however, after adjustment for multiplicity, there were no significant differences for any pairwise DOF comparisons.

There were no significant implant program × DOF interactions on carcass characteristics (Table 3.4), therefore, only main effects are reported. The number of pens analyzed was consistent with the number enrolled ($N = 36$). The discrepancy between the number of carcasses (Table 3.4) and the number of heifers completing the live phase of the trial (Table 3.3) is due to events incurred at the abattoir causing carcasses to be lost. Condemnations by the USDA, and carcasses that could not be successfully identified and tracked through the plant were the primary reasons for discrepancies. The IH + 200 heifers had 6 kg heavier HCW ($P < 0.01$) than XH, although there was no evidence for a difference in dressed yield between the two implant programs ($P = 0.11$). Ribeye areas were 3.7 cm^2 larger for IH + 200 than XH ($P < 0.01$), and IH + 200 carcasses were also leaner, as indicated by reduced 12^{th}-rib fat thickness ($P < 0.01$), marbling scores ($P = 0.02$), and lower calculated yield grades ($P < 0.01$). Furthermore, there was a 1.8% increase in calculated EBF for XH carcasses compared to IH + 200 ($P < 0.01$). Distributions within ordered categories of YG differed between implant programs ($P < 0.01$); the distribution for IH + 200 carcasses had a shift toward more YG 1 and 2 carcasses as compared to XH carcasses where there was a shift towards more YG 4 and 5 carcasses. Distributions within ordered categories of QG also differed between implant programs ($P < 0.01$) with fewer carcasses grading Select and more grading Prime for XH heifers compared to IH + 200.

Also in Table 3.4 are main effects of DOF on carcass characteristics. Hot carcass weight increased with increasing DOF ($P < 0.01$), as there was a 12 kg increase moving from BASE to +21, and an additional 18 kg increase moving from +21 to +42. Dressed yield was also affected by DOF ($P < 0.01$), where heifers fed +42 had a greater dressed yield than BASE and +21. Ribeye areas increased with each incremental increase in DOF ($P < 0.01$). There was an effect of DOF on mean 12^{th}-rib fat thickness ($P < 0.01$) and marbling score ($P < 0.01$), as both increased when comparing BASE to +21 and +42. Calculated yield grade was affected by DOF ($P = 0.03$), evidenced by an increase when comparing +42 to BASE. Calculated empty body fat was impacted by DOF ($P < 0.01$), where the percentage increased for +21 and +42 compared to BASE. The heavyweight carcass variable (HCW > 476 kg) was excluded from the results, as just three carcasses were over this threshold and could not be appropriately analyzed. The effect of DOF on carcass distributions within ordered categories of YG was marginally significant ($P = 0.07$). Days-on-feed affected distributions of QG ($P < 0.01$), evidenced by a shift towards more Prime carcasses and fewer Choice and Select carcasses in the +21 and +42 groups compared to BASE.

An additional exploratory analysis was performed to evaluate changes in live final BW and HCW gain in the pooled trials, where orthogonal polynomial contrasts were performed to test for linear and quadratic effects of increasing DOF (Fig. 3.1). There was no evidence that live or carcass weight gain increased in a quadratic manner ($P = 0.94$ or 0.20, respectively), but rather, increases were linear ($P < 0.01$) when feeding heifers an additional 42 DOF (Fig. 3.1). Estimated incremental dressing percentage calculated as HCW ADG / live ADG [which corresponds to the ratio between the two linear functions (Fig. 3.1)] over an extended 42-d feeding period in this trial was 83.3%, meaning an estimated 83.3% of live BW gain was converted to carcass weight gain over this timeframe.

Pooled trial results

The total number of pens used for analyses of all live feedlot performance and health outcomes was consistent with the total number of pens enrolled across all trials ($N = 144$; Table 3.5). The number of heifers enrolled and completing the trial phase for each treatment affected calculations of feedlot performance on a dead and removed animals included or excluded basis. Only main effects where no significant two-way interactions occurred are reported in Table 3.5, while outcomes resulting in an implant program × DOF interaction are reported elsewhere (DMI; Fig. 3.2).

For the implant program treatment effect, there was no evidence of a difference in initial BW to start the trials ($P = 0.69$). On a dead and removed animals excluded basis, effects of implant program on final BW ($P = 0.15$) and ADG ($P = 0.25$) were not significant, while gain:feed increased slightly (1.3%) for IH + 200 heifers compared to XH ($P < 0.01$). On a dead and removed animals included basis, there was no evidence for a difference between implant programs on final BW ($P = 0.18$) and ADG ($P = 0.28$), but gain:feed improved 1.4% for IH + 200 heifers compared to XH heifers ($P < 0.01$). There were no significant effects of implant program on morbidity ($P = 0.63$), mortality ($P = 0.29$), animals removed from trials ($P = 0.32$), or total fallouts ($P = 0.96$).

Main effects of the DOF treatment from the pooled trial analyses are also reported in Table 3.5. There was no evidence of a difference in initial BW between DOF treatments ($P = 0.36$). On the basis of dead and removed animals excluded, final BW increased with each additional 21 DOF increase ($P < 0.01$). Conversely, ADG ($P < 0.01$), and gain:feed ($P < 0.01$), decreased with each incremental increase in DOF. Similar observations can be made when calculated with dead and removed animals included, as final BW increased ($P < 0.01$), while ADG ($P < 0.01$) and gain:feed ($P < 0.01$) decreased with incremental increases in DOF. There was no evidence for a difference in morbidity ($P = 0.58$) or mortality ($P = 0.47$) with differing DOF. However, an effect of DOF on animals removed from trials was observed ($P = 0.03$); with

BASE having a smaller proportion of removals than +21 (Table 3.5). Proportions of total trial fallouts were not significantly different between DOF groups (*P* = 0.70).

Implant program × DOF interactions occurred for daily DMI (Fig. 3.2; *P* = 0.02). Dry matter intake for XH heifers was greater than IH + 200 when fed an additional 42 DOF, while there was no evidence of differences between implant programs within BASE or +21 DOF groups.

Treatment factors in the pooled trial analyses did not result in any significant two-way interactions for carcass characteristics; therefore, main effects of implant program and DOF are reported in Table 3.6. Similar to the Kansas trial, the discrepancy between the number of carcasses (Table 3.6) and number of heifers completing the live phase (Table 3.5) is due to events incurred at the abattoir. All pens enrolled (*N* = 144) were accounted for in carcass data analyses.

For the implant program factor, mean HCW increased by 2 kg (*P* < 0.01), and dressed yield was higher for IH + 200 pens compared to XH (*P* < 0.01). The proportion of heavyweight carcasses were not significantly impacted by implant program (*P* = 0.47). The distribution of carcasses within ordered categories of YG shifted (*P* < 0.01) with IH + 200 carcasses having more YG 1 and 2, and fewer YG 4 and 5 carcasses compared to XH. Distributions of QG also shifted (*P* < 0.01) with more Prime, and fewer Choice and Select carcasses in the XH program compared to IH + 200.

When feeding heifers additional DOF, HCW increased by 16 kg with each incremental 21-d increase in DOF (*P* < 0.01; Table 3.6). Dressed yield also increased by increasing heifer DOF (*P* < 0.01). There was an effect of DOF on the proportion of heavyweight carcass (*P* < 0.01); heifers fed +42 DOF were more likely to have carcasses greater than 476 kg compared to BASE and +21 (Table 3.6). The YG distribution shifted for different DOF categories (*P* < 0.01); frequency of YG 1, 2, and 3 carcasses decreased while YG 4 and 5 carcasses increased for +42 heifers when compared to BASE and +21 (Table 3.6). Distributions within ordered categories of QG changed (*P* < 0.01), evidenced by increasing numbers of Prime carcasses with fewer Select with each incremental increase in DOF.

Orthogonal polynomial contrasts for linear and quadratic effects of increasing DOF on live BW and HCW gain were performed for exploratory purposes (Fig. 3). There was no evidence that final BW or HCW increased in a quadratic manner (*P* = 0.15 and 0.93, respectively). Final BW and HCW increased linearly ($P < 0.01$) with increasing DOF. The slope of the linear functions represents live and carcass ADG, respectively. The ratio between carcass and live ADG is incremental dressing percentage, also referred to as carcass transfer (Streeter et al., 2012). In the pooled trials, estimated incremental dressing percentage over a 42-d extended feeding period was 76.2%, or, 0.76 kg HCW gain per 1 kg live BW gain.

Discussion

Across the three trials, BASE DOF was determined primarily by initial BW of study populations, and marketing decisions of an ideal finish weight. Heifers in the Kansas trial were harvested at a lighter final BW on average compared to exp. 1 and exp. 2 reported by Smith et al. (2019). However, in the Kansas trial there were greater proportions of USDA Choice and Prime, as well as YG 4 and 5 carcasses, indicating there may have been some differences in frame-size across trials or genetic propensity for fat deposition, which altered BASE finish weights. It is also possible that the dietary change from SFC to DRC partway through the Kansas trial created some additional variability. While the SFC finishing diet was fed for the same number of days for all DOF treatments, the change to DRC could have affected cattle performance near the end of the trial, as SFC-based finishing diets have been reported to improve ADG by 5.4%, and feed efficiency by 12% when compared to dry-processed corn (Zinn et al., 2002). This could have hampered the rate of growth following the dietary change for +21 and +42; however, the observed linear increases in BW and HCW for incremental increases in DOF may suggest that performance losses were minimal (perhaps aided by the concurrent feeding of ractopamine for the final 28 DOF).

In comparison to published results from the Smith et al. (2019) experiments, greater effects of implant programs on live heifer performance (dead and removed animals excluded) were observed in the Kansas trial. In the Kansas trial, IH + 200 had greater final BW and ADG than XH, while there was no evidence of differences for these variables in individually analyzed Smith et al. (2019) experiments. Evidence of a gain:feed improvement for IH + 200 heifers occurred in the Kansas trial and Smith et al., (2019) exp. 1, but not exp. 2. Results from comparisons of carcass characteristics between implant programs generally agreed between the Kansas trial and Smith et al. (2019) trials. There was greater evidence for a HCW difference in the Kansas trial than in Smith et al. (2019); but all three trials seem to support the effect of IH + 200 heifers producing leaner carcasses than XH, while XH led to overall improvements in QG.

For the DOF treatment factor, live performance (dead and removed animals excluded) was very similar across the three trials; all demonstrated increased final BW, and decreased ADG and gain:feed with additional DOF. There were no significant effects of DOF on DMI in the Kansas trial or Smith et al. (2019) exp. 2, while Smith et al. (2019) exp. 1 observed decreased DMI in heifers fed additional DOF, and marginal significance for an implant program × DOF interaction. Days-on-feed impacts on carcass characteristics were comparable between the Kansas trial and Smith et al. (2019) trials, as HCW, and outcomes related to muscle and fat all increased with additional DOF. Estimated incremental dressing percent for heifers fed an additional 42 days in the Kansas trial was 83.3%, while Smith et al. (2019) reported 79.6% and 72.5% in exp. 1 and 2 respectively. Again, this is the estimated proportion of live weight gain that resulted in carcass weight gain. Differences in these estimates could potentially be attributed to differences in total DOF [Kansas trial heifers and Smith et al. (2019) exp. 1 heifers were the most similar, while Smith et al. (2019) exp. 2 had the shortest total DOF], seasonal effects, frame-size, body composition, and other factors associated with individual trials.

By performing pooled analyses the scope of inference from these three trials is broadened, statistical power to detect differences improves, as does the accuracy of mean treatment effect estimates (Tempelman, 2009; Bello and Renter, 2018). Findings in the pooled trial analyses indicate that differences in finishing heifer live weight gain may not be expected between the two implant programs, which would agree with a six-trial pooled analysis of similar implant programs (Smith et al., 2020). Note that the two Texas trials from Smith et al. (2019) were included in the Smith et al. (2020) dataset. Slight improvements in gain:feed were observed here, which has not been consistently reported in the literature. Greater gain:feed is expected in implanted cattle compared to nonimplanted controls (Reinhardt and Wagner, 2014; Smith and Johnson, 2020), and a meta-analysis suggested that greater total doses of anabolic hormones may improve feed efficiency in feedlot steers (Reinhardt and Wagner, 2014). However, this effect has not been frequently observed in heifers (Hilscher et al., 2016; Smith et al., 2020; Ohnoutka et al., 2021). Dry matter intake has increased routinely in implanted cattle compared to nonimplanted controls (Bartle et al., 1992; Herschler et al., 1995; Parr et al., 2011a; Parr et al., 2011b). Some research indicates that different hormonal doses from different implant programs may not impact DMI in heifers (Hilscher et al., 2016; Ohnoutka et al., 2021), while others have reported reduced intake in re-implanted heifers who receive greater total anabolic hormonal doses than those administered a single, semicoated implant [IH + 200 vs XH equivalent; Smith et al., (2020)]. The interactive effect of implant program × DOF on DMI in the current pooled analyses, where IH + 200 heifers fed +42 DOF consumed less feed on average than their XH counterparts, is difficult to explain biologically, and one that may warrant further investigation. It is unclear why this observation would occur in only +42 heifers but not BASE or +21, but the magnitude of this effect could have implications related to feed costs if multiplied across large populations of heifers.

Differences between implant programs for HCW and dressed yield were variable between Kansas and Smith et al. (2019) trials when analyzed separately, but were significant after the data were pooled and the corresponding effective sample size was larger. Shifts in QG and YG distributions between implant programs were consistent across individual trials and the pooled analyses. Smith and Johnson (2020) summarized known mechanisms for changes in carcass composition with different hormonal implant concentrations and strategies. Greater levels of TBA and E_2 lead to increased muscle synthesis and decreased fat deposition, which may alter optimal marketing points due to changes in QG and YG distributions. Overall, IH + 200 heifers had heavier, higher dressing, leaner carcasses, evidenced by shifts in QG and YG compared to XH. This observation was also noted by Smith et al. (2020). It should be recognized that the proportion of heavyweight carcasses that would commonly incur discounts in a grid-based pricing system (USDA, AMS) were not significantly impacted by implant programs in finishing heifers. Thus, if selling heifers on a grid, net revenue between the two programs will likely center around premiums and discounts incurred for QG and YG distributions, after accounting for HCW. It is important to note that outside of DMI, there were no other significant two-way interactions, meaning that there was no evidence to suggest that carcass compositions between implant programs differ when harvested at similar DOF.

It should be noted that total amounts of TBA and E_2 administered to heifers differed between implant program treatments, with IH + 200 receiving 80 mg more TBA and 8 mg more E_2 throughout the feeding period compared to XH. The process of re-implanting cattle may result in added handling stress, and also provides the opportunity to administer vaccines, anthelmintics, parasiticides, or other compounds that would not be given to cattle that aren't re-processed. This was the case in the Kansas trial, however, Smith et al. (2019) experiments did not administer any products to re-implanted cattle besides Revalor-200. Use of additional products with a re-implant program is likely the more common scenario in commercial settings. Research to isolate the effects of the implants themselves would require an alternative approach; however, the objective herein was to evaluate the implant programs as a whole, reflecting program application in a commercial production setting. Thus, while observed implant program effects in this study may be largely explained by differences in hormonal payout from the implants, there were other concurrent factors that cannot be separated and may have affected outcomes.

Live feedlot performance results of serially harvested beef cattle from the pooled analyses were consistent with previous research, indicating increased final BW, but decreased ADG and gain:feed with additional DOF (Sissom et al., 2007; Rathmann et al., 2012; Ohnoutka et al., 2021). Increases in carcass weight, dressed yield, and observed shifts in QG and YG distribution from incremental DOF increases also were expected based on the literature (Sissom et al., 2007; Rathmann et al., 2012; Ohnoutka et al., 2021). There was greater risk of incurring heavyweight discounts for carcasses weighing greater than 476 kg for heifers fed +42 DOF. It is worth noting that these heifers were never sorted by BW and frame-size into more homogenous groups, a common practice for some producers. For heifers, this allows feeding for extended DOF to primarily reduce the number of YG 4 and 5 carcasses, and to a lesser degree, the number of heavyweight heifers that may incur discounts in a grid-based pricing system. Exploratory analyses of polynomial functions for additional DOF indicated increases of both final BW and HCW were linear, and not quadratic. Similar analyses by Ohnoutka et al. (2021) indicated linear increases of these variables in feedlot heifers. In the pooled analyses, mean estimated incremental dressing percentage for heifers fed 42 days beyond a target final body composition for each trial and location was 76.2%, meaning that for every 1 kg of live weight gain, 0.76 kg of carcass weight was added. Incremental dressing percentage has been estimated in numerous trials with a serial harvest component; values are often variable (Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021), and may be influenced by sex, cattle type, diet, and total DOF. Wilken et al. (2015) suggested that in steers, the proportion of live weight transferred to the carcass may approach 100% as DOF continue to increase.

The majority of cattle in the US are sold on a carcass basis, rather than live (USDA, AMS). With that being the case, importance of live animal performance metrics, like ADG and gain:feed may become deceiving as cattle are fed for longer DOF. As DOF increase, and ADG and gain:feed seemingly decrease, it is easy to perceive that cattle are becoming less efficient; the paradox, however, is where gained weight is deposited. While rate of live gain may slow, rate of carcass gain may continue to increase (Wilken et al., 2015). Much of the live weight gain that occurs early in the feeding period is deposited in non-carcass components, including the gastrointestinal tract with its contents, other visceral organs, blood, hide, and the head; as cattle age and weight increases, proportions of these components decrease, while muscle, and particularly fat deposition increase (Berg and Butterfield, 1968; Buckley et al., 1990; Coleman et al., 1995; Owens et al., 1995; Honig et al., 2022). Thus, while rates of live weight gain seem to decline when feeding heifers beyond their "target" DOF, it appears that the majority of gained weight is being deposited on the carcass (in a linear manner), rather than to less valuable components of the animal.

Morbidity, mortality, and cattle removal data have not been frequently reported in published research with objectives regarding implant programs and different DOF. Evidence for a difference in these health related variables between implant programs was not observed in the Kansas trial or the pooled analyses, which would agree with Smith et al. (2020). The observed effects of DOF on mortality and total fallouts in the Kansas trial were unexpected as it is counterintuitive that heifers fed the fewest DOF would have the greatest mortality. Cumulative pen-level morbidity and mortality would presumably increase for groups of heifers fed for longer DOF; Vogel et al. (2015) indicated that pen mortality averaged 0.26% in the last 30 DOF for feedlot heifers. Mortality and total fallouts were not published in Smith et al. (2019), but when data from all three trials were pooled, these outcomes were not significantly affected by DOF. However, the pooled results indicated that the proportion of heifers removed (culled) increased when comparing BASE to +21, with no significant difference comparing BASE or +21 to +42. It is likely that a much larger population of heifers may be needed to better estimate health risks imposed by feeding heifers for longer DOF.

Pooling data from similar randomized controlled trials performed at different sites and years helps to improve external validity of findings. Still, there are limitations to consider. These trials were performed in a similar region, and effects could differ in others, due to factors such as climate, management, cattle type, and diet composition. A critical variable that was beyond the scope of this paper is a comprehensive economic analyses. While changes in carcass characteristics and heifer performance were described, decision making around implant programs and DOF is likely limited without knowing how their outcomes affect net returns from heifer sales. Future research should evaluate cost effectiveness of these interventions, taking into account sale basis (dressed or live), and temporal changes in feed cost, fed cattle price, and premiums and discounts incurred for changes in carcass characteristics.

Conclusions

Overall, effects of implant programs were not impacted by differing DOF. Heifers in an IH + 200 program had improved gain:feed, and produced heavier, leaner carcasses with less intramuscular fat than XH. These performance differences may be important when considering that certain re-implant programs will soon be restricted (FDA, 2021). Feeding heifers for additional DOF expectedly increased live and carcass weight gains, with a sacrifice in live feedlot performance metrics. While QGs improved by extending DOF, there was a shift towards more high YG (4 and 5) carcasses, indicating a possible tradeoff between premiums and discounts applied in a grid-based pricing system. Future research should evaluate economic impacts of changing carcass characteristics that result from feeding additional DOF, as this information is critical for producers to make informed marketing decisions.

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Co-authors MS and JH are employed by Merck Animal Health, but were not involved in data collection or analyses. Experimental treatments involved only Merck Animal Health products, therefore, no competitive interest was present. There are no conflicts of interest to disclose.

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Tables and Figures

Table 3.1. Dietary ingredient formulations and calculated nutrient composition of starter and finisher rations fed to feedlot heifers during the experimental period of the Kansas trial

Item	Starter	SFC finisher[‡,§]	DRC finisher[‡,§]
Ingredient[†], % dry matter			
Steam-flaked corn	35.1	66.9	-
Dry-rolled corn	-	-	64.0
Wet distiller's grains with solubles	19.5	16.5	18.7
Alfalfa hay	29.7	-	-
Corn silage	12.0	3.6	4.8
Corn stalks	-	5.2	4.6
Tallow	-	3.1	3.2
Supplement[ǁ]	3.7	4.7	4.7
Nutrient composition			
Dry matter, %	53.3	60.7	61.6
Crude protein, %	18.4	15.0	15.3
Calcium, %	0.96	0.70	0.70
Phosphorus, %	0.37	0.31	0.39
Sulfur, %	0.25	0.21	0.21
NE_m, Mcal/45.4 kg	80.7	100.6	98.7
NE_g, Mcal/45.4 kg	52.4	68.8	69.1

[†] Feed additives were dispensed directly into the feed truck using Micro-Weigh Systems (Micro Beef Technologies, Amarillo, TX).

[‡] Steam-flaked corn (SFC) finisher was fed as the primary finishing diet until a change to the dry-rolled corn (DRC) finisher was required due to feed-mill damage suffered after a tornado. Days-on-feed treatments were baseline BASE, +21, and +42, and the DRC finishing diet was fed for the final 28 or 42, 49 or 63, and 70 or 84-d, respectively for each treatment.

[§] Finisher diets were formulated to provide 50 g BactaShield (Legacy Animal Nutrition, Wamego, KS), 365 mg of monensin (Elanco Animal Health, Greenfield, IN), 75 mg of tylosin phosphate (Elanco Animal Health), and 0.4 mg of melengestrol acetate (Zoetis Animal Health, Parsippany, NJ) per animal daily. For the last 28 days-on-feed, 250 mg of ractopamine hydrochloride (Zoetis Animal Health) per animal daily were delivered.

[ǁ] A liquid protein supplement (molasses and urea based) containing 69.7% crude protein (67.1% non-protein nitrogen)

Table 3.2. Description of studies used in the pooled analyses of data from 3 commercial feedlot trials evaluating effects of 2 implant programs and differing days-on-feed (DOF) on feedlot performance and carcass characteristics of beef feedlot heifers[*,†,‡]

Trial	Dates of enrollment	Blocks[§], *N*	Pens, *N*	Animals, *N*	Animals/pen, mean (range)	Baseline DOF[ǀ], mean (± 1 SD)	Initial BW, kg/animal (± 1 SD)
Smith et al. (2019) exp. 1	Jul 23 to Sep 1, 2015	9	54	3,780	70 (70 to 70)	172 (4.4)	309 (6.4)
Smith et al. (2019) exp. 2	Mar 20 to May 8, 2018	9	54	3,719	69 (65 to 70)	152 (1.1)	337 (8.9)
Kansas trial	Dec 5 to Dec 27, 2018	6	36	3,084	86 (74 to 115)	179 (4.7)	291 (8.9)

[*] Three commercial feedlot trials were conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below[†]) and DOF (three levels, described below[‡]), enrolling a total of 10,583 crossbred beef heifers, which were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations (within a block within a trial).

[†] Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a 2-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.

[‡] Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.

[§] Blocks are analogous to the number of 2 × 3 factorial treatment replications.

[ǀ] Mean DOF for the BASE treatment group within the DOF treatment factor, with other groups being +21 or +42 additional days.

Table 3.3. Model adjusted means and standard errors of the mean (SEM) from the Kansas trial demonstrating the main effects of 2 implant programs and 3 differing days-on-feed (DOF) on pen-level feedlot performance and health related outcomes of feedlot heifers*

	Implant program†				Days-on-feed‡					*P*-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Heifers enrolled, *N*	1,542	1,542	-	-	1,027	1,027	1,030	-	-	-
Heifers completing trial, *N*	1,450	1,463	-	-	956	973	984	-	-	-
Initial body weight, kg	291	291	3.8	0.94	292	291	291	3.8	0.83	0.10
Dry matter intake, kg/d	9.19	9.23	0.079	0.47	9.17	9.24	9.22	0.084	0.70	0.46
Deads and removals excluded										
Final body weight§, kg	568	561	2.9	< 0.01	546[a]	564[b]	582[c]	3.1	< 0.01	0.48
Average daily gain, kg	1.39	1.35	0.020	< 0.01	1.42[a]	1.37[b]	1.32[c]	0.020	< 0.01	0.27
Gain:feed	0.151	0.147	0.0014	< 0.01	0.155[a]	0.148[b]	0.143[c]	0.0015	< 0.01	0.18
Deads and removals included										
Final body weight§, kg	543	540	5.9	0.45	518[a]	545[b]	562[c]	6.3	< 0.01	0.57
Average daily gain, kg	1.27	1.25	0.042	0.36	1.28	1.27	1.24	0.043	0.14	0.57
Gain:feed	0.138	0.136	0.0027	0.20	0.139	0.137	0.134	0.0028	0.06	0.58
Morbidity‖, % (SEM)	16.5 (2.38)	16.5 (2.39)	-	0.98	16.9 (2.51)	15.2 (2.33)	17.5 (2.58)	-	0.32	0.21
Mortality, % (SEM)	2.4 (0.53)	2.2 (0.49)	-	0.70	3.4[a] (0.74)	1.5[b] (0.43)	2.3[ab] (0.58)	-	0.02	0.50
Removals, % (SEM)	2.9 (0.84)	2.3 (0.69)	-	0.30	2.9 (0.88)	3.3 (0.98)	1.8 (0.61)	-	0.08	0.84
Total fallouts¶, % (SEM)	5.5 (1.21)	4.6 (1.05)	-	0.26	6.4 (1.45)	4.8 (1.16)	4.1 (1.01)	-	0.05	0.77

* Trial was conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), where crossbred beef heifers (*N* = 3,084) were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations within a block. There were of 36 pens total resulting in six treatment simple effect replications (all combinations of implant program × DOF), 18 replications of implant program main effects, and 12 replications of DOF main effects.

† Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a 2-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.

‡ Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint determined by marketing groups, or +21 or +42 additional DOF.

§ A 4% pencil shrink was applied to the total weight of each pen prior to calculations of final body weight on the bases of deceased and removed heifers included or excluded.

‖ The proportion of heifers that were pulled and treated at least one time for any reason.

¶ Total fallouts are heifers that died during the trial (accounted for in mortality) plus those that were removed from the trial for health related reasons (accounted for in removals).

a,b,c Differing superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

Table 3.4. Model adjusted means and standard errors of the mean (SEM) from the Kansas trial demonstrating the main effects of 2 implant programs and 3 differing days-on-feed (DOF) on pen-level carcass characteristics of beef feedlot heifers*

	Implant program†				Days-on-feed‡					*P*-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Carcasses, *N*	1,444	1,453	-	-	948	966	983	-	-	-
Hot carcass weight, kg	367	361	2.0	< 0.01	350^{a}	362^{b}	380^{c}	2.1	< 0.01	0.48
Dressed yield, %	64.57	64.38	0.151	0.11	64.02^{a}	64.22^{a}	65.20^{b}	0.163	< 0.01	0.98
Ribeye area, cm^2	86.71	82.97	0.523	< 0.01	82.45^{a}	84.90^{b}	87.16^{c}	0.600	< 0.01	0.29
12^{th}-rib fat thickness, cm	1.70	1.78	0.048	0.01	1.65^{a}	1.78^{b}	1.80^{b}	0.051	< 0.01	0.53
Marbling score§	568	582	7.2	0.02	555^{a}	582^{b}	588^{b}	7.7	< 0.01	0.21
Calculated yield grade	3.36	3.56	0.079	< 0.01	3.37^{a}	3.49^{ab}	3.53^{b}	0.082	0.03	0.30
Empty body fatǀ, %	31.66	32.24	0.323	< 0.01	31.21^{a}	32.12^{b}	32.53^{b}	0.335	< 0.01	0.39
USDA Yield Gradeǀ, % (*N*)	-	-	-	< 0.01	-	-	-	-	0.07	0.42
1	7.20 (104)	3.99 (58)			4.85 (46)	6.42 (62)	5.49 (54)			
2	27.15 (392)	21.61 (314)			27.43 (260)	21.84 (211)	23.91 (235)			
3	41.69 (602)	41.91 (609)			44.41 (421)	42.75 (413)	38.35 (377)			
4	20.57 (297)	26.91 (391)			20.78 (197)	24.84 (240)	25.53 (251)			
5	3.39 (49)	5.57 (81)			2.53 (24)	4.14 (40)	6.71 (66)			
USDA Quality Gradeǀ, % (*N*)	-	-	-	< 0.01	*x*	*y*	*y*	-	< 0.01	0.46
Prime	14.96 (216)	18.79 (273)			10.86 (103)	19.57 (189)	20.04 (197)			
Choice	77.98 (1126)	76.12 (1106)			82.17 (779)	74.12 (716)	74.97 (737)			
Select	6.72 (97)	4.82 (70)			6.86 (65)	6.11 (59)	4.37 (43)			
Other	0.35 (5)	0.28 (4)			0.11 (1)	0.21 (2)	0.61 (6)			

* Trial was conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), where crossbred beef heifers (*N* = 3,084) were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations within a block. There were of 36 pens total resulting in six treatment simple effect replications (all combinations of implant program × DOF), 18 replications of implant program main effects, and 12 replications of DOF main effects.

† Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a 2-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.

‡ Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.

§ Scores ranging from 500 to 599 indicate a Modest degree of marbling.

ǀ Estimated empty body fat using calculations described by Guiroy et al. (2001).

ǀ Overall *P*-value tests the null hypothesis that the proportions of carcasses distributed across ordinal categories are equal for all treatments groups within a treatment factor (implant program or DOF); values are raw frequency statistics (% and *N*).

a,b,c Differing superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

x,y Differing letters within row indicate significant difference ($P \leq 0.05$) from pre-planned contrasts comparing distributions of ordinal outcomes for DOF factor.

Table 3.5. Model adjusted means and standard errors of the mean (SEM) from pooled analyses of data from 3 commercial feedlot trials evaluating effects of 2 implant programs and differing days-on-feed (DOF) on feedlot performance and health related outcomes of beef feedlot heifers*

	Implant program†				Days-on-feed‡					*P*-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Heifers enrolled, *N*	5,291	5,292	-	-	3,526	3,527	3,530	-	-	-
Heifers completing trials, *N*	5,122	5,123	-	-	3,421	3,407	3,417	-	-	-
Initial body weight, kg	313	312	13.3	0.69	313	313	312	13.3	0.36	0.91
Deads and removals excluded										
Final body weight§, kg	586	584	10.1	0.15	563[a]	586[b]	605[c]	10.1	< 0.01	0.39
Average daily gain, kg	1.46	1.45	0.039	0.25	1.50[a]	1.45[b]	1.40[c]	0.040	< 0.01	0.47
Gain:feed	0.154	0.152	0.0021	< 0.01	0.158[a]	0.153[b]	0.148[c]	0.0021	< 0.01	0.27
Deads and removals included										
Final body weight§, kg	573	571	15.0	0.18	552[a]	573[b]	591[c]	15.1	< 0.01	0.74
Average daily gain, kg	1.38	1.37	0.059	0.31	1.43[a]	1.37[b]	1.32[c]	0.059	< 0.01	0.59
Gain:feed	0.146	0.144	0.0042	0.03	0.151[a]	0.144[b]	0.140[c]	0.0042	< 0.01	0.25
Morbidity‖, % (SEM)	6.0 (3.37)	5.8 (3.26)	-	0.63	5.7 (3.18)	5.8 (3.26)	6.4 (3.54)	-	0.58	0.70
Mortality, % (SEM)	1.2 (0.43)	1.4 (0.51)	-	0.29	1.3 (0.51)	1.1 (0.40)	1.5 (0.56)	-	0.47	0.52
Removals, % (SEM)	1.6 (0.66)	1.4 (0.57)	-	0.32	1.3[a] (0.53)	1.9[b] (0.79)	1.4[ab] (0.57)	-	0.03	0.93
Total fallouts¶, % (SEM)	2.8 (1.08)	2.8 (1.08)	-	0.96	2.6 (1.02)	3.0 (1.16)	2.8 (1.10)	-	0.70	0.70

* Three commercial feedlot trials were conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), enrolling a total of 10,583 crossbred beef heifers, which were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations (within a block within a trial). Across the three trials there were 144 pens total resulting in 24 treatment simple effect replications (all combinations of implant program × DOF), 72 replications of implant program main effects, and 48 replications of DOF main effects.

† Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a 2-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.

‡ Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.

§ A 4% pencil shrink was applied to the total weight of each pen prior to calculations of final body weight on the bases of deceased and removed heifers included or excluded.

‖ The proportion of heifers that were pulled and treated at least one time for any reason.

¶ Total fallouts are heifers that died during the trial (accounted for in mortality) plus those that were removed from the trial for health related reasons (accounted for in removals).

a,b,c Differing superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

Table 3.6. Model adjusted means and standard errors of the mean (SEM) from pooled analyses of data from 3 commercial feedlot trials evaluating main effects of 2 implant programs and differing days-on-feed (DOF) on carcass characteristics of beef feedlot heifers*

	Implant program†				Days-on-feed‡					*P*-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Carcasses, *N*	5,085	5,093	-	-	3,388	3,389	3,401	-	-	-
Hot carcass weight, kg	377	375	6.0	< 0.01	360[a]	376[b]	392[c]	6.0	< 0.01	0.27
Dressed yield, %	64.44	64.18	0.119	< 0.01	63.91[a]	64.19[b]	64.84[c]	0.126	< 0.01	0.61
Carcasses > 476 kg, % (SEM)	0.19 (0.131)	0.13 (0.090)	-	0.47	0.04[a] (0.039)	0.12[a] (0.087)	0.73[b] (0.433)	-	< 0.01	0.92
USDA Yield Grade§,ǀ, % (*N*)	-	-	-	< 0.01	*x*	*x*	*y*	-	< 0.01	0.49
1	7.85 (399)	5.52 (281)			6.65 (225)	7.52 (255)	5.88 (200)			
2	31.21 (1587)	26.09 (1328)			31.46 (1065)	29.06 (985)	25.43 (865)			
3	41.32 (2101)	42.02 (2139)			43.87 (1485)	41.52 (1407)	39.64 (1348)			
4	16.83 (856)	21.94 (1117)			15.86 (537)	18.68 (633)	23.61 (803)			
5	2.79 (142)	4.42 (225)			2.16 (73)	3.22 (109)	5.44 (185)			
USDA Quality Grade§, % (*N*)	-	-	-	< 0.01	*x*	*y*	*z*	-	< 0.01	0.71
Prime	7.53 (383)	9.6 (489)			5.81 (197)	9.12 (309)	10.76 (366)			
Choice	78.09 (3971)	77.71 (3958)			78.54 (2661)	77.54 (2628)	77.62 (2640)			
Select	12.66 (644)	11.07 (564)			14.76 (500)	11.92 (404)	8.94 (304)			
Other	1.71 (87)	1.61 (82)			0.89 (30)	1.42 (48)	2.68 (91)			

* Three commercial feedlot trials were conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), enrolling a total of 10,583 crossbred beef heifers, which were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations (within a block within a trial). Across the three trials there were 144 pens total resulting in 24 treatment simple effect replications (all combinations of implant program × DOF), 72 replications of implant program main effects, and 48 replications of DOF main effects.

† Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a 2-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.

‡ Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.

§ Overall *P*-value tests the null hypothesis that the proportions of carcasses distributed across ordinal categories are equal for all treatments groups within a treatment factor (implant program or DOF); values are raw frequency statistics (% and *N*).

ǀ *N* = 3 carcasses excluded from one pen from Smith et al. (2019) exp. 1 due to missing yield grade data.

a,b,c Differing superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

x,y Differing letters within row indicate significant difference ($P \leq 0.05$) from pre-planned contrasts comparing distributions of ordinal outcomes for DOF factor.

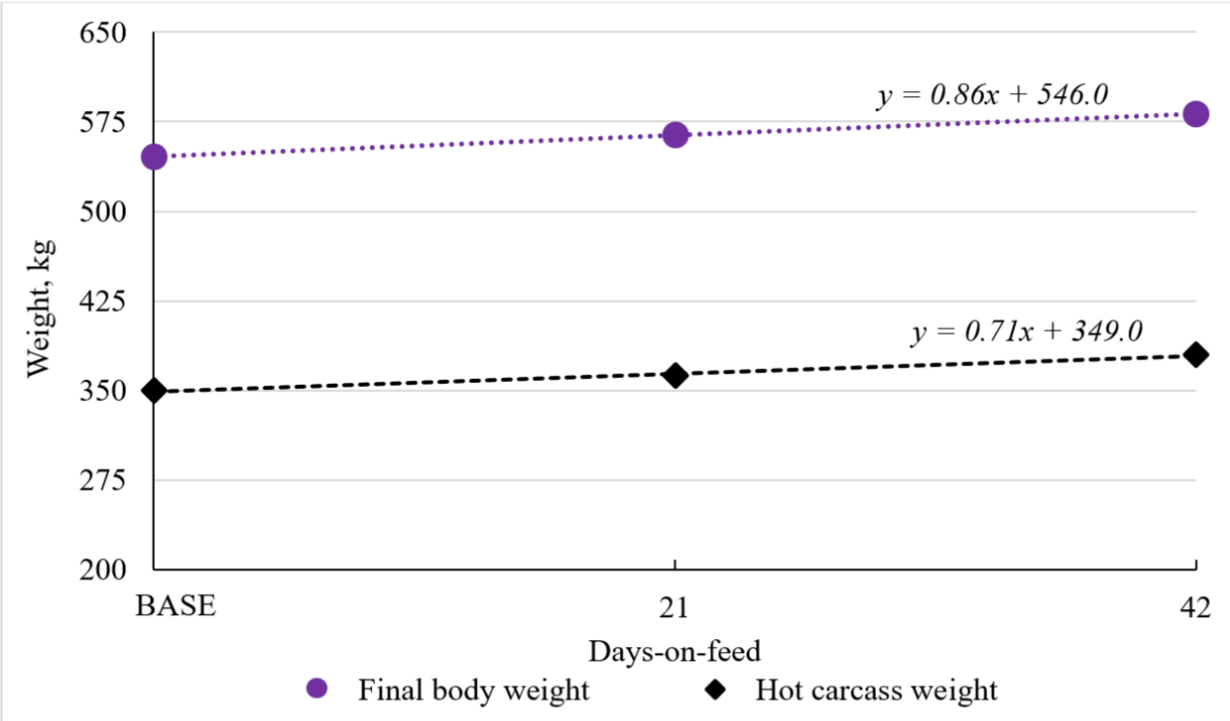

Figure 3.1. Kansas trial model adjusted means and linear functions for main effects of days-on-feed (DOF) on final body weight (BW; dead and removed animals excluded) and hot carcass weight (HCW) of beef feedlot heifers. Treatments in the DOF factor were cattle harvested at a baseline (BASE) endpoint, +21, or +42 additional DOF. *P*-values for the implant program × DOF interaction on final BW and HCW were 0.48 for both outcomes, thus DOF results are main effect means over levels of the implant program factor. For final BW: quadratic effect of DOF, $P = 0.94$; linear effect of DOF, $P < 0.01$; SEM = 3.1. For HCW: quadratic effect of DOF, $P = 0.20$; linear effect of DOF, $P < 0.01$; SEM = 2.1.

