DISSERTATION

MANAGEMENT AND BENCHMARKING STRATEGIES TO IMPROVE FINANCIAL HEALTH STATUS OF U.S. BEEF OPERATORS

Submitted by

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ABSTRACT

MANAGEMENT AND BENCHMARKING STRATEGIES TO IMPROVE FINANCIAL HEALTH STATUS OF U.S. BEEF OPERATORS

The objective of this dissertation was to obtain, analyze, and summarize historical Standardized Performance Analysis (SPA) benchmark information and subsequently determine significant Key Performance Indicators (KPI) influencing beef producer's Unit Cost of Production (UCOP). Using the KPI's, a Ranch Health Index (RHI) was developed to assist producers in simply analyzing their financial health while analyzing beef production and financial relationships. Lastly, producer information using the significant KPI's incorporated into the RHI was analyzed for sensitivity to explore potential leverage points to enhance overall financial health. The SPA Beef cattle production performance and financial data was obtained from the SPA program conducted by Texas A&M AgriLife Extension which has records from three states: Oklahoma, Texas, and New Mexico. The dataset contained 25 years of beef financial and production metrics from 1992 – 2016. Three models (linear regression, random forest, and step-wise) were used to assess the SPA data for KPI. Upon further analyses, six variables were considered most impactful to predict Unit Cost of Production: Financial Grazing per CWT, Financial Raised/Purchased Feed per CWT, Livestock Cost Basis per CWT, Weaning Pay Weight per CWT, Pounds Weaned, and Number of Adjusted Exposed Females. The RHI was developed from the six variables using a Random Forest machine learning model and their corresponding importance factors as weights in the model. The model selected was tested and showed concordance with all the SPA variables predicting UCOP. Therefore, the RHI results showed utility in usefulness to assess financial health. Subsequently, three producers with 5 consecutive years of data were tested for sensitivity at ± 5% and ± 10% from the original value to determine sensitivity of each KPI variable. Finally, the models were investigated for maximum and minimum RHI values. Results showed changes in RHI up to $13,000 when accounting for all KPI improvements at 10% sensitivity. In conclusion, knowledge of the SPA data and ultimately the RHI provides information to cattle producers on what may be the most indicative variables for enhanced profits. In addition, this research has provided a simple and effective way for producers to analyze their beef operation.

ACKNOWLEDGMENTS

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I would especially like thank my family for allowing me to take time away from them to complete my research and obtain this degree.

DEDICATION

I would like to dedicate this dissertation to my mother, Gayle Umberger Cornwell and my father, Rick Cornwell, who both passed away during the completion of this degree. They were the biggest reasons to continuing my education as they nurtured my passion for agriculture and always believed in me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: LITERATURE REVIEW

Beef Cattle Industry Outlook and Industry Challenges

The Beef Cattle industry is unique and diverse. For example, (Krehbiel et al., 2019) and (Blackburn et al., 2017) showed that genetically diverse cattle exist in varying climate conditions across the U.S. Therefore, beef management varies where a "one size fits all" concept does not apply given topographic, climatic, and market differences.

The cattle cycle has historically demonstrated the contraction and expansion of cattle numbers in concert with prices and harvested cattle numbers (Aadland, 2004). More specifically, the increase in cattle numbers decreased market price leading to cattle liquidation. Following liquidation, fewer cattle are available to harvest which increased market price. The Beef Industry is a break-even commodity; therefore, it is important that costs be maintained at a low level to remain profitable during the ebbs and flows of the cattle cycle.

Changes to cattle numbers and size have been well documented since the 1970s (USDA-ERS-NASS, 2020) where selection for heavier carcasses paired with improved nutrition has led to higher cattle weights and less numbers of cattle (Fig. 1.1).

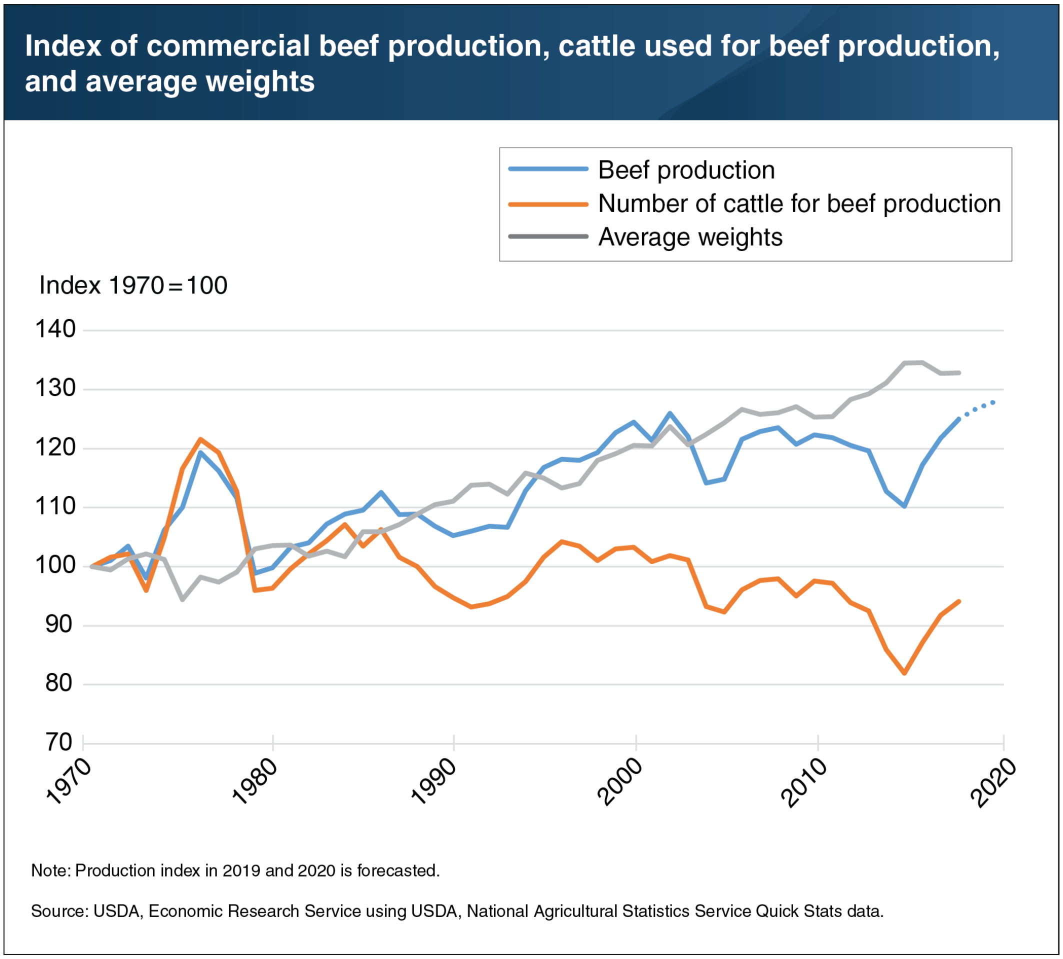

Figure 1.1 Average weights, cattle numbers, and beef produced over the course of 50 years in the U.S.

Despite this change in beef production, the cattle cycle has historically occurred in 10-year intervals. However, since the turn of the 21st century, the Beef Cattle Industry has endured multiple events that have disrupted the cycle (CNBC, 2019).

For example, drought has occurred frequently in the 21st century. Drought is one of the most widespread natural disasters resulting in negative impacts on animal agriculture including disrupting herd, sex-age structure, and rebreeding (Lesnoff et al., 2012).

Drought occurring in regions due to climate change is expected to severely impact developing countries whose residents depend on agriculture production for their livelihoods (Thornton et al., 2009). Internationally, studies have investigated the impact of drought duration and frequency in African countries (Oba, 2001; Lesnoff et al., 2012a). Oba (2001) stated that drought is the number one reason for cattle herd fluctuations in Kenya.

Nationally, the United States has undergone drought every decade since the 1930s. According to the National Oceanic and Atmospheric Administration (NOAA, 2019), the harshest droughts in Colorado have occurred in 2002, 2012, 2013, and most recently, 2018 (Fig. 1.2).

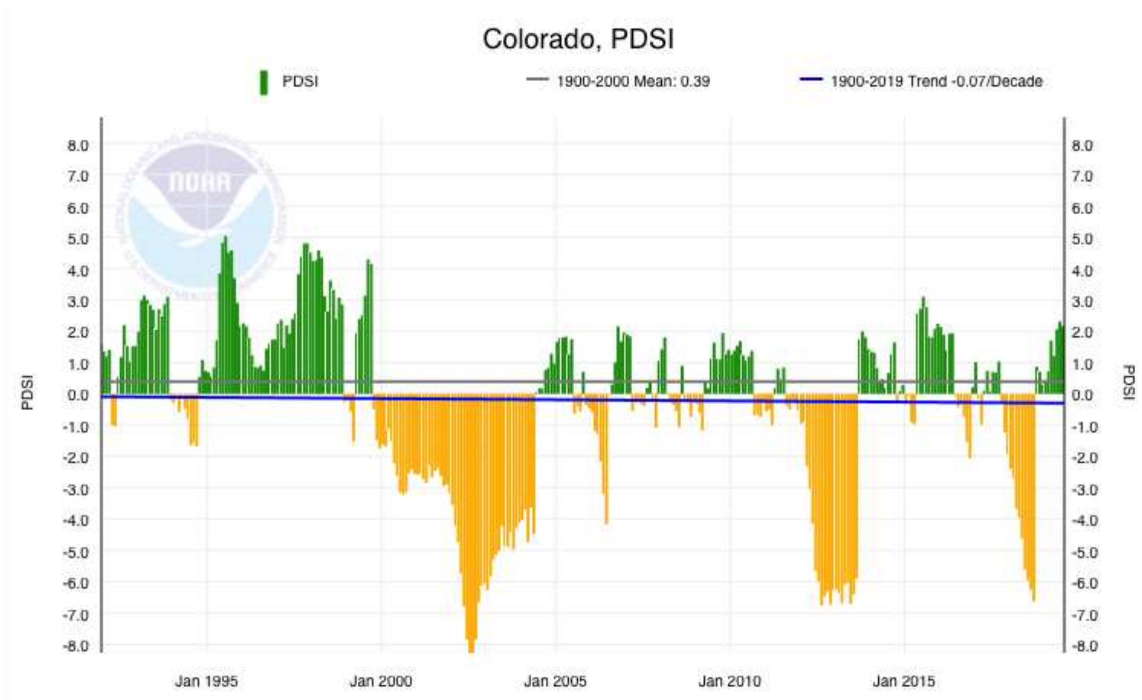

Figure 1.2 Palmer Drought Severity Index (PDSI). Years 2002, 2012, 2013, and 2018 have the highest-ranking droughts for Colorado.

The record driest year in Colorado was 2002. While recent years have been dry nationally, 2012 (ranking as the 4th highest drought in Colorado history) led to large impacts to the Beef Cattle Industry where calves priced more than a record breaking $2.50/lb on average in 2014 and 2015 in the U.S. (USDA-NASS, 2020).

The U.S. has few recent reports addressing the question of drought mitigation in beef operations and financial responses to drought events. According to Dr. Ryan Rhoades, (personal communication October 15, 2019) Colorado ranches are challenged with plans to stock and restock cattle because of drought. Scasta et al., (2016) suggested beef producers select cattle that match an environment's feed resources to decrease the effects of drought on feed production. Rhoades et al., (2014) proposed that ranchers increase units in a stocker enterprise for easy liquidation, rely on other stable revenue streams such as agritourism (e.g. hunting wildlife), or utilize irrigated lands to mitigate the impacts of drought on the cow herd. Similarly, Tinsley et al., (2019) analyzed beef cattle operations in limited forage environments. However, this analysis examined island beef operations and focused on cattle marketing. While studies suggest ways to mitigate drought effects, none of the studies specifically addressed the rancher's decisions to improve financial resiliency.

Because of the comprehensive and uncertain extent of the impacts that global warming, changing climates, drought, and aridification may have on livestock and crop production, it is necessary to understand the financial impacts on agricultural production systems throughout the U.S. to remain food secure. The economic ramifications of changing climates that lead to drought can be vast and inconsistent among farming households in the U.S. (Abson et al., 2013).

Trade relations have also altered U.S. beef market prices adding to the complexity and unpredictability of the cattle cycle. In 2001, the first outbreak of Bovine Spongiform Encephalopathy (BSE) occurred in Japan (Center for Food Safety, 2020). An ~$8 market price decline occurred from January 2001 to January 2002 (USDA-NASS, 2019). In 2003, Japan banned U.S. beef imports of cattle aged over 30 months when a BSE infected cow was identified in the U.S. (CNBC, 2019). Subsequently, beef exports sharply decreased (UN Comtrade Database, 2020). Seventeen years later, Japan permitted U.S. beef imports regardless of cow age and is currently the leading market for U.S. exports accounting for 21,280 tons of beef in January 2020 and 38,988 tons of beef in February 2020 (USMEF, 2020).

Additionally, trade war between U.S. and China resulted in tariffs averaging 16 percent on approximately $121 billion U.S. exports (Amiti et al., 2019). Subsequently, the U.S.-China trade agreement was established, where China pledged to purchase products from U.S. and U.S. removed tariffs on China made products. Amid the Phase 1 deal of the U.S.-China agreement, COVID-19, a lethal upper respiratory virus, spread throughout the world, halting global and local commerce in early 2020. Interestingly, according to the United States Meat Export Federation (2020), U.S. beef exports grew to recording breaking numbers with a 10% volume increase in January and February compared to 2019 (USMEF, 2020).

Along with dynamic and uncertain beef export trade relations, notable disasters in the U.S. such as wildfires in Kansas in 2017 which forced some producers to euthanize livestock (The Wichita Eagle, 2017) and flooding in Nebraska in 2019 that resulted in $400 million of cattle losses (NPR, 2019) contributed to a complex, unpredictable cattle cycle and market. Given natural disasters, trade policies, other factors leading to market volatility, it is more important now than ever for beef producers to understand and utilize practices that maintain or improve financial health to remain in business given extraneous variables affecting beef production and profits.