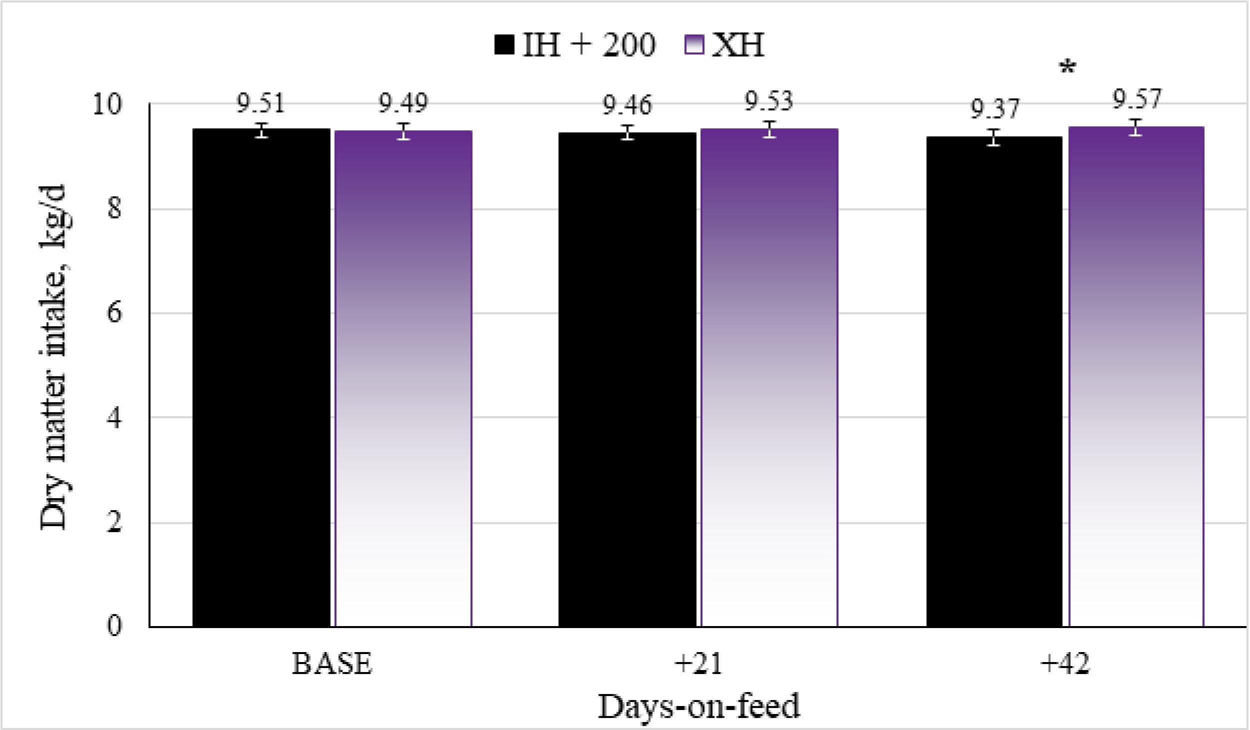

Figure 3.2. Model adjusted means and standard errors of the mean (SEM) comparing the interaction between treatment factors (implant program and days-on-feed [DOF]) and their effects on daily dry matter intake of beef feedlot heifers. Treatments in the implant program factor were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E^2. Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF. Implant program × DOF, P = 0.02, and SEM = 0.142. An asterisk (*) indicates a significant difference ($P \leq 0.05$) between implant programs within DOF category, after adjustment for multiple comparisons.

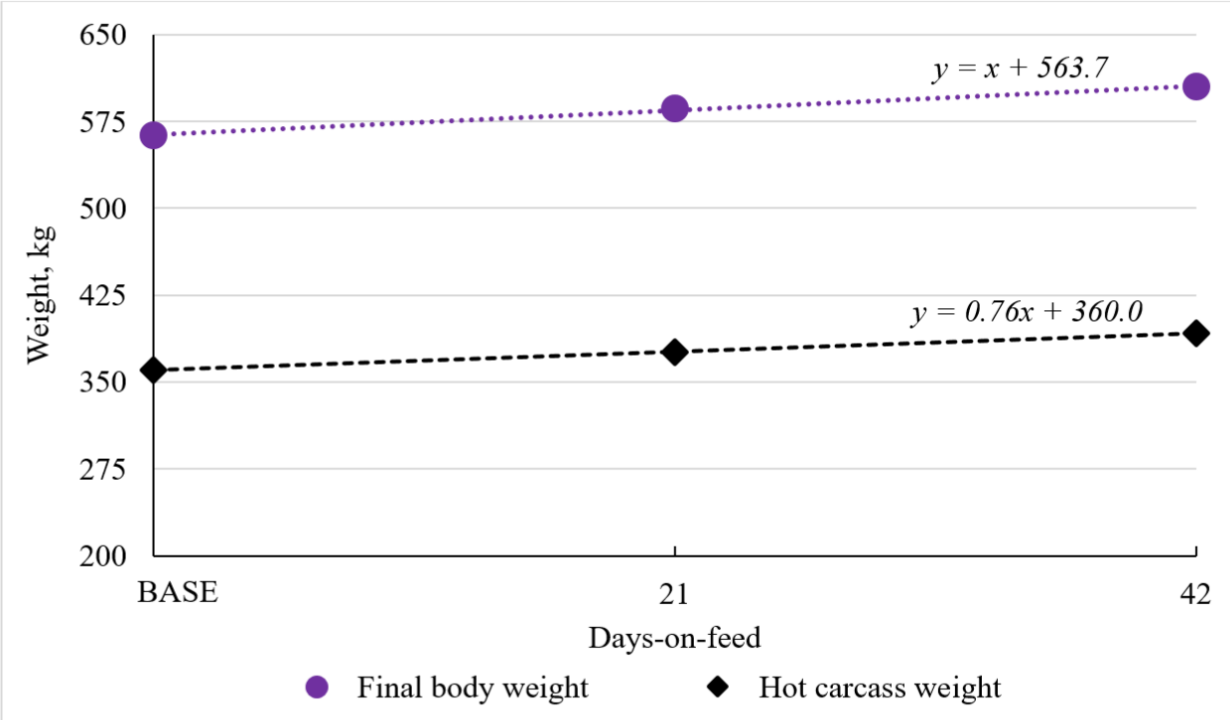

Figure 3.3. Pooled trials model adjusted means and linear functions for main effects of days-on-feed (DOF) on final body weight (BW; dead and removed animals excluded) and hot carcass weight (HCW) of beef feedlot heifers. Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint, +21, or +42 additional DOF. *P*-values for the implant program × DOF interaction on final BW and HCW were 0.39 and 0.27 respectively, thus DOF results are main effect means over levels of the implant program factor. For final BW: quadratic effect of DOF, $P = 0.15$; linear effect of DOF, $P < 0.01$; SEM = 10.1. For HCW: quadratic effect of DOF, $P = 0.93$; linear effect of DOF, $P < 0.01$; SEM = 6.0.

Chapter 4 - Impacts of economic factors influencing net returns of beef feedlot heifers administered two implant programs and fed for differing days-on-feed from pooled randomized controlled trials

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Abstract

The objective of this research was to evaluate the effects of two implant programs and differing days-on-feed (DOF) on net returns of beef feedlot heifers using sensitivity analyses of key economic factors. Crossbred beef heifers [*n* = 10,583; initial weight 315 kg (± 20.1 SD)] were enrolled across three trials (one Kansas, two Texas feedlot trials). Heifers were blocked by arrival and randomly allocated to one of six pens, resulting in a total of 144 pens and 24 blocks. Pen was randomly assigned to treatment as a 2 × 3 factorial. Implant programs were: IH + 200 – Revalor-IH at initial processing, and a terminal implant after approximately 90 DOF (Revalor-200), or, XH – a single implant at initial processing (Revalor-XH). The DOF treatments were: heifers fed to a standard baseline endpoint (BASE) or heifers fed for an additional + 21 or + 42 d beyond BASE. Pen-level partial budgets were used for economic sensitivity analyses, which varied price points of single pricing components with all other components fixed. Variable components were live-fed cattle prices, base carcass prices (i.e., dressed), Choice-Select spread

(CS-spread), and feed and yardage prices (FYP). For each, a Low, Mid-Low, Middle, Mid-High, and High price was chosen. Linear mixed models were fit for statistical analyses ($\alpha = 0.05$). There were no significant two-way interactions (P-values ≥ 0.14). Regardless of the variable component evaluated, XH heifers had poorer net returns than IH + 200 at all prices ($P \leq 0.04$). Selling live, the + 21 and (or) + 42 heifers had lower net returns than BASE at every fed cattle price point ($P < 0.01$). Selling dressed, the + 21 and (or) + 42 heifers had lower returns than BASE at Low, Mid-Low, and Middle fed cattle base prices ($P < 0.01$); there were no significant DOF differences at Mid-High, or High prices ($P \geq 0.24$). Net returns were lower for + 42 than BASE at all CS-spreads ($P \leq 0.03$), while BASE and + 21 did not differ significantly. Longer DOF had lower net returns than BASE when selling live at every FYP ($P < 0.01$) except at the Low price ($P = 0.14$). Selling dressed, there was no significant effect of DOF at Low or Mid-Low FYP ($P \geq 0.11$); conversely, extended DOF had lower net returns than BASE at Middle, Mid-High, and High FYP ($P < 0.01$). Overall, there was minimal economic evidence to support extending feedlot heifer DOF beyond the BASE endpoint, and when feeding longer, larger reductions in return were observed when marketing live as opposed to dressed.

Key words: days-on-feed, economics, feedlot, heifers, implant, net return

Lay Summary

In the United States, feedlot cattle are spending more time on feed and finishing with heavier weights than in past decades. With this comes increased costs, as well as performance and carcass compositional changes leading to economic implications. Key economic factors including feed and cattle sale prices may have differing impacts on the economic implications of longer feeding and alternative implant programs, depending on their price levels. This dynamic was evaluated for beef feedlot heifers with randomized controlled trial data. Heifers that received two implants during the finishing period had consistently higher economic returns compared to those receiving a single, extended-release implant. Despite recent industry trends, there was minimal evidence to support feeding heifers longer than a feedlot standard endpoint. When using low cattle sale prices, net returns were reduced for longer fed heifers compared to the standard endpoint; as prices increased, returns became closer to the standard. Estimated net returns for longer fed heifers became poorer compared to the standard endpoint as feed prices increased. Compared to the feedlot standard, positive net return estimates for longer fed heifers

occurred only when marketing on a carcass basis, and losses were less severe when marketing on a carcass basis as opposed to live.

Introduction

In recent years, feedlot cattle have progressively been fed to heavier endpoints (LM_CT150; USDA-AMS). The use of hormonal and steroidal implants has aided in production efficiency improvements (Reinhardt and Wagner, 2014; Smith and Johnson, 2020) that enable greater finished weights. Use of various implants and (or) extending days-on-feed (DOF) in the feedlot for both steers and heifers has received considerable past research (Herschler et al., 1995; Sissom et al., 2007; Parr et al., 2011; Rathmann et al., 2012; Reinhardt and Wagner, 2014; Hilscher et al., 2016; Smith et al., 2019; Smith et al., 2020; Ohnoutka et al., 2021; Word et al., 2021; Horton et al., 2022). However, while most prior studies mention economic importance or implications, none (to the knowledge of the authors) have performed a concurrent economic analysis. Economics as a measurable (or estimable) outcome is a critical factor for decision-making by industry stakeholders (Cernicchiaro et al., 2022; Dewsbury et al., 2022). As is often the case, economic incentive may be required for producer-level change to occur for any treatment intervention or management practice.

Horton et al. (2023) evaluated feedlot performance and carcass characteristics of beef feedlot heifers administered two alternative implant programs and fed for differing DOF with pooled data from three randomized controlled trials. The implant programs had significant impacts on live feed efficiency, as well as hot carcass weight (HCW) and dressed yield, which were accompanied by shifts in the distributions of US Department of Agriculture (USDA) Quality Grades (QG) and Yield Grades (YG). Heifers fed for longer DOF than a common endpoint had linear increases in final body weight (BW) but had reduced average daily gain (ADG) and feed efficiency. From a carcass standpoint, longer-fed heifers had heavier HCW, higher dressed yields, and shifted carcass grades towards higher QG and YG (i.e., heavier, fatter carcasses with more intramuscular fat). Taken together, controlled trials with treatment factors incorporating a serial harvest component may have substantial economic impacts due to the alterations in production outcomes, which have not been well quantified by peer-reviewed literature. There may be differing implications when considering alternative marketing strategies (i.e., live vs carcass sales); additionally, carcass-based cattle sales may incorporate premiums and discounts (a “grid”) for value-based carcass pricing.

Due to changes in both live performance and carcass characteristics, alternative treatment factors may result in varied economic returns. Pen-level economic outcomes are also affected by varying market conditions, resulting in alternative management decisions being economically optimal at different times. Mark et al. (2000) estimated that fed cattle price was the most influential factor on feedlot cattle profit, followed by feeder cattle and corn prices. From an experimental trial perspective, feeder cattle prices are of lesser consequence as they are a “sunk” cost that should not vary amongst well randomized treatment groups. With these observations in mind, it was desirable to perform analyses evaluating differing fed cattle prices, feed prices, and premiums and discounts for QG under live and dressed (i.e., carcass) sales scenarios, in order to generate a more robust economic assessment. In economics, sensitivity analysis is a method to evaluate “risk” when there is uncertainty regarding input and output prices, as well as when there may be variability in output quantities (Rushton, 2007). Risk may be defined differently across disciplines; in this case risk is characterized as uncertainty pertaining to deviation(s) from expectations and potential financial loss, and is inherent in any investment decision. In general, people are considered to be risk-averse, meaning that they are cautious when decision-making and often forego additional income or increase their costs in order to avert risk (Rushton, 2007). In economic sensitivity analyses, a range of possible prices for parameters that have high influence and (or) uncertainty are evaluated for their impact on an outcome variable. Producers and other stakeholders can use the output of sensitivity analyses to monitor key variables, based on how sensitive an outcome is to changes in the variables (Rushton, 2007). For this research, the outcome variable of interest is net return. To summarize, sensitivity analyses would provide stakeholders with the estimated impact and implications of individual pricing components on economic returns. Using the randomized controlled trial data described by Horton et al. (2023), the primary objective was to evaluate the effects of alternative implant programs and differing DOF on net returns of beef feedlot heifers, along with the impact of varying key economic factors using sensitivity analyses. A secondary objective was to evaluate the effects of treatments on net grid revenue adjustments from carcass-based premiums and discounts.

Materials and Methods

Background

Data used for economic sensitivity analyses are from pooled clinical trials, for which feedlot performance and carcass characteristics have been previously summarized by Horton et al. (2023). In brief, three commercial trials were conducted with identical treatment and design structures, making them compatible for pooled analyses. The trials had a 2 × 3 factorial treatment structure in a randomized complete block design. The treatment factors included two implant programs and three differing DOF.

Implant programs were: IH + 200, where heifers received an implant at initial processing (Revalor-IH; Merck Animal Health, Lenexa, KS) containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and were later removed from their home pens after approximately 90 DOF and re-implanted with a terminal implant containing 200 mg TBA and 20 mg E_2 (Revalor-200; Merck Animal Health); or, XH, a single, extended-release implant (Revalor-XH; Merck Animal Health) containing a total of 200 mg TBA and 20 mg E_2 administered at initial processing. Revalor-XH contains both uncoated (80 mg TBA and 8 mg E_2) and coated (120 mg TBA and 12 mg E_2) components; the uncoated pellets (n = 4) degrade and have immediate bioavailability of anabolic steroid hormones to the animal, whereas the outer layer of the coated pellets (n = 6) begins to degrade after approximately 70 d and the remaining steroid hormones are gradually released thereafter. Revalor-IH and Revalor-200 are uncoated implants that have immediate bioavailability after administration, but therefore have a shorter effective duration.

Days-on-feed treatments were: BASE, heifers fed to a baseline endpoint as determined by feedlot marketing groups (i.e., the time-point or degree of finish where heifers were normally harvested in the feedlots); + 21, heifers fed an additional 21 d beyond BASE pens (within block); and + 42, heifers fed an additional 42 d beyond BASE pens (within block).

The 2 Texas trials have been described independently (Smith et al., 2019; experiments 1 and 2) as has the Kansas trial (Horton et al., 2023). In Smith et al. (2019), experiment 1, there were 3,780 crossbred beef heifers [mean initial BW 309 ± 6.4 kg (1 SD)] that were enrolled in the summer of 2015 in nine blocks with a total of 54 pens (70 animals per pen), and had a mean BASE DOF of 172 ± 4.4 (1 SD). Smith et al. (2019), experiment 2, used 3,719 crossbred beef heifers [mean initial BW 337 ± 8.9 kg (1 SD)] that were enrolled in the spring of 2018 in nine blocks with a total of 54 pens [mean 69 animals per pen (range 65 to 70)], and had a mean BASE

DOF of 152 ± 1.1 (1 SD). In the Kansas trial, 3,084 crossbred beef heifers [mean initial BW 291 ± 8.9 kg (1 SD)] were enrolled in December of 2018 in 6 blocks with a total of 36 pens [mean 86 animals per pen (range 74 to 115)] and had a mean BASE DOF of 179 ± 4.7 (1 SD). For additional detail on the individual trials (e.g., allocation, cattle management, dietary formulations) see Smith et al. (2019) and Horton et al. (2023).

Sensitivity analyses

A partial budget approach was used to conduct sensitivity analyses for economic factors, to evaluate how individual pricing components affect net returns of beef feedlot heifers subjected to the experimental treatments. Sensitivity analyses were conducted by varying one component (e.g., fed cattle price) while holding all other components in the partial budget(s) constant. Two mechanisms are commonly used for fed cattle sales in the US; these are a live sale basis (live weight multiplied by live fed cattle price) and a dressed sale basis (carcass weight multiplied by dressed fed cattle price), where "dressed" and "carcass" are synonymous. Both scenarios were considered in this analysis. The pricing components varied in sensitivity analyses were: fed cattle price [live price for live weight sales, dressed base price for carcass weight sales accounting for carcass quality-based premiums and discounts (a "grid")], the Choice-Select spread (CS-spread), and feed and yardage price (FYP). Pricing components that were held constant were: feeder cattle purchase price, initial processing charge, implant charge (accounting for the difference between XH and IH + 200 protocols), animal morbidity, animal mortality (rendering cost), interest, and opportunity cost which accounts for the cost of waiting additional days beyond BASE to market cattle. Fixed prices for revenue sources were: a fixed grid for YG and weight-based [under 249 kg (550 lb) and over 476 kg (1,050 lb)] premiums and discounts under the dressed (i.e., carcass) sale basis scenario, and revenue from culled animals removed from the trials for health reasons.

Reported prices from January 2017 through December 2022 were sourced for the selection of price points for variable components in the sensitivity analyses. For each variable component, five price points were selected for evaluation and were categorized as a Low, Mid-Low, Middle, Mid-High, or High price over the date range. The minimum and maximum values for each variable component that occurred in the date range (from weekly or monthly prices) were used to determine Low and High price points. It was preferable to use whole numbers that are easy to interpret and would result in equal intervals for the chosen prices; therefore, the numbers closest to the minimum and maximum of each component which would achieve this were utilized. For example, the minimum weekly live-fed cattle price (2017 through 2022) was $95.14/cwt (cwt = 100 lb = 45.4 kg), and the maximum was $156.80/cwt (LM_CT150; USDA-AMS); therefore, $95.00/cwt was selected for the Low price, and $155.00/cwt was selected for the High price, creating equal intervals of 110.00, 125.00, and 140.00 $/cwt for Mid-Low, Middle, and Mid-High prices, respectively. Consequently, the Middle price is not necessarily near the mean or median price for a given component within the date range; it is simply a moderate value located approximately at the center of the most extreme observed prices. This process was repeated for monthly Central Plains FYP (CattleFax), and weekly CS-spread (LM_CT169; USDA-AMS). The one exception for price selection was for dressed-fed cattle base prices, where the base price was determined by dividing each live-fed cattle price point by a fixed dressed yield of 0.639, the mean dressing percent (63.9%) of BASE heifers (Horton et al., 2023), and rounding the result to the nearest whole number. This was done so the implied dressing percent difference between live and dressed-fed cattle prices would be equivalent between price points. The result was dressed-fed cattle base prices of 149.00, 172.00, 196.00, 219.00, and 243.00 $/cwt for Low, Mid-Low, Middle, Mid-High, and High prices, respectively. Selected price points for FYP were 230.00, 275.00, 320.00, 365.00, and 410.00 $/907 kg [1 US ton (2,000 lb)] dry matter (DM) for Low, Mid-Low, Middle, Mid-High, and High prices, respectively.

The LM_CT169 USDA-AMS 5 Area Weekly Slaughter Cattle – Premiums and Discounts report sets Choice as the base category for QG therefore the CS-spread was the Select discount. Chosen price points for Select discounts were -5.00, -10.00, -15.00, -20.00, and -25.00 $/cwt for Low, Mid-Low, Middle, Mid-High, and High spreads, respectively. Other QG included in the grid were Prime and sub-Select; the discount for Standard grades was used for all carcasses that graded sub-Select. While the objective was to evaluate the CS-spread, Prime and sub-Select prices were allowed to fluctuate along with Choice and Select grades. To calculate prices for Prime premiums and sub-Select discounts for each CS-spread price point, two linear regression models were used. Data used for the models were the same as sourced for price determination above of weekly reported prices from 2017 through 2022. For each model, the Select discount, and a quadratic term for Select discount were the independent variables, and

Prime premium or Standard discount was the dependent variable. The resulting coefficients and SE from the regression equation for estimation of Prime premiums was:

$$\textit{Prime premium} = 15.799 + 0.482\textit{Select discount} + 0.027(\textit{Select discount})^2 \quad (1)$$

$$\pm \text{SE} = (1.403)\ (0.199)\qquad\qquad (0.006)$$

For Eq. (1), *Select discount* and $(\textit{Select discount})^2$ were significant ($P = 0.02$ and $P < 0.01$, respectively), RMSE = 5.37, and $R^2 = 0.24$.

The coefficients and SE from the regression equation for estimation of Standard discounts was:

$$\textit{Standard discount} = -16.042 + 0.985\textit{Select discount} + 0.006(\textit{Select discount})^2 \quad (2)$$

$$\pm \text{SE} = (0.349)\ (0.049)\qquad\qquad (0.002)$$

For Eq. (2), *Select discount* and $(\textit{Select discount})^2$ were significant ($P < 0.01$), RMSE = 1.34, and $R^2 = 0.95$.

This resulted in Prime premiums of 14.00, 14.00, 15.00, 17.00, and 21.00 $/cwt for Low, Mid-Low, Middle, Mid-High, and High CS-spreads, respectively. Low and Mid-Low Prime premiums were equivalent due to rounding and the quadratic nature of the relationship. Standard discounts were -21.00, -25.00, -29.00, -33.00, and -37.00 $/cwt for Low, Mid-Low, Middle, Mid-High, and High CS-spreads, respectively.

The sensitivity analyses were conducted by varying a single component, while holding all others constant at either the fixed value for fixed components or at the Middle price point for other variable components. For example, when evaluating each FYP variable price point, the live-fed cattle price was fixed at $125.00/cwt for live cattle sales, and under the dressed sales scenario, the base fed cattle price was fixed at $196.00/cwt and the CS-spread was fixed at $-15.00/cwt. All selected price points of variable components evaluated in sensitivity analyses are in Table 4.1. Note that rows (variable components) are independent of the columns (price points), in that each column does not represent a set of prices used concurrently; rather, each specific price for any component was evaluated with all others set at the Middle value. The Middle price point column is an exception, as all variable components were implemented at the Middle value.

Partial budgeting

For evaluation, multiple partial budgets were built, one for each price point for each variable component. Partial budgets were applied at the pen-level for all relevant outcomes measured in the trials, regardless of statistical significance reported by Horton et al. (2023). For example, while not statistically significant, morbidity was accounted for in the partial budgets. Net return was defined as the difference between total pen revenue and total pen costs, per animal sold.

Heifer purchase prices were assumed using weekly prices from 2017 through 2022 for medium and large frame #1 feeder heifers from Oklahoma City auctions sourced from the Livestock Marketing and Information Center (LMIC); this is a large market, geographically near trial locations. Trial average initial BW were classified into two different 45.4 kg (100 lb) weight categories; mean initial BW in Smith et al. (2019) experiment 1 and the Kansas trial (Horton et al., 2023) was in the 272 to 317 kg (600 to 699 lb) feeder weight range, while Smith et al. (2019) experiment 2 mean initial BW was in the 318 to 362 kg (700 to 799 lb) feeder weight range. To use the same purchase price across all pens, a weighted mean from reported feeder heifer purchase prices based on the number of pens in each trial was calculated by averaging 272 to 317 kg and 318 to 362 kg feeder heifer price categories. While feeder heifer purchase price was held constant in the budgets, the price was determined similarly to the variable components, where a value reflective of the Middle price over the date range was chosen. To estimate the total pen purchase price, a weighted feeder heifer price of $135/cwt was multiplied by the total initial pen weight for each pen.

Processing costs were fixed, with a slight difference between implant programs. A standard processing protocol was assumed for animal health and related products used across the three trials. Products and prices were sourced from PBS Animal Health on March 3, 2022, and dosage to estimate price/animal was calculated based on manufacturer recommendations and a 318 kg animal weight (see Table 4.2 for additional detail). The initial processing charge including an assumed $1.50/animal chute charge accounting for equipment and labor was $13.25/animal before incorporating costs for implant program treatments. Heifers in the XH treatment were charged an additional $8.32/animal for Revalor-XH, for a total of $21.57/animal. Heifers in the IH + 200 treatment were charged an additional $3.08/animal for Revalor-IH, $3.75/animal for Revalor-200, and a $1.50 chute charge for re-implant processing, for a total of $21.59/animal.

No major animal health differences occurred in the Horton et al. (2023) feeding trials, but observed morbidity and mortality were accounted for in the partial budget. Morbidity was not differentiated by diagnosis, and a $23.60/treatment charge (USDA-NAHMS, 2013) was assumed for any treatments administered. An estimated render fee of $40.50/animal mortality was used. This value was determined with an assumed inflation adjustment based on a $24.11 cost for rendering a beef animal as reported by Sparks Companies Inc. (2002); the value is anecdotally similar to what feedlots indicate they pay currently. The inflation adjustment was performed by adjusting the 2002 Producer Price Index (PPI) for animal slaughtering and processing (U.S. BLS) to the mean PPI from 2017 through 2022.

The only variable cost component was FYP. These were monthly price data from the CattleFax ration price database for the Central Plains region. The prices account for dry feed, feed markup, and yardage. Feedlots use various custom feeding charge structures as some markup feed and charge yardage; others only markup feed with no yardage; and some only charge yardage with no feed markup. Therefore, a single FYP is used rather than incorporating feed, markup, or yardage as individual components. Price points for FYP (Table 4.1) were multiplied by the total amount of dry feed delivered per pen throughout the period to estimate total feed and yardage cost, with each price point representing a separate partial budget with all other variable components fixed at the Middle value.

To account for money borrowing for the purchase of feeder heifers and feed, a fixed yearly interest rate of 5.85% [based on the mean rate for operation loans in Kansas from 2017 through 2022 (Ag Credit Survey, Federal Reserve Bank of KS City)] was incorporated with the purchase cost of heifers, and one-half of the total cost of feed and yardage. Interest cost was applied as the interest rate [5.85% × (pen DOF / 365)] multiplied by the total heifer purchase cost of the pen, and one-half of the total pen feed and yardage cost. Rushton (2007) describes "discounting" as the process of converting future dollar values into current dollar values, as there is a basic principle that a current dollar (or other unit of currency) is worth more than any future dollar yet to be received, because the current dollar can accumulate more than its original value by being invested; here, discounting is synonymous with accounting for opportunity cost. In order to approximate the opportunity cost of waiting additional days to market cattle when revenue could instead be received earlier, interest was used for estimation. The same 5.85% rate was applied only to + 21 and + 42 pens, which was the interest rate [5.85% × (21 or 42 / 365)] multiplied by the revenue received for the corresponding BASE treatment pen within each block.

Revenue components were either from live or dressed (adjusted for carcass-based premiums and discounts) fed heifer prices (Table 4.1), in addition to revenue from culled animals. For the live sale scenario, variable fed cattle prices were determined from weekly negotiated heifer prices (live free-on-board, over 80% Choice) from the USDA-AMS 5 Area Weekly Weighted Average Direct Slaughter Cattle report with 4% pencil shrink. For the dressed sale scenario, variable fed cattle base prices were determined using a fixed dressed yield applied to live prices. The base pen revenue was then adjusted for QG, YG, and weight premiums or discounts using the pen-level HCW in each category. Specific prices for QG were described in the prior section and are listed in Table 4.1. Premiums and discounts for YG and weight (LM_CT169; USDA-AMS) had little variability from 2017 through 2022 and have minimal influence on revenue variability (Schroeder and Graff, 2000; Tatum et al., 2006), therefore, those components were held constant. Price determination was similar to that of variable components in the sensitivity analyses, where the minimum and maximum values from the date range were determined, and the Middle value was used for YG and weight premiums and discounts. Specific prices are reported in Table 4.2.

Revenue from culled cattle removed from the trial for health reasons was estimated by using a proportion of reported cull cow prices, determined by removed animal weight, per Horton et al. (2021). Prices from the National Weekly Direct Cow and Bull Report – Negotiated Price for dressed Breaker cows over 227 kg (500 lb) were used (LM_CT168; USDA-AMS). Weekly prices from 2017 through 2022 were selected, and a fixed Middle price of $125.00/cwt was chosen using methodology similar to the selection of variable components. Mean pen-level HCW of removed trial cattle was estimated using the following formula: $HCW = 0.2598 \times \text{live } BW^{1.1378}$ (Tatum et al., 2012), where live BW was the actual live weight of the animal at the time of trial removal. A percentage of the Breaker cow price was used, as determined by mean estimated HCW categorization, where HCW less than 181 kg (400 lb) received 59.5% of the price, HCW between 181 and 271 kg (400 to 599 lb) received 76.3% of the price, and HCW greater than 272 kg (600 lb) received 92.0% of the price (Horton et al., 2021). Estimated total pen-level HCW from culls was multiplied by the appropriate adjusted price to estimate culled cattle revenue. Values of fixed components used in partial budgets for sensitivity analyses are in Table 4.2.

Statistical analyses

Linear mixed models were fit to evaluate treatment effects on net return and net grid revenue adjustments using commercially available software (Proc GLIMMIX, SAS 9.4; SAS

Institute Inc., Cary, NC). The models were specified with a Gaussian distribution and identity link function using restricted maximum likelihood estimation and a Kenward-Rodger degrees of freedom adjustment. Fixed effects were implant program, DOF, and implant program × DOF; random intercepts for trial, and block within trial were used to account for clustering by the experimental design. Pen served as the experimental unit in all analyses. Conditional and marginal plots of studentized residuals were assessed visually to evaluate model assumptions of normality and homogeneous residual variance. Statistical significance was declared *a priori* at $\alpha = 0.05$. Main effects are reported in the absence of significant two-way interactions, and a Tukey-Kramer adjustment for multiple comparisons was used for evaluating pairwise comparisons of treatment differences. For interpretation, model-adjusted mean differences (as opposed to means) and standard errors of the differences (SED) compared to a referent treatment are reported.

Results and Discussion

There were no significant two-way interactions in any statistical model (*P*-values ≥ 0.14), therefore, only main effects of implant programs and DOF are shown. The mean purchase cost per heifer did not significantly differ between implant programs (*P* = 0.64) or differing DOF (*P* = 0.18), even though additional interest cost on the purchase of feeder heifers was applied to pens fed for longer days (data not shown). There was no significant difference in initial BW between treatments (Horton et al., 2023), which provides rationale for finding similar purchase costs. While feeder cattle price is highly influential on cattle feeding profit (Mark et al., 2000), it was not incorporated as a variable component in sensitivity analyses because it was a "sunk" cost that would have minimal impact treatment differences.

Heifers in the XH treatment had consistently lower net returns of more than $10/animal compared to IH + 200 when sold on a live basis (FYP fixed at $320.00/907 kg DM), regardless of live-fed cattle price (*P*-values ≤ 0.03) (Table 4.3). The estimated difference between implant programs increased by $0.55/animal with each $15.00/cwt increase in live-fed price. These results were expected being that there were negligible processing cost differences across implant programs and no evidence of differences in cattle health (Horton et al., 2023), thus, the main factors influencing live net return are feed costs and sales revenue. Heifers administered IH + 200 were more feed efficient than XH (Horton et al., 2023), meaning reduced feed costs per unit of weight gain. Feed efficiency on its own can often be a misleading metric as it may be improved by (1) increased ADG, (2) decreased dry matter intake (DMI), or (3) the combination of both. As is often the case in animal science literature, significant treatment effects on gain:feed may occur while significant differences in weight and intake are not observed (as was the case for Horton et al. 2022), even though they are the two drivers. Therefore, it is important to not discard numerical differences of components that trigger feed efficiency changes because when combined, the numerical differences may result in significant differences in net returns. While not statistically significant, IH + 200 had 2 kg heavier final BW and numerically greater ADG (Horton et al., 2023), which would result in more revenue compared to XH. Additionally, there was an implant program × DOF interaction for DMI, where XH heifers had greater DMI than IH + 200 when fed for longer DOF (Horton et al., 2023), which would contribute to increased feed and yardage costs.

On a dressed sale basis (FYP fixed at $320.00/907 kg DM; CS-spread fixed at $15.00/cwt), net returns were again lower for XH compared to IH + 200, regardless of the dressed-fed cattle base price (P-values ≤ 0.02; Table 4.3). With each increase in dressed base price (Low through High), the net return difference between implant programs increased by over $1.30/carcass. In addition to having a feed efficiency advantage (discussed previously), on a carcass basis IH + 200 heifers had 2 kg heavier HCW, and a greater dressed yield than XH (Horton et al., 2023). Net return differences between implant programs were numerically greater on a dressed sale basis than live, by $5.16 (Low price) to $8.35 (High price) per animal (Table 4.3). While selling cattle on a grid has been noted to increase cattle price variability, cattle with higher dressing percentages typically return more revenue when sold on a dressed basis when compared to live (Schroeder and Graff, 2000); this may explain why the magnitude of differences between implant programs was greater when sold on a carcass basis than when sold live.

On a live-sale basis (Table 4.3; FYP fixed at $320.00/907 kg DM), extending DOF reduced net returns with fed cattle prices of 95.00, 110.00, 125.00, or 140.00 $/cwt ($P$-values < 0.01), where net returns for heifers fed + 21 DOF were lower than BASE but greater than + 42 heifers, which had the overall poorest net returns. Using the High live-fed cattle price ($155.00/cwt), feeding for + 42 DOF reduced net returns compared to BASE and + 21 ($P < 0.01$), while there was no evidence of a difference comparing + 21 with BASE at this price. Compared to BASE, estimated decreases in net return for + 21 and + 42 were greatest when live-fed cattle prices were low, and were less severe at higher prices, holding FYP constant. Relative differences compared to BASE decreased by approximately 6.75 and 12.33 $/cwt for each incremental increase in the live-fed cattle price for + 21 and + 42, respectively. Additional revenue from having heavier final BW for longer-fed heifers did not outweigh costs associated with additional feed and yardage, opportunity cost, and having reduced feed efficiency through poorer ADG (Horton et al., 2023). While reductions in net return for + 21 and + 42 heifers compared to BASE became smaller with higher live-fed cattle prices, none of the selected fed cattle prices would incentivize longer feeding horizons.

On a dressed sale basis (FYP fixed at $320.00/907 kg DM; CS-spread fixed at $15.00/cwt), there was a DOF effect on net returns when the dressed-fed cattle base price was 149.00, 172.00, and 196.00 $/cwt ($P$-values < 0.01; Table 4.3). For these prices, net returns were poorest for + 42 heifers compared to BASE and + 21. At the Low price ($149.00/cwt) + 21 net returns were also significantly lower than BASE; conversely, there was no evidence of a difference in returns between BASE and + 21 at Mid-Low ($172.00/cwt) and Middle ($196.00/cwt) dressed-fed cattle base prices. There was no evidence of a difference between DOF treatments when dressed-fed cattle base prices were 219.00 (P = 0.24) or 243.00 $/cwt ($P$ = 0.64). With each incremental increase in the dressed base price (Low through High), estimated net return differences per animal were reduced by over 7.44 and 14.96 $/cwt for + 21 and + 42, respectively, compared to BASE. The estimated net return differences compared to BASE were larger in magnitude at each respective price on a live sale basis than on a dressed sale basis; meaning that when feeding for longer DOF, one may expect larger changes in net return to occur when marketing live as opposed to dressed. When extending DOF, the importance of live feed efficiency and daily gain is of lesser consequence when marketing dressed (vs live). While these metrics have been shown to decrease with additional DOF (Horton et al., 2023), the proportion of weight being deposited in carcass components increases while growth of non-carcass components (e.g., hide, internal organs, head) become more stagnant (Berg and Butterfield, 1968; Buckley et al., 1990; Coleman et al., 1995; Owens et al., 1995; Wilken et al., 2015; Honig et al., 2022), thereby providing a mechanism for the distinction between live and dressed-sale basis net returns. Horton et al. 2022 described this concept as incremental dressing percentage, which is a contrast between live growth and carcass growth, or, the proportion of live BW gain that results in carcass weight gain. On average, the estimated incremental dressing percentage was 76.2% for heifers fed + 42 d beyond BASE. As heifers fed for additional DOF were depositing more salable weight in the carcass as opposed to “drop” (non-carcass) components, dressing percent concurrently increased. Because the dressed-fed base prices were a fixed percentage of the corresponding live-fed prices, heifers with higher dressed yields and marketed dressed have an advantage when opposed to live marketing. In other words, heifers fed additional DOF beyond BASE capitalize by having a greater proportion of weight sold on a dressed basis compared to the live price equivalent (more weight multiplied by the same reference price). Nevertheless, there was minimal evidence to support extending DOF when evaluating variable dressed-fed cattle prices; the only occurrence of positive net return estimates for both + 21 and + 42 compared to BASE, while not significant, was with a High dressed-fed cattle base price.

The opportunity cost of feeding cattle for longer DOF had a substantial impact on model estimates. Descriptively, mean opportunity costs (± 1 SD) for + 21 heifers sold live were 4.13 (0.416), 4.78 (0.480), 5.43 (0.544), 6.08 (0.609), and 6.73 (0.673) $/animal for Low, Mid-Low, Middle, Mid-High, and High fed cattle price points, respectively. For + 42 heifers sold live, mean opportunity costs (± 1 SD) were 8.27 (0.831), 9.57 (0.960), 10.87 (1.089), 12.17 (1.217), and 13.47 (1.346) $/animal for Low, Mid-Low, Middle, Mid-High, and High fed cattle price points, respectively. On a dressed sale basis, mean opportunity costs were nearly identical to live sale opportunity costs at each price point for + 21 (within -0.02 and -0.05 $/carcass difference) and + 42 DOF (within -0.04 and -0.10 $/carcass difference). When considering feeding pens of cattle longer, producers are likely to consider factors such as additional feed and yardage cost, interest on feed and cattle purchase, and the potential increased risk of late-day morbidity and mortality [(Engler et al., 2014; Vogel et al., 2015; Smith et al., 2022) although evidence of effects on these health outcomes was not observed in the data used herein (Horton et al., 2023)]. As an additional consideration, the opportunity cost of keeping cattle on feed longer represents a sizeable “penalty” on net returns of heifers fed for extended DOF.

As a secondary objective, net grid revenue adjustments from carcass-based premiums and discounts were evaluated at varying CS-spread prices (Table 4.4). This is the estimated difference in $/carcass revenue adjustments that are applied to base carcass value (heifers grading Choice, YG 3). Compared to IH + 200, heifers administered XH received more revenue from grid adjustments, regardless of the CS-spread (*P*-values < 0.01), and as CS-spreads increased (from Low to High), estimated grid revenue differences became larger. Net return per carcass when varying the CS-spread is also in Table 4.4 (FYP fixed at \$320.00/907 kg DM; dressed-fed cattle price fixed at \$196.00/cwt). Heifers in the XH program had poorer net returns per carcass than IH + 200 at all CS-spread price points (*P*-values ≤ 0.03); the estimated difference was greatest at the Low CS-Spread (\$-19.57/carcass), decreased incrementally at each higher CS-spread, and was lowest at the High CS-spread (\$-15.57/carcass). The observed decrease in net return differences with increasing CS-spreads relates to the decreases in net grid revenue for IH + 200, as XH heifers received more grid revenue from having carcasses with higher QG.