Benchmarking Programs

Beef producers regularly make decisions through periods of high stress and risk. The results of these decisions have long-term effects on production and profits. Beef financial and performance benchmarks provide statistics for beef producers to use to make decisions. Multiple benchmarking programs exist. These programs collect information from producers to provide benchmarks for an operation over time in addition to other operations statewide, regionally, and nationally. While these programs offer benchmarks for independent beef and financial variables of an operation, none of the programs help in decision-making to decrease financial stress and improve ranch financial health.

National Programs

Beef Cattle Standard Performance Analysis

The Beef Cattle Standard Performance Analysis (SPA) was initiated by the National Cattlemen's Beef Association (NCBA) and directed by Texas A&M AgriLife Extension. This program was primarily used in the Southwestern United States for use in New Mexico, Oklahoma, and Texas for beef cattle producers of any size. Standardization of beef cattle performance and financial data was the impetus for SPA development, as no prior standardized methodology was widely used.

SPA Demographics and Data Acquisition

Farm financial and performance reports are reported for states regionally, statewide, and collectively among Oklahoma, Texas, and New Mexico in 5-year and Long-Term averages. While most reporting ranches reside in Texas (n = ~450), 619 ranch enterprises from all states have been included in the Long-Term average. The public has access to the benchmarking reports from 1992-2016.

The SPA data entry consists of six Microsoft Excel sheets representing beef performance and financial information, in addition to seven worksheets that report results (SPA, 2019). While limited one-on-one support exists to assist producers inputting benchmark data, three informational packets are available with in-depth definitions, directions, and datasheets for producer support. These packets are organized as general farm/ranch information, financial information, and beef performance and feed information.

Cow Herd Appraisal Performance Software

The North Dakota Beef Cattle Improvement Association (NDBCIA) maintains one of the largest cattle performance software in the United States – the Cow Herd Appraisal of Performance Software (CHAPS). North Dakota State University Extension Service and NDBCIA have maintained cow calf records since 1963 (NDSU, 2019). NCBA-Integrated Resources Management Standardized Performance Analysis approved the standardization of beef performance data in CHAPS software, much like the Beef Cattle SPA discussed previously. While previously discussed benchmarking programs have evaluated performance and financial aspects of a ranch, CHAPS focuses upon beef production data and beef cattle genetic improvement.

FINBIN

Benchmarking is a strategic management tool that reports statistics of beef industry practices. FINBIN is one of the United States' largest farm financial databases that allow users to compare financial variables of whole farm, crop, or livestock operations (FINBIN, 2019). FINBIN is supported by the Center for Farm Financial Management, an entity within the University of Minnesota; USDA's National Institute of Food and Agriculture (NIFA); and the University of Minnesota Extension.

FINBIN Demographics

Currently, 12 Farm Business Management Associations contribute to the FINBIN database, representing 11 states (Illinois, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Carolina, South Dakota, Utah, and Wisconsin). FINBIN reported that 3,393 farms contributed to the farm financial database in 2017. The database captured 11 crop and land use information on 3,247,002 acres. This included 19,083 enterprises. An additional 1,679,115 enterprises represented beef, hog, dairy, and sheep industries.

According to Dale Norquist, FINBIN manager (personal communication 6/20/2018), approximately 35,000 reports were executed in the FINBIN database in 2018. This is in comparison to the approximately 3,500 producers contributing information to the database, illustrating the extensive use of the financial information collected. Producers who utilized FINBIN reported an average savings of $12,000. However, most producers reported a $2,000 - $5,000 savings (Dale Norquist, personal communication 6/20/2018).

FINBIN Data Acquisition

Users enter farm financial information into FINBIN through FINPACK, a software package supported by the Center for Farm Financial Management, an entity of the University of Minnesota. However, local educators facilitate data entry into FINBIN, each offering support to 40-65 farms. Data provided in the benchmarking reports include financial ratios among livestock performance data and farm expenses such as veterinary care, feed costs, insurance, and labor (FINBIN, 2018).

Documentation for FINPACK data entry includes beginning balance sheets, ending balance sheets, and totals for the year. The database system also builds off previous year's report to limit data errors. However, three reviews for data accuracy are conducted: individual and local FINBIN professional input data together, uniform data entry conducted by the farm business management association, and FINBIN management review. Quality controls also include outlier tests in which outliers are verified or removed from the data.

Individual Benchmarking Tools

The University of Nebraska-Lincoln promotes a management program called the Unit Cost of Production in beef cattle (UCOP). Although no specific software analysis or database exists to benchmark producer data, the UCOP tool/equation exists to assist producers in benchmarking their costs per unit produced. The equation is listed below:

$$\boldsymbol{Unit\ Cost\ of\ Production = Cost\ \div Units\ Produced}$$

University of Nebraska-Lincoln Extension hosts workshops for producers to learn about financial assessment of their operation (Logan Hoffman, personal communication 12/5/2019) along with providing information in the form of worksheets and university personnel.

The University of Purdue provides excel sheets and an information packet on assessing and measuring farm financial performance (Dobbins et al., n.d.). Like SPA and FINBIN, balance sheets, total sales, etc., are included. However, this analysis lacks the use of beef performance data and provides little to no assistance for completion.

Oklahoma State University created a Farm and Ranch Stress Test (2018). The Stress Test consists of nine measurements to determine financial stress of an operation including: liquidity, solvency, and ratios representing profitability, repayment capacity, and efficiency. Furthermore, the Stress Test provides financial assessment and lacks the ability to analyze beef production variables. While informative, there are many measurements to analyze to determine overall financial health.

The Balanced Scorecard Method (BSM) explained by Dunn et al., (2006) suggests utilizing all critical components of an operation such as Customer Feedback, Lifestyle, Financials, and Natural Resources to obtain and reach goals. While no mathematical assessment is utilized to analyze financial operational components, the BSM provides a straight-forward approach producers can complete to create and address goals.

The Ag Decision Maker at Iowa State University approaches beef producer assistance dissimilarly to other programs discussed. While no producer financial or beef performance data is needed, Iowa State Extension along with the Department of Economic faculty provide and compile facts of information that aid in decision making for whole farm, livestock, and crops (Iowa State University, 2020).

Simulation Modeling

Simulation modeling is the process of creating and analyzing quantitative equations to describe a physical model which can be used to predict performance in the real world. A system is any set of objects that interact. A mathematical model is a set of equations, which describes the interrelationships among system components. By solving the equations using a mathematical model we can mimic, or simulate, the dynamic (time-varying) behavior of the system (Grant, 1986). A system is used to answer a question or describe a theory and is the process of simulating real-world behavior.

There are four phases to systems analysis: Conceptual Model Formulation, Quantitative Specification of the Model, Model Validation, and Model Use. Conceptual Model Formulation demonstrates how the objects in the systems are related to each other. Quantitative Specification of the model entails equation development. Additionally, during this phase the basic time unit for the simulation is chosen. The third phase of systems analysis is model validation, where the model is explored to determine utility in analyzing a problem. Model Use is the last phase of systems analysis, in which simulation results are analyzed and interpreted.

Systems Dynamics

Systems Dynamics Modeling (SDM) is a multidisciplinary approach that utilizes causal loops, feedback, mental models, and quantitative models to describe nonlinear relationships (Forrester, 2009). Mental models are the internal conceptual representation of an external system (Craik, 1967; Forrester, 1961; and Doyle and Ford, 1998). Integration of mental model information builds the structure of the model and the perceived practices within the system. While mental models play a central role within SD, it is challenging to simultaneously account for feedback processes (Forrester, 1994; Sterman, 1994; Sterman, 2002). Feedback exists when components in the system change and give rise to new information that dictates future decisions of the system (Sterman, 1994).

An externalized representation of a mental model can be better understood using a causal loop diagram which defines the causal relationships and feedback processes between components. Feedback is positive (reinforcing; R) or negative (balancing; B). Positive feedback drives more of the same action whereas negative feedback is self-correcting as shown in Fig. 1.3 (Sterman, 1994).

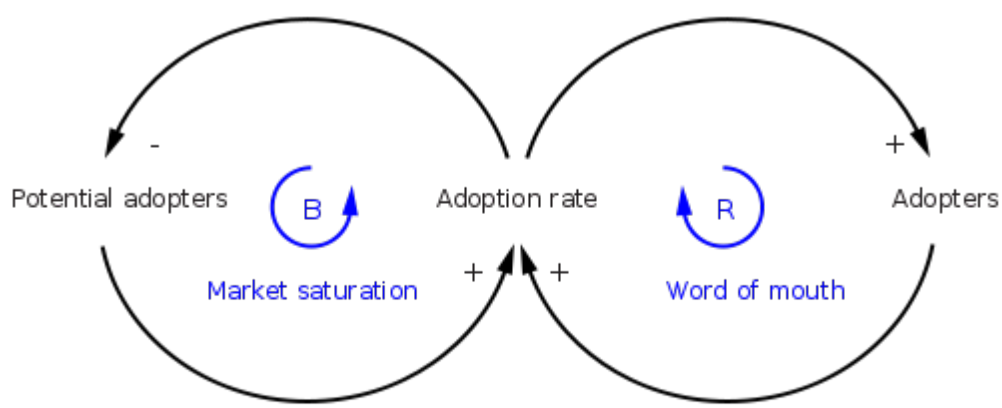

Figure 1.3 Causal loop diagram.

Next, the causal loop is transformed into a stock and flow model where stocks are material accumulations and flows change the amount of material in the stock (Sterman, 1994; Sterman, 2002). While stocks and flows are the two most important concepts to systems modeling (Forrester, 2009), converters modify rates of change and are connected through action connectors which facilitate feedback processes and system communication (Fig. 1.4). Measurable and relevant stocks, flows, and connectors create a quantitative model using algebraic equations. Lastly, the algebraic equations defining each component of the system can be tested for validity or sensitivity (i.e. small changes in the system that produce large results).

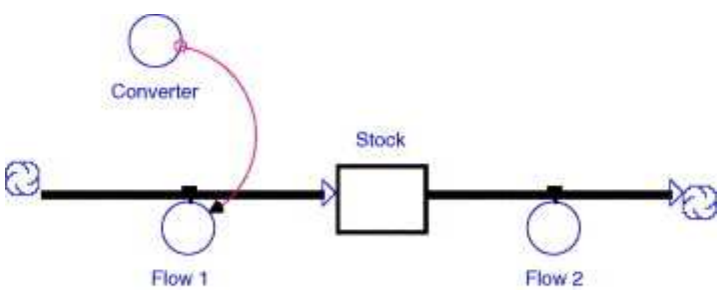

Figure 1.4 Example of a simple stock and flow diagram.

Simulation Uses

Historically, animal scientists produced numerous simulation models to aid beef cattle production (TAMU, SPUR, DECI, CBCPM, FORAGE, FLIPSIM, FORBEEF, CVDS; Sanders and Cartwright, 1979a; Sanders and Cartwright, 1979b; Sanders and Cartwright, 1979; Stringer et al.,1987; Jenkins and Williams, 1998; Baker et al., 1992; Shafer et al., 2005; Tess and Kolstad, 2000a; Wight and Skiles, 1987; and Williams et al., 2006). However, the simulations have limited use for beef cattle producers. Various reasons are noted why beef cattle simulations were not successfully utilized in the industry: no end user input for simulation development, simulation complexity, distrust for simulation output, mismatch of simulation output with the decision-making style of the producer, and lack of field testing (Newman et al., 2000). One of the first simulations in the beef cattle industry was performed by Calvin Ferrell and Thomas Jenkins. This was called the DECI model, or the Decision Evaluator for the Cattle Industry.

Foran and Smith (1991) and Lesnoff et al. (2012b) used simulation to determine the impacts of drought and the post-recovery of cattle in Australia and Sahel region of Africa, respectively. More specifically, Foran and Smith (1991) explored financial differences in "good", "average", and "bad" drought years utilizing differences in animal units (AU; e.g. 2,000 AU, 3,000 AU, and 4,000 AU). Results showed that the low stock operation had higher annual returns when droughts lasted for 2 years or longer. However, average and high stock operations quickly recovered from drought that lasted 1 year.

Alternatively, Lesnoff et al., (2012b) explored biological responses to drought of cattle in the Sahel region of Africa. A Leslie matrix model was used to simulate the hypothetical cattle and their reproduction, fertility, and mortality rates (Leslie, 1945). Population declines due to simulation shock (e.g. drought), calving rate (i.e. "the expected number of calves born alive per month and reproductive female") and animal liquidation strategies were the most influential components of population recovery (e.g. populations returning to initial sizes prior to shock) assuming that no livestock was imported from outside sources. Financial aspects of this simulation were not investigated. However, it was determined that recovery time of cattle populations after a drought could vary even when most influential factors are controlled.

Composite Indexes

Indexes are used in many industries and are a succinct way to provide information on multiple components. An index, also known in this case as a simple additive weighting method, is the combination of weighted coefficients and multiple numerical components resulting in one informative value. Indexes are one way to advance assessments made by benchmarks and simulation modeling through development of a financial health measure for beef operations.

The Beef Cattle Industry along with other livestock organizations use selection indexes to select for traits yielding profit (HAU, 2020; NSR, 2020; AAA, 2020; Lahav et al., 2006). In fact, this methodology has been studied as early as 1957 (Lindholm and Stonaker, 1957). Economic selection indexes in the livestock industry include a weighting factor paired with a breeding value (BV) for multiple traits. Additionally, indexes are widely used in many industries such as waste quality (Praus, 2019), economics (Levanon et al., 2015) and health (Ardern, et al., 2003; Lan, et al., 2002; Trigg & Wood, 2003).