When evaluating effects of DOF on premiums and discounts (Table 4.4), heifers fed for + 21 or + 42 DOF received more revenue from grid adjustments compared to BASE, regardless of the CS-spread (*P*-values < 0.01), and grid revenue differences became larger as CS-spreads widened. There was no evidence of a difference in net grid revenue between + 21 and + 42 DOF treatments at any selected CS-spread. Results suggest that under the CS-spreads selected, treatment groups with higher QG received more revenue from grid adjustments, even with a corresponding increase in YG 4 and 5 carcasses (Horton et al., 2023). There also was not a discernably negative impact of heavyweight carcasses (> 476 kg) which occurred for + 42 heifers compared to + 21 and BASE (Horton et al., 2023), likely because the magnitude of the increase was small at less than 1 out of 100 carcasses. While these estimated grid revenue adjustments may be useful for conceptualizing the impacts that shifts in QG and YG have when using a value-based pricing structure, base revenue from Choice and YG 3 carcasses, and costs associated with extending DOF are not accounted for. The circumstances change once accounting for the additional factors that contribute to overall net returns. Days-on-feed affected net returns (Table 4.4) at all CS-spreads (FYP fixed at \$320.00/907 kg DM; dressed-fed cattle price fixed at \$196.00/cwt). At Low, Mid-Low, and Middle CS-spreads (5.00, 10.00, and 15.00 \$/cwt, respectively; *P*-values < 0.01), heifers fed + 42 DOF had lower net returns compared to BASE and + 21. Note that results from the Middle CS-spread are identical to those for the Middle dressed-fed cattle base price (\$196.00/cwt) in Table 4.3, as both are reflective of having all variable components set at the Middle price point. Days-on-feed also affected net returns at Mid-High (\$20.00/cwt; *P* < 0.01) and High (\$25.00/cwt; *P* = 0.03) CS-spreads, where + 42 heifers had poorer net returns than BASE, while there was not a significant difference comparing

+ 21 heifers with BASE or + 42. While additional DOF beyond BASE resulted in greater net grid revenue adjustments at every CS-spread, there was no evidence of an advantage for longer DOF in net returns as a whole once accounting for additional variables such as FYP and opportunity cost.

Previous research has reported that HCW is the most important determinant for revenue when using grid-based pricing, while grid premiums and discounts and carcass performance comprise a smaller proportion of revenue variability (McDonald and Schroeder, 2003; Johnson and Ward, 2005; Tatum et al., 2006; Tatum et al., 2012). The magnitude of grid importance increases with wider CS-spreads, with higher premiums paid to higher QG (Johnson and Ward, 2005; Tatum et al., 2006). Our results concur with these prior studies. Varying dressed-fed cattle base prices resulted in larger estimated treatment differences with each increase in price compared to incremental increases of the CS-spread. This indicates that in terms of feeding heifers longer, the dressed-fed cattle base price is likely a more influential deciding factor than the CS-spread. Programs such as Certified Angus Beef, which award premiums for carcasses grading in the upper 2/3 Choice (while requiring other conditions met), were not incorporated in these analyses. Such programs could provide additional revenue opportunities when using grid-based pricing.

Sensitivity analyses of FYP are in Table 4.5. Note the $320.00/907 kg DM FYP analyses are identical to Middle price points in Table 4.3, as they are representative of setting all variable components at the Middle price point. On a live sale basis (live-fed cattle price fixed at $125.00/cwt), XH heifers had lower net returns than IH + 200 regardless of the FYP (*P*-values ≤ 0.04); the difference between implant programs increased by approximately $0.96/animal for every $45.00/907 kg increase in FYP. Similarly, on a dressed sale basis (dressed-fed cattle base price fixed at $196.00/cwt; CS-spread fixed at $15.00/cwt), XH heifers had lower net returns than IH + 200 regardless of the FYP (*P*-values < 0.01); and the difference between implant programs increased by approximately $0.84/animal for every $45.00/907 kg increase in FYP. In essence, the value-added by the IH + 200 implant program compared to XH increased with increasing FYP. The previous discussion on the effects of implant programs on feed efficiency are of high relevance here as well. The capability to convert similar or reduced feed resources to heavier live or carcass weight is of particular importance when varying FYP, providing probable reasoning for the observed increasing advantage of IH + 200 heifers when increasing FYP compared to XH.

On a live sale basis, there was no evidence of a difference between differing DOF when using the Low ($230.00/907 kg DM) FYP (Table 4.5; $P = 0.14$). Days-on-feed affected net returns at all other FYP when sold live (P-values < 0.01). Heifers fed + 42 DOF had lower net returns compared to BASE and + 21 at the Mid-Low ($275.00/907 kg DM) FYP. At all other FYP (Middle, Mid-High, and High), + 21 heifers had lower net returns than BASE, and + 42 had lower returns than both + 21 and BASE. With each $45.00 increase in FYP, the net return difference between + 21 and BASE widened by over $10.50/animal, and the difference between + 42 and BASE widened by over $20.75/animal. On a dressed sale basis, the only case of positive estimated net return differences for + 21 and + 42 compared to BASE was at the Low FYP, however, these differences were not significant (Table 4.5; $P = 0.11$). There also was not evidence of a DOF effect using the Mid-Low FYP ($P = 0.48$). Net returns decreased with additional DOF at Middle ($320.00/907 kg DM), Mid-High ($365.00/907 kg DM), and High ($410.00/907 kg DM) price points (P-values < 0.01). At the Middle and Mid-High FYP, + 42 heifers had lower net returns compared to BASE and + 21. At the High FYP, + 21 heifers had lower net returns than BASE, and + 42 had lower returns than both + 21 and BASE. With each $45.00 increase in FYP and selling dressed, the net return difference between + 21 and BASE became more negative by approximately $10.25/animal, and the difference between + 42 and BASE widened by nearly $20.50/animal.

Use of a common re-implanting program (IH + 200) had an economic advantage over a single extended-duration implant (XH), regardless of the variable pricing component. Estimated differences between the programs were greater when heifers were sold dressed (vs live), and increased with higher fed cattle prices as well as with higher FYP. The only case of a moderate decrease in estimated net return differences between implant programs was with increasing CS-spreads. Recently updated US Food and Drug Administration (FDA) guidance currently restricts the use of the IH + 200 implant program among others (FDA, 2021; FDA, 2023). Therefore, model estimates provided herein may be less meaningful to producers, but represent an important constraint of a management tool. Economic advantages of re-implanting cattle with combination implants containing estrogenic and anabolic androgenic steroid components compared to non-implanted controls, or cattle receiving a single implant have previously been reported [(Duckett et al., 1996; Duckett and Pratt, 2014) noting that Revalor-XH was not available at the time for inclusion]. Economic and environmental efficiencies improve for beef production systems that use growth enhancing technologies compared to those that do not (Wileman et al., 2009; Capper and Hayes, 2012). While the FDA guidance does not constitute complete removal of a technology, as some alternative implants labeled for use sequentially in the same production phase are available [e.g., Synovex Choice (10 mg estradiol benzoate, 100 mg TBA) followed by Synovex Plus (28 mg estradiol benzoate, 200 mg TBA), Zoetis Animal Health, Parsippany, NJ], industry stakeholders should expect a reduction in both economic and environmental sustainability by limiting certain cattle implanting programs that had previously been available.

When evaluating extending DOF in the feedlot, past publications have mentioned economic implications. However, this is the first peer-reviewed publication known by the authors to conduct economic analyses from clinical trial data which incorporate a serial harvest component as part of the experimental design. A recent systematic review indicated inconsistent reporting of methodologies behind calculation of economic outcomes from experimental trials evaluating feedlot cattle performance and health, often leading to the inability to reproduce, or properly interpret the validity of results (Dixon et al., 2022). These factors limit some formal comparisons with the literature. Wilken et al. (2015) evaluated a similar research question for steers using differing methodology. Regression equations were applied to pooled clinical trial data without a DOF treatment factor, to predict performance of steers had they been fed for 75%, 100%, or 125% of their normal DOF. They evaluated differing DOF with steers sold on a live or carcass basis not accounting for carcass-based premiums and discounts at 3 different feed prices (158.96, 249.79, and 340.63 $/907 kg DM). General findings from Wilken et al. (2015) were that net returns were similar when sold live or dressed at any feed price when marketing at 100% DOF. When marketing at 125% DOF, net returns were greatest when selling dressed at any feed price selected compared to live. When selling live, only at the $158.96/kg feed price was 125% DOF advantageous compared to 75% or 100% DOF. These results contrast those observed herein, where there was no significant evidence for increased returns when extending DOF. Dissimilarities between study results could be due to biological differences between heifers and steers, the prices evaluated, and experimental design (i.e., use of a DOF treatment factor vs cattle performance predictions from regression equations). Additionally, it is unclear if Wilken et al. (2015) accounted for opportunity cost when extending DOF in their analyses.

Overall, our results do not support extended feeding of feedlot heifers. Reduced net returns compared to BASE occurred in every analysis when selling on a live basis, except with Low FYP showing no significant difference. Similarly, when selling on a dressed basis, there was no evidence of greater net returns for extended DOF. Instances where there was no evidence of a DOF effect on net returns when selling dressed were with Mid-high and High fed cattle base prices, and Low to Mid-Low FYP. At the time of this publication, current FYP are nearest to the High price point (CattleFax), while fed cattle prices have exceeded the High price used herein (LM_CT150; USDA-AMS).

There are limitations of this publication to consider. For one, it is critical to keep the scope of inference in mind as it pertains to generalization of results. Time of trial conduct, region, and cattle demographics are all important considerations. For example, it is uncertain how similar analyses would apply to steers, which should likely be an area of future research. In addition to physiological distinctions between heifers and steers due to differences in growth and maturity (Owens et al., 1995), one should also consider that the selection of a BASE reference group is relative, and likely changes with time. Where a group of heifers stand physiologically on a growth curve will in all likelihood result in alternative implications when adding DOF. Heifers were never sorted by BW or other measurement factors into more homogeneous groups (pens) due to design of the trials; this practice is often used to reduce the number of YG 4, 5, and heavyweight carcasses that would receive discounts under grid-based pricing. This management strategy could be conducive with extending DOF, but could not be evaluated in this research. Estimates provided in results are reflective of pen-level management of feedlot heifers, but do not necessarily reflect what is always optimal for feedlot-level management decisions. For example, marketing cattle earlier allows pen-space for the next set of feeder cattle to be placed in the feedlot, which may be a viable option when feeder prices are low. Conversely, if feeder cattle prices are high and (or) they are of limited availability, producers may opt towards feeding current cattle longer to maintain fuller feedlot occupancy. Finally, while the sensitivity analysis approach is valuable for depicting the relative importance, magnitude, and direction of changes that occur when varying individual pricing components, the reality is more dynamic, where the components are often associated with each other and fluctuate concurrently. One could envision pricing conditions where it may be favorable to extend feedlot heifer DOF; e.g., it is probable that cattle fed longer will receive a different sale price then those marketed earlier, which could be advantageous (or disadvantageous) as marketing windows could be shifted based on yearly market trends (Mark et al., 2002; Peel and Meyer, 2002). In other words, there may be seasonal effects on whether one would extend or shorten the finishing period of feedlot heifers, depending on anticipated prices. However, such pursuit was outside the objective of the analyses performed.

Conclusions and Implications

Fed cattle prices, CS-spread, and FYP all had important implications on the net returns of feedlot heifers administered differing implant programs and fed for varying DOF. The re-implant program (IH + 200) consistently had greater net returns compared to the single delayed-release implant program (XH), regardless of the pricing component. Differences can be expected to be larger between implant programs when marketing heifers on a dressed basis compared to live. However, as of the time of this publication, the IH + 200 program cannot be used in the US per current FDA regulations. While current trends have been to feed cattle to heavier endpoints, there was no evidence to support longer feeding of heifers beyond BASE from an economic standpoint in the pooled trials. If one opts to feed heifers beyond their standard endpoint, it would be advisable to market them on a dressed basis (assuming a constant relationship between live and dressed prices, and no major changes to premiums and discounts for YG and weight), be under high fed cattle pricing conditions, and to consider additional costs incurred, particularly for feed, yardage, interest, and opportunity cost.

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Conflict of Interest Statement

Merck Animal Health employs JH and MS; their contributions were intellectual as they did not partake in data collection or analyses. No competitive interest was present due to non-use or evaluation of competing products. There are no conflicts of interest to disclose.

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Tables

Table 4.1. Price points selected for partial budget sensitivity analyses from reported prices (2017 through 2022) for evaluation of their impact on estimated net return differences of beef feedlot heifers administered differing implant programs and fed for differing days-on-feed

	Price point[*]					
Variable components	Low	Mid-Low	Middle	Mid-High	High	Source
Cost						
Feed and yardage price, $/907 kg DM[†]	230.00	275.00	320.00	365.00	410.00	CattleFax, Englewood, CO
Revenue						
Live-fed cattle price[‡], $/cwt	95.00	110.00	125.00	140.00	155.00	LM_CT150 (USDA-AMS)
Dressed base fed cattle price[§], $/cwt	149.00	172.00	196.00	219.00	243.00	LM_CT150 (USDA-AMS)
Choice-Select spread[‖], $/cwt						LM_CT169 (USDA-AMS)
Prime[¶]	14.00	14.00	15.00	17.00	21.00	
Choice	0.00	0.00	0.00	0.00	0.00	
Select	-5.00	-10.00	-15.00	-20.00	-25.00	
Sub-Select[**]	-21.00	-25.00	-29.00	-33.00	-37.00	

[*] Price point columns do not represent sets of prices used concurrently, rather, only the specific prices that were selected for each variable component in the leftmost column; sensitivity analyses on a component (e.g., feed and yardage price) varied its prices (Low through High) while holding all others (e.g., live-fed cattle price) constant at the Middle price point.

[†] 907 kg = 1 US ton (2,000 lb); DM = dry matter.

[‡] 5-area negotiated heifer price (live free-on-board; over 80% Choice); cwt = 45.4 kg (100 lb).

[§] Determined by multiplying the live-fed cattle price by a common dressing percent of 63.9% (the mean dressed yield of control cattle), and rounded to the nearest whole number; cwt = 45.4 kg (100 lb).

[‖] Choice-Select spread is the difference between Choice premiums and Select discounts, with Choice set to zero (i.e., sensitivity analyses were based on the Select discount); cwt = 45.4 kg (100 lb).

[¶] Prime premiums were estimated using coefficients from a linear regression model with Prime premium as the dependent variable and Select discount as the explanatory variable from the same set of 2017 through 2022 price data.

[**] Carcasses graded sub-Select received the discount for Standard grading carcasses; Standard discounts were estimated using coefficients from a linear regression model with Standard discount as the dependent variable and Select discount as the explanatory variable from the same set of 2017 through 2022 price data.

Table 4.2. Prices used for fixed components that were not varied in partial budget sensitivity analyses

Fixed components	Price	Source
Cost		
Feeder heifer purchase price*, $/cwt	135.00	Livestock Marketing Information Center
Initial processing charge†, $/animal	13.25	Estimated (PBS Animal Health)
Implant charge‡, $/animal	8.34 (IH + 200) or 8.32 (XH)	Estimated (PBS Animal Health)
Morbidity, $/treatment	23.60	USDA-NAHMS, 2013
Mortality§, $/death	40.50	Sparks Companies Inc., 2002; inflation adjusted (U.S. BLS)
Interest and opportunity cost‖, yearly rate (%)	5.85	Fed. Res. Bank of KS City - Ag Credit Survey
Revenue		
Carcass premiums/discounts¶, $/cwt dressed		LM_CT169 (USDA-AMS)
YG 1	5.25	
YG 2	2.50	
YG 3	0.00	
YG 4	-10.00	
YG 5	-14.00	
Under 249 kg discount	-21.50	
Over 476 kg discount	-18.00	
Culled animals**, $/cwt dressed	125.00	LM_CT168 (USDA-AMS), Horton et al., 2021

* Price for medium and large frame #1 feeder heifers from Oklahoma City auctions using a weighted average price of 272 to 317 kg (600 to 699 lb) and 318 to 362 kg (700 to 799 lb) pricing categories (weighted average based on initial body weight of cattle across the three trials); cwt = 45.4 kg (100 lb).

† Estimated by sourcing prices for individual products from a standardized processing protocol. The products and prices were: a modified-live antiviral vaccine at $4.20/animal (Vista Once; Merck Animal Health, Lenexa, KS), a clostridial vaccine at $0.88/animal (Vision 8; Merck Animal Health), an oral anthelmintic at $1.71/animal (Safeguard; Merck Animal Health), an injectable parasiticide at $2.16/animal (Dectomax; Zoetis Animal Health, Parsippany, NJ), a topical insecticide at $0.81/animal (Clean-up II; Elanco Animal Health, Greenfield, IN), two ear tags for identification at $1.99/animal (ATag; Allflex, Kenilworth, NJ), plus a $1.50/animal chute charge. Sales tax was not accounted for in any of these prices, as they likely overestimate what is actually paid by commercial feedlots that receive discounts and order in bulk.

‡ Implant charge for IH + 200 is the sourced price for Revalor-IH at initial processing ($3.08/animal; Merck Animal Health, Lenexa, KS) plus the sourced price for Revalor-200 ($3.75/animal; Merck Animal Health) and an assumed $1.50/animal chute charge for re-implanting; implant charge for XH is the sourced price for Revalor-XH ($8.32/animal; Merck Animal Health) at initial processing only.

§ Mortality cost is the estimated cost of rendering a dead animal, inflation adjusted from the Sparks Companies Inc. (2002) report.

‖ Interest cost was added to total heifer purchase and ½ of the total feed and yardage cost as the rate [5.85% × (pen DOF / 365)] multiplied by each respective cost. Opportunity cost of waiting additional days (+ 21 or + 42) to market heifers beyond the baseline cattle endpoint (BASE) was estimated using the interest rate; opportunity cost was applied to only + 21 and + 42 pens, which was the interest rate [5.85% × (21 or 42 / 365)] multiplied by the revenue received by the corresponding BASE treatment pen within each block.

¶ YG = USDA Yield Grade; 249 kg = 550 lb; 476 kg = 1,050 lb; cwt = 45.4 kg (100 lb).

** To estimate prices for revenue received from animals removed from the trials, a percentage of the reported dressed Breaker cow (over 227 kg) price (determined by the estimated carcass weight of the animal) was used (Horton et al., 2021); cwt = 45.4 kg (100 lb).

Table 4.3. Model-adjusted mean differences and standard errors of the differences (SED) for estimated net returns of beef feedlot heifers administered one of two implant programs and fed for three differing days-on-feed (DOF) from sensitivity analyses with varying live and dressed-fed cattle base prices while holding all other budget components constant*

	Implant program†				Days-on-feed‡					*P*-value
Fed cattle base price	IH + 200	XH	SED	*P*-value	BASE	+ 21	+ 42	SED	*P*-value	Implant × DOF
Live price, net return ($/animal)§										
$95.00 / cwt	ref	-10.12	4.401	0.03	ref^{a}	-36.40^{b}	-75.96^{c}	5.391	< 0.01	0.18
$110.00 / cwt	ref	-10.67	4.441	0.02	ref^{a}	-29.64^{b}	-63.62^{c}	5.438	< 0.01	0.22
$125.00 / cwt	ref	-11.22	4.512	0.02	ref^{a}	-22.89^{b}	-51.29^{c}	5.526	< 0.01	0.27
$140.00 / cwt	ref	-11.77	4.614	0.02	ref^{a}	-16.14^{b}	-38.96^{c}	5.651	< 0.01	0.33
$155.00 / cwt	ref	-12.32	4.744	0.02	ref^{a}	-9.38^{a}	-26.63^{b}	5.811	< 0.01	0.40
Dressed base price, net return ($/carcass)‖										
$149.00 / cwt	ref	-15.28	6.428	0.02	ref^{a}	-22.81^{b}	-57.39^{c}	7.873	< 0.01	0.33
$172.00 / cwt	ref	-16.60	6.435	0.02	ref^{a}	-15.37^{a}	-42.43^{b}	7.881	< 0.01	0.38
$196.00 / cwt	ref	-17.98	6.466	< 0.01	ref^{a}	-7.60^{a}	-26.83^{b}	7.919	< 0.01	0.44
$219.00 / cwt	ref	-19.29	6.519	< 0.01	ref	-0.16	-11.87	7.984	0.24	0.50
$243.00 / cwt	ref	-20.67	6.598	< 0.01	ref	7.61	3.73	8.080	0.64	0.57

* Data are from pooled analyses from three trials described by Horton et al. (2023), using a 2 × 3 factorial treatment arrangement in a randomized complete block design with 10,583 crossbred beef heifers that were blocked by arrival within trial and allocated to pens (144 total) which were randomized to treatment (within block), resulting in 24, 72, and 48 replications of simple effects, implant program effects, and DOF effects, respectively.

† Implant programs: XH = cattle implanted only at trial enrollment with Revalor-XH (Merck Animal Health, Lenexa, KS), a dual-component extended release implant with a total of 200 mg trenbolone acetate (TBA) and 20 mg estradiol (E_2); or IH + 200 = cattle implanted at trial enrollment with Revalor-IH (Merck Animal Health; 80 mg TBA and 8 mg E_2) and re-implanted with Revalor-200 (Merck Animal Health; 200 mg TBA and 20 mg E_2) after approximately 90 DOF.

‡ Days-on-feed: cattle were fed to a feedlot standard baseline (BASE) endpoint, or an additional + 21 or + 42 DOF beyond BASE (within block).

§ Differences in net return means [(total pen revenue – total pen cost) / animal shipped] compared to a referent (ref) category with varying live-fed cattle prices; the feed and yardage price was fixed at 320.00 $/907 kg (2,000 lb) dry matter; cwt = 45.4 kg (100 lb).

‖ Differences in net return means [(total pen revenue – total pen cost) / carcass] compared to a referent (ref) category with varying dressed-fed cattle base prices; the feed and yardage price was fixed at 320.00 $/907 kg (2,000 lb) dry matter; carcass premiums and discounts ($/cwt) for USDA Quality Grade were fixed at 15.00, 0.00, -15.00, and -29.00 for Prime, Choice, Select, and sub-Select grades, respectively; cwt = 45.4 kg (100 lb).

a,b,c Uncommon superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

Table 4.4. Model-adjusted mean differences and standard errors of the differences (SED) for net grid revenue adjustments and overall net returns of beef feedlot heifers administered one of two implant programs and fed for three differing days-on-feed (DOF) from sensitivity analyses varying the Choice-Select spread for USDA Quality Grade premiums and discounts while holding all other budget components constant[*]

	Implant program[†]				Days-on-feed[‡]					*P*-value
Choice-Select spread	IH + 200	XH	SED	*P*-value	BASE	+ 21	+ 42	SED	*P*-value	Implant × DOF
Spread, net grid revenue[§] ($/carcass)										
$5.00 / cwt[ǁ]	ref	3.20	1.198	< 0.01	ref[a]	3.55[b]	4.51[b]	1.467	< 0.01	0.71
$10.00 / cwt[¶]	ref	3.92	1.446	< 0.01	ref[a]	4.23[b]	5.75[b]	1.770	< 0.01	0.72
$15.00 / cwt[**]	ref	4.80	1.766	< 0.01	ref[a]	5.17[b]	7.44[b]	2.163	< 0.01	0.69
$20.00 / cwt[††]	ref	5.84	2.136	< 0.01	ref[a]	6.38[b]	9.58[b]	2.616	< 0.01	0.66
$25.00 / cwt[‡‡]	ref	7.21	2.573	< 0.01	ref[a]	8.11[b]	12.62[b]	3.151	< 0.01	0.65
Spread, net return[§§] ($/carcass)										
$5.00 / cwt[ǁ]	ref	-19.57	6.367	< 0.01	ref[a]	-9.27[a]	-29.84[b]	7.798	< 0.01	0.51
$10.00 / cwt[¶]	ref	-18.85	6.401	< 0.01	ref[a]	-8.56[a]	-28.56[b]	7.834	< 0.01	0.47
$15.00 / cwt[**]	ref	-17.98	6.466	< 0.01	ref[a]	-7.60[a]	-26.83[b]	7.919	< 0.01	0.44
$20.00 / cwt[††]	ref	-16.94	6.563	0.02	ref[a]	-6.38[ab]	-24.65[b]	8.038	< 0.01	0.41
$25.00 / cwt[‡‡]	ref	-15.57	6.708	0.03	ref[a]	-4.63[ab]	-21.59[b]	8.215	0.03	0.39

[*] Data are from pooled analyses from three trials described by Horton et al. (2023), using a 2 × 3 factorial treatment arrangement in a randomized complete block design with 10,583 crossbred beef heifers that were blocked by arrival within trial and allocated to pens (144 total) which were randomized to treatment (within block), resulting in 24, 72, and 48 replications of simple effects, implant program effects, and DOF effects, respectively.

[†] Implant programs: XH = cattle implanted only at trial enrollment with Revalor-XH (Merck Animal Health, Lenexa, KS), a dual-component extended release implant with a total of 200 mg trenbolone acetate (TBA) and 20 mg estradiol (E_2); or IH + 200 = cattle implanted at trial enrollment with Revalor-IH (Merck Animal Health; 80 mg TBA and 8 mg E_2) and re-implanted with Revalor-200 (Merck Animal Health; 200 mg TBA and 20 mg E_2) after approximately 90 DOF.

[‡] Days-on-feed: cattle were fed to a feedlot standard baseline (BASE) endpoint, or an additional + 21 or + 42 DOF beyond BASE (within block).

[§] Mean differences in grid revenue from premiums and discounts compared to a referent (ref) category with varying Choice-Select spreads (i.e., the pen-level sum of Quality, Yield, and weight-based premium and discount revenue divided by *n* carcasses per pen).

[ǁ] Carcass premiums and discounts ($/cwt) for USDA Quality Grade: Prime = 14.00, Choice = 0.00, Select = -5.00, sub-Select = -21.00; cwt = 45.4 kg (100 lb).

[¶] Carcass premiums and discounts ($/cwt) for USDA Quality Grade: Prime = 14.00, Choice = 0.00, Select = -10.00, sub-Select = -25.00; cwt = 45.4 kg (100 lb).

[**] Carcass premiums and discounts ($/cwt) for USDA Quality Grade: Prime = 15.00, Choice = 0.00, Select = -15.00, sub-Select = -29.00; cwt = 45.4 kg (100 lb).

[††] Carcass premiums and discounts ($/cwt) for USDA Quality Grade: Prime = 17.00, Choice = 0.00, Select = -20.00, sub-Select = -33.00; cwt = 45.4 kg (100 lb).

[‡‡] Carcass premiums and discounts ($/cwt) for USDA Quality Grade: Prime = 21.00, Choice = 0.00, Select = -25.00, sub-Select = -37.00; cwt = 45.4 kg (100 lb).

[§§] Differences in net return means [(total pen revenue – total pen cost) / carcass] compared to a referent (ref) category with varying Choice-Select spreads (with Prime and sub-Select premiums and discounts adjusted accordingly); the dressed-fed cattle base price was fixed at 196.00 $/cwt; feed and yardage price was fixed at 320.00 $/907 kg (2,000 lb) dry matter.

[a,b] Uncommon superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

Table 4.5. Model-adjusted mean differences and standard errors of the differences (SED) for estimated net returns of beef feedlot heifers administered one of two implant programs and fed for three differing days-on-feed (DOF) from sensitivity analyses with varying feed and yardage prices on a live or dressed cattle sale basis while holding all other budget components constant*

	Implant program†				Days-on-feed‡					*P*-value
Feed and yardage price	IH + 200	XH	SED	*P*-value	BASE	+ 21	+ 42	SED	*P*-value	Implant × DOF
Live sales net return, $/animal§										
$230.00 / 907 kg DM	ref	-9.30	4.270	0.04	ref	-1.76	-9.73	5.230	0.14	0.49
$275.00 / 907 kg DM	ref	-10.26	4.381	0.03	ref[a]	-12.32[a]	-30.51[b]	5.366	< 0.01	0.37
$320.00 / 907 kg DM	ref	-11.22	4.512	0.02	ref[a]	-22.89[b]	-51.29[c]	5.526	< 0.01	0.27
$365.00 / 907 kg DM	ref	-12.18	4.661	0.02	ref[a]	-33.46[b]	-72.07[c]	5.709	< 0.01	0.20
$410.00 / 907 kg DM	ref	-13.15	4.827	< 0.01	ref[a]	-44.02[b]	-92.85[c]	5.912	< 0.01	0.14
Dressed sales net return, $/carcass‖										
$230.00 / 907 kg DM	ref	-16.29	6.025	< 0.01	ref	12.89	14.10	7.379	0.11	0.60
$275.00 / 907 kg DM	ref	-17.13	6.238	< 0.01	ref	2.65	-6.37	7.640	0.48	0.51
$320.00 / 907 kg DM	ref	-17.98	6.466	< 0.01	ref[a]	-7.60[a]	-26.83[b]	7.919	< 0.01	0.44
$365.00 / 907 kg DM	ref	-18.82	6.708	< 0.01	ref[a]	-17.85[a]	-47.29[b]	8.215	< 0.01	0.37
$410.00 / 907 kg DM	ref	-19.66	6.961	< 0.01	ref[a]	-28.09[b]	-67.75[c]	8.526	< 0.01	0.32

* Data are from pooled analyses from three trials described by Horton et al. (2023), using a 2 × 3 factorial treatment arrangement in a randomized complete block design with 10,583 crossbred beef heifers that were blocked by arrival within trial and allocated to pens (144 total) which were randomized to treatment (within block), resulting in 24, 72, and 48 replications of simple effects, implant program effects, and DOF effects, respectively.

† Implant programs: XH = cattle implanted only at trial enrollment with Revalor-XH (Merck Animal Health, Lenexa, KS), a dual-component extended release implant with a total of 200 mg trenbolone acetate (TBA) and 20 mg estradiol (E_2); or IH + 200 = cattle implanted at trial enrollment with Revalor-IH (Merck Animal Health; 80 mg TBA and 8 mg E_2) and re-implanted with Revalor-200 (Merck Animal Health; 200 mg TBA and 20 mg E_2) after approximately 90 DOF.

‡ Days-on-feed: cattle were fed to a feedlot standard baseline (BASE) endpoint, or an additional + 21 or + 42 DOF beyond BASE (within block).

§ Differences in net return means [(total pen revenue – total pen cost) / animal shipped] compared to a referent (ref) category with varying feed and yardage prices; 907 kg = 1 US ton (2,000 lb); DM = dry matter; the live-fed cattle price was fixed at 125.00 $/cwt.

‖ Differences in net return means [(total pen revenue – total pen cost) / carcass] compared to a referent (ref) category with varying feed and yardage prices; the dressed-fed cattle base price was fixed at 196.00 $/cwt; carcass premiums and discounts ($/cwt) for USDA Quality Grade were fixed at 15.00, 0.00, -15.00, and -29.00 for Prime, Choice, Select, and sub-Select grades, respectively.

a,b,c Uncommon superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

Chapter 5 - Stochastic modelling of economic risk and net return distributions for feedlot steers marketed at alternative endpoints

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Abstract

Feedlot cattle in the U.S. have been progressively fed to heavier, more extreme endpoints (EPs) in recent decades. The primary objective was to evaluate the economic risks associated with extending days-on-feed (DOF) by characterizing net return distributions of feedlot steers fed to later EPs, compared to current industry standards. Stochastic simulation modeling was employed to simulate a variety of conditions, including cattle performance, health, carcass characteristics, and economic market variability at the pen-level. The model was parameterized using data from a large commercial feedlot trial and industry reports. The trial involved cattle harvested at four EPs (EP1, EP2, EP3, EP4), each separated by 14 DOF. EP1 represented the industry standard, with live and carcass weights reflective of industry averages from 2021 to mid-2024. The model's final outcome was net return difference – the difference in net returns for EP2, EP3, and EP4 compared to if pens had alternatively been marketed at EP1 under a given set of simulated conditions. Conditional random forest models were used to compute variable importance scores to determine the most influential factors on net return differences. Results indicated that as steers were fed to later EPs, net return distributions widened, reflecting increased economic risk. Steers marketed on a dressed (carcass) basis using a grid for premiums and discounts showed a higher frequency of negative net returns compared to a live marketing basis, primarily due to discounts for Yield Grade and heavyweight carcasses. Across both sale basis, negative net returns became more frequent with increasing EPs. The most influential variable was the difference in fed cattle prices received between later-fed EPs and EP1, accounting for price changes when delaying marketing. Other important economic factors included base fed cattle prices, corn prices, and the Quality Grade grid when grid marketing. Mortality risk was the most significant non-economic variable, while other animal performance variables, such as weight and carcass traits, were of marginal to minimal importance. These findings highlight the dominant role of economic factors on influencing net returns when feeding steers to later EPs, emphasizing the need to prioritize market conditions in EP management decisions.

Keywords: beef, days-on-feed, economics, endpoint management, feedlot, net return, steers, stochastic simulation

Introduction

Over the past several decades, feedlot cattle in the U.S. have been fed to increasingly heavier endpoints (Livestock Marketing Information Center; LMIC). Although the beef-cow herd size has declined over the last 50-plus years, total beef production has continued to rise due to advancements in genetics, technologies, and management practices (Wileman and Thomson, 2010; Meyer and Gunn, 2015). Numerous research efforts have evaluated the effects of extending days-on-feed (DOF) on the performance and carcass characteristics of feedlot cattle, providing guidance on endpoint (EP) management. Much of this work has been summarized by Galyean et al. (2023). As feedlot cattle are fed longer, they accumulate more total weight and fat deposition, leading to higher U.S. Department of Agriculture (USDA) Quality and Yield Grades (QG and YG, respectively). However, live performance metrics such as daily gain and feed efficiency decline as DOF increases. This trend can be misleading, as the rate of carcass weight gain may increase while live weight gain rates decrease (Wilken et al., 2015). This is because carcass weight gain as a proportion of live weight gain increases as steers and heifers are fed for longer periods. This concept, known as carcass transfer or incremental dressing percentage, has been documented by several studies (Streeter et al., 2012; Walter et al., 2018; Ohnoutka et al., 2021; Horton et al., 2023). Thus, when extending the DOF of feedlot cattle, it may be advantageous to market them on a dressed (carcass) basis rather than by live weight (Wilken et al., 2015; Horton et al., 2024), due in part to incremental dressing percentage.

Although extensive research has been conducted on differing DOF and feedlot cattle EPs, concurrent economic analyses have been relatively scarce, despite economics being a major consideration for producers. It has been suggested that profitability may increase by feeding steers beyond industry norms (Wilken et al., 2015; Poss et al., 2022). It is also important to consider that the cost of underfeeding cattle may be lower than the cost of overfeeding beyond an "optimal" EP (Koontz et al., 2008). However, current industry weights now surpass those referenced in these studies, reflecting shifts in industry standards. In a sensitivity analysis of economic factors, Horton et al. (2024) found minimal evidence supporting feeding beef heifers beyond a baseline EP. Their study demonstrated that net return differences are influenced by variable market conditions. Horton et al. (2024) characterized the relative impact of individual pricing variables on net returns while holding other factors constant. While this approach is valuable for isolating effects of individual variables, economic factors and cattle populations fluctuate concurrently. As a result, the potential range of outcomes is broader than those described by Horton et al. (2024), with different combinations of market conditions and cattle characteristics potentially leading to varying optimal EPs for feedlot cattle.

An important consideration in extending DOF is added risk. Economic risk includes inherent uncertainty of variable market conditions (Rushton, 2007). Various methods of analysis can account for economic risk, with stochastic simulation being a widely accepted strategy for modeling and characterizing such uncertainty (Corbin and Griffin, 2006; Rushton, 2007). Stochastic simulation involves specifying variables of interest within probability distributions, accounting for correlations between and within variables, and simulating numerous iterations – often thousands – to generate distributions of potential outcomes under varying conditions (Corbin and Griffin, 2006). This approach has been applied to address a variety of economic issues in animal agriculture (Belasco et al., 2009; Silva et al., 2017; Dennis et al., 2020).

A substantive task in stochastic simulation is deciding what to model as stochastic and parameterizing the model. Recently, Martinez et al. (2023) conducted a robust randomized controlled trial evaluating effects of feeding steers beyond industry-standard EPs. Using trial data combined with other industry data to parameterize a stochastic simulation model enables the characterization of economic risk when feeding steers to later EPs under recent market conditions. This information is valuable for producers and industry stakeholders, as it provides expected variability of net returns when feeding to alternative EPs. Therefore, the primary objective of this study was to characterize and evaluate marginal net return distributions for beef feedlot steers fed to later EPs by using stochastic simulation of key economic and performance variables, with cattle marketed either live or dressed with a carcass-based premium and discount grid. A secondary objective was to assess the relative importance of economic and cattle performance variables on net return variation when feeding to later EPs, and to describe the conditions of these variables when extended feeding was unfavorable or advantageous.

Materials and Methods

Background information

A combination of industry reported data and trial data (Martinez et al., 2023) were used for parameterization of a stochastic cattle feeding net return simulation model. The trial employed a 3 × 4 factorial design with implant program (IP) and days-on-feed (DOF) as factors in a randomized complete block design. Three IP treatments were compared: a single extended-release implant at initial processing, and two re-implant programs with differing timing of terminal implant delivery. Treatments in the DOF factor were steers harvested at 166, 180, 194, or 208 DOF. A total of 6,840 crossbred beef steers were blocked by arrival, and pens were randomly assigned to treatment within block. Blocks were allocated over three enrollment periods spanning different seasons: fall 2019; late spring 2020; and late winter to early spring, 2021. The trial was conducted at a commercial feedlot in the Texas Panhandle. For further detail (e.g., dietary formulations, cattle management), the reader is referred to Martinez et al. (2023).

For the simulation model, most published results from Martinez et al. (2023) could not be used for parameterization as we required either different or alternative forms of the outcomes. Raw data were obtained for the analyses, hereafter referred to as "trial data." We reclassified the DOF factor as "endpoint" (EP), since actual DOF are relative to initial body weight (BW). We evaluated four feedlot steer EPs which are characterized by final weight and carcass composition, each separated by 14 DOF. Therefore, the four DOF treatments were classified as Endpoint 1, Endpoint 2, Endpoint 3, and Endpoint 4 (EP1, EP2, EP3, and EP4, respectively).

The simulation model framework considered only events occurring after EP1, as prior conditions are irrelevant for assessing the incremental economic impacts of extending DOF. Analysis of the trial data (described in later section) showed no significant IP × EP interactions for outcomes required for parameterization. Therefore, only main effect estimates of EP were used for parameterization, as there was no evidence that EP estimates depended on IP treatment.

Simulation model framework

Each individual simulation (i.e., iteration) compared four scenarios representing the same pen of feedlot steers marketed at each of the four EPs. The key question was: *what* would have been the marginal net return difference *if* we had marketed the same pen at each EP? Although producers ultimately need to decide on a single marketing date (EP) in advance, and what would have happened to net returns at alternative EPs is largely unknown, by framing the simulations in this manner, we can better inform producers or other decision-makers by providing net return expectations when marketing at these alternative EPs. In essence, each iteration simulated net returns for the same pen, *if* it had been fed to EP1, *if* it had been fed to EP2, *if* it had been fed to EP3, or *if* it had been fed to EP4, ultimately computing marginal net return differences for EP2, EP3, and EP4 compared to EP1. Endpoint 1 represents the contemporary industry standard; thus, marketing earlier than EP1 was not considered. Since our interest is in the marginal net return differences compared to EP1, only gross revenue is simulated for EP1, as prior costs (e.g., feeder cattle purchase, feed cost, health events) are "sunk" and constant across EPs, and would not impact net return differences. For EP2, EP3, and EP4, costs associated with longer feeding were incorporated, along with revenue. All simulations were conducted at the pen-level, with EP1 having 200 steers marketed. We considered two primary sale bases: which were *if* the steers were marketed on a live basis, or *if* the steers were marketed dressed (i.e., carcass) basis with a premium and discount grid (termed "grid sale basis"). Marketing on a dressed-cash basis without grid was also evaluated, but as relatively few cattle are sold in this manner in the U.S., results are confined to supplementary material and are minimally discussed.

The simulation model was stochastic, with random values drawn from specified probability distributions for each simulated economic and cattle variable (health, performance, carcass characteristics). Furthermore, correlation matrices were used to account for relationships between and within simulated variables. Some variables were held constant across simulations, varied in a sensitivity analysis, or predicted based on estimated regression relationships with a simulated variable.