The weighted coefficients of indexes are calculated using subjective or objective measures, or a combination of the two. Subjective indexes derive from industry experts or recommended standards (Karlen et al., 1998) where objective indexes derive from statistical measures (Miyake, 2001; Lau, 2011; Vasu et al., 2016; Praus, 2019). Chung et al., (2017) demonstrated the utility in combining subjective and objective measures to assess vulnerability of the Han River Basin in South Korea. Furthermore, indexes can be developed utilizing fuzzy multi-criteria decision-making (Bellman and Zadeh, 1970) in which weights of the index are vague and provide constraints to specific variables rather than be a discrete integer.

Multiple ways to develop an objective weighted index exist. A Principle Component Weighted Index (PCWI) uses latent factors in a plane to illustrate orthogonal relationships of multiple variables (Li et al., 2006; Mallya et al., 2013; Pearson, 1901; Wold et al.,1987). This methodology helps describe the variation in non-correlated variables. The eigenvalue of each principle component is considered the weight for each variable described in the PCWI.

Conclusion

Given the brief explanation of tools and their uses in the beef industry, I propose to utilize statistically significant benchmarking measures to derive a ranch financial health index to aid producers in decision-making. Benchmarking measures known as Key Performance Indicators (KPI) will be used to analyze the financial and biological components of the beef operations. This will occur by performing analyses on current benchmarking databases and including those results into a selection index (Ranch Health index; RHI) and a Systems Dynamics model to test for sensitivity of the results. These methodologies will assist in mitigating financial stress.

CHAPTER 2: HISTORICAL ANALYSIS OF BEEF PRODUCTION AND FINANCIAL BENCHMARK DATA OF THE STANDARDIZED PERFORMANCE ANALYSIS PROGRAM

Introduction

The Beef Cattle Industry faces unique and diverse challenges. Beef management strategies to handle economic and environmental stressors largely vary based on producer, topographic, climatic, and market differences. Each of these factors have varying effects on animal agriculture and create complex situations for beef producers that result in long-term consequences for production and profits. To assist beef producers in evaluating their operations using standardized financial and beef production variables, the Beef Cattle Standard Performance Analysis (SPA) was initiated by the National Cattlemen's Beef Association (NCBA). Texas A&M AgriLife Extension directed SPA, which consists of producer entries ranging from 1992 - 2016 (McCorkle and Bevers, 2009; Bevers, 2016).

Genetic prediction, reproductive success, health and welfare, and nutritional improvements are continuously researched facets of the beef cattle industry (Silva et al., 2023; Dressler et al., 2024; Miller et al., 2024). While most producers strive to continuously improve beef production or utilize products or implement practices that improve beef production, the SPA program among others have encouraged improvement of beef financial measures. The finances of producers who participated in the SPA program has been analyzed in a host of ways investigating costs, inefficiencies of operations, and other metrics over short time periods (Ramsey et al., 2005; Cho et al., 2011, and Lalman et al., 2019). However, to date, a complete analysis of the dataset with most recent data entries to evaluate financial or beef production trends, summary statistics, and decision-making during high stress times has not been conducted.

Therefore, the objective of this research was to perform a comprehensive analysis over a large beef cattle production dataset to understand beef production and cost trends in the industry that have occurred through multiple decades and cattle cycles that may be informative for future success of beef cattle producers. Aim one of this research included identifying which variables (financial and beef production) that have or have not changed over a 25-year period. Aim two of this research included comparing the beef financial variables to determine which are most costly. The third aim of this research included analyzing holistic success of the producers by evaluating Unit Cost of Production and Percentage Return on Assets.

Materials and Methods

SPA Data

Beef cattle production performance and financial data was obtained from the Standard Performance Analysis (SPA) program conducted by Texas A&M AgriLife Extension (Bevers, 2016) which has records from three states: Oklahoma, Texas, and New Mexico. Texas is the largest producer of cattle in the U.S., at 4.3 million head and more than double than the next highest producing state included in this analysis - Oklahoma at 1.98 million head (USDA-NASS, 2023). The dataset contained 25 years of beef financial and production metrics from 1992 – 2016. The dataset contained nearly 600 data entries from 319 unique producers encompassing commercial and seedstock cow-calf operations that had fall and spring calving seasons. There was no operation size limit for entry into this program; size of operation based on exposed females of those who reported ranged from 15 to 6,005 head of cattle (median = 263). Data entry into SPA was performed by producers during workshops, individually, or by Extension educators at Texas A&M AgriLife. The information collected for SPA analysis includes 120 metrics.

Data Cleaning

Summary statistics were performed on the 120 SPA financial and beef production variables. Manual inspection of each variable resulted in removal of some entries or variables. For example, a reported value of “0” for an unknown measure was considered inaccurate. Initially, to resolve these concerns, data was removed three standard deviations outside of the average for each metric analyzed. However, this procedure removed a significant amount of data, especially related to financial measures. Therefore, a more liberal approach of manual curation was conducted wherein 14 individual producer entries were removed due to inability to distinguish between dependable data and artifacts of the survey process. One producer was removed due to the lack of information on multiple variables. Next, fall calving herds were removed from the dataset to remove seasonal effects on the production year analysis. Thirdly, the second observation from three duplicates entries were removed. One observation was removed due to unknown location. The final data frame consisted of 273 entries (139 unique producers) and 194 datapoints (including financial data, beef production data, metadata of the producers, and intermediate results conducted before this research).

Statistical Analyses

Statistical analyses were performed on beef production metrics, financial metrics, and beef and financial integrated variables of the cleaned data. Specific variables were considered due to their importance to producer profits or as a metric for herd evaluation. Weaning weight (WW) was evaluated as a priority for a beef production metric. Financial health metrics of specific interest included debt, managerial cost (machinery, equipment, and real estate cost), livestock costs, feed costs, and operating costs. All financial variables were on a cost basis which incorporated accumulated depreciation.

The beef and financial integrated variables included Percentage Return on Assets (ROA) and Unit Cost of Production (UCOP). Percentage return on assets measures a producer's profitability relative to its own assets. The higher the ROA, the more efficient that producer is at utilizing their own assets to be profitable. This metric is calculated as follows:

$$\frac{Net\ Income}{Total\ Assets} = Percentage\ Return\ on\ Assets$$

Financial Pretax Cost before Non-Calf Revenue adjustment also known as the Unit Cost of Production (UCOP) was also evaluated, which are the costs required to produce one pound of beef without cull cow revenue adjustment. This variable was chosen as the UCOP of production measure to formulate a more conservative approach to identifying cost of a weaned calf.

Additionally, Financial Pretax Cost before Non-Calf Revenue Adjustment per CWT (excludes cull cow revenue) compared to the Financial Pretax Cost Non-Calf Revenue Adjusted per CWT (includes cull cow revenue) showed a 0.98% correlation from the SPA dataset. Moreover, UNL (2016) showed various methods to account for UCOP where in two methods cull cow sales were assumed to be a break-even enterprise.

Unit Cost of Production is calculated as follows:

$$\frac{Costs}{Units\ Produced} = Unit\ Cost\ of\ Production$$

Summary statistics of variables were performed. Additionally, the average value of participant entries for each year was used to evaluate trends over time and relationships between variables. Relationships were evaluated based on the costs of the operation and why the profit margin for cattle producers have or have not changed; the potential reasons behinds those changes, and opportunities that may exist to improve profitability. More specifically, linear regression of multiple variables (e.g. costs) was performed in comparison to other variables to identify how industry aspects have impacted producer profits over 25 years.

Results

SPA Data

The SPA data ranged from 1992 – 2016 and was evaluated for the number of participating producers, producer entries per year and the corresponding location (Fig. 2.1). The average herd size of each producer is shown in Fig. 2.2 and Table 2.1 showed the average herd size per year in the SPA dataset. Figure 2.3 showed the average precipitation for the regions and states of producers who were participants in the SPA program. Table 2.2 showed the number of producers and how many years they entered data in the SPA program. Additionally, parameter descriptions are shown in Table 2.3 and summary statistics for common beef production metrics are shown in Table 2.4.

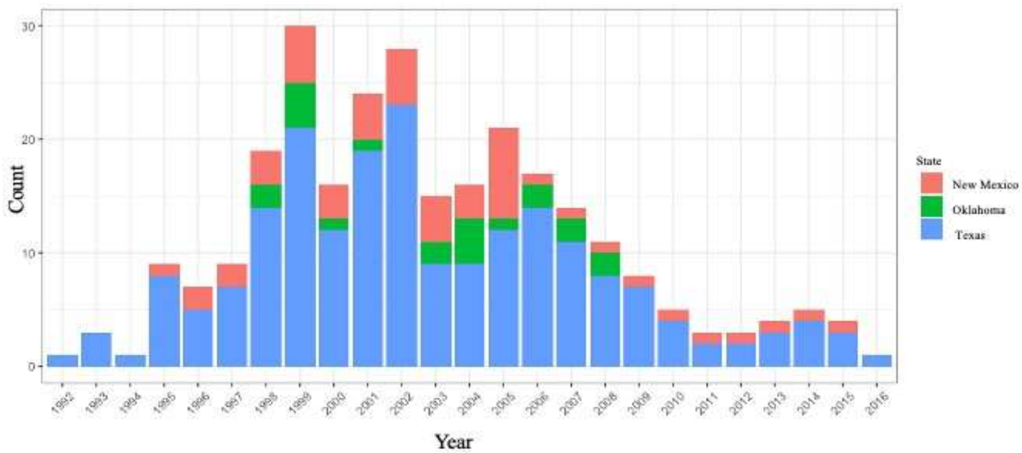

Figure 2.1 Summary of producers who participated in SPA from 1992 – 2016.

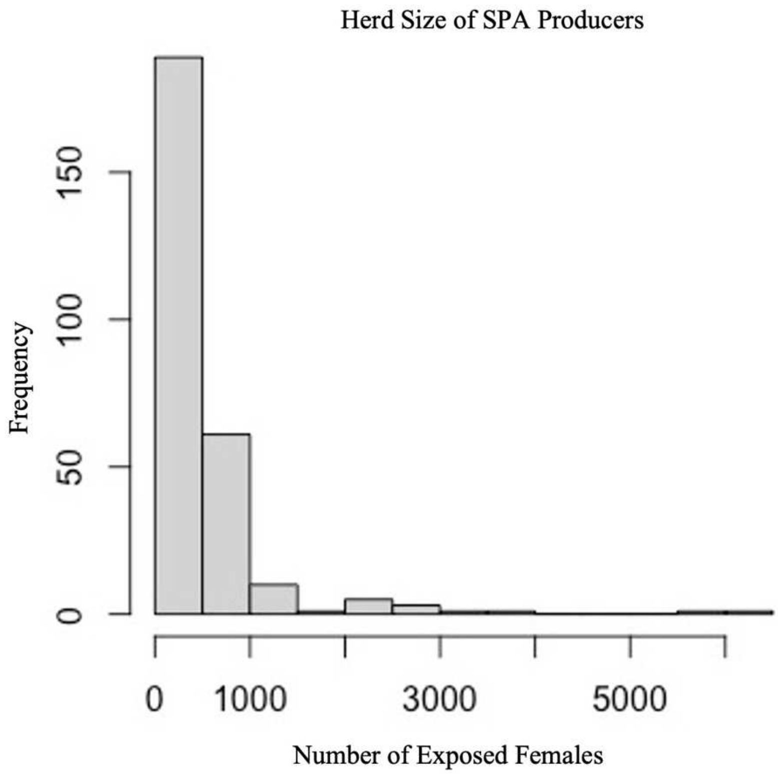

Fig. 2.2 The average herd size and number of producers who entered data into the Standardized Performance Analysis (SPA).

Table 2.1 The average herd size per year of producers who entered data into the Standardized Performance Analysis (SPA).

Year	Average Herd Size
1992	50
1993	529
1994	647
1995	662
1996	700
1997	1269
1998	500
1999	331
2000	542
2001	646
2002	308
2003	439
2004	477
2005	323
2006	362
2007	500
2008	667
2009	319
2010	237
2011	296
2012	259
2013	298
2014	940
2015	1369
2016	119