In each iteration, EP1 serves as a baseline with simulated characteristics (e.g., weight, distribution of QG and YG) that are then built upon correspondingly for later EPs using correlation matrices or simulated coefficients (e.g., average daily gain). Events occurring between EPs (e.g., mortalities) were carried over to subsequent EPs, linking them together. Revenue was calculated for all EPs by multiplying cattle variables by corresponding pricing variables. For EP2, EP3, and EP4, added production costs and costs from adverse health events were subtracted to obtain net return post extended DOF. Marginal pen-level net return differences compared to EP1 were computed by subtracting EP2, EP3, and EP4 returns from EP1 revenue. This partial budgeting approach measures the dollar gain or loss when feeding the pen beyond EP1, without estimating overall profitability since costs prior to EP1 are not included. For interpretation, pen-level net return differences are converted to net return difference per animal marketed. With the simulation model framework described, components are detailed in the following sections.

Statistical analyses of simulation model variables

Variables from the trial data used to parameterize the simulation model were validated, and their estimates and variability were extracted. Validation involved: (1) evaluating potential IP × EP interactions; (2) testing for treatment effects and linear and quadratic effects of EP; and (3) generating parameter estimates for use in the simulation model. General and generalized linear mixed models (LMM and GLMM, respectively) were employed (Proc GLIMMIX, SAS 9.4; SAS Institute Inc., Cary, NC), with pen as the experimental unit. To assess validations (1) and (2), IP, EP, and the IP × EP interaction were modeled as fixed effects, with random intercepts for period (n = 3 enrollment periods) and block within period to account for clustering. Linear and quadratic orthogonal polynomial contrasts for EP were included. Continuous outcomes [i.e., dry matter intake (DMI), final body weight (BW), and hot carcass weight (HCW)] were modeled using LMM with a Gaussian distribution, identity link function, Kenward-Roger degrees of freedom adjustment, and restricted maximum likelihood estimation. Model assumptions of normality and homogeneous residual variances were assessed visually using plots of conditional and marginal studentized residuals. Ordinal outcomes (i.e., QG and YG) were modeled using GLMM with a multinomial distribution, cumulative logit link function, Kenward-Roger degrees of freedom adjustment, and residual pseudo-likelihood estimation. Since these ordinal data were at the individual carcass-level (unlike pen-level for other outcomes), an additional random intercept for pen was included to account for clustering of steers within pens. Significance was declared a priori at $\alpha = 0.05$.

There were no IP × EP interactions (*P*-values ≥ 0.27), indicating that incorporation of interactive effects into the simulation model was not needed. There also was no evidence of quadratic effects with increasing EPs (*P*-values ≥ 0.43). All outcomes had significant main (*P*-values < 0.01) and linear effects (*P*-values < 0.01) for EP, except for DOF, which had no significant EP (*P* = 0.29) or linear effect (*P* = 0.35). Notably, the DMI analyzed was for the final 14 days for each EP only (i.e., consumption prior to EP1 is irrelevant), as we tested whether differences in DMI between EPs existed during their final 14 DOF (corresponding to the 14 days separating each EP). The results indicate no evidence to suggest a change in mean DMI as DOF increased.

Simulation model parameterization

The simulations were performed using Python (Python Software Foundation, version 3.12.3), executed within a JupyterLab (Jupyter Team, version 4.2.2) environment. The primary Python packages utilized for the stochastic simulations were ‘NumPy’ (version 2.0.0) and ‘SciPy’ (version 1.14.0) for numerical computations, statistical distributions, and correlation matrices. When necessary, a Cholesky decomposition was used to generate correlated random variables, applying the decomposition to correlation matrices tailored to each variable's distribution (e.g., normal, logistic) to maintain realistic correlations among simulated outcomes. Additionally, ‘Pandas’ (version 2.2.2) was used for data manipulation, and ‘Matplotlib’ (version 3.9.0) along with ‘Seaborn’ (version 0.13.2) were employed for data visualization. The final outcome of the model was net return difference for EP2, EP3, and EP4 compared to EP1 under the alternative sale bases. To determine the total number of simulations, model convergence was defined by stabilization at specified percentiles. This was evaluated by initially performing 135,000 simulations and increasing the number by 45,000 until the values at percentiles (0.5, 2.5, 10, 25, 75, 90, 97.5, and 99.5) remained within a 1% change from the previous simulation count. Convergence on the median was not required because as certain values approach zero, small dollar changes can result in percentage changes exceeding 1%, which could prevent convergence or necessitate an impractically large number of simulations.

Economic variables

To frame this assessment under contemporary cattle populations and pricing conditions, we selected prices from January 1, 2021, through June 16, 2024. Mean cattle prices ($/cwt; cwt = 45.4 kg = 100 lb) used as inputs were rounded to the nearest $0.25/cwt (USD). Only two market prices were simulated: corn price and fed cattle price, both following log-normal distributions (see Table 5.1 for means and SDs). Corn prices were sourced from the LMIC grain prices database [compiled from USDA Agricultural Marketing Service (AMS) reports], specifically weekly prices for Kansas City #2 yellow corn. To approximate feed prices corresponding to simulated corn prices, we fitted a linear regression with feed and yardage price (FYP) as the dependent variable and corn price as the explanatory variable (Proc REG, SAS 9.4). Dry FYP were sourced from the CattleFax ration prices database (CattleFax, Centennial, CO) for the central plains region; since these prices are reported monthly, monthly corn prices were used for the regression. Feedlots use varying structures for feed markup and yardage – including feed markup with no yardage, no feed markup with yardage, and combinations thereof – so FYP are reported as a single sum. Yardage accounts for overhead costs associated with managing a feedlot (e.g., labor, equipment, utilities). The regression results are in Equation 1 (Equations section); corn price ($P < 0.01$) and its quadratic term ($P = 0.04$) were significant. In summary, the corn price ($/bu; 1 bushel = 25.4 kg = 56 lb) is simulated based on the parameterized distribution, and Equation 1 estimates FYP ($/dry US ton; 1 ton = 907 kg = 2,000 lb) from the simulated corn price. The same simulated corn price was used for all EPs within an iteration, assuming grain was contracted for the pen beforehand.

Unlike corn price, fed cattle prices were allowed to vary for each EP, mimicking real-world conditions where producers face uncertain and fluctuating prices when marketing cattle on different weeks. We evaluated the correlation between live fed cattle prices at four time intervals separated by two weeks from industry reported data (corresponding to the four EPs), resulting in a 4 × 4 correlation matrix where nearer time points have stronger relationships. All EPs used the same mean live fed cattle price and parameterization (Table 5.1), so the distribution of prices across EPs was consistent across simulations, but prices varied within each iteration. Live fed cattle prices were sourced from the "5 Area Weekly Weighted Average Direct Slaughter Cattle – Negotiated Purchases" report (LMIC; USDA AMS data) for steers sold live free-on-board on a negotiated cash basis. Dressed fed cattle base prices were calculated by dividing simulated live prices by 0.63, the mean ratio of live to dressed prices in the date range. For the grid marketing sale basis, the dressed base price was adjusted for premiums and discounts, dependent on the QG grid and simulated QG, YG, and heavyweight carcasses (described below and in later section).

The remaining economic variables not simulated are listed in Table 5.2. Carcass premiums and discounts for QG, YG, and heavyweight carcasses [over 476 kg (1,050 lb)] were sourced from LMIC's "5-Area Weekly Slaughter Cattle - Premiums and Discounts" report (USDA AMS data). Since premiums and discounts for YG and heavyweight carcasses are relatively constant, the YG grid and heavyweight discount were fixed across simulations at their approximate mean (Table 5.2). In contrast, QG fluctuate often; instead of simulating QG grids, we selected three grids to evaluate low, middle, and high reward scenarios in terms of their preference towards higher QG (Grids 1 to 3 in Table 5.2). One of the three QG grids was randomly selected in each simulation iteration, with each grid used equally. The grids were based on the Choice-Select spread (i.e., Select discount, as USDA sets Choice to zero), selecting low, moderate, and high values at equal intervals. The simulation model combined all carcasses grading sub-Select into a single category, using the discount for Standard carcasses. Linear regressions (Proc REG, SAS 9.4) with Select discount as the independent variable and Prime premium or sub-Select (Standard) discount as the dependent variable were performed to estimate corresponding values for each QG grid. Equation 2 shows the regression used to estimate Prime premiums, and Equation 3 shows the regression for sub-Select discounts (Equations section); in both, the Select discount and its quadratic term were significant (P-values < 0.05). As with fed cattle prices, premiums and discounts are on a \$/cwt basis. The grid-adjusted price in each iteration is calculated by multiplying the premiums and discounts from the QG grid, YG grid, and heavyweight discount by the proportion of carcasses in each category and adding the result to the base price (Feuz et al., 2003).

"Removals" are cattle culled from the pen for health reasons (i.e., railers) and sold separately at a discounted price. The number of removals was simulated (detailed later), and the price received for removals (\$/cwt HCW) was estimated by multiplying cull cow prices [dressed Breaker cows over 227 kg (500 lb)] by 0.92 (Horton et al., 2021). Cull cow prices were estimated via a linear regression (Proc REG, SAS 9.4) with live fed cattle price as the independent variable and cull cow price as the dependent variable, using data from LMIC's "Weekly National Direct Cows and Bulls" report (USDA AMS data). Live fed cattle price was a significant predictor ($P < 0.01$), as shown in Equation 4 (Equations section). While removals provided a revenue source (albeit discounted compared to finished cattle), other health events – treatments and mortalities – resulted in costs. Treatment costs were fixed at $23.60 per treatment (USDA-NAHMS, 2013). For mortalities, besides the loss of revenue, a $40.50 per mortality fee for rendering was applied; this is an inflation-adjusted value (Sparks Companies Inc., 2002; Horton et al., 2024).

The final components in the economic model were interest on feed and opportunity cost. In our model, opportunity cost refers to the cost associated with delaying revenue by marketing cattle at later EPs. To account for interest on feed and estimate opportunity cost, we chose three fixed yearly interest rates – 5%, 7%, and 9% – representing recent rates for operating loans (Ag Credit Survey, Federal Reserve Bank of Kansas City). Each rate was randomly selected for use in each simulation iteration (Table 5.2), with all rates used equally. Interest was not compounded. Opportunity cost was applied as a "penalty" to EP2, EP3, and EP4 for delaying marketing and not receiving revenue at EP1. To calculate it, the selected yearly interest rate was multiplied by the additional days to reach each later-fed EP (14, 28, or 42 days), divided by 365, and then multiplied by the total pen revenue received at EP1; this opportunity cost was applied to the corresponding later EPs. For interest on feed, we used the same randomly selected interest rate as for opportunity cost. The interest for EP2, EP3, and EP4 was calculated similarly and applied to 50% of the total pen feed and yardage cost to account for money borrowing.

Animal performance, carcass, and health variables

All animal performance, health, and carcass variables were simulated, except for the percentage of heavyweight carcasses, which was derived from the simulated HCW (Table 5.1). DMI was simulated from a normal distribution using the mean DMI (10.5 kg/day) and standard deviation averaged across all EPs over their final 14 DOF in the trial data. As previously noted, there was no evidence of DMI changing with increasing DOF; therefore, the same simulated DMI was used for EP2, EP3, and EP4 within each simulation iteration. Gross pen-level dry feed delivered was the simulated DMI multiplied by the number of animal-days (detailed in health simulations). To establish baseline final BW and HCW for EP1 in each iteration, we calculated the approximate mean (667 kg final BW, 431 kg HCW; rounded up) and standard deviation from the same LMIC database used for price sourcing, covering January 1, 2021, through June 16, 2024. These baseline weights and their variability reflect contemporary reported weights for steers marketed at EP1 and are nearly identical to EP1 weights in the trial data (Martinez et al., 2023). Final BW and HCW for EP1 were parameterized with a normal distribution (Table 5.1) and were correlated (a 2 × 2 matrix) so that within each iteration, final BW and HCW corresponded realistically.

After simulating baseline weights for EP1, we simulated the rate of gain on both live and carcass weight bases to calculate weights for EP2, EP3, and EP4 when extending DOF. To determine appropriate rates of gain, LMMs for final BW and HCW were fitted as described in the statistical analysis of simulation model variables section, except EP was modeled as a continuous variable for DOF rather than fixed. This resulted in adjusted coefficients expressed as weight gain per day (1.32 kg/day live BW gain, 1.00 kg/day HCW gain). This approach assumes linearity with increasing EP, supported by our trial data analysis. These coefficients were simulated (and correlated in a 2 × 2 matrix, similar to EP1 final BW and HCW) and multiplied by the additional DOF required for EP2, EP3, and EP4 to determine total weight gained. Within each iteration, the same simulated coefficients for weight gain were used across EP2, EP3, and EP4 to calculate their final live BW and HCW. The weight gain coefficients were simulated from a normal distribution, with SDs specified to produce 2.5^{th} and 97.5^{th} percentile values matching the 95% confidence interval (CI) around the mean weight gain coefficients from the LMMs (Table 5.1).

The simulation model accounted for changes in carcass characteristics affecting fed cattle marketing when extending DOF. Instead of simulating the percentage of heavyweight carcasses (weights > 476 kg), this was calculated by assuming a normal distribution of individual HCWs (with SD 38.6 kg) around the mean simulated HCW for each EP and determining the percentage exceeding the heavyweight threshold (Table 5.2). The same SD derived from the trial data of within-pen individual carcasses was used across all simulations.

Simulation of carcass YG and QG for each EP was based on multinomial GLMM analyses of the trial data, using a proportional odds framework (Dohoo et al., 2009). In this framework, the model estimated separate intercepts (log odds) for each grade, representing the probability of being in that grade or higher for EP1 (the referent EP). Referent grades were YG 1 and Sub-select, and their corresponding intercepts were dropped. This setup allowed establishment of a baseline distribution of YGs and QGs for EP1, from which subsequent EP distributions were adjusted – similar to how baseline live BW and HCW were simulated for EP1 before adjustments for sequential EPs. For each subsequent EP (EP2, EP3, EP4), the log odds for YG and QG were adjusted by adding coefficients derived from the GLMMs to the baseline EP1 intercepts, reflecting the proportional odds assumption. The mean log odds estimates for EP1 and coefficients used for EP adjustments are provided in Table 5.1. Once the log odds distributions for each EP were determined, they were transformed into probabilities of being in a given grade or higher. Individual probabilities for each grade were calculated by subtracting the probability of being in the next higher grade. For example, the transformed probabilities for EP1 YG resulted in median values of 2.7%, 12.5%, 38.5%, 37.2%, and 9.2% for YG 5, 4, 3, 2, and 1, respectively.

To simulate YG and QG distributions, we employed logistic simulations aligned with the proportional odds framework, using correlation matrices derived from the GLMMs. These matrices (a 4 × 4 and 3 × 3 matrix for YG and QG, respectively) accounted for relationships between grades in the EP1 baseline distribution, ensuring that grades closer together were more correlated, preserving biological realism of the distributions. Log odds coefficients for adjusting the baseline distribution for subsequent EPs were generated with correlated simulations (a 3 × 3 matrix) to ensure consistent proportional changes between EPs within each iteration. Scale parameters in the logistic simulations controlled the spread of the distributions, parameterized to produce 2.5^{th} and 97.5^{th} percentile log odds matching the 95% CI of intercepts and coefficients from the GLMM estimates. In summary, each simulation iteration began by generating a baseline distribution of YG and QG for EP1, resulting in a range of low to high grading pens with mean distributions similar to the trial data. The baseline distributions were then adjusted for subsequent EPs using the simulated log odds coefficients, creating upward shifts. Finally, distributions were converted into percentage values through backtransformation and subtraction, representing the proportion of carcasses in each YG and QG category for each EP.

We assumed that risk of health events occurring before harvest increases with additional DOF. Although most health events in feedlots occur early in the feeding period (Edwards, 1996; Sanderson et al., 2008; Babcock et al., 2009), the risk during extended feeding was expected to be small, but potentially costly. To parameterize health outcomes (morbidity, removal, mortality), additional GLMMs were fitted using the trial data. Health data for EP1 pens were excluded, and only events occurring after EP1 harvest (within block) for EP2, EP3, and EP4 pens were included. These pen-level count data were analyzed with random-effects-only GLMMs using a Poisson distribution and log link function, with block within season as a random intercept and log animal-days at risk as the offset. The models first employed a Laplace approximation to evaluate overdispersion; in the absence of overdispersion, they were re-fitted using residual pseudo-likelihood estimation. The intercept (log incidence rate ratio) was backtransformed to obtain the model-adjusted mean incidence per animal-day at risk. Mean incidence rate estimates for morbidity, removal, and mortality were multiplied by 1,000 for interpretation and are expressed in Table 5.1 as events per 1,000 animal-days at risk. Note that for pens where no simulated fallouts (removal or mortality) occur, there would be 2,800, 5,600, and 8,400 animal-days at risk for EP2, EP3, and EP4, respectively.

Health events were simulated from a Poisson distribution, parameterized using the incidence rates specified in Table 5.1 and the total animal-days at risk for each EP within each iteration. Since in a Poisson distribution the variance equals the mean, no separate measure of variability is used. Health events occurring between EPs were carried over to the next EP. For example, if two removals occurred between EP1 and EP2, those removals would also be present at EP3, plus any additional removals occurring between EP2 and EP3, and so on. Also, revenues from removals in earlier EPs carried over to subsequent EPs. Fallouts reduced the number of animal-days at risk for subsequent EPs, as there were fewer animals to experience health events. These adjusted animal-days were also used for calculating pen-level DMI. Since the Poisson simulations did not specify when health events occurred within the interval, we assumed animal fallouts occurred midway between EPs (on day 7 of 14), contributing 7 animal-days, while other animals contributed 14 animal-days. We assumed removals weighed the simulated HCW of the prior EP for calculating revenue from these animals, therefore, the removal price was estimated using the fed cattle price from the prior EP as the predictor variable in Equation 4 (Equations section), simplifying the estimation process. Finally, the number of animals marketed in the pen for EP2, EP3, and EP4 was the initial number marketed at EP1 (200) minus any animal fallouts.

Final calculations

After simulating all economic and cattle variables, we calculated the net return differences between EPs. For EP1, only revenue from fed cattle sales was considered, while for EP2, EP3, and EP4, both revenues (from fed cattle sales and removals) and costs associated with extended feeding were included. All calculations were performed at the pen-level until the final step. Total pen weight for each EP was calculated by multiplying the simulated final BW or

HCW by the final number of animals marketed. Revenue from fed cattle sales was determined based on the marketing strategy. Returns for the later-fed EPs were calculated by subtracting total pen costs from total pen revenue under each sale basis. Marginal net return differences for EP2, EP3, and EP4 compared to EP1 were computed by subtracting the total pen returns of these EPs from EP1's total pen revenue in each simulation iteration and converting the results to per-animal marketed values.

Data evaluation and visualization

Analyses and reporting of results were mainly descriptive, as minimal statistical tests are appropriate with simulated data. For our primary objective, distributions of net return differences for EP2, EP3, and EP4 were visualized with overlaid density plots, along with boxplots with rainclouds (strip plots). Due to the large number of simulations, rainclouds used a random subsample of the data for improved visualization, while boxplots used the full dataset. Specific percentile values are also reported in tabular formats for precision.

To address our secondary objective of identifying variables that most influenced net return differences, we used conditional random forest models to compute variable importance scores. Conditional random forests, which implement a conditional permutation scheme for computation of importance scores, mitigate biases from correlated predictor variables better than traditional random forests (Strobl et al., 2008). While random forests are primarily employed for predictive purposes, they can be a tool for causal inference through importance scores with certain assumptions (van der Laan, 2006). Models were built using the ‘party’ package (version 1.3-15; Strobl et al., 2008) and used ‘permimp’ (version 1.0-2; Debeer and Strobl, 2020) for faster computation importance scores, in R (version 4.4.1; R Core Team, 2024), which was called within a JupyterLab environment using the ‘rpy2’ (version 3.5.16) interface for the execution of R code embedded in Python processes. We constructed nine models – one for each EP within each of the three sale bases – and summarized the variable importance scores within each sale basis. Only importance scores were evaluated; predictive accuracy was not assessed, as our purpose was to visualize and rank the variables by importance for their impact on net returns. Due to processing demands, a random subsample of the simulated data was used, with sample size and number of trees increased until variable importance rankings stabilized. Models used a fixed number of randomly sampled variables selected as candidates at each split (node) in the trees (‘mtry’ n = 4), which was the square-root of the number of parameters included, rounded up. Predictor variables for live and dressed-cash sale bases included DMI, final weight, weight gain, number of treatments, removals, mortalities, corn price, fed cattle price, price difference compared to EP1, interest rate, and opportunity cost. For the grid sale basis, additional variables were percent heavyweight carcasses, percent Choice or better carcasses (proxy for QG), percent YG 4 and 5 carcasses (proxy for YG), and the QG grid. After model execution, raw scores were scaled from 0 to 100 and variables were ranked by importance.

Lastly, we categorized the simulated data based on the magnitude and direction of net return differences for EP2, EP3, and EP4 to visualize changes in variables of interest and identify conditions under which feeding to a later EP was advantageous or not. Net return differences were grouped into five categories: less than $-25/animal, $-25 to $-5/animal, $-5 to $5/animal, $5 to $25/animal, and greater than $25/animal compared to EP1. This framework allowed us to evaluate the frequency of simulations in each category and to descriptively assess variable values when net return differences ranged from negative to positive.

Equations

Equation 1: where FYP = feed and yardage price, $Corn_P$ = corn price, RMSE = 21.80, R^2 = 0.88.

$$FYP = 26.80 + 71.64Corn_p + -2.97Corn_p^2$$
$$\pm SE = (36.18) \quad (14.87) \quad (1.40)$$

Equation 2: where Prime = Prime premium, Select = Select discount, RMSE = 4.51, R^2 = 0.13.

$$Prime = 17.05 + 0.35Select + 0.02Select^2$$
$$\pm SE = (0.76) \quad (0.11) \quad (0.004)$$

Equation 3: where sub-Select = sub-Select discount, Select = Select discount, RMSE = 1.72, R^2 = 0.93.

$$sub\text{-}Select = -14.61 + 1.00Select + 0.004Select^2$$
$$\pm SE = (0.29) \quad (0.04) \quad (0.001)$$

Equation 4: where $CCow_P$ = cull cow price, Fed_P = live fed cattle price, RMSE = 17.21, R^2 = 0.75.

$$CCow_p = -27.18 + 1.30Fed_p$$
$$\pm SE = (4.42) \quad (0.03)$$

Results

Model convergence was achieved with 360,000 simulations. Distributions of the simulated economic, cattle performance, carcass characteristics, and health outcomes are reported in Supplemental Tables 5.1 to 5.4.

Figures 5.1 and 5.2 illustrate the distributions of net return differences for EP2, EP3, and EP4 compared to EP1 when marketing on live and grid sale bases, respectively. Median net return differences were negative for EP2, EP3, and EP4, under both sale bases, indicating that feeding to later EPs was more frequently disadvantageous than not. When live marketing, net return differences were positive (greater than $0/animal) in 45.4%, 43.7%, and 42.0% of the simulations for EP2, EP3, and EP4, respectively. When grid marketing, net return differences were positive in 44.1%, 38.4%, and 29.1% of the simulations for EP2, EP3, and EP4, respectively. As expected, EP2 exhibited a narrower distribution around the median, while EP3 and EP4 showed wider distributions, suggesting increased potential gains but also greater risk of substantial losses with extended feeding. In contrast to live marketing (Figure 5.1), EP3 and EP4 had more pronounced shifts toward negative net returns when marketing on a grid basis (Figure 5.2). Table 5.3 presents the percentile values of these distributions for both sale bases. When marketing on a live basis, net return differences for EP2, EP3, and EP4 became positive by the 60th percentile. On a grid basis, net returns turned positive by the 60th, 70th, and 80th percentiles for EP2, EP3, and EP4, respectively. When net returns were negative at any given percentile, returns declined consistently with increasing EP for both sale bases. When live marketing, EP3 net returns exceeded EP2 above the 60th percentile, and EP4 surpassed both EP2 and EP3 above the 70th percentile. In contrast, on a grid basis, EP3 did not surpass EP2 until the 80th percentile, and EP4 only exceeded EP2 and EP3 at the 97.5th percentile. Lastly, EP2 distributions were similar between live and grid marketing, with slightly lower negative values on a grid basis that narrowed and ultimately resulted in slightly higher positive values at greater percentiles. Conversely, EP3 and EP4 net returns were almost always lower at every percentile on a grid basis compared to live. Supplemental Figure 5.1 and Supplemental Table 5.5 show net return distributions when marketing on a dressed-cash basis. Contrary to live and grid models, median net return differences compared to EP1 were positive for each later-fed EP and increased with each incremental EP.

Table 5.4 shows categorized range frequencies of net return changes for EP2, EP3, and EP4 compared to EP1 for live and grid sales. On a live basis, net returns exceeding $5/animal compared to EP1 occurred in 41.6%, 41.2%, and 39.8% of the simulations for EP2, EP3, and EP4, respectively. Conversely, a loss of -$5/animal or more occurred in 50.9%, 53.8%, and 55.9% of the simulations for EP2, EP3, and EP4, respectively. When marketing on a grid basis, more than $5/animal was returned for later-fed EPs compared to EP1 in 40.7%, 36.2%, and 27.5% of the simulations for EP2, EP3, and EP4, respectively. In contrast, a loss of -$5/animal or more occurred in 52.3%, 59.3%, and 69.2% of the simulations for EP2, EP3, and EP4, respectively, when marketing on a grid.

For ranking conditional variable importance scores, the conditional random forest models were deemed stable using a 12.5% random subsample of the simulated data (n = 45,000 samples) and 200 trees. Under the chosen parameters, the average run-times for the conditional random forest models were 19.3 hours for live, 23.9 hours for dressed-cash, and 37.2 hours for grid sale basis models, leading to a total processing time of 10 days across the final models. The conditional importance scores are determined via permutation accuracy, which in essence evaluates changes in predictive accuracy of the model with and without each variable included (Strobl et al., 2008). Raw scores do not necessarily have a straightforward or intuitive meaning (hence scaling to 100); therefore, only relative magnitudes and rankings of the scores are compared. For visualization, variables are sorted by their EP3 score ranking. When marketing live (Figure 5.3), the most important variable, by a substantial margin, was the live fed cattle price difference—the marginal difference in fed cattle price received for each EP compared to EP1. The next "cluster" of variables with higher importance included corn price, the live fed cattle price itself, and the number of mortalities. In terms of rankings (from high to low, 1 to 11; Figure 5.3), corn price and live fed cattle price were more important for EP3 and EP4 than the number of mortalities. Conversely, mortalities were potentially more influential for EP2 net return differences than corn price or live fed cattle price. Variables such as DMI, interest rate, and final live BW had marginal to low importance scores, while removals, opportunity cost, live weight gain rate, and the number of treatments were of minimal importance.

When marketing on a grid basis (Figure 5.4), variable importance scores were similar to live marketing, with a few additions. The difference in dressed fed cattle price compared to EP1 remained the most critical variable. The next tier encompassed the corn price, dressed fed cattle base price, the number of mortalities, and now included the QG grid number. Rankings (from high to low, 1 to 15; Figure 5.4) in this cluster were consistent for EP3 and EP4, with minor switches between corn price and dressed base price. Mortalities were again of greater relative importance for EP2 than other variables in this cluster, contrasting EP3 and EP4. Interest rate and DMI were arguably the only two variables with marginal importance when grid marketing, depending on the EP. The remaining variables, including the percentage of carcasses grading Choice or better (Choice plus), the percentage of YG 4 and 5 carcasses, and the percentage of heavyweight carcasses, were of minimal importance. Variable importance scores when marketing on a dressed-cash basis are shown in Supplemental Figure 5.2.

Since the difference in fed cattle prices compared to EP1 was the most influential factor in net return differences, these price differences are visualized in Figure 5.5, which shows the distributions of live fed cattle price changes from EP1 across each EP when marketing on a live basis; additional descriptive statistics are in Supplemental Table 5.6. As expected, receiving lower fed cattle prices than EP1 at later EPs was associated with lower net returns, and vice versa. As EPs increased, the price change distributions within net return categories (except for the < $-25/animal category) shifted upward, indicating that larger price increases were more often needed for later-fed EPs to achieve higher net returns compared to EP1. Additionally, the spread of live fed cattle price differences widened with increasing EPs, reflecting increased price volatility as feeding horizons lengthen.

Grid marketing results (Figure 5.6) are similar to live marketing. Except in the < $-25/animal category, the distributions of dressed fed cattle base price changes within net return categories also shifted upward and widened as EPs increased. A notable difference in grid marketing is that larger differences in the dressed base price were more often required for net returns to increase with later EPs compared to live marketing. For example, the median live fed cattle price differences (vs. EP1) for the $5 to $25/animal net return category were $1.31, $1.65, and $1.89/cwt for EP2, EP3, and EP4, respectively. In contrast, when marketing on a grid, the median dressed base price differences were $2.15, $3.46, and $5.51/cwt for EP2, EP3, and EP4, respectively (Figure 5.6; Supplemental Table 5.6). These values not only incrementally increased more with each subsequent EP when marketing on a grid, but were also substantially higher overall than live marketing. While dressed fed cattle prices are inherently higher than live prices due to the live-to-dressed conversion factor (0.63), the median values specified surpass this ratio. The most extreme examples occurred with EP4, where much higher price changes were frequently required to observe increased net returns. For instance, even in the net return category where $-25 to $-5/animal was lost, the median dressed base price difference was $3.19/cwt, with an interquartile range (IQR) of $0.51 to $5.70/cwt (i.e., all higher prices than EP1). While some instances of near-zero or negative price changes from EP1 resulted in increased net returns for later-fed EPs, these occurrences were infrequent. Distributions of dressed base price differences when marketing on a dressed-cash basis are in Supplemental Figure 5.3.

Although the difference in fed cattle prices received was the most influential factor on net returns, other important variables also showed notable characteristics within net return categories. Supplemental Table 5.6 provides descriptive statistics for all common variables used in the random forest models (Figures 5.3 and 5.4), categorized by net return category and EP. The most noteworthy observations are that the descriptive statistics align with the implications of the variable importance scores. For instance, as net return categories moved toward more positive returns, fed cattle prices increased, while corn prices decreased. The median and IQR values for the number of mortalities remained relatively unchanged across net return categories; however, the mean number of mortalities tended to decrease as net returns improved. Variables previously described as marginally important, such as DMI and interest, showed slight differences across net return categories. In contrast, variables identified as the least important (e.g., final live BW or HCW, weight gain, treatments) exhibited very similar statistics across net return categories, supporting their lower importance.

Additional variables included in the conditional random forest models for the grid sale basis only were grid number, percent of YG 4 and 5 carcasses, percent of Choice and Prime carcasses, and percent of heavyweight carcasses. The grid number, in particular, was part of the cluster of variables with higher importance (after the dressed base price difference). Table 5.5 shows frequency statistics for each grid number within net return difference categories and EP. For EP2, EP3, and EP4, grid number 2 occurred relatively consistently, about 33% of the time, across all net return categories. However, as net return increased, the frequency of grid number 1 decreased, while the frequency of grid number 3 increased, regardless of EP (Table 5.5). While a higher grid number was not necessarily required to achieve higher net return categories (grid number 1 occurred in the > $25/animal category 28.9%, 28.5%, and 27.3% of the time for

EP2, EP3, and EP4, respectively), grid number 3, which gives the greatest reward to higher QGs, was more commonly associated with higher net return differences. Specifically, grid number 3 occurred 38.1%, 38.4%, and 39.9% of the time for EP2, EP3, and EP4, respectively, in the > $25/animal category. While grid number was important for QG premiums and discounts, it was interesting to note that the percentage of Choice-plus carcasses, YG 4 and 5 carcasses, and heavyweight carcasses had minimal importance in the conditional random forest models (Figure 5.4). Descriptive statistics for these variables are available in Supplemental Table 5.8. Overall, the descriptive statistics align with the variable importance scores, as there were minimal differences – unlikely to be biologically meaningful – when evaluating these carcass characteristics across net return categories and within EPs.

Given the limited literature on the opportunity cost of extending DOF in feedlot steers, we provide a more detailed description of our findings. Descriptive statistics of opportunity cost for live and grid sale bases, broken down by net return category within each EP, are provided in Supplemental Table 5.6. However, these values are not distinguished by interest rate. When live marketing, for each additional 14 DOF beyond EP1, the median opportunity cost [95% inter-percentile range (95IPR; 2.5^{th} to 97.5^{th}) in parentheses] was $4.23 ($3.06 to $5.85), $5.92 ($4.28 to $8.18), and $7.60 ($5.50 to $10.53) per animal at interest rates of 5%, 7%, and 9%, respectively. When grid marketing, the median opportunity cost for each additional 14 DOF beyond EP1 was $4.20 ($2.99 to $5.86), $5.87 ($4.18 to $8.20), and $7.55 ($5.38 to $10.56) per animal at interest rates of 5%, 7%, and 9%, respectively.

Because no direct comparisons were made between marketing scenarios, nor between EP2, EP3, and EP4 (all comparisons were with EP1 within each sale basis), between-variable correlations (e.g., live BW gain and HCW gain) were not impactful and altering the matrices did not affect net return distributions. However, within-variable correlations (i.e., YG, QG, and fed cattle prices across EPs) were critical and had strong impacts on the results. Therefore – for reproducibility purposes – these matrices are provided in Supplemental Table 5.9.

Discussion

Results presented here are applicable to contemporary feedlot steer populations under recent market conditions. Numerous research efforts have evaluated the performance and carcass changes of feedlot steers and heifers when extending DOF. Much of this work has been pooled and summarized in a comprehensive multi-trial analysis (Galyean et al., 2023). However, the studies included in Galyean et al.'s (2023) analysis may not necessarily reflect current standards for cattle populations which have been progressively fed to heavier EPs with higher QG and YGs. In contrast, the trial data used to support parameterization of the simulation model represents contemporary cattle populations (EP1) and evaluates feeding to more extreme EPs than previously reported. Although one might argue for using a wider date range for cattle and grain market prices to illustrate longer-run distributions of potential outcomes, this introduces challenges like apparent structural changes in premiums and discounts for grid-marketed cattle, particularly for heavyweight and YG 4 and 5 discounts, which have substantially decreased in recent years (LMIC). Therefore, we focused on a shorter time frame reflecting contemporary populations and economic conditions, recognizing that models like ours may require adjustments for future market shifts.

Feeding to later EPs resulted in wider distributions of net returns across all marketing schemes, indicating increased risk and uncertainty when extending DOF. Much of this variability was driven by changes in fed cattle prices compared to EP1, reflecting market volatility when marketing on different dates. Varying prices and other mutable simulated variables naturally lead to increased variability, especially as EPs are extended. The distributions showed that the risk of reduced returns was lower when marketing on a live basis compared to a grid basis. However, it is important to note that "net return" in this model does not equate to profit. While grid marketing generally offers greater potential for revenue and profit than live marketing, it is more variable and highly dependent on cattle quality (Schroeder and Graff, 2000). Previous studies suggest that when extending DOF, marketing on a carcass basis is more advantageous than live (Wilken et al., 2015; Horton et al., 2024). Our model does not determine whether profit increased or decreased between live and grid marketing; it quantifies net return differences within each sale basis. Although grid marketing more frequently resulted in reduced net returns compared to live marketing, it may still have been more profitable. Since the model does not distinguish differences in EP1 baseline profits between marketing schemes, it does not infer which sale basis was optimal but only contrasts net return differences within each sale basis. Nevertheless, a distinct pattern emerged: net return reductions were more frequent and substantial with each successive EP when marketing on a grid basis.

While the weights of steers at EP1 reflected industry averages (also mirroring the trial data), it was necessary to use estimates from the trial data to specify QG and YG distributions and their shifts for later-fed EPs. Steers in the trial data reflected Texas QG averages (LMIC), which tend to be lower (fewer Choice and Prime carcasses) than other regions and the national average. Since industry averages for QGs are not distinguished by sex and may be biased due to combined reporting with heifers, which tend to have higher marbling scores and QGs than steers (Choat et al., 2006). Although the median simulated QGs aligned most closely with Texas-fed cattle, wide distributions of grades were simulated, including values reflective of higher-grading regions in the U.S., albeit less frequently. Therefore, both high- and low-grading conditions were accounted for in the simulation model. Even with grid pricing and dressed marketing, HCW (Johnson and Ward, 2005; Tatum et al., 2006; Tatum et al., 2012) and base fed cattle prices (McDonald and Schroeder, 2003; Harri et al., 2009) remain the most influential factors on revenue, with QG and YG importance increasing as the Choice-Select spread widens (Johnson and Ward, 2005; Tatum et al., 2006).

Overall, when grid marketing and feeding to later EPs, the shift toward higher QGs did not offset the corresponding higher YGs and increased heavyweight carcasses; the premiums did not outweigh the discounts. In contrast, cattle marketed on a dressed-cash basis – reported only in the supplemental material due to its limited use in the U.S. – showed that all EPs had positive net return differences compared to EP1 at the median, with these differences increasing as EPs were extended. The only difference between dressed-cash and grid sale bases was the inclusion of carcass-based premiums and discounts in the grid sale basis. This provides evidence that grid price adjustments on average negatively impacted revenue when feeding to later EPs, explaining the more frequent need for higher dressed base prices from EP1 to achieve greater net returns. This observation differs from Horton et al. (2024), who found that grid revenue (from grid adjustments, excluding base price) increased for feedlot heifers fed for 21 or 42 days beyond a baseline EP, implying that QG premiums outweighed discounts for YG and heavyweight carcasses. However, their study focused on heifers, which had minimal heavyweight carcasses and were fed to lighter EPs, further from current industry standards.

Despite this, QG (Choice-plus), YG (4 and 5), heavyweight carcasses, and even HCW were of low relative importance in our models. This does not suggest these variables are not critical revenue determinants; that is not the question our simulation model addresses. Rather, it indicates that when extending DOF beyond EP1, neither HCW nor any of the simulated carcass characteristics appreciably influenced the marginal net return changes across EPs. These variables might be more important in different contexts (e.g., simulations with a high baseline HCW for EP1 should result in more total revenue than those with a lower baseline HCW). However, since our primary research question focused on comparisons within individual simulations back to EP1, there was no evidence that these variables impacted the net return difference. In other words, when making pen-level decisions, it appears more prudent for producers to prioritize factors other than weight gain or carcass grade improvements when deciding whether to extend the feeding period for a pen of steers beyond their anticipated EP.

In the stochastic simulation model, economic factors accounted for three of the four most important variables when live marketing and four of the top five when grid marketing. This suggests that economic conditions are the primary drivers for deciding whether to extend the DOF of feedlot steers beyond a standard EP, rather than the characteristics of the steers themselves. Seasonal trends in U.S. cattle and grain prices are well-documented (Mark et al., 2002; Peel and Meyer, 2002; Sørensen, 2002; Ji et al., 2017). Although seasonality was not explicitly included in our model, one can infer that extending DOF may not be advantageous when fed cattle prices are expected to drop, given the high importance of fed cattle price changes in our model. For example, the most extreme price declines typically occur between May and July, before prices begin to rise again in August or September (Mark et al., 2002; Peel and Meyer, 2002). Corn prices also tend to peak in early summer (LMIC; Sørensen, 2002), compounding the disincentive to add DOF during this period. Conversely, conditions may favor extending DOF when fed cattle prices are expected to rise, as is historically typical of fall through early spring (LMIC; Mark, Jones and James, 2002; Peel and Meyer, 2002). Futures markets could serve as indicators to help producers anticipate higher fed cattle prices, and consider delaying marketing. Regardless of the strategy, price volatility should be expected, and risk-management strategies are advisable (Harri et al., 2009).