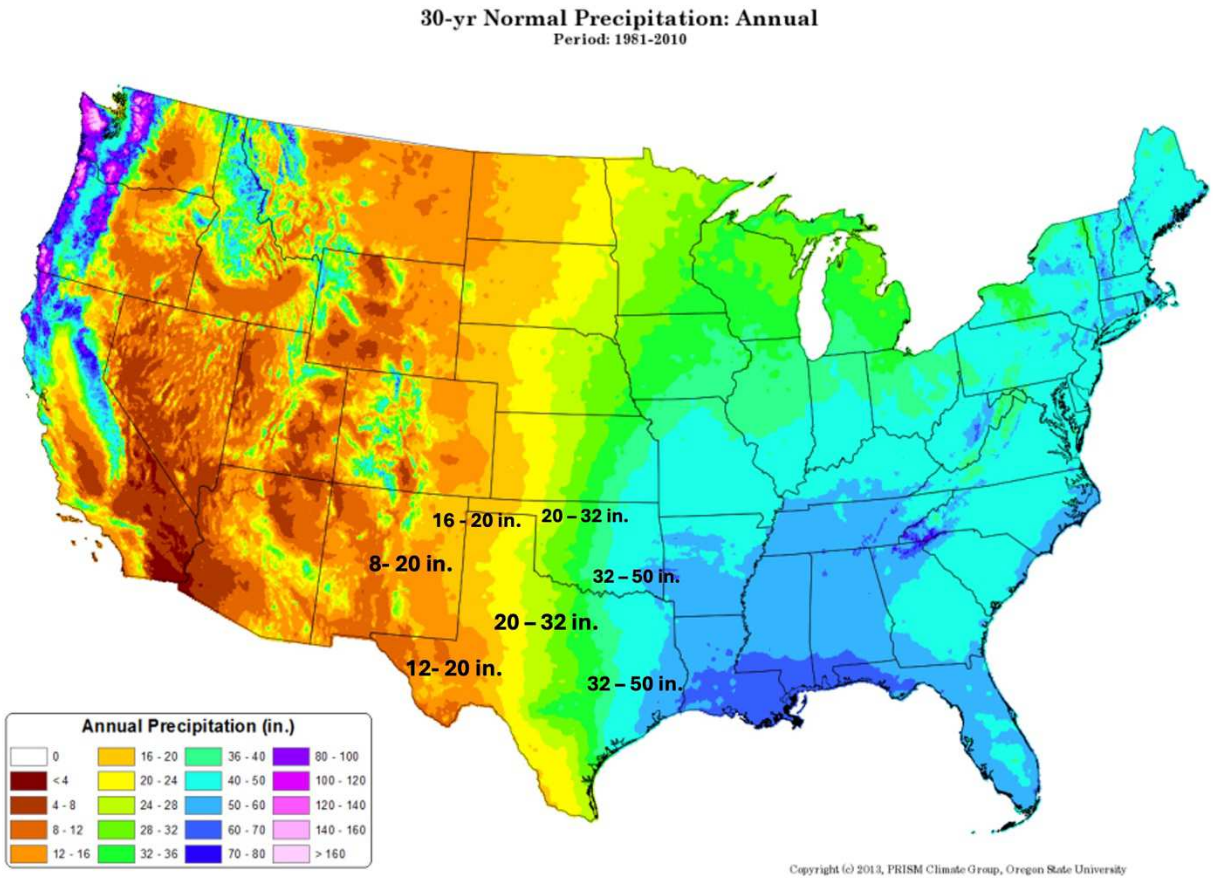

Figure 2.3 The 30-year normal precipitation for the United States. Texas, Oklahoma, and New Mexico averages are shown on the map (Daly et al., 2023).

Table 2.2 The number of producers and how many years they entered data in the Standardized Performance Analysis (SPA) program.

Number of Years Participating in SPA	Number of Producers
1	85
2	27
3	9
4	6
5	6
6	3
9	1
13	1
14	1

Table 2.3 Parameter descriptions included in the Standardized Performance Analysis (SPA).

Parameter	Description
Pounds Weaned Per Exposed Female	Total pounds of calf weaned/total number of females exposed
Pounds per acre utilized by the cow-calf enterprise	Total pounds of weaned calves/total number of females exposed per acre
Percent Return on Assets (cost basis)	(Accrual-adjusted net enterprise income from operations + total interest expenses - family living withdrawals/average total enterprise assets x 100)
Livestock (cost basis)	Average asset value/number of breeding cows
Managerial costs	Real estate improvements (cost basis) + Machinery and equipment (cost basis)
Pounds of raised/purchased feed per breeding cow	Total pounds of raised and/or purchased feed fed/number of breeding females
Calving percentage	(Number of calves born/number of exposed females) x 100
Hired Labor Management	Total labor management expenses/total revenue
Debt per breeding cow	Enterprise liabilities
Financial Pretax cost before Non-Calf Revenue Adjustment per CWT	Unit Cost of Production price without non-calf revenue adjustment
Financial Pretax Cost Non-Calf Revenue Adjusted per CWT	Unit Cost of Production price with non-calf revenue adjustment
Total Investment	Value of assets (current assets, livestock, managerial costs, other non-current assets, real estate)
Weaning percentage	Number of calves weaned/total number of exposed females
Weaned Calf Pay Weight (weighted average)	Weighted average price of steers, bulls, and heifers

Table 2.4 Summary statistics of notable beef production variables.

Variable	N	Mean	Std. Dev.	Min	Max	Pctl. 25	Pctl. 75
Pregnancy Percentage	191	88.83	7.31	52.78	100	86.95	93.49
Calving Percentage	269	84.63	9.12	46.1	100	80.13	90.62
Weaning percentage	274	81.79	8.61	45.12	100	77.97	87.59
Actual Weaning Weight Steers and Bulls	274	537.93	74.03	267	807	498.21	578.38
Actual Weaning Weight Heifers	274	509.6	60.47	275	730	474.84	543.19
Average Weaning Weight	274	523.85	65.07	275	773	488	560
Pounds Weaned Per Exposed Female	274	429.12	77.04	221	638	373	481.75
Pounds Weaned Per Acre Utilized	274	48.15	42.68	1.57	264.66	11.6	80.34

Pregnancy percentage is the combination of pregnancy of both heifer and mature cows. The rate reported here, 88.83%, was slightly lower than previous data. In terms of heifer conception, Moorey and Biase (2020) found that a first bred heifer typically breeds at a rate of 85-95% while Bormann et al. (2006) found the overall heifer pregnancy rate to be around 93%. Penn State extension provided one example of herd pregnancy rate at 94.9%. While the reasons for pregnancy rate and loss are varied (Reese et al., 2020) one reason for the seemly lower number could be attributable to the droughts experienced in these years, as humidity and temperature have been known to negatively affect pregnancy rates (Amundson et al., 2006)

The trendline for the variables of interest are largely stagnant with slight increases to pregnancy percentage and calving percentage across the two decades (Fig. 2.4). Pounds weaned per exposed female reflects many aspects of a beef operation – pregnancy percentage, calving percentage, weaned calf crop percentage, and pounds weaned. The trendline for pounds weaned per exposed female showed a slight increase over 25 years (Fig. 2.5). Penn State (2022) reported herd weaning percentage to be 87.5%, validating the weaning percentage achieved here. When validating the actual weaning weight of males (574 pounds), females (510 pounds), and overall average (524 pounds), these numbers are slightly lower than a study on weaning weight by month (Rouqette and Norman, 2020). However, as shown in Fig. 2.2, vast differences in precipitation amounts are shown in New Mexico, Oklahoma, and Texas ranging from 8 – 50 inches which ultimately effects feed resources available in these areas subsequently impacting weaning weights.

Minor improvement to average weaning weight for this data has been reported previously (Lalman et al., 2019). Although genetic potential for calf weaning weight can reach 1,000 lb (AAA, 2023), the industry achieves lower weaning weight performance given feed price, type, and availability in certain climate environments such as the southwest (Fig. 2.2). Additionally, cattle type differs in harsher climates, as an optimum for some traits (e.g. milk, frame size) is more productive than a maximum (Scasta et al., 2015) therefore limiting overall growth of weaned calves.