For both live and grid marketing, after the fed cattle price difference, the most important economic variables were, in no particular order, the fed cattle price itself (live or dressed base), corn price, and for grid sales, the QG grid. Previous research indicates that fed cattle price is the most critical factor for profit determination in the feedlot, followed by feeder cattle prices and corn prices (Mark et al., 2000). As previously mentioned, the importance of the dressed base price and QG grid prices for grid marketing is well-established (McDonald and Schroeder, 2003; Johnson and Ward, 2005; Tatum et al., 2006; Harri et al., 2009). In a sensitivity analysis of economic factors, Horton et al. (2024) found minimal evidence to support extending the DOF of feedlot heifers. The authors reported that net returns for later-fed EPs compared to a baseline EP were poorest when fed cattle prices (live or dressed base) were low. This aligns with our study, where higher net returns frequently had higher live or dressed fed cattle base prices. Although we observed that price adjustments from the premium and discount-based grid had an overall negative impact on net returns for later-fed EPs – which as previously discussed, disagreed with Horton et al. (2024) – we did find that increased net returns occurred more frequently (to some degree) with higher Choice-Select spreads, aligning with implications from Horton et al. (2024). We also note that beef marketing programs like Certified Angus Beef, which capitalize on cattle grading in the upper 2/3 Choice (along with additional requirements), were not simulated or incorporated in the QG grid and could provide additional revenue opportunities when grid marketing. Changes in premium and discount grids would likely impact the results. Specifically, heavyweight discounts have decreased substantially over past decades. While we used the industry average ($-16.50/cwt) which has been relatively stable, the USDA AMS has reported low-range discounts as little as $-5/cwt (LMIC). Reducing, or potentially removing the heavyweight discount would likely result in more favorable conditions for extending DOF.

Horton et al. (2024) reported that as FYP increased, net returns worsened for heifers fed to later EPs. This also aligns with our study, where higher net returns frequently had lower corn prices within each EP, relative to when returns were negative. Additionally, our findings indicate that corn price may be more critical than DMI, suggesting that the price of corn is a more important consideration than the amount cattle consume, relative to adding DOF. Furthermore, the relative importance of corn price and, to a lesser extent DMI, increased with each successive EP, highlighting the growing cost of feed as more days were added for both sale bases.

Late-day morbidity and mortality have become growing issues in the beef industry (Engler et al., 2014; Vogel et al., 2015; Smith et al., 2022b; Smith et al., 2022a), with risks increasing as cattle spend more time on feed. We parameterized health outcomes from trial data, as no other published data known by the authors report these risks for cattle fed extended DOF in the specific timeframe evaluated. The incidence rates used for health outcomes reflect the trial's study populations and may differ in other feedlot cattle. Vogel et al. (2015) reported 0.21% mortality during the last 30 DOF from observational data across all placement weight classes of feedlot steers. Extrapolating this value, it approximates to 0.07 mortalities per 1,000 animal-days at risk, slightly lower but comparable to our simulated mean of 0.09 mortalities per 1,000 animal-days. Despite changes in cattle populations and potential environmental or management differences between the studies, the similarity between these values supports our mortality parameterization. In the simulation model, the number of mortalities was the most important non-economic variable influencing net return differences across both live and grid sale bases. Mortality was of higher relative importance within EP2 than EP3 or EP4, even though only 22.2% of simulations for EP2 had at least one mortality (out of 200 animals), compared to 39.6% and 53.0% for EP3 and EP4, respectively. While mortality was less frequent for EP2, its higher importance likely stems from less pen-weight gain (i.e., revenue) between EPs compared to EP3 and EP4, making it harder to compensate for the loss of a deceased animal. Consequently, while infrequent for EP2, when mortality does occur, it may be a more important driver of net return differences than other economic variables.

Other health outcomes were of lesser importance. The number of treatments was the lowest-ranked variable based on conditional importance scores, while removals had marginal to minimal importance. Several assumptions were required for the valuation (weight and price) of removed animals. The reasons for which feedlot cattle are culled are associated with weight (Horton et al., 2021), and we assumed removals in our model weighed similar to their pen mates. Horton et al. (2021) is the only known resource to provide a basis for estimating revenue from feedlot culls, therefore, adjusted cull cow prices were used. Although cattle populations differ between Horton et al. (2021) and those represented in the simulation model, substantial changes in our removal and revenue methodology would likely not alter interpretations of the simulation results due to the limited frequency of removals and their minimal impact on net returns.

Opportunity cost can vary in definition depending on the context. Some have characterized it as the cost of under- or overfeeding cattle relative to an "optimal" endpoint (Koontz et al., 2008); the cost of using a traditional marketing strategy instead of a profit-maximization rule (e.g., accounting for individual growth rate, where the value of marginal product equals the marginal cost; Maples et al., 2015); or the cost of not considering carcass characteristics in non-value-adjusted versus value-adjusted marketing (Poss et al., 2022). These references emphasize the importance of optimal market timing for fed cattle. Similarly, our use of “net return differences” could be considered synonymous with opportunity cost, as it reflects the marginal costs or benefits of marketing at different EPs versus current standards. However, our definition of opportunity cost accounts for the cost of delayed marketing, where a longer wait period is required to receive revenue. Other than Horton et al. (2024), we have found no other peer-reviewed publications that discount the value of future dollars when evaluating differing DOF of feedlot cattle, despite this being standard in other economic applications (Rushton, 2007). A dollar today is more valuable than a future dollar because the current dollar can be invested to grow in value. Thus, future dollars must be discounted to reflect the cost of delaying revenue (Rushton, 2007). For example, if steers were marketed at EP1, the revenue could be invested, pay off operating loans, or be utilized elsewhere during the time spent waiting to market at later EPs.

Using a 5.85% fixed interest rate, Horton et al. (2024) estimated mean opportunity costs of approximately $4.13, $5.43, and $6.73 per animal for feedlot heifers marketed 21 days beyond a baseline EP, at live fed cattle prices of $95, $125, and $155/cwt, respectively. Adjusted to 14-day increments to align with our simulations, these costs would be $2.75, $3.62, and $4.49 per animal. These opportunity costs for heifers were generally lower than what we found for steers, likely due to differences in weight (i.e., baseline revenue), interest rate, and fed cattle prices between the studies. Similarly, we also observed comparable opportunity costs between live and grid marketing bases. It is unclear how much producers consider opportunity cost when delaying marketing, and this likely varies among operations. In our evaluation, the interest rate was of marginal importance, while opportunity cost was minimal. Given the expected strong correlation between these variables in a non-conditional model, the higher ranking of interest rate suggests that opportunity cost may be more significant when interest rates are higher. However, neither variable appeared to be a major influencer of net return differences compared to other economic variables, suggesting that opportunity cost may act more as a “penalty” that producers should consider rather than a key predictor of net return differences when feeding to later EPs.

It is important to recognize the extreme nature of the EPs in the trial data and our simulations, particularly EP4. Over 25% of simulated pens fed to EP4 had a mean HCW exceeding the threshold for heavyweight discounts, meaning more than half the animals were over 746 kg. The SD used to estimate the distribution of individual carcasses around the mean pen HCW was sourced from the trial data. Cattle in the trial were not sorted for pen uniformity, which could reduce carcass variability and help manage heavyweight and YG 4 and 5 carcasses (Koontz et al., 2008; Hilscher et al., 2015). However, a significant proportion of heavyweight carcasses should be expected when feeding to such extremes, regardless of how well sorting is implemented. By using trial data to parameterize the simulation model, we avoided relying on potentially outdated literature estimates that might require extrapolation beyond their source range. It is unclear how applicable growth or performance estimates from past literature are to contemporary cattle populations, especially when feeding well beyond norms. While feedlot cattle harvest weights may continue to increase, the steer population represented in our analyses will likely remain relevant for some time, while economic conditions like changing base prices and carcass discounts may benefit from adjustment in future years.

Beyond the considerations already discussed, additional limitations of the model should be acknowledged. Our simulation model framework addressed *what if* a pen with specific baseline characteristics (EP1) was alternatively fed to each of three later EPs, allowing comparison and characterization of distributions of marginal costs or benefits when extending DOF. The purpose of this framework was to describe the potential risks of feeding steers to later EPs so producers can make more informed decisions. In practice, producers must choose an EP in advance. Traditionally, the marketing window is refined when beginning to feed a beta-agonist like ractopamine HCl (Optaflexx; Elanco Animal Health), which was used in the trial and is labeled for 28 to 42 days of feeding. This has two main implications. First, once ractopamine is introduced, the marketing window is narrowed (i.e., changing to an alternative EP becomes more difficult when outside the labeled feeding duration). Lubabegron (Elanco Animal Health), a relatively new beta-agonist/-antagonist in the U.S. market, offers a wider feeding duration (14 to 91 days), potentially allowing for more flexibility in determining EPs. Lubabegron also has been shown to alter growth and carcass characteristics compared to ractopamine (McAtee et al., 2024), which may require additional considerations when feeding to later EPs. Second, there is a lag time between deciding the marketing window and actual harvest. Our results show that much of the risk and variability in net returns occurred due to fed cattle price changes when feeding to later EPs. Forecasting cattle prices is challenging, and the longer the time between decision and harvest, the greater the risk. Another limitation of the model is that it was constructed with pen-level inference rather than feedlot-level. Each simulation compared the optimal EP for the pen under specific conditions, without considering that marketing a pen opens space for new cattle. Feedlot-level opportunity costs may arise when determining the EP of a pen (i.e., what is optimal for a pen may not be so for the feedlot), which may vary depending on available pen space, as well as feeder cattle price, availability, and quality. Additionally, the model did not account for adverse events, such as extreme weather, that could occur between EPs and affect net returns.

Finally, no model can perfectly replicate biological or real-world systems, and models are limited by their assumptions. We used specific distributions, correlations, and parameters for stochastic simulation that, while evidence-based, must be interpreted with caveats regarding their applicability. Conditional random forest models were used to aid in identification of important variables in the simulation model and guide discussion. As with any model, the conditional variable importance scores reflect what was most important in the model, but this may not necessarily correspond to real-world importance. Moreover, many of the variables included in the random forests – such as actual fed cattle price differences, carcass grades, and future mortality – are unknown to producers at the time of EP decision-making. While machine learning models may offer viable approaches for EP management, that was not our objective. Future research may explore artificial intelligence or machine learning as tools for EP management in feedlot cattle; in some cases, such strategies may already be in place. Additionally, evaluating the environmental sustainability of feeding cattle to later EPs could be beneficial. While more time on feed likely increases resource use and carbon emissions per animal, producing more beef with fewer animals might offset this impact.

Conclusions and implications

We have effectively characterized the risks of feeding contemporary feedlot cattle to later EPs under recent pricing conditions, across differing sale bases. The findings from this study provide critical insights into economic and performance considerations when extending DOF for contemporary feedlot steers under recent and varying market conditions. Feeding steers to later EPs introduces greater variability and risk in net returns, with grid marketing showing a higher potential for negative returns compared to live marketing, primarily due to the impact of carcass-based discounts. If marketing on a dressed-cash basis is an option for producers, it could be highly advantageous to feed to later EPs, as net returns increased more frequently as feeding durations extended. The most important factors in the simulation model were economic variables, with the differences in fed cattle prices received between later-fed EPs and EP1 being the most critical. While managing mortality risk is a relevant consideration when adding DOF, other cattle production and quality characteristics were of marginal to minimal importance. This implies that what may be considered an optimal EP based on weight and body composition of a pen, may not be the optimal economic EP, as timing and market conditions were more influential on net returns. Therefore, future research should recognize that the optimal EP for an animal or pen – based on body characteristics (e.g., weight, back-fat, carcass grade distribution) or marginal cost of gain – is likely a moving target, dependent on both economic conditions and risk. Ultimately, extending DOF and feeding steers to later EPs can be advantageous under favorable market conditions but carries inherent and increasing risks as feeding durations lengthen, with net return differences more often negative when marketing live or on a grid. Therefore, implementing appropriate risk management strategies may become increasingly important when feeding cattle to later EPs. All things considered, when selecting feedlot steer EPs and potentially extending DOF, producers aiming to optimize returns may need to prioritize market dynamics over traditional production metrics, while proactively managing risk.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. TS: Conceptualization, Methodology, Supervision, Writing – review & editing. MS: Data curation, Funding acquisition, Writing – review & editing. JH: Data curation, Funding acquisition, Writing – review & editing. DR: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

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Conflict of interest

Authors MS and JH are employed by Merck Animal Health; DR and TS have received previous funding from Merck Animal Health. As there was no evaluation of competing products, there are no conflicts of interest to disclose.

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Tables and Figures

Table 5.1. Parameterization of simulated economic, cattle performance, carcass, and health variables used for evaluation of net return differences when feeding beef steers to later endpoints

Variable*	Mean	SD	Distribution	Source
Corn price, $/bu	6.00	1.10	Log-normal	LMIC
Live fed cattle price, $/cwt	152.00	25.10	Log-normal	LMIC
Dry matter intake, kg/d	10.5	0.58	Normal	Trial data
EP1 final live weight, kg	667	11.4	Normal	LMIC
EP1 hot carcass weight, kg	431	8.8	Normal	LMIC
Live weight gain, kg/d	1.32	0.06	Normal	Trial data
Carcass weight gain, kg/d	1.00	0.04	Normal	Trial data
Heavyweight carcasses,† %	-	38.6	-	Trial data
Mortality, n/1,000 animal-days	0.09	-	Poisson	Trial data
Removal, n/1,000 animal-days	0.18	-	Poisson	Trial data
Morbidity, n/1,000 animal-days	0.29	-	Poisson	Trial data
Ordinal variables	**Mean**	**Scale**	**Distribution**	**Source**
EP1 Yield Grade distribution, log odds			Logistic	Trial data
5	-3.59	0.170		
4	-1.72	0.167		
3	0.15	0.166		
2	2.29	0.170		
Yield Grade coefficient, log odds			Logistic	Trial data
EP2	0.43	0.081		
EP3	0.73	0.081		
EP4	1.31	0.081		
EP1 Quality Grade distribution, log odds			Logistic	Trial data
Prime	-3.67	0.332		
Choice	0.82	0.322		
Select	4.62	0.362		
Quality Grade coefficient, log odds			Logistic	Trial data
EP2	0.31	0.067		
EP3	0.52	0.067		
EP4	0.73	0.067		

* Abbreviations: bu = bushel (25.4 kg or 56 lb); cwt = hundred-weight (45.4 kg or 100 lb); EP1 = endpoint 1

† Heavyweight carcasses were not directly simulated, rather they were estimated by assuming the specified SD around the mean simulated hot carcass weight, and calculating the percent that would be over 476 kg (1,050 lb)

Table 5.2. Economic variables in the simulation model that were either fixed, regressed, or varied for sensitivity analysis, that were incorporated for the evaluation of net return differences when feeding beef steers to later endpoints

Variable*	Value			Source
Dressed fed cattle base price,† $/cwt	Regression			LMIC
Feed and yardage price,‡ $/US ton	Regression			CattleFax, LMIC
Removal price,§ $/cwt HCW	Regression			Horton et al., 2021; LMIC
Treatment cost, $/n morbidity	23.60			USDA-NAHMS, 2013
Render fee, $/n mortality	40.50			Horton et al., 2024; Sparks Companies Inc., 2002
Yield Grade grid, $/cwt				LMIC
1	5.00			
2	2.00			
3	0.00			
4	-10.00			
5	-14.00			
Heavyweight discount,ǀ $/cwt	-16.50			LMIC
Sensitivity analysis variables	**Values**			**Source**
Quality Grade grid, $/cwt	Grid 1	Grid 2	Grid 3	LMIC
Prime	15.75	16.50	22.75	
Choice	0.00	0.00	0.00	
Select	-5.00	-17.50	-30.00	
Sub-Select	-19.50	-31.00	-41.00	
	Rate 1	Rate 2	Rate 3	
Interest rate, fixed yearly %	5.0	7.0	9.0	Ag Credit Survey, Fed. Res. Bank of KS City

* Abbreviations: cwt = hundred-weight (45.4 kg or 100 lb); HCW = hot carcass weight
† Simulated live fed cattle price divided by 0.63
‡ Dry matter basis, US ton = 907 kg or 2,000 lb; regression based on the simulated corn price
§ Regression for cull cow price based on the simulated live fed cattle price, then multiplied by 0.92
ǀ Carcasses weighing over 476 kg (1,050 lb)

Table 5.3. Tabular percentile values of the distributions of net return differences comparing later fed endpoints (EPs) to EP1 from stochastic simulation models of beef feedlot steers*

	Percentile														
Net return difference from EP1, $/animal	0.5	2.5	5	10	20	30	40	50	60	70	80	90	95	97.5	99.5
Live sale basis															
EP2	-144.95	-109.44	-92.43	-72.99	-49.94	-33.63	-19.51	-6.18	7.28	21.96	39.76	65.24	87.28	107.19	149.70
EP3	-210.92	-161.34	-136.93	-109.24	-76.16	-52.23	-31.84	-12.45	7.42	29.13	55.14	93.02	125.76	156.02	218.06
EP4	-246.36	-190.51	-162.69	-130.99	-93.11	-65.31	-41.47	-18.72	4.53	30.05	60.82	105.94	145.64	181.05	257.42
Grid sale basis															
EP2	-152.03	-115.44	-97.99	-77.79	-53.87	-36.85	-22.18	-8.16	5.95	21.33	40.02	66.78	89.89	110.94	154.98
EP3	-230.65	-179.29	-154.30	-125.79	-91.17	-66.06	-44.58	-24.18	-3.38	19.61	46.95	86.98	121.78	153.37	220.16
EP4	-291.90	-234.40	-206.06	-173.12	-133.04	-103.80	-78.51	-54.35	-29.62	-2.58	30.11	78.24	120.54	158.46	239.29

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

Table 5.4. Frequency statistics of categorized net return differences compared to endpoint 1 (EP1) for feedlot steers fed to later EP in a stochastic simulation model when marketed live or dressed with a premium and discount based grid*

	Live basis			Grid basis		
Net return difference category, %	EP2	EP3	EP4	EP2	EP3	EP4
< $-25/animal	36.0	43.5	47.2	38.0	49.6	61.8
$-25 to $-5/animal	14.9	10.3	8.7	14.3	9.7	7.4
$-5 to $5/animal	7.4	5.0	4.3	7.1	4.6	3.4
$5 to $25/animal	13.5	9.4	8.0	12.8	8.4	6.1
> $25/animal	28.1	31.8	31.8	27.9	27.8	21.4

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

Table 5.5. Frequency statistics of grid numbers and their occurrence within net return difference categories for later fed endpoints from a stochastic simulation model of feedlot steers marketed on a premium and discount based grid

	Grid number,[†] %		
Net return difference category	1	2	3
Endpoint 2			
< $-25/animal	37.3	33.5	29.2
$-25 to $-5/animal	33.5	33.6	32.9
$-5 to $5/animal	33.1	33.2	33.7
$5 to $25/animal	31.2	33.4	35.4
> $25/animal	28.9	33.0	38.1
Endpoint 3			
< $-25/animal	36.8	33.5	29.7
$-25 to $-5/animal	32.4	33.5	34.1
$-5 to $5/animal	31.6	33.3	35.1
$5 to $25/animal	30.9	33.1	36.0
> $25/animal	28.5	33.1	38.4
Endpoint 4			
< $-25/animal	36.3	33.5	30.2
$-25 to $-5/animal	31.3	33.1	35.6
$-5 to $5/animal	29.4	33.3	37.4
$5 to $25/animal	29.5	33.5	37.0
> $25/animal	27.3	32.8	39.9

[*] Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

[†] Each grid number awarded different Quality Grade premiums and discounts, with each based on the Choice-Select spread; grid number 1 had the smallest Choice-Select spread while grid number 3 had the largest Choice-Select spread

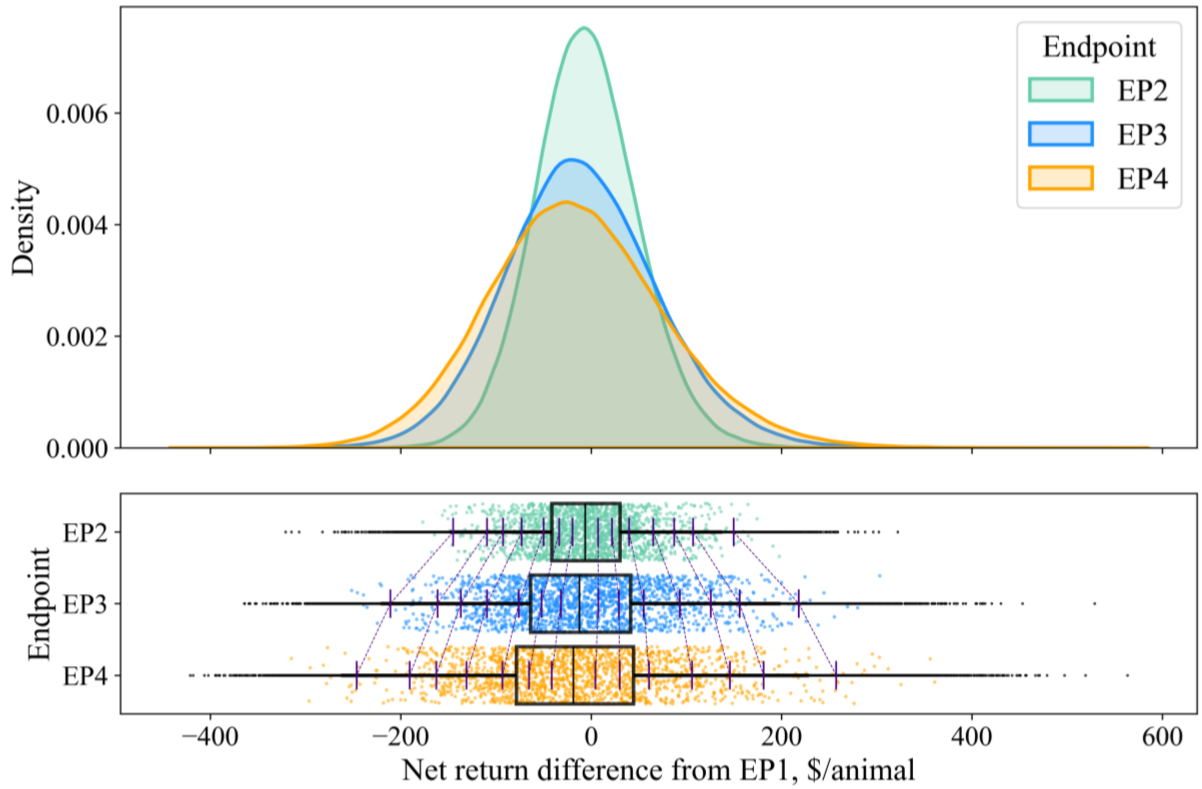


Figure 5.1. Distributions of net return differences comparing later fed endpoints (EPs) to EP1 from a stochastic simulation model of beef feedlot steers marketed on a live basis (n = 360,000 simulations). Purple bars with connecting dotted lines are percentiles (from left to right: 0.5, 2.5, 5, 10, 20, 30, 40, 60, 70, 80, 90, 95, 97.5, and 99.5th percentiles, respectively). Raincloud plots show a random subsample of the data for visualization purposes, while boxplots and overlaid density plots use the full dataset.

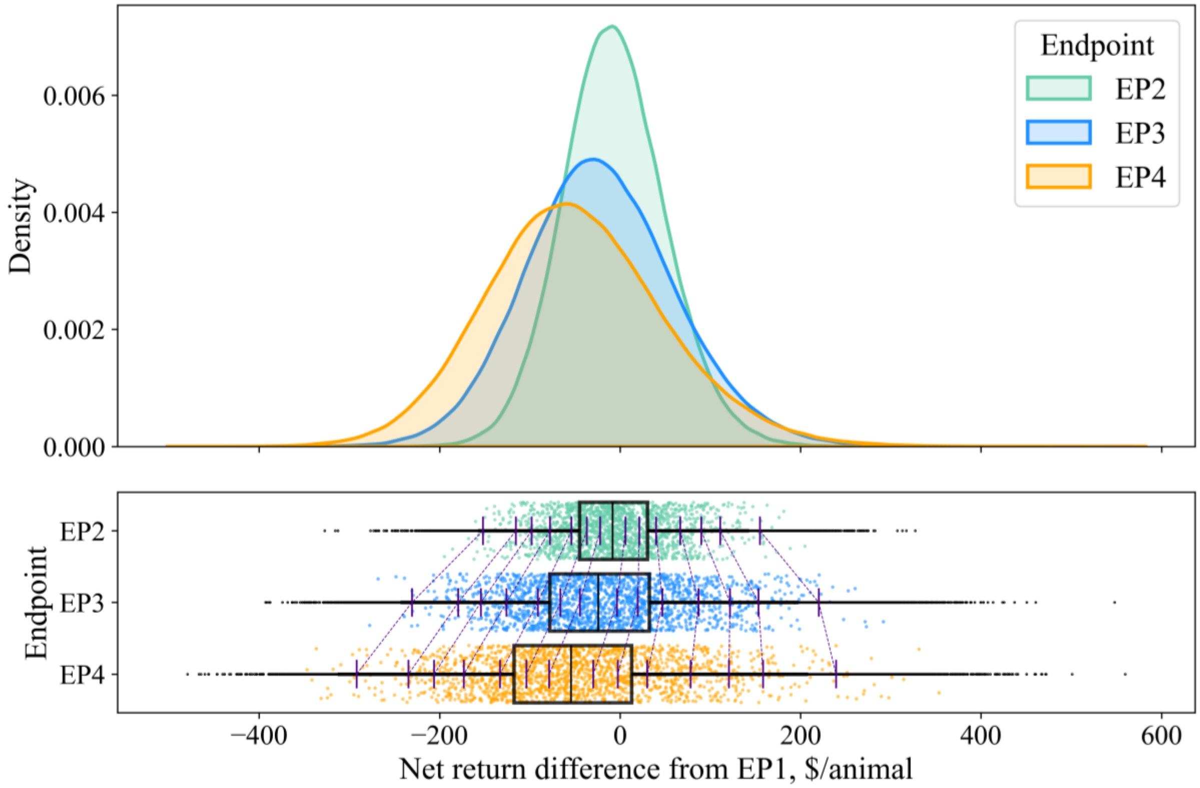


Figure 5.2. Distributions of net return differences comparing later fed endpoints (EPs) to EP1 from a stochastic simulation model of beef feedlot steers marketed dressed with a premium and discount based grid (n = 360,000 simulations). Purple bars with connecting dotted lines are percentiles (from left to right: 0.5, 2.5, 5, 10, 20, 30, 40, 60, 70, 80, 90, 95, 97.5, and 99.5th percentiles, respectively). Raincloud plots show a random subsample of the data for visualization purposes, while boxplots and overlaid density plots use the full dataset.

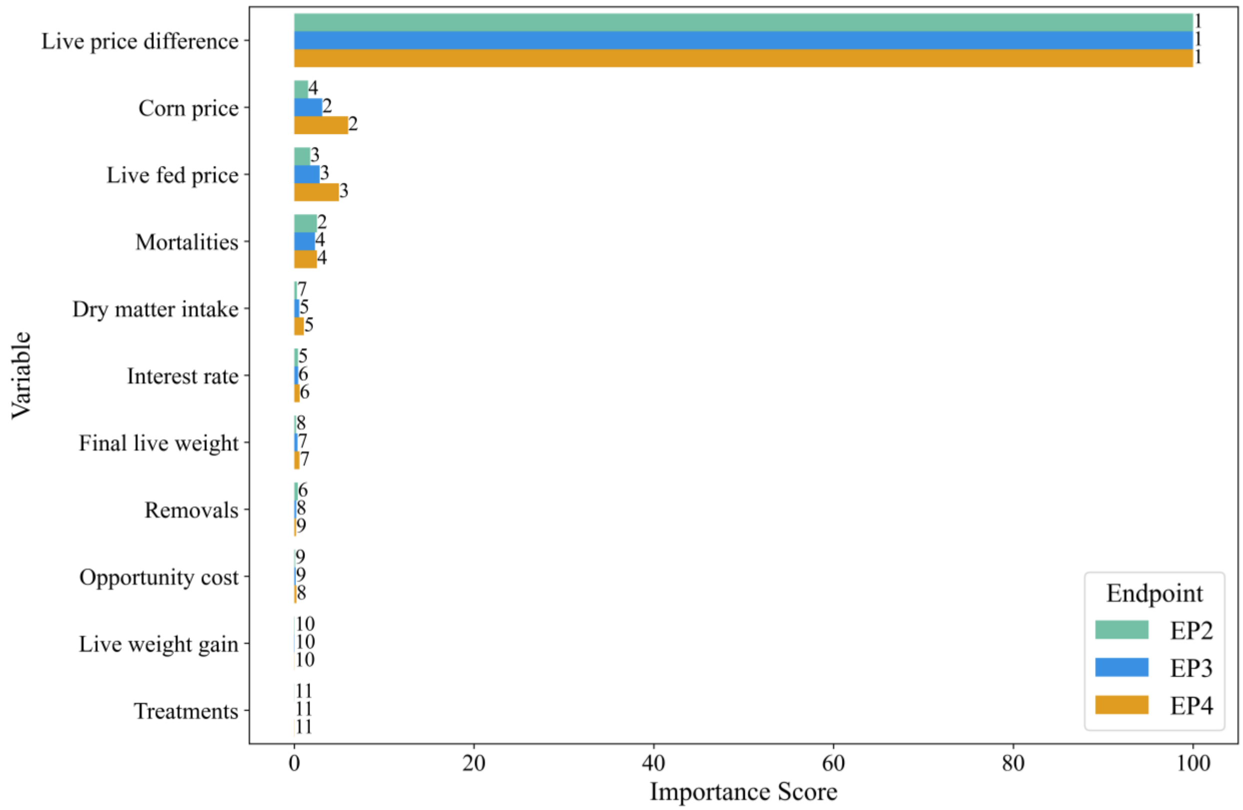


Figure 5.3. Conditional variable importance scores from conditional random forest models to estimate the relative importance of the specified variables influencing net return differences of later fed endpoints (EP2, EP3, and EP4) compared to EP1 when marketing feedlot steers on a live sale basis in the stochastic simulation model. Data labels indicate the ranking from most to least important (1 to 11, respectively) within each EP.

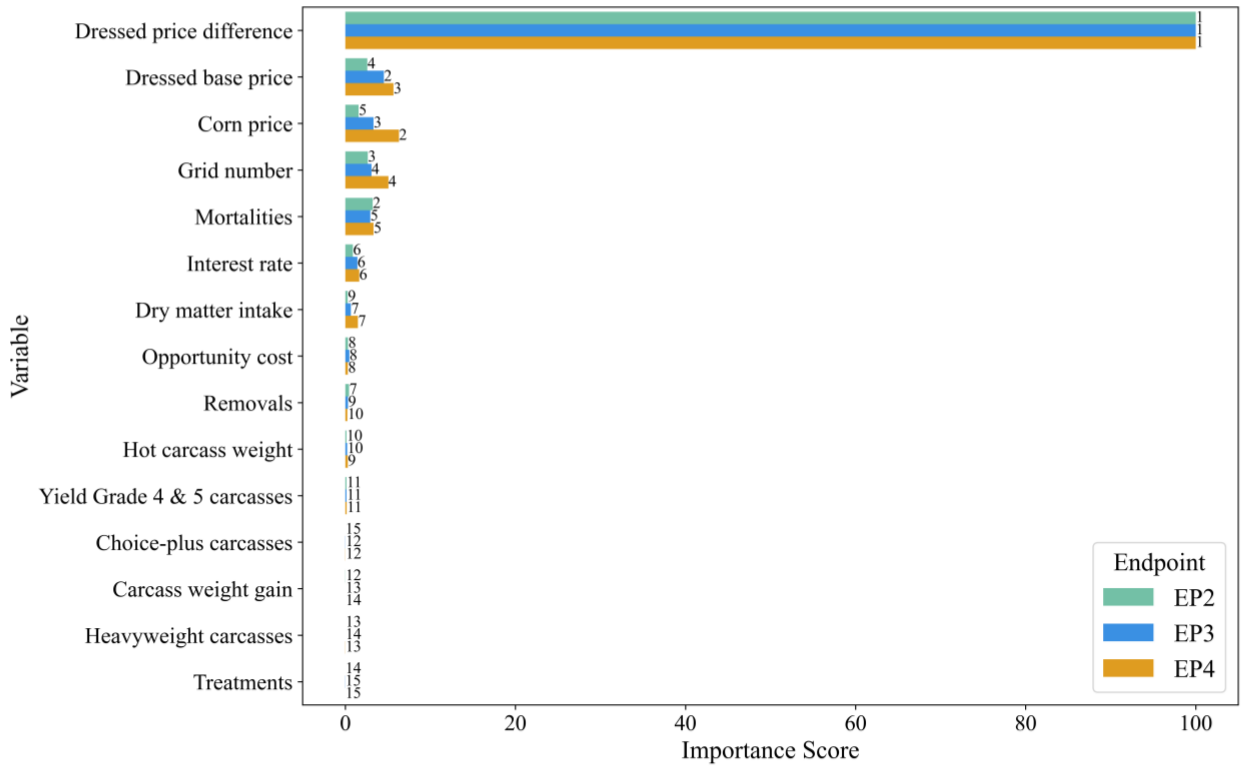


Figure 5.4. Conditional variable importance scores from conditional random forest models to estimate the relative importance of the specified variables influencing net return differences of later fed endpoints (EP2, EP3, and EP4) compared to EP1 when marketing feedlot steers on a dressed basis with a premium and discount based grid in the stochastic simulation model. Data labels indicate the ranking from most to least important (1 to 15, respectively) within each EP.

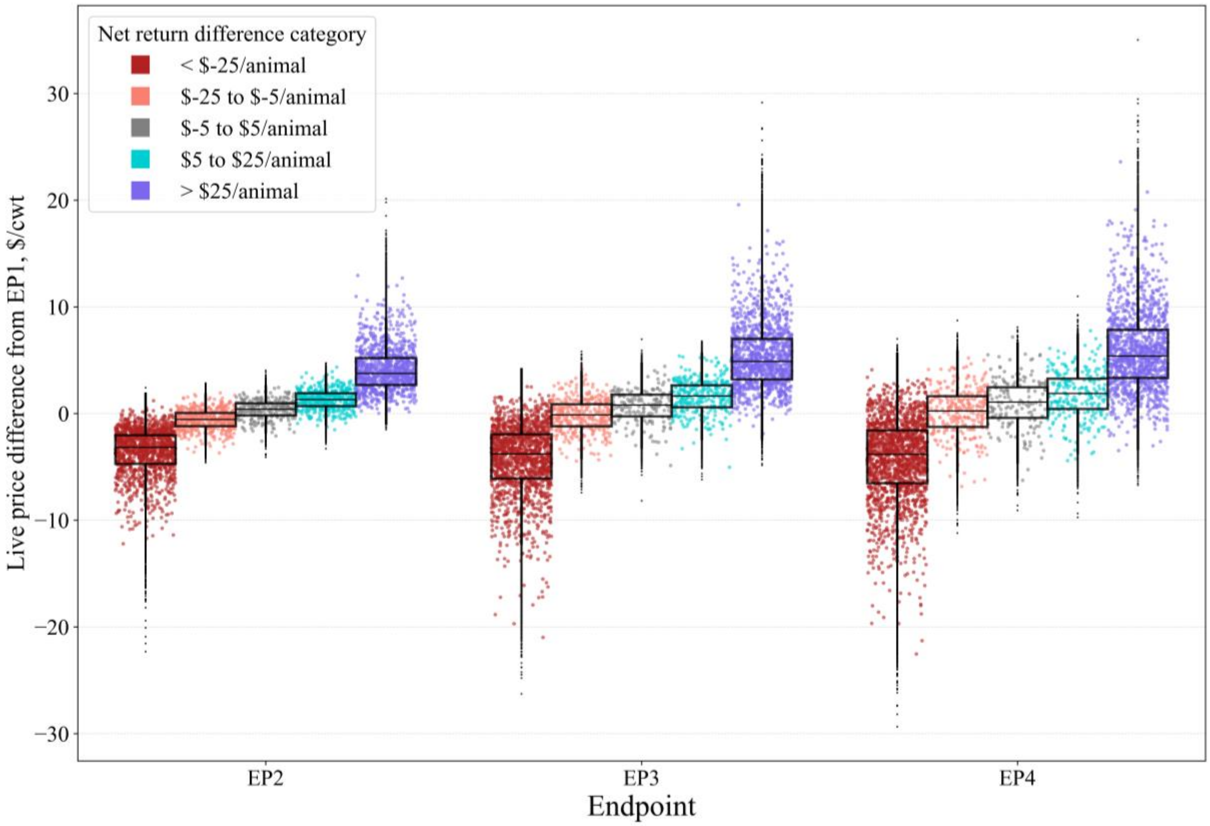


Figure 5.5. Distribution of simulated live fed cattle price differences compared to endpoint 1 (EP1), when categorized by net return differences (compared to EP1) when feeding steers to later EP and marketed live in a stochastic simulation model. Raincloud plots show a random subsample of the data for visualization purposes, while boxplots use the full dataset.

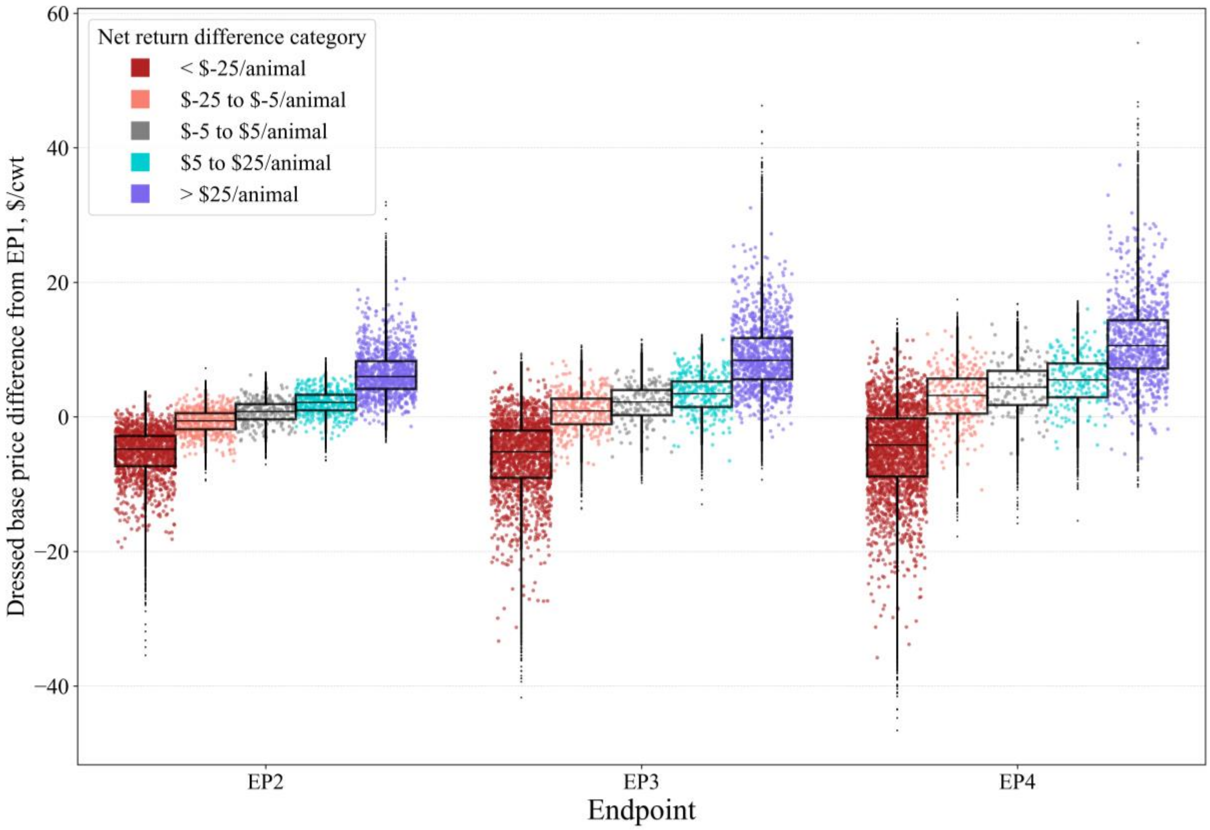


Figure 5.6. Distribution of simulated dressed feed cattle base price differences compared to endpoint 1 (EP1), when categorized by net return differences (compared to EP1) when feeding steers to later EP and marketed dressed with a premium and discount based grid in a stochastic simulation model. Raincloud plots show a random subsample of the data for visualization purposes, while boxplots use the full dataset.

Supplemental Tables and Figures

Supplemental Table 5.1. Distributions of stochastic simulation results from parameterization of pricing variables that were used in economic models to evaluate distributions of net return differences when feeding steers to later endpoints (EPs)*

	Percentile								
Variable†	0.5	2.5	10	25	50	75	90	97.5	99.5
Corn price, $/bu	3.69	4.13	4.67	5.22	5.90	6.67	7.45	8.42	9.43
Feed and yardage price, $/ton DM	250.90	272.04	296.69	319.84	346.03	372.48	395.55	419.36	438.10
EP1 live fed price,‡ $/cwt	98.35	108.70	121.52	134.23	149.98	167.59	185.14	207.08	228.97
Difference from EP1 live price, $/cwt									
EP2	-9.58	-7.08	-4.49	-2.33	0.00	2.34	4.50	7.08	9.64
EP3	-13.61	-9.98	-6.34	-3.29	0.01	3.29	6.35	10.01	13.55
EP4	-15.21	-11.20	-7.09	-3.67	0.01	3.69	7.11	11.20	15.24
EP1 dressed fed base price,‡ $/cwt	156.10	172.55	192.88	213.07	238.06	266.01	293.87	328.70	363.45
Difference from EP1 dressed price , $/cwt									
EP2	-15.21	-11.23	-7.13	-3.69	0.00	3.72	7.15	11.23	15.30
EP3	-21.60	-15.83	-10.06	-5.22	0.01	5.22	10.08	15.89	21.51
EP4	-24.14	-17.77	-11.26	-5.82	0.01	5.86	11.29	17.78	24.19

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

† Abbreviations: bu = bushel (25.4 kg or 56 lb); US ton = 907 kg or 2,000 lb; DM = dry matter; cwt = hundred-weight (45.4 kg or 100 lb)

‡ Later-fed EPs had nominally identical distributions of fed cattle prices

Supplemental Table 5.2. Distributions of stochastic simulation results from parameterization of steer performance variables that were used in the economic model to evaluate distributions of net return differences when feeding steers to later endpoints (EPs)*

	Percentile								
Variable	0.5	2.5	10	25	50	75	90	97.5	99.5
Dry matter intake, kg/d	8.98	9.34	9.73	10.09	10.48	10.87	11.22	11.62	11.97
Live weight gain, kg/d	1.17	1.21	1.25	1.28	1.32	1.37	1.40	1.45	1.48
Carcass weight gain, kg/d	0.89	0.92	0.94	0.97	1.00	1.03	1.05	1.08	1.11
Final live weight, kg									
EP1	637	644	652	659	667	674	681	689	696
EP2	656	663	671	678	685	693	700	708	715
EP3	674	681	689	696	704	712	719	727	734
EP4	692	699	707	715	722	730	737	745	753
Hot carcass weight, kg									
EP1	408	414	420	425	431	437	442	448	454
EP2	422	428	434	439	445	451	456	462	468
EP3	436	441	447	453	459	465	470	476	482
EP4	450	455	461	467	473	479	484	491	496

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

Supplemental Table 5.3. Distributions of stochastic simulation results from parameterization of carcass characteristic variables that were used in economic models to evaluate distributions of net return differences when feeding steers to later endpoints (EPs)*

	Percentile								
Variable†	0.5	2.5	10	25	50	75	90	97.5	99.5
Yield Grade 1, %									
EP1	4.0	5.2	6.5	7.8	9.2	10.9	12.8	15.9	19.9
EP2	2.4	3.2	4.1	5.1	6.2	7.5	9.1	11.6	14.7
EP3	1.8	2.4	3.1	3.8	4.6	5.7	6.9	8.8	11.4
EP4	1.0	1.4	1.8	2.2	2.7	3.3	4.0	5.2	6.7
Yield Grade 2, %									
EP1	22.3	26.7	30.9	34.0	37.1	40.0	42.7	45.8	48.6
EP2	15.3	19.1	22.9	26.2	29.8	33.4	36.8	41.0	44.9
EP3	12.0	15.1	18.5	21.4	24.7	28.2	31.7	36.2	40.7
EP4	7.3	9.3	11.6	13.8	16.3	19.1	22.1	26.3	31.1
Yield Grade 3, %									
EP1	25.5	29.7	33.5	36.1	38.4	40.4	42.0	43.5	44.7
EP2	31.1	35.2	38.5	40.6	42.2	43.1	43.9	44.6	45.2
EP3	34.4	38.0	40.7	42.0	42.9	43.6	44.2	44.8	45.3
EP4	28.4	32.7	36.4	39.0	41.1	42.6	43.6	44.5	45.3
Yield Grade 4, %									
EP1	5.7	7.3	9.2	10.7	12.5	14.5	16.7	20.0	24.1
EP2	8.0	10.1	12.7	14.9	17.5	20.4	23.4	27.5	31.9
EP3	10.4	13.0	16.1	18.7	21.7	24.9	28.1	32.2	36.5
EP4	16.5	20.2	24.1	27.2	30.5	33.8	36.7	40.0	43.0
Yield Grade 5, %									
EP1	1.1	1.5	1.9	2.2	2.7	3.2	3.9	4.9	6.4
EP2	1.6	2.1	2.7	3.3	4.1	5.0	6.1	7.8	10.1
EP3	2.1	2.8	3.6	4.4	5.4	6.6	8.0	10.2	13.1
EP4	3.7	4.9	6.3	7.6	9.3	11.2	13.4	16.8	21.2

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

† Yield and Quality Grade values are percentage values that were backtransformed after simulation on the logit scale using a proportional odds model framework

Supplemental Table 5.3. Continued

	Percentile								
Variable†	0.5	2.5	10	25	50	75	90	97.5	99.5
Prime, %									
EP1	0.4	0.8	1.2	1.7	2.5	3.5	5.0	7.9	12.8
EP2	0.6	1.0	1.6	2.3	3.4	4.8	6.8	10.7	17.1
EP3	0.7	1.2	2.0	2.9	4.1	5.9	8.3	12.8	20.2
EP4	0.9	1.5	2.4	3.5	5.0	7.1	10.0	15.3	23.8
Choice, %									
EP1	28.8	40.3	51.6	59.7	66.9	72.8	77.1	80.2	82.1
EP2	34.9	47.2	58.4	65.9	72.2	76.8	79.4	81.3	82.7
EP3	39.6	52.1	62.9	69.7	75.0	78.5	80.3	81.8	82.9
EP4	44.3	56.8	66.8	72.8	77.1	79.5	80.9	82.0	83.0
Select, %									
EP1	7.2	11.7	17.3	22.9	29.6	37.1	45.1	55.7	65.6
EP2	5.3	8.6	13.1	17.7	23.6	30.6	38.4	49.3	60.5
EP3	4.3	7.1	11.0	14.9	20.1	26.5	33.8	44.5	56.3
EP4	3.6	5.9	9.1	12.5	17.1	22.8	29.5	39.8	51.9
Sub-Select, %									
EP1	0.2	0.3	0.4	0.7	1.0	1.5	2.1	3.6	6.3
EP2	0.1	0.2	0.3	0.5	0.7	1.1	1.6	2.7	4.8
EP3	0.1	0.2	0.3	0.4	0.6	0.9	1.3	2.2	3.9
EP4	0.1	0.1	0.2	0.3	0.5	0.7	1.1	1.8	3.2
Heavyweight carcasses,‡ %									
EP1	3.9	5.2	7.1	9.2	12.0	15.3	18.9	23.4	27.9
EP2	8.0	10.3	13.4	16.6	20.8	25.5	30.2	35.8	41.3
EP3	14.8	18.3	22.7	27.2	32.6	38.3	43.8	50.1	55.8
EP4	24.4	29.2	34.9	40.3	46.5	52.7	58.3	64.4	69.7

† Yield and Quality Grade values are percentage values that were backtransformed after simulation on the logit scale using a proportional odds model framework

‡ Heavyweight carcasses were those greater than or equal to 746 kg (1,050 lb)

Supplemental Table 5.4. Distributions of stochastic simulation results from parameterization of health variables that were used in economic models to evaluate distributions of net return differences when feeding steers to later endpoints (EPs)[*,†]

	Percentile								
Variable	0.5	2.5	10	25	50	75	90	97.5	99.5
Morbidity, n/pen									
EP2	0	0	0	0	1	1	2	3	4
EP3	0	0	0	1	1	2	3	5	6
EP4	0	0	1	1	2	3	5	6	7
Removals, n/pen									
EP2	0	0	0	0	0	1	1	2	3
EP3	0	0	0	0	1	2	2	3	4
EP4	0	0	0	1	1	2	3	4	5
Mortality, n/pen									
EP2	0	0	0	0	0	0	1	2	2
EP3	0	0	0	0	0	1	1	2	3
EP4	0	0	0	0	1	1	2	3	4

[*] Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

[†] The number of morbidities, removals, and mortalities were simulated with an initial population of 200 animals in the pen (i.e., values are the counts of events per 200 animals given the animal-time at risk for each EP)

Supplemental Table 5.5. Tabular percentile values of the distributions of net return differences comparing later fed endpoints (EPs) to EP1 from a stochastic simulation model of beef feedlot steers marketed on a dressed-cash basis*

	Percentile														
Net return difference from EP1, $/animal	0.5	2.5	5	10	20	30	40	50	60	70	80	90	95	97.5	99.5
EP2	-136.39	-100.36	-83.13	-63.27	-39.72	-22.96	-8.45	5.27	19.25	34.46	52.94	79.50	102.46	123.30	167.99
EP3	-192.28	-142.63	-117.72	-89.49	-55.47	-30.81	-9.61	10.40	31.08	53.88	81.16	120.82	155.30	187.01	252.97
EP4	-218.54	-161.74	-133.52	-101.06	-61.76	-33.06	-8.18	15.59	40.02	66.87	99.32	147.15	189.39	227.15	308.49

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

Supplemental Table 5.6. Descriptive statistics of economic and cattle performance variables which were included in conditional random forest models, categorized by net return difference categories for later fed endpoints (EPs) from a stochastic simulation model of feedlot steers marketed live or dressed with a premium and discount based grid*,†

	Live price difference from EP1, $/cwt					Dressed base price difference from EP1, $/cwt				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	-3.56	2.14	-3.16	-4.71 to -2.02	-8.71 to -0.45	-5.34	3.53	-4.78	-7.30 to -2.81	-13.70 to -0.01
$-25 to $-5/animal	-0.56	0.93	-0.55	-1.17 to 0.06	-2.43 to 1.21	-0.66	1.77	-0.59	-1.82 to 0.56	-4.31 to 2.64
$-5 to $5/animal	0.39	0.86	0.41	-0.17 to 0.96	-1.35 to 2.01	0.75	1.67	0.82	-0.34 to 1.91	-2.69 to 3.84
$5 to $25/animal	1.30	0.91	1.31	0.70 to 1.91	-0.51 to 3.03	2.10	1.73	2.15	0.97 to 3.30	-1.47 to 5.34
> $25/animal	4.14	2.04	3.77	2.69 to 5.21	1.14 to 9.10	6.49	3.35	6.00	4.18 to 8.30	1.22 to 14.46
Endpoint 3										
< $-25/animal	-4.27	3.24	-3.78	-6.09 to -1.94	-11.87 to 0.66	-5.92	5.41	-5.19	-9.04 to -2.03	-18.40 to 2.58
$-25 to $-5/animal	-0.18	1.56	-0.12	-1.19 to 0.89	-3.43 to 2.71	0.75	2.86	0.89	-1.07 to 2.73	-5.29 to 5.99
$-5 to $5/animal	0.72	1.53	0.80	-0.26 to 1.77	-2.44 to 3.53	2.08	2.82	2.23	0.28 to 4.02	-3.85 to 7.26
$5 to $25/animal	1.59	1.55	1.65	0.59 to 2.66	-1.61 to 4.47	3.32	2.82	3.46	1.50 to 5.27	-2.57 to 8.51
> $25/animal	5.34	3.07	4.89	3.21 to 7.01	0.52 to 12.57	8.98	4.95	8.40	5.59 to 11.73	0.80 to 20.40
Endpoint 4										
< $-25/animal	-4.32	3.82	-3.82	-6.52 to -1.58	-13.13 to 1.78	-4.92	6.58	-4.19	-8.86 to -0.21	-19.80 to 5.84
$-25 to $-5/animal	0.14	2.15	0.24	-1.24 to 1.63	-4.32 to 4.08	2.99	3.85	3.19	0.51 to 5.70	-5.15 to 9.93
$-5 to $5/animal	0.99	2.14	1.08	-0.40 to 2.46	-3.50 to 4.95	4.19	3.81	4.40	1.78 to 6.85	-3.83 to 11.08
$5 to $25/animal	1.80	2.14	1.89	0.44 to 3.27	-2.66 to 5.72	5.33	3.77	5.51	2.93 to 7.96	-2.49 to 12.27
> $25/animal	5.81	3.62	5.40	3.34 to 7.86	-0.28 to 14.11	11.05	5.76	10.59	7.21 to 14.39	0.90 to 23.92

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

† Abbreviations: Med = median; IQR = interquartile range (25^{th} to 75^{th} percentile); 95IPR = 95^{th} inter-percentile range (2.5^{th} to 97.5^{th} percentile); cwt = hundred-weight (45.4 kg or 100 lb); bu = bushel (25.4 kg or 56 lb)

Supplemental Table 5.6. Continued

Net return difference category	Live fed cattle price, $/cwt					Dressed fed cattle base price, $/cwt				
	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	147.82	24.36	145.79	130.57 to 162.88	105.87 to 201.11	233.48	38.42	230.35	206.22 to 257.22	167.40 to 317.50
$-25 to $-5/animal	147.34	23.87	145.46	130.46 to 162.28	106.18 to 199.44	234.29	37.59	231.29	207.89 to 257.50	169.60 to 316.68
$-5 to $5/animal	148.85	23.85	147.00	132.13 to 163.38	107.90 to 201.00	236.98	37.48	234.16	210.13 to 260.33	172.77 to 318.46
$5 to $25/animal	151.06	23.80	149.11	134.13 to 165.80	110.23 to 203.32	240.59	37.61	237.39	213.94 to 263.65	176.02 to 323.28
> $25/animal	161.23	25.32	159.17	143.32 to 176.89	117.72 to 216.73	257.10	40.13	253.86	228.64 to 281.82	188.06 to 344.98
Endpoint 3										
< $-25/animal	145.73	23.73	143.81	128.93 to 160.35	104.87 to 197.70	230.68	37.19	227.64	204.35 to 253.60	166.69 to 311.98
$-25 to $-5/animal	148.18	23.24	146.17	131.87 to 162.67	108.30 to 199.05	237.33	36.71	234.26	211.30 to 260.24	174.35 to 317.01
$-5 to $5/animal	149.74	23.39	147.71	133.18 to 164.36	109.96 to 200.62	240.26	36.51	237.27	214.52 to 262.92	177.16 to 320.48
$5 to $25/animal	151.53	23.32	149.74	135.10 to 165.89	111.42 to 202.66	243.59	36.28	240.66	218.16 to 265.82	181.11 to 323.00
> $25/animal	162.43	25.05	160.39	144.72 to 177.90	119.39 to 217.50	261.23	39.66	258.00	233.14 to 285.66	193.26 to 348.37
Endpoint 4										
< $-25/animal	144.48	23.15	142.61	128.15 to 158.81	104.65 to 194.89	230.42	36.26	227.62	204.89 to 252.85	167.60 to 309.20
$-25 to $-5/animal	149.11	22.87	147.31	133.13 to 163.02	109.72 to 199.09	243.48	35.57	240.61	218.28 to 265.48	182.23 to 321.80
$-5 to $5/animal	150.78	22.55	148.98	135.00 to 164.66	112.19 to 200.38	246.45	35.31	243.11	221.73 to 268.34	186.03 to 324.23
$5 to $25/animal	152.35	22.69	150.33	136.46 to 166.20	113.41 to 202.39	250.00	35.60	247.13	224.82 to 272.32	188.37 to 327.10
> $25/animal	164.16	24.85	162.15	146.53 to 179.55	121.48 to 218.61	268.86	39.13	265.79	241.22 to 292.90	201.61 to 354.71

Supplemental Table 5.6. Continued

	Corn price, $/bu (live sale basis)					Corn price, $/bu (grid sale basis)				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	6.13	1.12	6.03	5.34 to 6.82	4.23 to 8.59	6.12	1.12	6.02	5.33 to 6.80	4.22 to 8.58
$-25 to $-5/animal	6.01	1.09	5.92	5.24 to 6.68	4.15 to 8.41	6.01	1.10	5.92	5.23 to 6.68	4.14 to 8.41
$-5 to $5/animal	5.98	1.09	5.88	5.21 to 6.65	4.13 to 8.37	5.98	1.09	5.88	5.22 to 6.65	4.13 to 8.39
$5 to $25/animal	5.95	1.08	5.85	5.18 to 6.61	4.10 to 8.32	5.94	1.08	5.84	5.17 to 6.60	4.10 to 8.30
> $25/animal	5.86	1.07	5.76	5.10 to 6.51	4.04 to 8.23	5.86	1.07	5.76	5.11 to 6.52	4.04 to 8.24
Endpoint 3										
< $-25/animal	6.16	1.12	6.06	5.37 to 6.84	4.25 to 8.62	6.13	1.11	6.03	5.34 to 6.81	4.23 to 8.58
$-25 to $-5/animal	5.99	1.09	5.90	5.22 to 6.65	4.13 to 8.37	5.98	1.09	5.88	5.21 to 6.64	4.11 to 8.37
$-5 to $5/animal	5.96	1.09	5.87	5.19 to 6.63	4.12 to 8.38	5.95	1.08	5.85	5.18 to 6.63	4.13 to 8.30
$5 to $25/animal	5.93	1.07	5.83	5.17 to 6.60	4.11 to 8.30	5.91	1.07	5.81	5.16 to 6.56	4.09 to 8.28
> $25/animal	5.81	1.06	5.72	5.07 to 6.46	4.02 to 8.15	5.81	1.06	5.71	5.06 to 6.46	4.02 to 8.15
Endpoint 4										
< $-25/animal	6.19	1.12	6.09	5.40 to 6.87	4.28 to 8.64	6.13	1.11	6.03	5.34 to 6.81	4.23 to 8.56
$-25 to $-5/animal	5.97	1.07	5.88	5.21 to 6.63	4.12 to 8.30	5.89	1.07	5.80	5.14 to 6.54	4.08 to 8.24
$-5 to $5/animal	5.94	1.06	5.85	5.20 to 6.59	4.11 to 8.24	5.88	1.07	5.78	5.12 to 6.53	4.06 to 8.21
$5 to $25/animal	5.90	1.07	5.80	5.15 to 6.55	4.10 to 8.26	5.85	1.06	5.75	5.10 to 6.49	4.03 to 8.24
> $25/animal	5.76	1.05	5.67	5.02 to 6.40	3.99 to 8.09	5.74	1.04	5.64	5.00 to 6.37	3.98 to 8.04

Supplemental Table 5.6. Continued

	Opportunity cost, $/animal (live sale basis)					Opportunity cost, $/animal (grid sale basis)				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	6.02	1.73	5.87	4.60 to 7.21	3.33 to 9.67	5.95	1.74	5.79	4.54 to 7.13	3.26 to 9.63
$-25 to $-5/animal	5.83	1.68	5.68	4.45 to 6.99	3.25 to 9.37	5.79	1.70	5.62	4.41 to 6.95	3.19 to 9.41
$-5 to $5/animal	5.85	1.69	5.70	4.46 to 7.03	3.25 to 9.41	5.81	1.70	5.65	4.43 to 6.99	3.19 to 9.42
$5 to $25/animal	5.90	1.70	5.74	4.52 to 7.08	3.30 to 9.50	5.88	1.71	5.72	4.49 to 7.05	3.25 to 9.55
> $25/animal	6.16	1.77	5.99	4.70 to 7.38	3.46 to 9.90	6.13	1.79	5.96	4.68 to 7.36	3.40 to 9.94
Endpoint 3										
< $-25/animal	11.93	3.44	11.66	9.13 to 14.30	6.60 to 19.21	11.78	3.44	11.47	8.99 to 14.12	6.45 to 19.11
$-25 to $-5/animal	11.70	3.38	11.39	8.93 to 14.04	6.51 to 18.80	11.66	3.42	11.31	8.89 to 14.01	6.40 to 18.91
$-5 to $5/animal	11.74	3.40	11.43	8.93 to 14.09	6.53 to 18.95	11.71	3.42	11.39	8.92 to 14.10	6.47 to 18.94
$5 to $25/animal	11.81	3.41	11.50	9.02 to 14.22	6.61 to 18.94	11.81	3.44	11.47	9.01 to 14.22	6.55 to 19.11
> $25/animal	12.28	3.53	11.93	9.39 to 14.74	6.91 to 19.76	12.31	3.58	11.95	9.40 to 14.77	6.86 to 19.95
Endpoint 4										
< $-25/animal	17.78	5.12	17.37	13.61 to 21.31	9.83 to 28.60	17.57	5.13	17.12	13.41 to 21.07	9.63 to 28.45
$-25 to $-5/animal	17.64	5.11	17.20	13.44 to 21.16	9.79 to 28.41	17.71	5.16	17.18	13.49 to 21.26	9.86 to 28.62
$-5 to $5/animal	17.74	5.09	17.30	13.57 to 21.26	9.92 to 28.44	17.75	5.19	17.26	13.50 to 21.27	9.91 to 29.01
$5 to $25/animal	17.75	5.12	17.28	13.54 to 21.32	9.99 to 28.53	17.95	5.23	17.45	13.67 to 21.53	10.05 to 29.23
> $25/animal	18.52	5.33	17.98	14.14 to 22.23	10.45 to 29.79	18.80	5.45	18.24	14.32 to 22.60	10.53 to 30.37

Supplemental Table 5.6. Continued

	Dry matter intake, kg/animal/d (live sale basis)					Dry matter intake, kg/animal/d (grid sale basis)				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	10.51	0.58	10.51	10.13 to 10.91	9.37 to 11.65	10.51	0.58	10.51	10.12 to 10.90	9.37 to 11.65
$-25 to $-5/animal	10.48	0.58	10.48	10.09 to 10.87	9.34 to 11.61	10.48	0.58	10.48	10.09 to 10.87	9.33 to 11.62
$-5 to $5/animal	10.47	0.58	10.47	10.08 to 10.86	9.33 to 11.62	10.47	0.58	10.47	10.08 to 10.86	9.34 to 11.60
$5 to $25/animal	10.46	0.58	10.46	10.07 to 10.85	9.34 to 11.60	10.47	0.58	10.47	10.08 to 10.85	9.35 to 11.60
> $25/animal	10.44	0.58	10.44	10.05 to 10.83	9.30 to 11.57	10.44	0.58	10.44	10.05 to 10.83	9.30 to 11.57
Endpoint 3										
< $-25/animal	10.52	0.58	10.52	10.13 to 10.91	9.38 to 11.66	10.51	0.58	10.51	10.13 to 10.90	9.37 to 11.65
$-25 to $-5/animal	10.47	0.58	10.47	10.09 to 10.86	9.34 to 11.60	10.46	0.58	10.46	10.07 to 10.86	9.33 to 11.60
$-5 to $5/animal	10.47	0.58	10.47	10.08 to 10.86	9.34 to 11.60	10.47	0.58	10.47	10.08 to 10.86	9.33 to 11.59
$5 to $25/animal	10.45	0.58	10.45	10.06 to 10.84	9.33 to 11.58	10.45	0.58	10.45	10.06 to 10.84	9.33 to 11.58
> $25/animal	10.43	0.58	10.43	10.04 to 10.82	9.30 to 11.57	10.43	0.58	10.43	10.04 to 10.82	9.30 to 11.57
Endpoint 4										
< $-25/animal	10.53	0.58	10.53	10.14 to 10.92	9.39 to 11.66	10.51	0.58	10.51	10.12 to 10.90	9.38 to 11.65
$-25 to $-5/animal	10.47	0.57	10.47	10.08 to 10.85	9.34 to 11.58	10.45	0.58	10.45	10.06 to 10.84	9.32 to 11.58
$-5 to $5/animal	10.46	0.58	10.46	10.08 to 10.85	9.33 to 11.58	10.44	0.59	10.44	10.05 to 10.84	9.30 to 11.58
$5 to $25/animal	10.45	0.58	10.45	10.05 to 10.84	9.31 to 11.58	10.43	0.58	10.44	10.04 to 10.82	9.28 to 11.56
> $25/animal	10.42	0.58	10.41	10.03 to 10.80	9.28 to 11.55	10.41	0.58	10.41	10.02 to 10.80	9.28 to 11.54

Supplemental Table 5.6. Continued

	Final live weight, kg/animal					Hot carcass weight, kg/carcass				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	685	11.4	685	678 to 693	663 to 708	445	8.8	446	440 to 451	428 to 463
$-25 to $-5/animal	685	11.5	685	677 to 693	663 to 707	445	8.8	445	439 to 451	427 to 462
$-5 to $5/animal	685	11.5	685	677 to 693	662 to 708	445	8.9	445	439 to 451	427 to 462
$5 to $25/animal	685	11.5	685	677 to 693	663 to 708	444	8.9	445	439 to 450	427 to 462
> $25/animal	686	11.4	685	678 to 693	663 to 708	444	8.8	444	438 to 450	427 to 462
Endpoint 3										
< $-25/animal	704	11.6	704	696 to 712	681 to 726	459	8.9	459	453 to 465	442 to 477
$-25 to $-5/animal	704	11.6	704	696 to 711	681 to 726	459	8.9	458	453 to 464	441 to 476
$-5 to $5/animal	704	11.5	704	696 to 711	681 to 726	459	8.8	459	453 to 464	441 to 476
$5 to $25/animal	704	11.5	704	696 to 712	681 to 726	458	8.9	458	452 to 464	441 to 476
> $25/animal	704	11.5	704	696 to 712	681 to 727	458	9.0	458	452 to 464	441 to 476
Endpoint 4										
< $-25/animal	722	11.7	722	714 to 730	699 to 745	473	9.0	473	467 to 479	456 to 491
$-25 to $-5/animal	722	11.8	722	714 to 730	699 to 745	472	9.0	472	466 to 478	454 to 490
$-5 to $5/animal	722	11.8	722	714 to 730	699 to 745	472	9.1	472	466 to 478	454 to 490
$5 to $25/animal	722	11.7	722	714 to 730	699 to 745	472	9.0	472	466 to 478	455 to 490
> $25/animal	723	11.7	723	715 to 731	700 to 746	472	9.1	472	466 to 478	454 to 490

Supplemental Table 5.6. Continued

	Live weight gain, kg/animal/d					Carcass weight gain, kg/carcass/d				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	1.32	0.06	1.32	1.28 to 1.36	1.20 to 1.44	1.00	0.04	1.00	0.97 to 1.02	0.91 to 1.08
$-25 to $-5/animal	1.32	0.06	1.32	1.28 to 1.37	1.21 to 1.44	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
$-5 to $5/animal	1.32	0.06	1.32	1.28 to 1.37	1.20 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
$5 to $25/animal	1.33	0.06	1.33	1.28 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
> $25/animal	1.33	0.06	1.33	1.29 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
Endpoint 3										
< $-25/animal	1.32	0.06	1.32	1.28 to 1.36	1.20 to 1.44	1.00	0.04	1.00	0.97 to 1.02	0.91 to 1.08
$-25 to $-5/animal	1.32	0.06	1.32	1.28 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
$-5 to $5/animal	1.33	0.06	1.33	1.28 to 1.37	1.21 to 1.44	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
$5 to $25/animal	1.33	0.06	1.33	1.29 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
> $25/animal	1.33	0.06	1.33	1.29 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
Endpoint 4										
< $-25/animal	1.32	0.06	1.32	1.28 to 1.36	1.20 to 1.44	1.00	0.04	1.00	0.97 to 1.02	0.91 to 1.08
$-25 to $-5/animal	1.33	0.06	1.32	1.28 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
$-5 to $5/animal	1.33	0.06	1.33	1.29 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
$5 to $25/animal	1.33	0.06	1.33	1.29 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08
> $25/animal	1.33	0.06	1.33	1.29 to 1.37	1.21 to 1.45	1.00	0.04	1.00	0.97 to 1.03	0.92 to 1.08

Supplemental Table 5.6. Continued

	Mortality, n/pen (live sale basis)					Mortality, n/pen (grid sale basis)				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	0.31	0.55	0	0 to 1	0 to 2	0.30	0.55	0	0 to 1	0 to 2
$-25 to $-5/animal	0.25	0.50	0	0 to 0	0 to 2	0.25	0.50	0	0 to 0	0 to 2
$-5 to $5/animal	0.24	0.49	0	0 to 0	0 to 1	0.24	0.49	0	0 to 0	0 to 1
$5 to $25/animal	0.22	0.47	0	0 to 0	0 to 1	0.22	0.47	0	0 to 0	0 to 1
> $25/animal	0.19	0.44	0	0 to 0	0 to 1	0.19	0.44	0	0 to 0	0 to 1
Endpoint 3										
< $-25/animal	0.57	0.75	0	0 to 1	0 to 2	0.56	0.74	0	0 to 1	0 to 2
$-25 to $-5/animal	0.50	0.70	0	0 to 1	0 to 2	0.49	0.69	0	0 to 1	0 to 2
$-5 to $5/animal	0.49	0.69	0	0 to 1	0 to 2	0.48	0.69	0	0 to 1	0 to 2
$5 to $25/animal	0.47	0.68	0	0 to 1	0 to 2	0.47	0.68	0	0 to 1	0 to 2
> $25/animal	0.42	0.65	0	0 to 1	0 to 2	0.42	0.65	0	0 to 1	0 to 2
Endpoint 4										
< $-25/animal	0.84	0.91	1	0 to 1	0 to 3	0.81	0.89	1	0 to 1	0 to 3
$-25 to $-5/animal	0.73	0.85	1	0 to 1	0 to 3	0.71	0.83	1	0 to 1	0 to 3
$-5 to $5/animal	0.73	0.84	1	0 to 1	0 to 3	0.70	0.82	1	0 to 1	0 to 3
$5 to $25/animal	0.71	0.83	1	0 to 1	0 to 3	0.68	0.82	0	0 to 1	0 to 3
> $25/animal	0.65	0.80	0	0 to 1	0 to 3	0.64	0.79	0	0 to 1	0 to 3

Supplemental Table 5.6. Continued

	Removals, n/pen (live sale basis)					Removals, n/pen (grid sale basis)				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	0.55	0.74	0	0 to 1	0 to 2	0.55	0.74	0	0 to 1	0 to 2
$-25 to $-5/animal	0.51	0.72	0	0 to 1	0 to 2	0.51	0.71	0	0 to 1	0 to 2
$-5 to $5/animal	0.50	0.71	0	0 to 1	0 to 2	0.51	0.71	0	0 to 1	0 to 2
$5 to $25/animal	0.49	0.70	0	0 to 1	0 to 2	0.50	0.70	0	0 to 1	0 to 2
> $25/animal	0.47	0.69	0	0 to 1	0 to 2	0.47	0.69	0	0 to 1	0 to 2
Endpoint 3										
< $-25/animal	1.07	1.03	1	0 to 2	0 to 3	1.06	1.02	1	0 to 2	0 to 3
$-25 to $-5/animal	1.01	1.01	1	0 to 2	0 to 3	1.02	1.02	1	0 to 2	0 to 3
$-5 to $5/animal	1.01	1.00	1	0 to 2	0 to 3	1.00	1.00	1	0 to 2	0 to 3
$5 to $25/animal	1.00	1.01	1	0 to 2	0 to 3	0.99	0.99	1	0 to 2	0 to 3
> $25/animal	0.96	0.98	1	0 to 2	0 to 3	0.96	0.98	1	0 to 2	0 to 3
Endpoint 4										
< $-25/animal	1.58	1.26	1	1 to 2	0 to 4	1.56	1.25	1	1 to 2	0 to 4
$-25 to $-5/animal	1.52	1.24	1	1 to 2	0 to 4	1.50	1.21	1	1 to 2	0 to 4
$-5 to $5/animal	1.50	1.22	1	1 to 2	0 to 4	1.49	1.23	1	1 to 2	0 to 4
$5 to $25/animal	1.49	1.21	1	1 to 2	0 to 4	1.48	1.22	1	1 to 2	0 to 4
> $25/animal	1.46	1.21	1	1 to 2	0 to 4	1.45	1.20	1	1 to 2	0 to 4

Supplemental Table 5.6. Continued

	Treatments, n/pen (live sale basis)					Treatments, n/pen (grid sale basis)				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	0.83	0.91	1	0 to 1	0 to 3	0.82	0.91	1	0 to 1	0 to 3
$-25 to $-5/animal	0.82	0.91	1	0 to 1	0 to 3	0.82	0.91	1	0 to 1	0 to 3
$-5 to $5/animal	0.82	0.90	1	0 to 1	0 to 3	0.82	0.90	1	0 to 1	0 to 3
$5 to $25/animal	0.81	0.90	1	0 to 1	0 to 3	0.82	0.91	1	0 to 1	0 to 3
> $25/animal	0.82	0.91	1	0 to 1	0 to 3	0.82	0.91	1	0 to 1	0 to 3
Endpoint 3										
< $-25/animal	1.64	1.28	1	1 to 2	0 to 5	1.64	1.28	1	1 to 2	0 to 5
$-25 to $-5/animal	1.65	1.29	1	1 to 2	0 to 5	1.65	1.29	1	1 to 2	0 to 5
$-5 to $5/animal	1.65	1.27	1	1 to 2	0 to 5	1.64	1.27	1	1 to 2	0 to 5
$5 to $25/animal	1.64	1.28	1	1 to 2	0 to 5	1.64	1.28	1	1 to 2	0 to 4
> $25/animal	1.64	1.28	1	1 to 2	0 to 5	1.64	1.28	1	1 to 2	0 to 5
Endpoint 4										
< $-25/animal	2.46	1.57	2	1 to 3	0 to 6	2.46	1.57	2	1 to 3	0 to 6
$-25 to $-5/animal	2.46	1.58	2	1 to 3	0 to 6	2.46	1.57	2	1 to 3	0 to 6
$-5 to $5/animal	2.46	1.57	2	1 to 3	0 to 6	2.45	1.57	2	1 to 3	0 to 6
$5 to $25/animal	2.46	1.57	2	1 to 3	0 to 6	2.46	1.57	2	1 to 3	0 to 6
> $25/animal	2.45	1.56	2	1 to 3	0 to 6	2.45	1.56	2	1 to 3	0 to 6

Supplemental Table 5.7. Frequency statistics of interest rates and their occurrence within net return difference categories for later fed endpoints (EPs) from a stochastic simulation model of feedlot steers marketed live or dressed with a premium and discount based grid[*,†]

	Interest rate, EP2			Interest rate, EP3			Interest rate, EP4		
Net return difference category, %	5%	7%	9%	5%	7%	9%	5%	7%	9%
Live sale basis									
< $-25/animal	32.2	33.2	34.6	31.9	33.4	34.7	31.8	33.3	35.0
$-25 to $-5/animal	33.5	33.2	33.4	33.6	33.1	33.3	33.3	33.4	33.3
$-5 to $5/animal	33.6	33.3	33.1	33.7	33.4	33.0	33.1	33.7	33.2
$5 to $25/animal	33.6	33.3	33.1	33.8	33.2	33.1	34.0	33.4	32.6
> $25/animal	34.5	33.6	31.9	35.0	33.4	31.6	35.5	33.3	31.1
Grid sale basis									
< $-25/animal	32.3	33.2	34.5	32.2	33.3	34.4	32.2	33.3	34.5
$-25 to $-5/animal	33.6	33.2	33.2	33.5	33.3	33.2	34.0	33.5	32.4
$-5 to $5/animal	33.8	33.1	33.1	33.9	33.3	32.8	34.8	33.4	31.8
$5 to $25/animal	33.3	33.3	33.4	33.8	33.4	32.9	34.6	33.7	31.7
> $25/animal	34.5	33.6	31.9	35.0	33.4	31.6	35.8	33.2	31.0

[*] Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

[†] Interest rates represented yearly fixed rates for operating loans, and were used to account for interest on 50% of feed as well as for accounting for opportunity cost when feeding to later EP

Supplemental Table 5.8. Descriptive statistics of carcass characteristic variables which were included in conditional random forest models, categorized by net return difference categories for later fed endpoints (EPs) from a stochastic simulation model of feedlot steers marketed dressed with a premium and discount based grid*,†

	Yield Grade 4 and 5 carcasses, %					Choice and Prime carcasses, %				
Net return difference category	Mean	SD	Med	IQR	95IPR	Mean	SD	Med	IQR	95IPR
Endpoint 2										
< $-25/animal	22.4	5.8	21.9	18.5 to 25.7	12.4 to 35.6	74.1	11.0	75.7	68.3 to 81.8	47.7 to 91.1
$-25 to $-5/animal	22.2	5.8	21.7	18.3 to 25.4	12.4 to 35.2	74.2	10.8	75.7	68.4 to 81.7	48.4 to 91.2
$-5 to $5/animal	22.0	5.7	21.5	18.2 to 25.3	12.2 to 35.0	74.2	10.8	75.7	68.3 to 81.8	48.7 to 91.0
$5 to $25/animal	22.0	5.7	21.5	18.2 to 25.3	12.3 to 34.7	74.1	10.8	75.6	68.2 to 81.7	48.4 to 91.0
> $25/animal	21.8	5.6	21.4	18.0 to 25.1	12.1 to 34.5	74.2	10.8	75.7	68.4 to 81.7	48.7 to 91.2
Endpoint 3										
< $-25/animal	27.9	6.7	27.4	23.4 to 31.8	16.1 to 42.5	77.8	10.0	79.3	72.7 to 84.7	53.3 to 92.7
$-25 to $-5/animal	27.6	6.6	27.1	23.2 to 31.4	16.0 to 42.2	77.7	10.0	79.3	72.6 to 84.6	53.1 to 92.6
$-5 to $5/animal	27.6	6.5	27.1	23.2 to 31.5	16.1 to 41.9	77.7	9.9	79.2	72.6 to 84.5	53.8 to 92.7
$5 to $25/animal	27.4	6.6	27.0	23.0 to 31.3	15.7 to 41.9	77.7	10.0	79.3	72.6 to 84.6	53.6 to 92.8
> $25/animal	27.3	6.5	26.8	22.9 to 31.2	15.7 to 41.7	77.8	9.9	79.3	72.6 to 84.6	53.9 to 92.7
Endpoint 4										
< $-25/animal	40.4	7.8	40.1	35.2 to 45.2	25.5 to 56.8	81.0	9.1	82.5	76.6 to 87.2	58.4 to 94.0
$-25 to $-5/animal	39.9	7.8	39.7	34.8 to 44.8	25.0 to 56.0	80.9	9.1	82.4	76.5 to 87.1	58.4 to 94.1
$-5 to $5/animal	39.8	7.9	39.7	34.5 to 44.8	24.5 to 56.1	81.0	8.9	82.4	76.4 to 87.1	59.6 to 93.9
$5 to $25/animal	39.8	7.9	39.5	34.6 to 44.6	24.7 to 56.0	80.9	9.1	82.4	76.5 to 87.0	58.7 to 94.1
> $25/animal	39.6	7.8	39.3	34.4 to 44.5	24.7 to 55.8	80.9	9.0	82.4	76.4 to 87.1	58.7 to 94.0

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

† Abbreviations: Med = median; IQR = interquartile range (25^{th} to 75^{th} percentile); 95IPR = 95^{th} inter-percentile range (2.5^{th} to 97.5^{th} percentile);

Supplemental Table 5.8. Continued

	Heavyweight carcasses,[‡] %				
Net return difference category	Mean	SD	Med	IQR	95IPR
Endpoint 2					
< $-25/animal	21.8	6.6	21.3	17.0 to 26.0	10.6 to 36.3
$-25 to $-5/animal	21.3	6.6	20.7	16.6 to 25.4	10.3 to 35.8
$-5 to $5/animal	21.1	6.6	20.5	16.4 to 25.2	10.1 to 35.6
$5 to $25/animal	21.1	6.5	20.5	16.4 to 25.2	10.0 to 35.4
> $25/animal	21.0	6.5	20.4	16.3 to 25.0	10.1 to 35.4
Endpoint 3					
< $-25/animal	33.5	8.2	33.1	27.7 to 38.9	18.7 to 50.5
$-25 to $-5/animal	32.7	8.2	32.2	26.9 to 38.0	18.0 to 49.8
$-5 to $5/animal	32.7	8.1	32.3	26.9 to 38.0	18.2 to 49.7
$5 to $25/animal	32.6	8.1	32.2	26.8 to 38.0	18.0 to 49.6
> $25/animal	32.4	8.2	31.9	26.6 to 37.7	17.8 to 49.5
Endpoint 4					
< $-25/animal	47.0	9.0	46.9	40.7 to 53.1	29.7 to 64.7
$-25 to $-5/animal	46.0	9.1	45.8	39.7 to 52.2	28.6 to 63.8
$-5 to $5/animal	45.9	9.1	45.8	39.7 to 52.0	28.4 to 64.1
$5 to $25/animal	46.0	9.0	45.8	39.6 to 52.2	28.8 to 63.9
> $25/animal	45.8	9.1	45.6	39.5 to 51.9	28.4 to 63.8

[‡] Heavyweight carcasses were those weighing over 476 kg (1,050 lb)

Supplemental Table 5.9. Specified correlation coefficient matrices utilized for the parameterization of within-variable relationships during simulations*

Yield Grade correlation matrix†

	YG 5	YG 4	YG 3	YG 2
YG 5	1.00	0.97	0.96	0.93
YG 4	0.97	1.00	0.99	0.96
YG 3	0.96	0.99	1.00	0.97
YG 2	0.93	0.96	0.97	1.00

Quality Grade correlation matrix‡

	Prime	Choice	Select
Prime	1.00	0.97	0.86
Choice	0.97	1.00	0.89
Select	0.86	0.89	1.00

Fed cattle price correlation matrix§

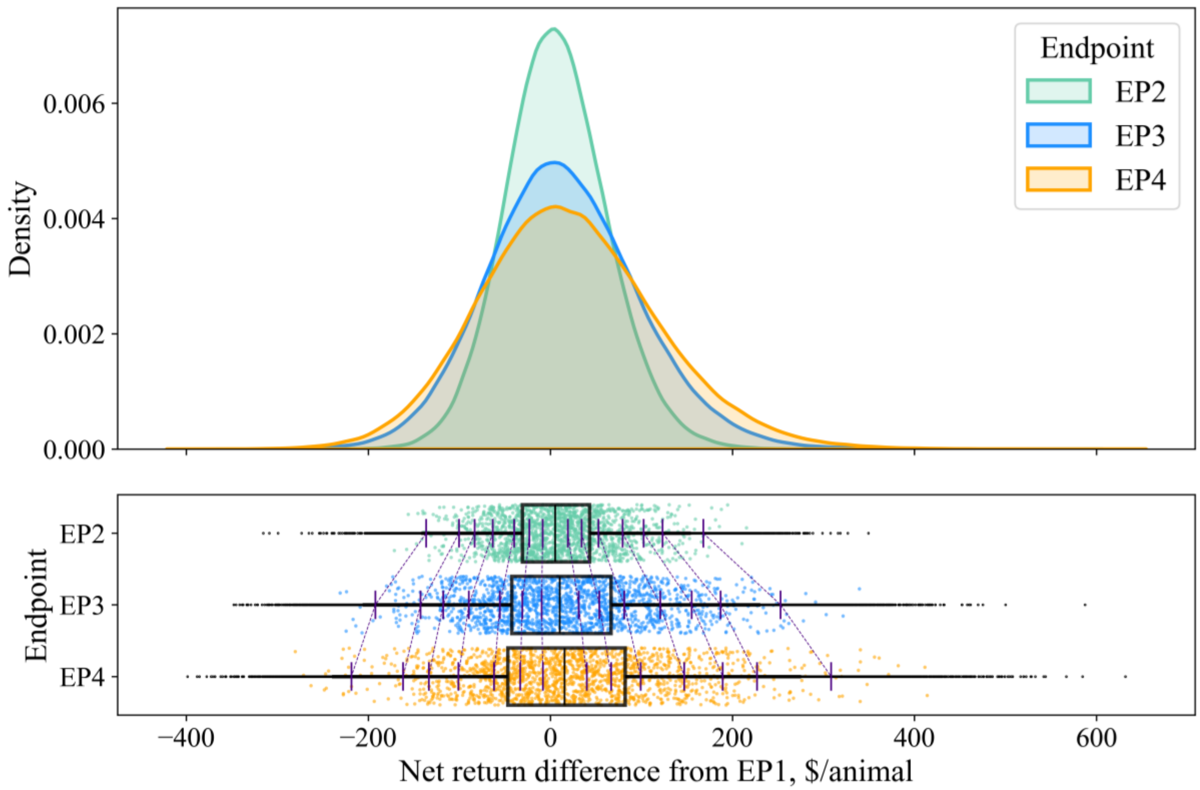
	EP1 price	EP2 price	EP3 price	EP4 price
EP1 price	1.000	0.990	0.980	0.975
EP2 price	0.990	1.000	0.990	0.980
EP3 price	0.980	0.990	1.000	0.990
EP4 price	0.975	0.980	0.990	1.000

* Stochastic simulation models (n = 360,000 simulations) parameterized animal performance, carcass characteristics, health, as well as economic variables to evaluate differences in net returns when feeding steers to later endpoints under variable conditions

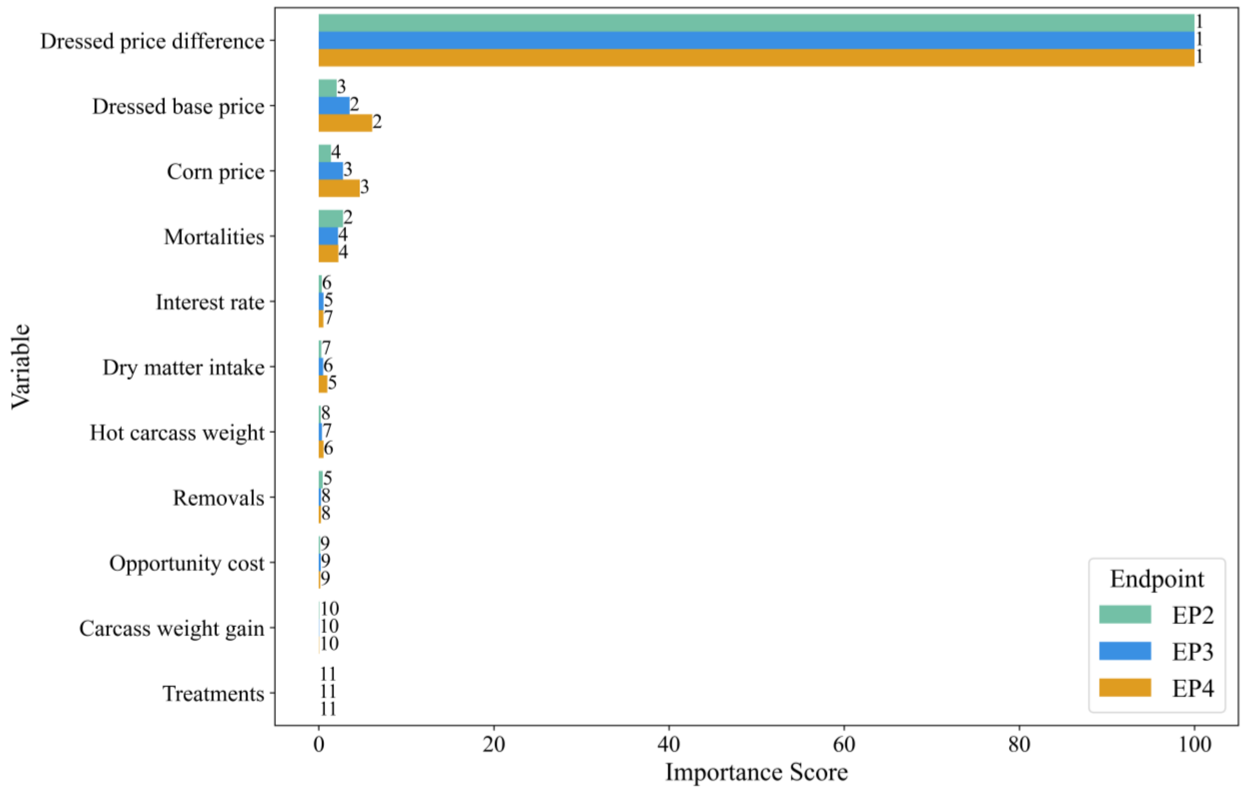
† Correlation matrix of USDA Yield Grades (YG) derived from the analysis of trial data using a generalized linear mixed model with a multinomial distribution and proportional odds framework; YG 1 was specified as the referent grade and was subsequently dropped from the model and therefore is not included in the matrix

‡ Correlation matrix of USDA Quality Grades (QG) derived from the analysis of trial data using a generalized linear mixed model with a multinomial distribution and proportional odds framework; Standard was specified as the referent grade and was subsequently dropped from the model and therefore is not included in the matrix

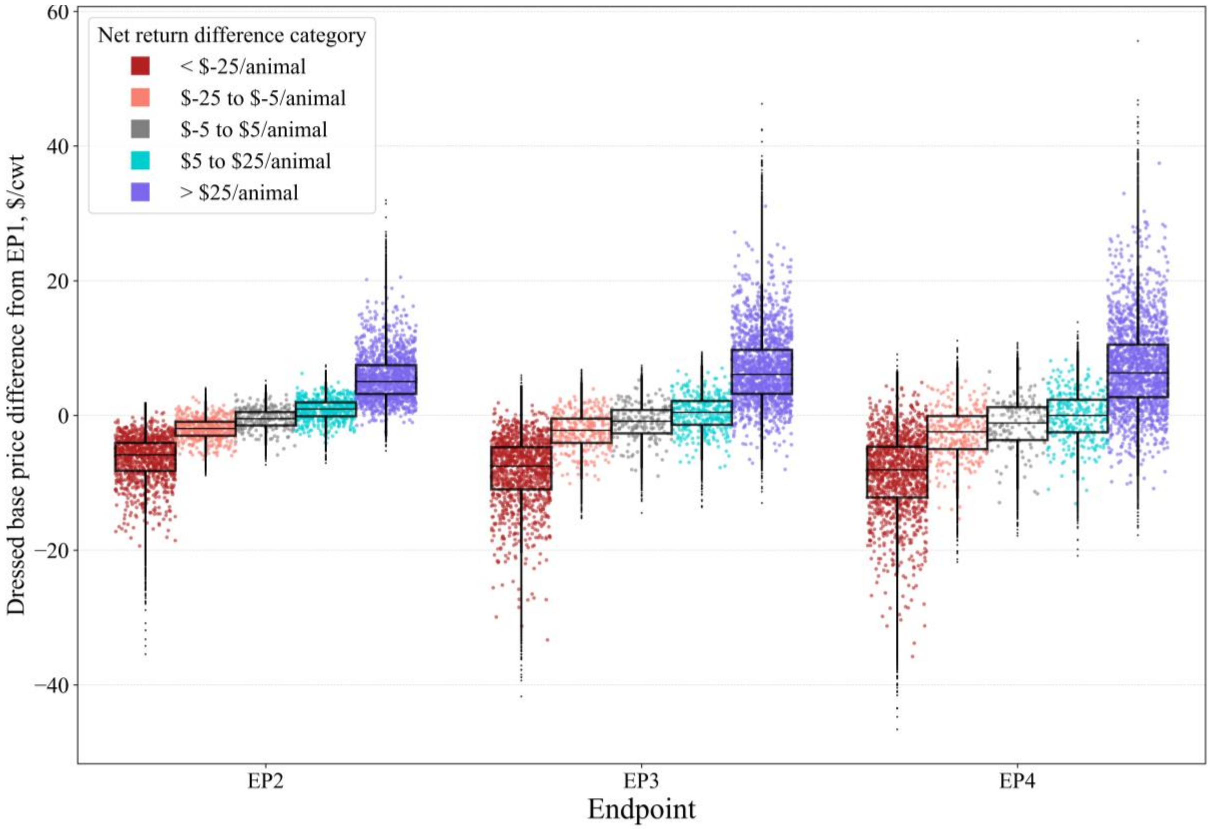
§ Correlation matrix of live fed cattle prices relative to each endpoint (EP) to account for changing prices when marketing on different weeks; correlations between weekly reported prices with two-week lags were analyzed to characterize the relationships and specify the matrix



Supplemental Figure 5.1. Distributions of net return differences comparing later fed endpoints (EPs) to EP1 from a stochastic simulation model of beef feedlot steers marketed on a dressed (cash) basis (n = 360,000 simulations). Purple bars with connecting dotted lines are percentiles (from left to right: 0.5, 2.5, 5, 10, 20, 30, 40, 60, 70, 80, 90, 95, 97.5, and 99.5th percentiles, respectively). Raincloud plots show a random subsample of the data for visualization purposes, while boxplots and overlaid density plots use the full dataset.



Supplemental Figure 5.2. Conditional variable importance scores from conditional random forest models to estimate the relative importance of the specified variables influencing net return differences of later fed endpoints (EP2, EP3, and EP4) compared to EP1 when marketing feedlot steers on a dressed (cash) sale basis in the stochastic simulation model. Data labels indicate the ranking from most to least important (1 to 11, respectively) within each EP.



Supplemental Figure 5.3. Distribution of simulated dressed feed cattle base price differences compared to endpoint 1 (EP1), when categorized by net return differences (compared to EP1) when feeding steers to later EP and marketed on a dressed (cash) basis in a stochastic simulation model. Raincloud plots show a random subsample of the data for visualization purposes, while boxplots use the full dataset.

Chapter 6 - Economic analysis of randomized controlled trial data: a framework and feedlot cattle case study

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Abstract

Livestock industry stakeholders rely on research, often randomized controlled trials (RCTs) to make evidence-based decisions. Economic implications of interventions are often a major deciding factor for adoption by producers. However, economic analyses in beef feedlot trials are infrequently conducted and often suffer from inconsistent methodologies. Gaps in planning, execution, and reporting of economic assessments underscore the need for guidance and standardized approaches in conducting economic evaluations on RCT data. Our objective was to compare and contrast methodologies for assessing costs and benefits associated with livestock health and production trials and to provide scientific guidance, rationale, and recommendations for future conduct of economic analyses on RCT data. Several types of economic analyses are frequently used by agricultural economists, including cash flow budgets, enterprise budgets, gross margin analysis, cost-benefit and -effectiveness analyses, and partial budgets. Partial budgeting emerges as the most pragmatic strategy for RCT data, focusing on the marginal impact of alternative interventions or management strategies, aligning well with RCT objectives. We provided an example of applying a partial budget to an RCT conducted at a commercial beef feedlot using published data. All observed data for relevant animal performance, health, and carcass variables were included, regardless of their original statistical significance. The budget was applied to each experimental unit (pen), with net return as the final outcome, and analyzed statistically using linear mixed models. While simple partial budgets use fixed prices that may not represent economic risk, incorporating statistical analyses at the pen-level accounts for biological variability and error in the estimates. When warranted, other strategies to account for economic risk (e.g., sensitivity analysis, stochastic simulation) can be incorporated within a partial budget framework. To encourage robust and transparent reporting, future research should explicitly state the type of economic assessment, the values and sources of all prices and the timeframe they represent, the methodology used, and how analyses were conducted. By adopting more consistent and transparent economic evaluation methods, researchers can enhance the applicability of RCT findings, ultimately supporting stakeholders in making economically sound decisions.

Key words: economics, feedlot cattle, livestock, net return, partial budget, randomized controlled trial

Introduction

Industry leaders in production livestock continually strive for advancements to improve operational efficiencies and sustainability. Sustainability can be broadly defined in three categories, which are: social, environmental, and economic sustainability (Goodland and Daly, 1996). Trade-offs exist among these categories, and stakeholders rely on research in order to make evidence-based decisions. When considering research outcomes in the animal sciences, economics is one of the most critical components, which fundamentally intersects with health and production outcomes (Dewsbury et al., 2022). In livestock production systems, economic considerations are paramount under an outcomes research framework, as they directly influence the adoption of interventions and management strategies by producers. The economic viability of a health or production intervention often serves as the deciding factor for its implementation by producers. In other words, no matter how innovative a new product or strategy may be, without economic incentive, adoption by producers may be limiting. Stakeholders must weigh the costs of adopting new practices against the potential benefits in terms of improved animal health, performance, and overall economic sustainability.

Despite the critical importance of economics in livestock decision-making, there is a notable inconsistency in the conduct and reporting of economic evaluations in animal health and production research. Saatkamp et al. (2016) highlighted the lack of a standardized framework for categorizing the costs associated with highly contagious livestock diseases, leading to difficulties in comparing studies and potential misinterpretations. They emphasized that without consistent methodologies rooted in sound economic principles, economic analyses can become fragmented and less useful for stakeholders. Further reinforcing this concern, Dixon et al. (2022) conducted a scoping review of experimental feedlot trials and found significant variability and inconsistencies in the methods and reporting of economic assessments. In their review, which included only articles with some form of economic assessment, just 28% of publications stated an economic outcome as a primary or secondary outcome of interest. The type of economic assessment and methodology [e.g., sourcing of prices, calculation of values and at what level(s)] was reported in 26% of trials; 48% reported methodology only; 19% only stated the type of economic assessment used; and 8% reported neither (Dixon et al., 2022). Selective use of data was apparent, as just 42% used all measured outcomes in the economic assessments; some used statistical tests for this selection, as 22% of articles included only statistically significant outcomes as variables.

Overall findings from Dixon et al. (2022) demonstrated that many studies lacked explicit statements of primary economic outcomes, did not adequately describe the methodologies used, and often failed to provide sufficient details for replication or critical evaluation. These are basic components needed for the assessment of reproducibility and validity by researchers (Sargeant et al., 2010). This inconsistency hampers the ability of researchers and industry stakeholders to fully understand and apply the findings of economic assessments, ultimately limiting their impact on industry practices and policy-making.

Randomized controlled trials (RCTs) have long been considered the gold standard for the evaluation of research outcomes from interventions, and rank near the top of the hierarchy of evidence for causal inference, just below systematic reviews and meta-analysis of multiple RCTs (Sargeant et al., 2014). Stakeholders commonly use findings from RCTs in livestock production to make better informed decisions when applying interventions or implementing new management strategies. Therefore, integrating robust economic analyses into randomized controlled trials (RCTs) is essential for providing stakeholders with comprehensive information. Given the critical role that economic outcomes play in influencing producer decisions and the observed inconsistencies in current research practices, there is a clear need for more guidance and standardization in conducting economic analyses on RCT data. Establishing consistent methodologies and reporting standards will enhance the reliability and comparability of economic assessments, aiding stakeholders in making better-informed decisions based on robust and transparent economic evidence. Our objective was to compare and contrast methodologies for assessing costs and benefits associated with livestock health and production trials, and to provide scientific guidance, rationale, and recommendations for future conduct of economic analyses on RCT data.

Review of analysis tools for economic assessments

There are a variety of budgeting strategies that have been developed and used in agricultural economics. Common budget types are described here, along with their potential utility for economic assessment of RCT data. Cash flow budgets are used to estimate incoming and outgoing cash over a specific time interval, typically a year. All income sources are considered (e.g., livestock sales, crop sales), along with all expenses (e.g., labor, operating costs), to assess an operation's liquidity and financial sustainability (Madsen, 1983; Hardie et al., 1984; Trejo-Pech et al., 2022). Timing of cash transactions is crucial, as the net difference in accumulated income and expenditures at specific time points determines if the operation can meet its financial obligations as they occur. Cash flow budgets have been incorporated in enterprise budgets (Julian and Seavert, 2011), which are described later in greater detail. While useful for overall financial planning, cash flow budgets are less suited for assessing the marginal impacts of specific interventions tested in RCTs.

Whole farm budgeting has a broad, overarching scope intended to assess all aspects of an operation, including primary (e.g., livestock, crop production) and secondary (e.g., manure sales, leasing hunting grounds) enterprises. This method provides a comprehensive evaluation of the overall health and sustainability of an operation through all its components, allowing assessment of resource allocation that may inform decisions on future diversification or consolidation (Rushton, 2007). However, whole farm budgets can be time-consuming and may not adequately account for unplanned investments, deviations in cost estimates, or unexpected yield changes, making them less practical for analyzing the specific changes evaluated in RCTs; it has been suggested that alternative models that better account for variability and risk are superior (Hansen and Nærland, 2017). Gross margin analysis is similar to whole farm budgeting in that it considers all enterprises within an operation. The primary difference is that gross margin analysis ignores fixed costs shared by different enterprises, comparing only differences or profitability between enterprises that stem from output (i.e., revenue) minus variable costs (Rushton, 2007). This simplification makes it somewhat more practical than whole farm budgeting. However, both methods are not particularly well-suited for assessing how a change to a given enterprise may impact marginal costs and benefits from that enterprise, which is generally the intention of RCTs.

An enterprise budget is a tool used for evaluating profitability of a single enterprise (e.g., cow-calf, stocker, a specific crop) within an operation. Consequently, performing a budget for each enterprise in an operation could enable, in aggregate, a whole farm budget (Rushton, 2007). Because enterprise budgets focus on a single entity within a larger production framework, they may be of greater utility than whole farm budgets due to their simplicity and reliance on fewer assumptions that may change during a production cycle (generally one year). The primary components of an enterprise budget are revenue and costs, which are further broken down into fixed and variable costs. Fixed costs, often referred to as "overhead costs," occur regardless of production output and may include items such as property taxes, labor, insurance, and depreciation of equipment and facilities (Madsen and Haider, 1983; Rushton, 2007). These costs are typically shared by multiple enterprises and cannot be easily assigned to a particular one. Variable costs can change in the short run (i.e., within a yearly production cycle) and may include livestock purchase costs (e.g., feeder cattle), feed costs, and veterinary expenses. These costs are avoidable in that if production is not undertaken, the costs are not incurred (Madsen and Haider, 1983). We should also note that purchased breeding livestock should be differentiated from market livestock, as purchased breeding livestock (e.g., cows) are depreciable assets and are therefore considered a fixed cost.

Interest is often accounted for in enterprise budgets by applying an interest rate to certain fixed and variable investments, reflecting the average amount of capital tied up over the production period. It is a common convention to estimate interest as the interest charged on half the initial cost of any capital item that is invested gradually over time (Rushton, 2007). For example, in a beef feedlot operation, interest would typically be applied to the full purchase cost of feeder cattle because they are purchased at the beginning of the feeding period and represent capital tied up for the entire duration. This means the entire cost of feeder cattle is subject to interest charges over the feeding period. Conversely, feed is purchased and consumed regularly throughout the feeding period. Therefore, interest is often applied to half of the total feed cost, based on the assumption that, on average, half of the feed investment is outstanding at any given time. This method accounts for the opportunity cost of money invested in both fixed and variable assets throughout the production cycle. By applying interest appropriately to these investments, the enterprise budget more accurately reflects the financial costs associated with the timing of expenditures and the capital tied up in the operation. The importance of interest also may apply to other methods as well, not just enterprise budgets.

Related to interest is the time-value of money, where a dollar received today is worth more than a dollar received in the future, because todays dollar can be invested to earn interest or returns, increasing its value over time (Rushton, 2007). Therefore, future dollars should be discounted to reflect the value of current dollars, for which interest rates are often used for this estimation. Discounting may be of lesser consequence in short-term production windows (e.g., swine or cattle finishing), but can have large impacts when interventions strongly influence future revenue. Horton et al. (2024) described this as opportunity cost, for which discounting was used to account for the opportunity cost of delaying when revenue from feedlot cattle was received, when marketing at alternative endpoints.

Readers may visit AgManager.info for examples of detailed enterprise budgets for beef, dairy, swine, and sheep farms under a variety of production systems; these budgets may be downloaded as spreadsheets and edited to fit different operations under diverse conditions. While enterprise budgets are useful for evaluating the profitability of a single enterprise, they do not inherently allow for the comparison of production changes, such as the use of a new feed additive or technology (Rushton, 2007). In the context of RCTs, where the primary interest lies in assessing impacts of specific interventions, an economic method that focuses on marginal changes (i.e., costs and benefits of an intervention) is more appropriate.

Cost-benefit analysis and cost-effectiveness analysis are methods often used in agricultural and health economics to evaluate the economic efficiency of interventions, generally for more complex policy-related decisions (Rushton, 2007). Cost-benefit analysis involves comparing the total expected costs and benefits (non-monetary, e.g., social welfare) of a project or intervention, with both costs and benefits expressed in monetary terms (Harrison, 1996; Adamson et al., 2020). This allows for a direct assessment of whether the benefits outweigh the costs. However, cost-benefit analyses can be complex and require assigning monetary values to all outcomes, which may not always be feasible or appropriate in RCTs focused on specific production changes. Cost-effectiveness analysis, on the other hand, compares the relative costs of interventions to their outcomes, which are not necessarily expressed in monetary terms but in natural units (e.g., weight gain, disease incidence reduction) (Babo Martins and Rushton, 2014). While useful in comparing interventions with similar goals, cost-effectiveness analyses may not capture the full economic impact in monetary terms, which is often the desired outcome in production-focused RCTs.

Partial budgeting is a pragmatic method for assessing economic impacts of interventions applied in RCTs. This method estimates the costs and benefits associated with a change (e.g., a change in management or production strategy, feed additive, medication, or precision technology). The objective is not to assess profits or losses of an enterprise as a whole, but to estimate the marginal net return (partial revenues minus partial costs) difference resulting from the alternative intervention(s) (Rushton, 2007). Partial revenues may represent total revenue in a partial budget, while partial costs likely will not represent total cost, as costs that are fixed or constant across interventions are excluded from the budget.

As described by Rushton (2007), partial budgeting focuses on four components:

1. Additional Costs: New costs incurred due to the change.
2. Reduced Revenue: Revenue lost as a result of the change.
3. Additional Revenue: New revenue generated by the change.
4. Reduced Costs: Costs saved because of the change.

The net economic impact is calculated by comparing the sum of additional costs and reduced revenue to the sum of additional revenue and reduced costs. Economic support for the proposed change (e.g., treatment intervention) is achieved when the net benefits exceed net costs. An important distinction in partial budgeting is that, because we are only interested in the marginal difference from a change, only items that are suspected to be impacted by the change need to be included in the budget (Corbin and Griffin, 2006). Inputs not expected to be modified by the change (e.g., property taxes, general overhead costs) can be excluded. However, if there is uncertainty about whether an item is affected, it is prudent to include it in the budget. An example of a partial budget for an RCT is implemented and described in greater detail, including additional considerations, in the following section of this publication.

A challenge with the methods discussed thus far is their general confinement to fixed production cycles or time intervals, which may not account for seasonal resource flows or the inherent variability and uncertainty (i.e., risk) associated with fluctuating economic conditions (Rushton, 2007). Advanced strategies can be employed to better account for risk, including sensitivity analysis, break-even analysis, and decision analysis (e.g., decision trees). Sensitivity analysis examines how the results of an economic evaluation change with variations in key assumptions or input parameters. By adjusting variables such as prices, costs, or production parameters, researchers can assess the robustness of their conclusions under different scenarios (Christopher Frey and Patil, 2002). Sensitivity analyses may be conducted within the framework of a partial budget; for example, Horton et al. (2024) performed sensitivity analyses to assess the impact of varying pricing components on net returns of feedlot heifers fed for differing days-on-feed and using alternative implant programs from pooled RCT data. Break-even analysis, a form of sensitivity analysis, identifies the point at which the net benefits of an intervention equal zero, providing valuable insights into the conditions required for an intervention to be economically viable (Berry, 1972; Rushton, 2007).

Decision analysis involves the use of decision trees or other models to evaluate the outcomes of different choices under uncertainty (Marsh, 1999; Morris, 1999). This method can incorporate probabilities of various outcomes and is useful in complex situations where multiple decisions and uncertainties interact. Somewhat similarly, dynamic, stochastic simulation modeling allows researchers to account for probability distributions around independent variables and their co-dependencies, enabling the model to conduct numerous iterations simulating a wide variety of potential conditions and outcomes (Corbin and Griffin, 2006). Agricultural economists have used stochastic simulation models to address complex, but pragmatic questions in the livestock production sector (Belasco et al., 2009; Dennis et al., 2018; Dennis et al., 2020). While these models offer additional robustness, they are generally more complex and resource-intensive, and often not solely based on RCT data. These advanced methods that address risk are beyond the scope of this publication, as they are better suited for analyses where the primary objective is economic evaluation under uncertainty. In most RCTs, the primary objective is related to some aspect of animal health and production, with economics as a secondary or supplementary objective. Therefore, simpler budgeting methods like partial budgeting should suffice.

To summarize, while there are several economic analysis methods available, partial budgeting emerges as the most appropriate and practical tool for evaluating the marginal economic impacts of interventions tested in RCTs within livestock health and production. Its focus on changes directly related to the intervention, combined with its simplicity and adaptability, makes it a valuable method. These features allow transparent reporting, thus enabling improved research reproducibility. Additionally, the partial budget framework may be tailored and used as a foundation for more complex methodologies that account for risk, if so desired (Berry, 1972; Marsh, 1999; Morris, 1999; Corbin and Griffin, 2006; Rushton, 2007; Horton et al., 2024). Therefore, a case study of the implementation of a partial budget using RCT data as an example, is described and executed in the next section.

Case study – applying a partial budget to RCT data

To provide an example and guidance on applying partial budgeting to evaluate economic implications from RCT data, we utilized data from Nickell et al. (2021) for the Oklahoma (OK) trial site. In brief, the objective of this trial was to evaluate effects on feedlot steer health, performance, and carcass characteristics of bovine respiratory disease (BRD) control programs targeted at the animal level using predictive algorithms, compared to industry-standard pen-level management strategies (metaphylaxis or none) of BRD. The control programs were based on data from a precision agriculture technology (TECH) designed to predict animal-level risk of BRD using machine learning algorithms that process chute-side diagnostics (e.g., weight, heart and lung sounds, temperature) as input variables. Based on the algorithm, the TECH indicates whether each animal should be administered an antimicrobial at initial processing, and the system's "aggressiveness" in indicating animals for BRD treatment can be adjusted, where a more aggressive threshold targets fewer animals to receive an antimicrobial. Thus, the proportion of animals within a pen that receive an antimicrobial based on the TECH will vary depending on the overall BRD risk of the pen and the programmed threshold.

The trial was conducted as a randomized complete block design with a 1-way factorial arrangement of 4 experimental treatments. Treatments consisted of a negative control (NEG; no metaphylaxis), a positive control (META; metaphylaxis to all animals), TECH-high proportion (metaphylaxis administered to individual animals based on a conservative algorithm threshold), and TECH-low proportion (metaphylaxis administered to individual animals based on an aggressive algorithm threshold). A total of 1,980 beef steer calves were allocated across 28 pens, with 69 to 72 animals per pen. Calves were blocked by arrival, randomly allocated to pens within blocks, and pens were randomly assigned to treatments. The primary health outcomes were BRD morbidity and mortality. Different antimicrobials were used for first, second, and third clinical BRD treatments, but did not differ among experimental treatments (Table 6.1). Steers requiring more than three treatments for clinical BRD were removed from the trial (culled). Performance, health, and carcass outcomes were monitored through harvest. For additional information on the RCT used for our case study, readers are referred to Nickell et al. (2021).

As pen was the experimental unit in the RCT, a budget was applied at the pen-level to each pen in the trial. The final outcome of the budgets is a net return, which is defined here as: total pen revenue minus partial pen costs, converted to a per-animal or per-carcass basis for interpretation. Economic variables from the partial budgets then can be analyzed statistically, similar to continuous performance outcomes (e.g., average daily gain), allowing for comparison of marginal differences between treatments. First, we describe the partial budget framework, followed by an example showing all calculations applied to one of the trial pens.

Partial budget framework

All relevant observed cattle health, performance, and carcass data were included in the partial budgets, regardless of their statistical significance reported by Nickell et al. (2021). This approach is recommended because most RCTs are designed to detect treatment effects on a primary outcome of interest (e.g., BRD morbidity, carcass weight) and may not have sufficient statistical power to detect significance for secondary outcomes, risking Type II error (Esposito et al., 2009). Researchers must exercise caution when interpreting non-significant *P*-values, as absence of evidence is not evidence of absence (Bello and Renter, 2018). Excluding variables from an economic analysis due to a lack of statistical significance may introduce bias if Type II error is present, and the researcher falsely concludes that treatment effects were equivalent when they are in fact not. Therefore, we do not recommend using *P*-values as inclusion criteria for variable selection in a partial budget or other economic assessments. Even if certain production variables do not show statistical significance, they may still have substantial economic significance, particularly when aggregated to a total dollar value for a pen. Although only items that have the potential to be impacted by the change need to be included in the partial budget (Corbin and Griffin, 2006), *P*-values should not be solely relied upon to determine potential or suspected impacts.

Dixon et al. (2022) noted insufficient reporting of parameter values and sources in their review of economic assessments in feedlot cattle trials. All or some of the values used in economic assessments were reported in 86% of trials, but only 57% reported the sources of these values, and only 39% reported the dates when values were estimated or sourced. For our example, the prices (USD) used in the partial budget were reflective of prices at the time of trial conduct (September 2018 through March 2019). Alternatively, contemporary prices could be applied to data from historical RCTs, which may be appropriate if researchers are comfortable with the assumption that animal populations, management strategies, and effect estimates remain valid. A complete list of prices used for calculating pen-level costs and revenues in this example, and their sources, are reported in Table 6.1.

Feeder steer purchase prices were sourced from the Livestock Marketing Information Center (LMIC) database, which compiles reports from feeder cattle auctions reported by the U.S. Department of Agriculture (USDA) Agricultural Marketing Service (AMS). Weekly prices for medium and large frame #1 feeder steers weighing 272 to 295 kg (600 to 650 lb) – reflective of the average initial body weight (BW) of calves enrolled in the trial – were obtained for each enrollment block, based on enrollment date and origin (Missouri, Oklahoma, Texas) of the trial cattle. An average feeder steer price of $163.70/cwt (hundredweight; cwt = 45.4 kg = 100 lb) was calculated. A processing regimen that included routine vaccinations, anthelmintic and parasitic control, identification, and implanting was constructed to reflect the products administered in the RCT. Apart from an assumed $1.50/animal chute charge, which accounts for equipment and labor, all other prices for pharmaceutical products were sourced from Valleyvet.com after the trial had been completed and are listed in Table 6.1. Note that antimicrobial metaphylaxis was administered only to META pens and selected animals within TECH-high and -low pens. Some of these processing products are administered on a per-animal (or per-dose) basis, while others are priced per milliliter, with the amount administered calculated based on pen weight and manufacturer dosage instructions. Differing antimicrobials were administered depending on how many times an animal had been treated for clinical BRD, and their prices, again sourced from Valleyvet.com, are in Table 6.1. Additionally, each time an animal within a pen was treated for clinical BRD, a $3.00/animal pull-and-treat charge was applied, accounting for equipment use and labor to pull, diagnose, and treat individual animals. The main impact of feedlot mortalities is the absence of revenue from the purchased animal and subsequent inputs (e.g., consumed feed). Additionally, a $32.85 rendering fee was applied, adjusted for inflation to 2019 USD from a 2002 reported value ($24.11; Sparks Companies Inc., 2002) using the Producer Price Index (U.S. Bureau of Labor Statistics).

The feed and yardage price ($249.40 per ton of dry matter; 1 U.S. ton = 907 kg = 2,000 lb) was calculated from the CattleFax ration prices database for the Central Plains region of the U.S. This value represents an average reflective of the months during which the steers were on feed in the trial. As all cattle in the trial were fed common diets, this was deemed a reasonable approach. In trials comparing different dietary formulations, ingredients, or management practices, it may be necessary to determine prices for specific diets and apply those prices to specific amounts fed of each. In feedlots, yardage accounts for overhead costs including labor, equipment, and utilities. CattleFax reports industry average feed and yardage prices from commercial beef feedlots monthly. As different pricing structures for feed, feed markup, and yardage are used (e.g., some feed markup and some yardage, yardage and no feed markup, or feed markup and no yardage), a single combined value for feed and yardage is reported. If researchers desire more precision, prices of individual ingredients can be used to calculate total ration prices. Note, however, that unless prices for all ingredients are readily available, it may be challenging to source prices for certain ingredients (e.g., micro-ingredients or others used in small quantities). The final cost variable included in the partial budget was interest, for which an average reported rate of 7% for Oklahoma during the trial period was used. This rate was sourced from the Federal Reserve Bank of KC – Ag Credit Survey of yearly fixed interest rates for operating loans. For rationale previously described, interest was applied to both the purchase cost of feeder cattle for the time they were on feed and half of the feed cost, using simple, non-compounding interest.

Revenue in the partial budget was derived from fed cattle sales and removals (i.e., animals culled or "railed" from the trial for health reasons and sold individually at a discounted price). Here, we considered only marketing fed cattle on a dressed (carcass) basis with a premium and discount-based grid for carcass characteristics (Table 6.1). In some cases, there may be benefit to considering multiple sale bases (e.g., live marketing). The dressed fed cattle base price ($196.40/cwt) was sourced from the National Weekly Direct Slaughter Cattle - Negotiated Purchases report (LM_CT154; USDA-AMS). This price reflects steers grading over 80% Choice, sold dressed delivered on a negotiated cash basis, and was calculated based on the average price of steers sold during the timeframe when trial cattle were harvested in the trial. The base price was then adjusted for premiums and discounts for USDA Quality Grade and Yield Grade (QG and YG, respectively), as well as a discount for heavyweight carcasses [those weighing over 477 kg (1,050 lb)]. There were no cattle in the trial weighing less than 249 kg (550 lb); therefore, no lightweight discount was included. Values for these premiums and discounts are reported in Table 6.1 and were sourced from the National Weekly Direct Slaughter Cattle - Premiums and Discounts report (LM_CT155; USDA-AMS), again averaging the timeframe when trial cattle were harvested.

The USDA AMS sets Choice and YG 3 to $0.00/cwt, meaning no premium is given to carcasses grading Choice in the partial budget. While this likely impacts total revenue, the Choice-Select spread remains intact, and it does not impact marginal revenue or net return differences between treatment groups, which is the objective of the partial budget. Additionally, as very few cattle in the trial graded sub-Select, those that did were combined into a single "other" category (Nickell et al., 2021), and the QG discount for carcasses grading Standard was applied to these carcasses. For simplicity in our example, the final grid price was calculated per Feuz et al. (2003), where the premiums and discounts were multiplied by the proportion of carcasses in each category for each pen, and the net adjustment was added to (or subtracted from) the dressed fed cattle base price. Alternatively, one could multiply the grid prices by the respective cumulative weight of carcasses in each category (if those data are available) to determine dollar adjustments for premiums and discounts for pen revenue from fed cattle sales. Anecdotally, when comparing these two methods for grid pricing with RCT data, we have found very similar to equivalent results, with approximately a 0.25% difference between pen revenue calculations on average.

The last component of the partial budget involved estimating revenue for animals removed from the trial, for which there is no publicly available source for obtaining these prices. Horton et al. (2021) reported that prices received for feedlot culls were most correlated with cull cow prices – specifically dressed Breaker cows weighing over 227 kg (500 lb) – and recommended a corresponding adjustment of the cull cow price. As removals could occur at any point in the trial, an average cull cow price ($111.40/cwt dressed) was calculated from the trial timeframe using the National Weekly Direct Cow and Bull Report - Negotiated Price report (LM_CT168; USDA-AMS). To adjust the price to estimate removal revenue, the hot carcass weight (HCW) of removals needed to be estimated, for which the inverse of a formula from Tatum et al. (2012) was used, where HCW = 0.2598 × live $BW^{1.1378}$. The mean live BW of steers at the time of their removal for a pen was used to estimate the mean HCW of removals from that pen. Then, the cull cow price was adjusted by multiplying it by 0.595, 0.763, or 0.92 when the mean estimated HCW of removed animals for a pen was less than 181 kg (400 lb), between 181 to 271 kg (400 to 599 lb), or greater than 272 kg (600 lb), respectively (Horton et al., 2021).

Calculations and partial budgeting analysis

With all prices used in the partial budget and their sources identified (Table 6.1), we demonstrate how the budget can be applied to an example pen (experimental unit) from the trial, showing all calculations (Table 6.2). The pen chosen was from the positive control (META) treatment, with basic demographic and performance metrics including: 71 steers enrolled, mean initial BW 262 kg, 260 days-on-feed, 12 first-time BRD treatments, 4 second-time BRD treatments, 2 third-time BRD treatments, 0 removals, 1 mortality, 7.85 kg/d mean dry matter intake, 70 steers shipped and harvested, and 402 kg mean HCW. Note that pen-level totals (e.g., total kg HCW, dry feed delivered) are used in the budget (Table 6.2), not mean values, and that background conversion of units (e.g., cwt to kg) are not shown. Notably, Table 6.2 appears like a gross margin analysis for a single pen, excluding constant or fixed costs unaffected by treatment. Its purpose is to show how pen-level calculations were performed. The partial budget is formed when the data are analyzed using statistical models (described later), where the models estimate the marginal treatment effects of the interventions on net returns (or other economic outcomes of interest), using the results of the budget when applied to each pen from the RCT.

The cost of cattle purchased was calculated by multiplying the feeder steer price by the total initial weight of the pen (Table 6.2). Processing products administered on a per-animal or per-dose basis (as listed in Table 6.1) were summed to a total price per animal and termed “per n processing” in Table 6.2. This price was multiplied by the number of animals enrolled in the pen. Processing products and clinical BRD treatment products priced on a $/mL basis were multiplied by the number of milliliters delivered to animals, determined by manufacturer-labeled dosages and the mean weight of the pen at processing or the actual weight of individual animals when treated for BRD. The BRD pull charge and render fee were multiplied by the total number of clinical BRD treatments and mortalities, respectively, in the pen. The feed and yardage price was multiplied by the total weight of dry feed delivered to the pen. Interest was applied to both feed and cattle by converting the yearly interest rate (7%) to the actual interest based on the days-on-feed for the pen and multiplying it by the total cattle and feed costs. To account for interest on one-half of the feed cost, half of the interest rate was used in this calculation.

Before proceeding to revenue calculations, the grid price was determined by adjusting the dressed fed cattle base price according to premiums and discounts and the frequencies of quality grades and heavyweight carcasses in the pen (Table 6.2). The premium or discount for each category was multiplied by the percentage of animals in the pen within each respective category to determine the adjustments. The adjustments were then added to the base price to calculate the grid price. Revenue from fed cattle sales was calculated by multiplying the grid price by the total HCW of the pen (Table 6.2). As previously described, the price for cattle removed from the trial would vary between pens, depending on the weight of removed animals. As there were no removed animals in the example pen, no price or revenue is listed in Table 6.2 for removals.

The final net return calculation is the total pen revenue minus the sum of partial pen costs (Table 6.2). This value can then be converted to a per-animal enrolled or per-carcass basis. We note that while this may seem similar to "deads-in" vs "deads-out" calculations of animal performance variables, all economic calculations were performed with all dead and removed animals included. Therefore, net return per carcass calculations would still be interpreted as deads-in. We present both denominators here to show that, in most cases, the difference is minimal and may be up to the preference of the researcher or producer. Table 6.2 is meant to be an example of how all prices and calculations can be applied at the pen-level in an RCT of feedlot steers. We note that a table like Table 6.2 is not created for each pen in the trial for calculations. Rather, this process is streamlined by conducting the calculations across rows (experimental units) in the dataset, using the researchers' software of choice.

Finally, to execute the partial budget, statistical analyses were performed on the results of the budget applied to each pen, similar to the analysis of continuous performance variables in the trial (Nickell et al., 2021). Linear mixed models (Proc GLIMMIX, SAS 9.4; SAS Institute Inc., Cary, NC) were fitted with a Gaussian distribution, an identity link function, a Kenward-Roger degrees of freedom adjustment, Newton-Raphson and Ridging optimization procedures, and used restricted maximum likelihood estimation. Pen was the experimental unit, treatment was the fixed effect, and block was included as a random intercept. Model assumptions of normally distributed and homogeneous residual variances were assessed visually using plots of studentized residuals. A Tukey-Kramer adjustment for multiplicity was used for pairwise comparisons between treatments. The primary outcome was net return; however, other variables within the partial budget (e.g., cost of gain) were also included for evaluation. An *a priori* significance threshold was set at $\alpha = 0.05$.

Results and reporting

Results of the partial budget analysis are presented in Table 6.3, with NEG set as the referent treatment and the marginal differences of the other treatments compared to NEG reported. As anticipated, there was no evidence of a difference in the purchase cost of steers ($P = 0.52$), due to the fixed feeder cattle price, and the randomization process resulting in similar initial BW between treatments (Nickell et al., 2021). Arguably, steer purchase costs could have been excluded from the partial budget since randomization of steers to treatments should result in BW, and thus purchase costs, that are not associated with experimental treatments. However, there is no harm in including additional variables in partial budgets, and mean initial BW varied numerically across individual pens and treatments, implying the potential for differing pen-level cattle purchase costs. Additionally – as previously mentioned – it is not recommended to rely on statistical significance for variable inclusion. Processing costs differed among all treatments ($P < 0.01$), reflecting the amount of metaphylactic doses administered to the pens. The pen-level cost of treating animals with clinical BRD was affected by treatment ($P = 0.02$), with META and TECH-high having lower costs per animal enrolled compared to NEG. Although TECH-high had higher feed and yardage costs compared to NEG ($P < 0.01$), there was no evidence of a treatment effect on cost of gain ($P = 0.14$). Metaphylaxis and TECH-high had higher total pen costs per animal than NEG ($P < 0.01$), while TECH-low did not differ significantly from any of the treatments. Total revenue was affected by treatment ($P = 0.02$); however, only TECH-high differed significantly from NEG by receiving more total revenue per animal, with no evidence of differences among the other treatments. Evaluating net return on a per-animal enrolled or per-carcass basis yielded similar results, both finding no significant differences between treatments ($P = 0.34$ and 0.31, respectively).

The reporting in Table 6.3 aligns with the objective of a partial budget, which is to evaluate the marginal differences between interventions or management strategies. Therefore, differences between the means (compared to NEG) are shown, rather than the means themselves.

If preferred, it would still be acceptable to report model-adjusted means, as the treatment differences would remain identical. However, this comes with some caveats. Firstly, we are not necessarily interested in whether the trial cattle were profitable overall, as this depends largely on the input prices used in the partial budget. Rather, we are interested in how much additional return was gained or foregone by using an alternative intervention, regardless of whether net returns were positive or negative on average. Additionally, since only variables that potentially differ among interventions need to be included in a partial budget, reporting mean values for profitability may be misleading unless the budget was comprehensive (i.e., includes all possible economic variables, even those shared among treatments). Although our example budget presented here was relatively comprehensive and, if reported, the model-adjusted means may reasonably represent overall profitability under the given conditions, it would still lack the detail provided by whole farm or enterprise budgets. Finally, we note that the cost of using the TECH was not accounted for in the partial budget, meaning that for it to be economically advantageous, its cost would need to be less than the marginal improvement in net return.

Discussion and future guidance

The partial budget analysis using RCT data effectively demonstrated the four components of partial budgeting, particularly when comparing NEG with TECH-high. Steers in the NEG treatment experienced reduced costs but also reduced revenue, while TECH-high steers had increased revenue accompanied by increased costs. The combination of these components resulted in non-significant net return differences between the treatments. It should be acknowledged that although there were no significant differences in net return, mean dollar values exceeding $30 per animal, as observed here, would certainly carry substantial economic significance for producers. This highlights an inherent challenge when performing economic analyses in this manner: net return is a derived or composite variable that relies on a multitude of cattle production and economic variables – each with their own variability – for calculation. This suggests that, in some cases, economic analyses conducted on RCT data would benefit from larger sample sizes with greater statistical power. Nevertheless, researchers should not be discouraged by this observation and should not forgo economic analyses; such analyses are a critical part of the decision-making process for industry stakeholders and should not be left obscure (Antle and Wagenet, 1995; Cernicchiaro et al., 2022; Dewsbury et al., 2022).

Cattle and economic variables included in a partial budget can (and should) vary on a case-by-case basis, depending on specific research objectives and experimental designs of RCTs. In other words, there is no one-size-fits-all budget, and researchers should adapt the partial budget framework to fit specific needs. For example, if the primary objective of an RCT is health-focused (e.g., morbidity), where differences among treatments are expected, it is advisable to distinguish health costs for differing diagnoses and clinical treatment regimens (e.g., Valencia et al., 2019; Nickell et al., 2021; Horton et al., 2023). Conversely, if a research objective is production-focused without hypothesized health effects, it may be reasonable to use a fixed cost for health events rather than extensive differentiation (Horton et al., 2024). Alternative research questions and study designs may also require more complex considerations, such as discounting or the opportunity cost of money (Horton et al., 2024). Therefore, our example partial budget analysis is meant to provide guidance as a framework, which should be tailored to fit specific research questions, hypotheses, and study designs. Other variables and sources for prices can certainly be used, as long as they are economically sound and well justified. In complex situations, it may be wise to consult with an economist when there is uncertainty regarding variable inclusion, market conditions, or other economic factors that may not be immediately apparent. Ideally this should occur before trial initiation, to ensure that all necessary data for economic analyses are collected.

The primary limitations of partial budget analyses are that they are generally static and do not account for the variability that occurs from market fluctuations affecting prices or, typically, the variability of biological responses such as animal health and performance due to genetics, management, and environmental factors. In their review, Dixon et al. (2022) found that just 44% of trials used a statistical evaluation for economic or financial outcomes. However, in addition to providing more evidence for effects, by performing statistical analysis on a partial budget of RCT data, the second aforementioned limitation is somewhat mitigated because the variability of cattle responses in the trial data is accounted for, and this variability is reflected in the standard errors from the statistical models. The same limitations that apply to any RCT still hold – that is, the scope of inference is relative to the animal population, environment, management, and overall external validity of the trial. However, this approach is still highly advantageous over a traditional partial budget that would use fixed parameter values for animal health and performance variables (i.e., using treatment means for animal variables), due to the inclusion of biological variability. Nevertheless, partial budgets are most commonly a short-term, "snapshot" analysis under a specific set of fixed economic conditions that assume constant external market factors, and they do not fully account for the economic risk that may occur under long-term, fluctuating conditions.

There are potential methods to mitigate these concerns. For one, researchers do not need to feel confined to the economic conditions occurring at the time of an RCT. While we used contemporaneous prices in our example, we could have alternatively evaluated the economic effects of the BRD management interventions using prices from, for example, spring 2024, or average prices from 2021 to 2024, and compared the results of the budgets constructed under differing economic conditions. This would allow for the evaluation of economic implications under different scenarios, which may better inform industry stakeholders. However, this approach comes with the caveat that one must feel comfortable with the assumption that animal populations and treatment responses from an RCT can be extrapolated and still reasonably represent populations that would align with alternative economic conditions.

Horton et al. (2024) provides an example of a sensitivity analysis conducted within a partial budget framework to account for risk by evaluating how changes in key economic factors affect economic outcomes, thereby providing a range of possible results. In addition to sensitivity analyses, stochastic modeling may provide even more robust assessments of how interventions perform under varying conditions in order to characterize risk (Corbin and Griffin, 2006), which also may be built upon a partial budget framework. These more complex methodologies are likely better suited for cases where economics is the primary outcome or research question of interest, whereas simpler partial budgeting may suffice for supplementing common production outcomes in an RCT. Additionally, certain treatment or management interventions may have simpler, more consistent effects that are not heavily influenced by economic conditions, while that may not be the case for others. For example, Horton et al. (2024) found relatively consistent net return differences in terms of direction and magnitude for alternative implant programs in feedlot heifers, regardless of fluctuating economic factors. Conversely, the authors found that net returns were heavily influenced by differing economic conditions when extending feedlot heifer DOF, resulting in contrasting interpretations that were dependent on input prices. In summary, strategies exist to mitigate the primary limitations of partial budgets, and the research design and specific intervention in question may determine whether more complex methods are necessary.

An additional limitation of partial budgets, which is of lesser consequence under the context of RCTs but should still be considered, is the exclusion of fixed costs and opportunity costs (Rushton, 2007). Partial budgeting often focuses solely on variable costs and benefits directly affected by the intervention, neglecting fixed costs shared among treatments and the opportunity costs of resources utilized (e.g., time, labor, capital, land). Under the RCT setting, where fixed costs and resource allocations are consistent across treatments, this limitation is minimized. However, when applying results to broader production systems or evaluating long-run scenarios, variations in fixed costs and alternative uses of resources could influence the overall economic impact of an intervention. Therefore, while this limitation has a reduced effect within the controlled trial framework, researchers should still consider these factors when interpreting partial budget analyses and their potential implications in real-world scenarios.

There is a need for more consistent conduct and reporting of economic analyses in livestock research (Saatkamp et al., 2016; Dixon et al., 2022). The lack of clear economic evaluations hampers stakeholders' ability to make informed decisions based on research findings, and poor reporting practices limit the potential for meta-analyses or systematic reviews, which rely on consistent and comprehensive data. Reporting guidelines for animal research exist, many of which are compiled on the MEnagerie of Reporting guIDelines Involving Animals (MERIDIAN; https://meridian-network.org/) website. Additionally, reporting guidelines for economics conducted in human health research are available, such as the Consolidated Health Economic Evaluation Reporting Standards [CHEERS; Husereau et al. (2013)]. However, none of these guidelines directly apply to the conduct of economic analyses in animal research, particularly for production livestock species. The objective of this publication was not to create a detailed and comprehensive reporting guidelines checklist like those found at the previously mentioned sources. However, there are four basic principles that we strongly encourage be followed, in order to promote more transparent and reproducible economic analyses on RCT data, so that methodologies and findings may be better interpreted and critically evaluated by the reader.

1. Explicitly state and justify the type of economic assessment: the type of economic assessment performed should be explicitly stated and justified to fit the specific research question at hand.
2. Provide sources and descriptions of all parameters (prices and variables): sources and descriptions of all prices and other variables should be provided, including the timeframe they reflect.
3. Detail the methodology: a detailed description of the methodology should be provided, including how prices were applied and at what level(s) (e.g., animal-level, pen-level).
4. Describe the analytical methods: a description of how analyses for interpretation were performed, including whether statistical tests were used, along with justification of said analyses.

In our case study, the partial budget framework allowed explicit descriptions of principles 1 through 4, yielding high transparency and reproducibility of the findings. Along with these principles, there is an additional consideration that may impact the quality of economic assessments on RCTs. Like other primary study outcomes, the analysis and methodology should likely be planned *a priori*, being clearly conceived and described in study protocols. In other words, the type of assessment, variable descriptions and timeframes, methodological processes, and analytics can all be determined before starting a study. This further promotes transparency and dissuades "data fishing." If skipping this step, researchers also may find that the necessary data for thorough economic analyses were not collected, leading to lower quality assessments. This again relates to the benefit of collaboration with agricultural economists, particularly as the complexity of economic implications or scenarios rises.

We have recommended and demonstrated the use of partial budgets for economic assessment of RCT data, as the purpose of partial budgets is generally well aligned with the evaluation of alternative interventions or management strategies in RCTs. However, this does not mean that other methods are unacceptable; there may be cases for RCTs where, for example, a cost-benefit analysis may be more appropriate when the goal of the researcher is to incorporate evaluation of non-monetary costs and benefits. Additionally, we have recommended the use of traditional statistical analyses where budgets are constructed at the experimental unit level in an RCT, as this incorporates biological variability into the estimates. Still, there may be cases where statistical analyses become less appropriate, such as with stochastic simulation modeling where sample sizes may be artificially increased, and the objective is rather to characterize economic risk between interventions. Ultimately, the economic analysis type, price and variable sources, methodology, and analyses should be well justified and described by the researcher, so that readers and stakeholders may make better-informed decisions based on robust and transparent economic evidence.

Conclusions

Including economic outcomes in research involving production livestock, and RCTs in particular, is critical for providing a comprehensive evaluation of interventions and management strategies. While our examples were in the context of feedlot cattle research, there is no reason that the principles outlined here cannot be applied to other cattle sectors or production livestock species. Economic analyses offer valuable insights into the financial viability of alternative interventions or management strategies, which are essential factors for decision-making by producers and other industry stakeholders. By integrating economic outcomes with common outcomes in RCT data, researchers can present a more holistic view of the implications of their findings, thereby enhancing the practical applicability and impact of their research.

Thorough and robust reporting of economic analyses is imperative to ensure transparency, reproducibility, and credibility of the research. Partial budgeting emerges as a suitable and effective method for conducting economic assessments in RCTs due to its alignment with the evaluation of marginal changes associated with alternative treatments or interventions. When accompanied by appropriate statistical analyses, partial budgets can account for biological variability and provide more reliable estimates of economic impact. However, economic considerations are just another piece of the puzzle; they should be weighed alongside other important factors such as animal welfare, antimicrobial stewardship, and environmental and social sustainability. By embracing comprehensive and well-reported economic analyses, researchers can contribute to more informed and balanced decision-making processes that ultimately benefit the livestock industry as a whole.

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Tables

Table 6.1. Prices and their sources for use in a partial budget that was applied to feedlot steer pens from randomized controlled trial data

Item*	Price	Source
Cost		
Feeder steer price, $/cwt	$163.70	LMIC, USDA-AMS data
Initial Processing†		
Chute Charge, $/n	$1.50	Assumed
Ear Tag, $/n	$0.39	Valleyvet.com
Vista 5 SQ, $/n	$1.17	Valleyvet.com
Vision 7 with Spur, $/n	$0.65	Valleyvet.com
Revalor-XS, $/n	$8.44	Valleyvet.com
Doramectin, $/mL	$0.32	Valleyvet.com
Fenbendazole, $/mL	$0.10	Valleyvet.com
Tildipirosin (metaphylaxis), $/n	$3.96	Valleyvet.com
BRD pull charge,‡ $/n	$3.00	Assumed
1st BRD treatment,§ $/mL	$0.87	Valleyvet.com
2nd BRD treatment,ǀ $/mL	$0.56	Valleyvet.com
3rd BRD treatment,¶ $/mL	$0.15	Valleyvet.com
Render fee,** $/n	$32.85	Sparks Companies Inc. (2002)
Feed and yardage, $/dry ton	$249.40	CattleFax
Interest,†† fixed yearly %	7.00	Federal Reserve Bank of KC - Ag Credit Survey
Revenue		
Dressed fed cattle base price, $/cwt	$196.40	LM_CT154 (USDA-AMS)
Premiums and discounts‡‡		LM_CT155 (USDA-AMS)
Prime, $/cwt	$12.30	
Choice, $/cwt	$0.00	
Select, $/cwt	-$10.60	
Standard, $/cwt	-$30.20	
YG 1, $/cwt	$3.90	
YG 2, $/cwt	$1.80	
YG 3, $/cwt	$0.00	
YG 4, $/cwt	-$11.40	
YG 5, $/cwt	-$17.80	
Heavyweight, $/cwt	-$19.60	
Removal base price,§§ $/cwt	$111.40	LM_CT168 (USDA-AMS)

* Hundredweight = cwt = 45.4 kg (100 lb); 1 U.S. ton = 907 kg (2000 lb)

† Chute charge accounts for equipment and labor; Bovilis Vista 5 SQ (Merck Animal Health, Lenexa, KS); Bovilis Vision 7 with Spur (Merck Animal Health); Revalor-XS (Merck Animal Health); doramectin (Dectomax; Zoetis Animal Health, Parsippany, NJ); fenbendazole (Safe-Guard; Merck Animal Health); tildipirosin (Zuprevo; Merck Animal Health) administered to metaphylaxis, TECH-high, and TECH-low pens

‡ BRD (bovine respiratory disease) pull charge accounts for equipment and labor for both pulling, diagnosing, and treating the animal

§ Florfenicol and flunixin meglumine (Resflor gold; Merck Animal Health) administered SQ at 6 mL/45.4 kg

ǀ Enrofloxacin (Baytril 100; Elanco Animal Health) administered SQ at 5 mL/45.4 kg

¶ Oxytetracycline (Bio-Mycin 200; Boehringer Ingelheim Animal Health, Duluth, GA) administered SQ at 4 mL/45.4 kg

** Estimated cost of rendering a deceased animal ($24.11) reported by Sparks Companies Inc. (2002), inflation adjusted using the Producer Price Index to a value reflective of time of trial conduct

†† Yearly rate was adjusted to be reflective of the number of days-on-feed for each pen out of 365, and applied to the purchase cost of cattle, and one-half of the feed and yardage cost

‡‡ Adjustment of the base price is made via premiums and discounts, where the prices are multiplied by the corresponding percent of the pen within each category; YG = Yield Grade; heavyweight discount is for carcasses weighing over 746 kg (1,050 lb)

§§ Listed price is reflective of the price for dressed Breaker cows weighing over 227 kg (500 lb), and is further adjusted depending on the estimated carcass weight of animals removed from the trial (Horton et al., 2021)

Table 6.2. Example budget applied to one trial pen[*]

Costs	**Price**	**Unit**[†]		**Quantity**	**Unit**		**Value**
Cattle purchase	$163.70	per cwt	×	18575	kg	=	$67,036.62
Per n processing[‡]	$12.16	per n	×	71	n enrolled	=	$863.36
Doramectin[§]	$0.32	per mL	×	372	mL	=	$119.04
Fenbendazole[‖]	$0.10	per mL	×	942	mL	=	$94.20
Tildipirosin[¶] (metaphylaxis)	$3.96	per mL	×	410	mL	=	$1,623.60
BRD pull charge	$3.00	per n	×	18	n treated	=	$54.00
1st BRD treatment[**]	$0.87	per mL	×	428	mL	=	$372.36
2nd BRD treatment[††]	$0.56	per mL	×	114	mL	=	$63.84
3rd BRD treatment[‡‡]	$0.15	per mL	×	54	mL	=	$8.10
Render fee	$32.85	per n	×	1	n mortality	=	$32.85
Dry feed and yardage	$249.40	per ton	×	144385	kg	=	$39,693.84
Interest on feed[§§]	2.49	%	×	$39693.88	$	=	$989.63
Interest on cattle[‖‖]	4.99	%	×	$67035.15	$	=	$3,342.57
Total costs[¶¶]							$114,294.02

Premiums and discounts[***]	**Price**	**Unit**		**Quantity**	**Unit**		**Value**
Prime	$12.30	per cwt	×	8.6	%	=	$1.06
Choice	$0.00	per cwt	×	80.0	%	=	$0.00
Select	-$10.60	per cwt	×	11.4	%	=	-$1.21
Standard	-$30.20	per cwt	×	0.0	%	=	$0.00
YG 1	$3.90	per cwt	×	11.4	%	=	$0.44
YG 2	$1.80	per cwt	×	38.6	%	=	$0.69
YG 3	$0.00	per cwt	×	41.4	%	=	$0.00
YG 4	-$11.40	per cwt	×	8.6	%	=	-$0.98
YG 5	-$17.80	per cwt	×	0.0	%	=	$0.00
Heavyweight	-$19.60	per cwt	×	1.4	%	=	-$0.27
Total price adjustment							-$0.27
Grid price	$196.40	per cwt	+	-$0.27	per cwt	=	$196.13

Revenue	**Price**	**Unit**		**Quantity**	**Unit**		**Value**
Fed cattle sales	$196.13	per cwt	×	28164	kg	=	$121,781.64
Removal sales	-	per cwt	×	0	kg	=	$0.00
Total revenue							$121,781.64

Net return	**Quantity**	**Unit**		**Quantity**	**Unit**		**Value**
Pen total	$121,781.64	revenue	–	$114,294.02	cost	=	$7,487.63
Per animal enrolled	$7,487.63	return	÷	71	n enrolled	=	$105.46
Per carcass	$7,487.63	return	÷	70	n carcasses	=	$106.97

[*] Pen was in the negative control (metaphylaxis) treatment, and had 71 steers enrolled, mean initial BW 262 kg, 260 days-on-feed, 12 1st time BRD treatments, 4 2nd BRD treatments, 2 3rd BRD treatments, 0 removals, 1 mortality, 7.85 kg/d mean dry-matter-intake, 70 steers shipped and harvested, 590 kg mean shrunk final BW, 402 kg mean HCW.

[†] Hundredweight = cwt = 45.4 kg (100 lb); 1 U.S. ton = 907 kg (2000 lb)

[‡] Sum of processing product prices that were delivered on a per animal (dose) basis: $1.50 chute charge; $0.39 ear tag; $1.17 Bovilis Vista 5 SQ (Merck Animal Health, Lenexa, KS); $0.65 Bovilis Vision 7 with Spur (Merck Animal Health); $8.44 Revalor-XS (Merck Animal Health)

[§] Administered SQ at 1 mL/50 kg (Dectomax; Zoetis Animal Health, Parsippany, NJ)

[‖] Administered orally at 2.3 mL/45.4 kg (Safe-Guard; Merck Animal Health)

[¶] Administered SQ at 1 mL/45.4 kg (Zuprevo; Merck Animal Health)

[**] Florfenicol and flunixin meglumine (Resflor gold; Merck Animal Health) administered SQ at 6 mL/45.4 kg

[††] Enrofloxacin (Baytril 100; Elanco Animal Health) administered SQ at 5 mL/45.4 kg

[‡‡] Oxytetracycline (Bio-Mycin 200; Boehringer Ingelheim Animal Health, Duluth, GA) administered SQ at 4 mL/45.4 kg

[§§] Interest rate for interest on feed is half of the fixed interest rate multiplied by the number of days-on-feed divided by 365: (7% / 2) × (260 / 365)

[‖‖] Interest rate for interest on feeder cattle purchase is the fixed interest rate multiplied by the number of days-on-feed divided by 365: 7% × (260 / 365)

[¶¶] Total costs in the budget are total partial costs for the enterprise (i.e., constant or fixed costs unaffected by treatment are excluded from the budget)

[***] YG = Yield Grade; heavyweight discount is for carcasses weighing over 746 kg (1,050 lb)

Table 6.3. Model adjusted differences between the means and standard errors of the differences (SED) from a partial budget assessment of a randomized controlled trial comparing the effects of standard bovine respiratory disease (BRD) control programs with targeted programs for beef feedlot steers

	Treatment[*]					
Item	NEG	META	TECH-high	TECH-low	SED	*P*-value
Purchase cost,[†] $/n enrolled	Referent	4.55	-0.87	1.04	3.798	0.52
Processing cost,[‡] $/n enrolled	Referent[a]	24.64[b]	21.29[c]	15.26[d]	1.073	< 0.01
Clinical BRD treatment cost,[§] $/n enrolled	Referent[a]	-4.24[b]	-4.07[b]	-3.40[ab]	1.296	0.02
Feed and yardage cost,[†] $/n enrolled	Referent[a]	20.93[ab]	33.65[b]	10.12[ab]	8.748	< 0.01
Cost of gain,[ǀ] $/cwt	Referent	-5.24	-3.63	-3.39	2.145	0.14
Total cost, $/n enrolled	Referent[a]	45.62[b]	49.81[b]	23.02[ba]	9.627	< 0.01
Total revenue, $/n enrolled	Referent[a]	76.84[ab]	86.61[b]	20.50[ab]	28.924	0.02
Net return, $/n enrolled	Referent	31.21	36.81	-2.51	26.664	0.34
Net return, $/carcass	Referent	31.67	38.29	-4.55	27.261	0.31

[*] Negative control (NEG; no metaphylaxis), a positive control [META; tildipirosin (TIL) metaphylaxis], precision technology (TECH) TECH-high (TIL administered to individual animals based on a conservative algorithm threshold), and TECH-low (TIL administered to individual animals based on an aggressive algorithm threshold)

[†] Includes interest

[‡] Cost of all products given at initial processing, including TIL, with the amount dependent on the treatment

[§] Cost of all clinical BRD treatments administered to animals within a pen, divided by the number of animals enrolled in the pen

[ǀ] Feed, yardage, and interest cost per cwt live weight gain (cwt = 45.4 kg = 100 lb)

[a,b,c,d] Uncommon superscript letters within row indicate significance ($P \leq 0.05$) after adjustment for multiple comparisons

Chapter 7 - Conclusions

This dissertation utilized a variety of approaches to address key production questions in the beef industry, delivering meaningful outcomes to stakeholders. The themes and research gaps that necessitated evaluation were introduced in Chapter 1. As feedlot cattle in the U.S. have been progressively fed to heavier, more extreme endpoints (EPs), updated research with contemporary cattle populations on the health, performance, carcass characteristics, and economic implications of this practice was warranted. Economic considerations for extending days-on-feed (DOF) were addressed, as there are numerous performance, carcass, and potential health factors that need to be evaluated when marketing at alternative EPs. It was critical to account for economic risk due to the variability of both biological and economic factors. To perform comprehensive economic assessments, a better understanding of beef cattle culled from feedlots for health reasons, their revenue, and potential associations with beef market prices was needed to improve revenue estimation for these animals. Lastly, due to the inconsistency and variable reporting quality of economic assessments in randomized controlled trials (RCTs) – particularly in feedlot research – guidance and recommended frameworks for such assessments were called for. These issues were addressed by five original research Chapters (2 through 6), which sought to generate pragmatic and meaningful outcomes for researchers and beef industry stakeholders. The conclusions and implications of these chapters and the overall dissertation are as follows.

In Chapter 2, an observational study of 2,992 feedlot animals culled for slaughter was conducted to describe the characteristics of this population, reported the revenue received for these animals, and correlated the prices received for the feedlot culls with reported U.S. beef market prices. The majority of culls returned revenue, and the prices received, along with reasons for culling, were minimally affected by sex. The fact that the vast majority of culls returned revenue may have animal welfare implications, as it suggests that those sent for salvage harvest from the source feedlots were healthy enough for transport and avoided condemnation at the abattoir. The majority of the animals were culled for musculoskeletal/trauma, followed by respiratory and other reasons. The revenue received varied depending on the reason for culling and cattle weight, where heavier animals were more often culled for musculoskeletal/trauma reasons, and consequently received higher prices than lighter animals, which were more often culled for respiratory reasons. Prices received for feedlot culls were most correlated with cull cow prices, specifically those for dressed Breaker cows weighing over 227 kg (500 lb). These results provided a mechanism for the future estimation of feedlot cull prices, where a proportion of the cull cow price – dependent on the weight category of the feedlot cull – can be used as a predictor. This process and methodology became critical for accounting for the revenue from culled feedlot cattle in the future chapters of this dissertation. Additionally, these findings are of value to future researchers, as there was previously no published or known basis for estimating revenue from feedlot culls.

The next phase of the dissertation focused on extending the feeding horizons of feedlot cattle. Pooled data from three RCTs were used in Chapter 3 to evaluate feeding beef heifers for differing DOF while using alternative implant programs and examine the impacts on cattle health, performance, and carcass characteristics. The trials were conducted as a 2 × 3 factorial in a randomized complete block design, with two implant programs and three differing DOF. Compared to a single extended-release implant, heifers receiving two implants during the finishing period had improved feed efficiency and heavier carcasses, and the distributions of U.S. Department of Agriculture Quality and Yield Grades (QG and YG, respectively) shifted toward lower QGs and lower numerical YGs with the re-implant program. Aside from dry matter intake, the effects of DOF were not dependent on the implant programs. Extending the DOF of feedlot heifers led to poorer live performance (gain:feed and daily gain) but increased weight gains, with minimal impacts on animal health. Over the 42-day extended feeding period, 76% of the live weight gain was deposited in the carcass across the three trials. Heifers fed to later EPs had heavier carcasses with increased dressed yields, while the distributions of QG and YG shifted toward higher grades with extended feeding beyond the baseline EP. These changes in carcass characteristics suggest a potential tradeoff when marketing cattle on a premium and discount-based grid. Pooling three commercial RCTs provided a more robust analysis with broader applicability compared to individual trial summaries. These results provide updated insights for producers managing feedlot heifer EPs, but the economic implications of this practice required further evaluation, as economic factors are likely the primary drivers of EP management decisions.

Utilizing the pooled RCT data from Chapter 3, the economic implications of extending DOF of beef heifers when using alternative implant programs by conducting sensitivity analyses of key economic factors are addressed in Chapter 4. The economic factors of interest that were varied to assess the relative impact of price changes were fed cattle prices (live or dressed base price), feed and yardage prices (FYP), and the Choice-Select spread (CS-spread), which determined QG grids. Sensitivity analyses were conducted within a partial budget framework, applied at the pen-level for each experimental unit in the RCT, and the final outcome (net return) was statistically analyzed to evaluate the marginal net return differences between treatments. This approach allowed assessment of economic risk stemming from environmental and biological variability between the cattle populations, and market variability from differing prices. There were no significant interactions between implant programs and DOF. Regardless of the sale basis (live or dressed with a premium and discount-based grid), the re-implant program consistently showed greater net returns than the single extended-release implant program, indicating that economic risk considerations are minimal when comparing these programs. Conversely, substantial impacts on net returns for heifers fed for differing DOF were observed when varying economic components. When feeding beyond the baseline – feedlot standard EP – net returns for heifers fed for longer DOF were lowest with high FYPs or low fed cattle prices, and incrementally approached net returns of the baseline EP as FYPs lowered, or as fed cattle prices rose. Increasing the CS-spread favored later-fed heifers, but did not have a substantial impact on overall net returns. More adverse effects on net returns were observed when marketing live as opposed to dressed. Ultimately, there was minimal evidence to support feeding heifers beyond the baseline EP. Chapter 4 provided valuable insights to cattle feeders on the marginal impacts of key market factors on net return expectations when feeding beef heifers to later EPs, as well as critical cost considerations. However, a limitation of this approach is the sensitivity analyses varied each pricing component independently while holding all others fixed at a constant value. In Chapter 5, a more robust strategy accounting for concurrent price fluctuations was employed for the economic assessment of feeding steers to later EPs.

In Chapter 5 both RCT and industry data were utilized to parameterize a stochastic simulation model, which characterized marginal net return distributions to evaluate the economic risk of feeding contemporary feedlot steer populations to later EPs. Stochastic simulation allowed for concurrent variation of economic and cattle parameters, accounting for correlations, to simulate a wide range of conditions and potential outcomes. Compared to the recent industry-standard EP (EP1), net return variability increased for each later-fed EP (EP2, EP3, and EP4), as

DOF increased by 14-day increments. There was potential for increased net returns when feeding to later EPs, but this came with an increased risk of greater losses. Whether marketing live or dressed with a premium and discount-based grid, net return differences from EP1 were more frequently negative than positive, and the risk of negative returns increased with longer DOF. This effect was more pronounced when grid marketing, indicating that increased weight gains and QG premiums from later feeding did not outweigh the concurrent increases in YG and heavyweight carcass discounts. Conditional variable importance scores indicated that the most influential factors on marginal net return differences were economic, with the change in fed cattle prices received when marketing on different weeks being the most critical. This implies that what may be perceived as the optimal animal EP based on characteristics such as weight or the degree of finish, may not be the optimal economic EP, which is likely a moving target dependent on market conditions. Extending DOF for feedlot steers may be advantageous when prices are trending upward, for which seasonal patterns or futures prices may serve as indicators. However, producers should employ appropriate risk management strategies when making such decisions. Considered more broadly under the themes of beef industry sustainability, the optimal economic EP may not always align with the optimal environmental or social EP. Feedlot cattle endpoint management research has not focused on or quantified environmental or social outcomes, however, these values may warrant future investigation, and potential implications are explored on subsequent pages to follow.

In Chapter 6, the final research chapter, lessons from the previous chapters were used to provide recommendations for improving the conduct and standardization of economic assessments in RCTs. A need for such guidance was evident due to the notable lack of consistency in economic assessments and reporting in the literature. Common economic analysis strategies were reviewed, and the partial budget emerged as the most pragmatic method, as it is designed to assess the marginal impact of a change, aligning well with alternative treatment interventions or management strategies in RCTs. A case study of a commercial feedlot RCT was provided to demonstrate how to use the partial budgeting framework with RCT data. Although a simple partial budget uses fixed prices and does not account for market variability, environmental or biological variability can still be accounted for by applying the budget to each experimental unit and using statistical methods to conduct the partial budget. If desired, more complex strategies, such as sensitivity analysis and stochastic simulation, can be conducted within the partial budget framework. To ensure transparency and reproducibility, researchers should explicitly state the type of economic assessment performed, the sources of all parameters, the methodology used for calculations, and the analytical methods employed. Furthermore, it is recommended to determine economic analysis methods prior to trial initiation (i.e., as part of the protocol), to ensure that the appropriate considerations have been made and all required measurements or data for economic assessment are collected. Ultimately, stakeholders may be able to make more valid, evidence-based decisions if consistent and transparent methodologies for the conduct of economic analyses on RCTs are adopted.

Although all facets of sustainability – environmental, economic, and social – were not directly addressed, themes of this dissertation present strong implications for stakeholder values, for which trade-offs likely exist. For the producer, EP management decisions likely revolve around economic value propositions, for which feeding beyond current industry standards was found to be a risky endeavor overall. However, potential changes to grid pricing structures may continue to incentivize this practice in the future. Beyond economic values, there are several potential environmental and social considerations.

The majority of lifetime greenhouse gas emissions from beef production occur in production stages prior to the feedlot; yet, emissions from the feedlot phase are meaningful. In the feedlot, the majority of environmental impacts can be attributed to crop and grain production for subsequent feeding; this has water and land-use implications along with associated gas emissions from farming. Cattle fed for extended DOF will consume more feed, and as noted in this dissertation, use feed less efficiently on a live weight basis. Emissions on a per-animal basis will undoubtedly be higher when feeding to later EP compared to earlier marketing. However, emissions per unit of beef produced may have a different result, as extended feeding can yield similar or greater beef production levels with fewer total animals fed. To further extend this implication, stakeholders – including both producers and consumers – may find it pertinent to additionally consider the quality of beef produced when adding DOF, not only the quantity. As cattle are fed to greater extremes, carcass weight deposition shifts towards primarily fat, and while not valueless, it is certainly of less value than animal protein. Therefore, the value of carcass weight gain also needs to be evaluated when feeding to later EPs, from both environmental and product quality standpoints, which both impact social values as well.

While animal welfare is a prominent social value for consumers, it is a primary value for producers as well. In this dissertation, it was explicit that there are more animal days-at-risk for adverse health events to occur when extending DOF. In addition to the social impact, late-day animal mortality has substantial economic and environmental effects, due to the quantity of resources used to grow an animal from the time of conception that are ultimately wasted. The social acceptability of feeding cattle to later EPs is uncertain; it could be seen as beneficial to increase beef production with fewer animals needing harvested; conversely, feeding beyond norms and producing cattle with potentially less mobility and uncertain health effects could be seen as a negative. In addition to extended feeding, technologies such as growth promotants have enabled the increased beef production with fewer animals. Although it has been shown that growth promotants are associated with improved environmental sustainability, they are still generally underappreciated by the public. As an additional consideration, quality of life metrics are utilized in human medicine as outcomes of interest. Such metrics in animal agriculture are not well established; however, there may be quality of life implications when extending DOF, and if overlooked by producers, consumers may come to their own conclusions. Ultimately, while beef cattle EP management is primarily motivated by economic values, other potential implications on environmental and social sustainability require additional consideration by the decision-maker when determining feedlot cattle EPs, and the potential tradeoffs across values.

In conclusion, this dissertation not only addresses critical questions surrounding extending the feeding horizons of beef cattle, but also highlights the role of economics in guiding industry practices. Through a combination of study types, designs, and analysis strategies, pragmatic academic and industry-relevant issues were addressed, providing meaningful outcomes to various stakeholders. Primary findings highlighted the complexity of balancing biological factors with market variability, emphasizing that decisions to extend feeding periods should be made cautiously and with thorough consideration of economic risks. It remains to be seen if the beef industry will continue to trend toward heavier, more extreme EPs. Although it was found to be economically disadvantageous, more frequently than not, to feed cattle beyond current industry standards. However, conditions favorable to extended feeding existed, and structural changes to the beef market could incentivize longer feeding in future years. The considerations surrounding feedlot cattle EP management emphasized herein may better inform producers and industry stakeholders when decision-making. Future research should evaluate the environmental and social sustainability of extended feeding, in order to provide a more comprehensive set of values. Lastly, when evaluating producer-relevant issues, the importance of economic outcomes as a decision factor should not be overlooked, and researchers should strive to produce deliberate, transparent, and reproducible findings. This dissertation aims to support the advancement of sustainable and economically viable practices in beef production via collaborative research, spanning across disciplines, in order to provide meaningful implications to the beef industry.