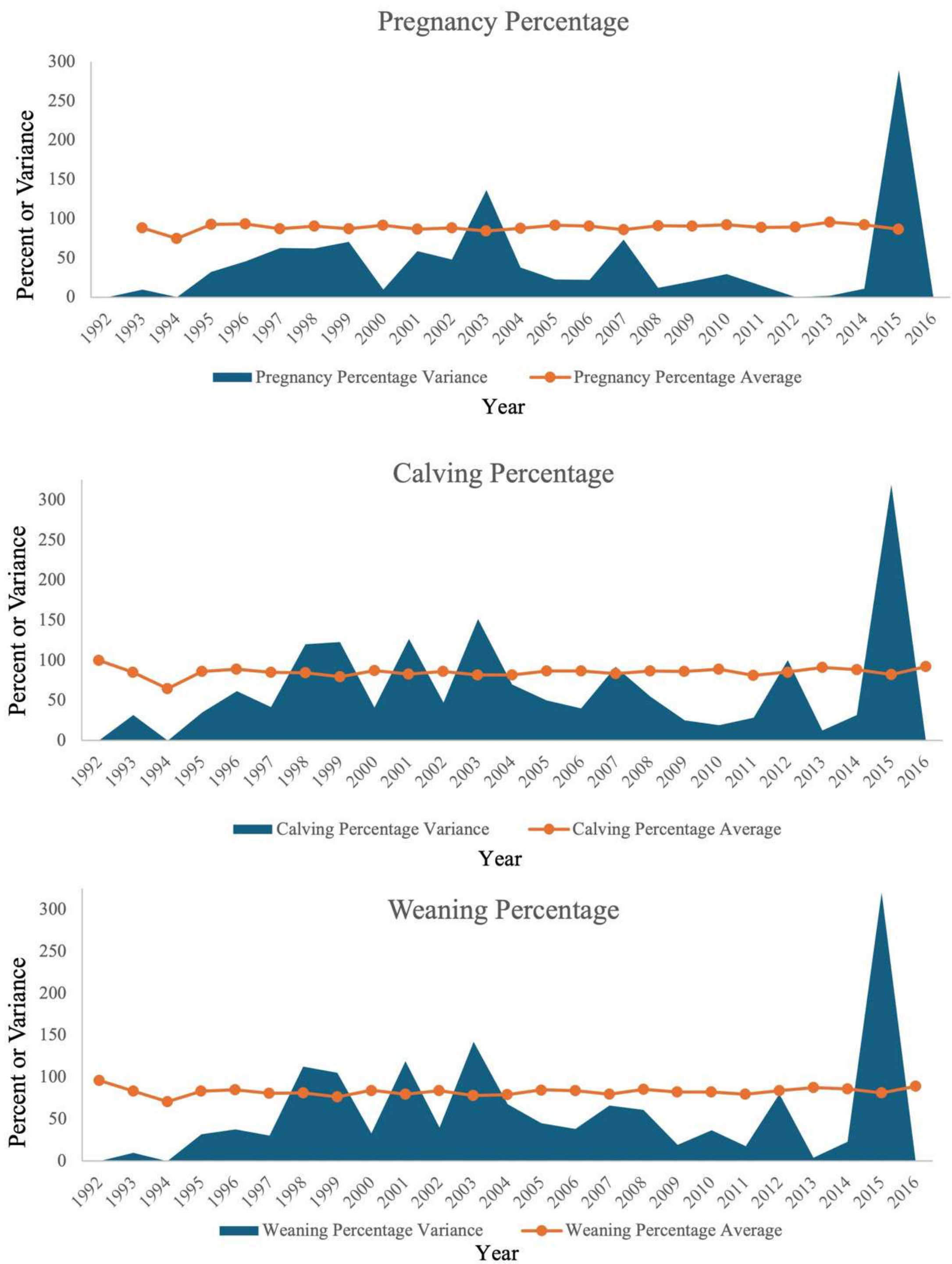

Figure 2.4. Three production variables measures (average percent and variances) from producers who contributed to the Standardized Performance Analysis.

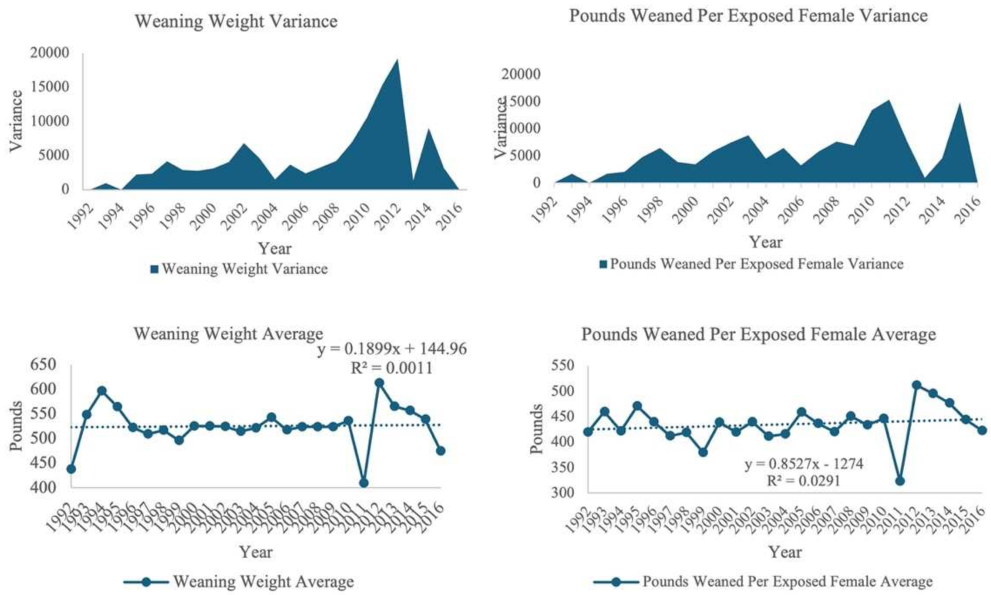

Figure 2.5 Weaning weight and Pounds Weaned per Exposed female average and variance records from 1992 – 2016.

Financial datapoints of interest were analyzed across the 25 years to identify potential changes to the overall ROA and UCOP (Table 2.5).

Table 2.5 Standardized Performance Analysis (SPA) financial variables of interest summary statistics per cow.

Variable	Unit	N	Mean	Std. Dev.	Min	Max	Pctl. 25	Pctl. 75
Managerial Cost	$	272	2226.475	2747.34	0	18395.785	180.902	3253.07
Livestock Cost Basis	$	273	740.239	288.32	29.03	1909.94	577.48	871.151
Debt	$	273	463.879	934.19	0	7416.667	0	506.332
Total Investment	$	274	3122.927	2813.71	406.47	20260.953	1240.43	4169.74
Raised and Purchased Feed Costs	$	274	105.23	84.181	4.24	465.26	52.3	136.66
Total Operating Cost	$	273	475.62	207.69	149.3	1472.6	341.73	573.51
Gross Revenue	$	273	488.13	215.36	126.63	1614.5	361.1	558.5
Percentage Return on Assets	%	274	-0.15	11.035	-45.08	54.15	-3.1	3.38

Multiple reports have previously reported feed costs are approximately 70% of total operating costs in beef operations (Becker, 2012) and UNL, 2021). Here, feed costs ranged from 11% to 65% percent of total operating costs (Fig. 2.6). Feed costs included variables described as raised/purchased feed cost per cow and grazing cost per cow. Results here showed a difference of ~$461 per head in feed costs.

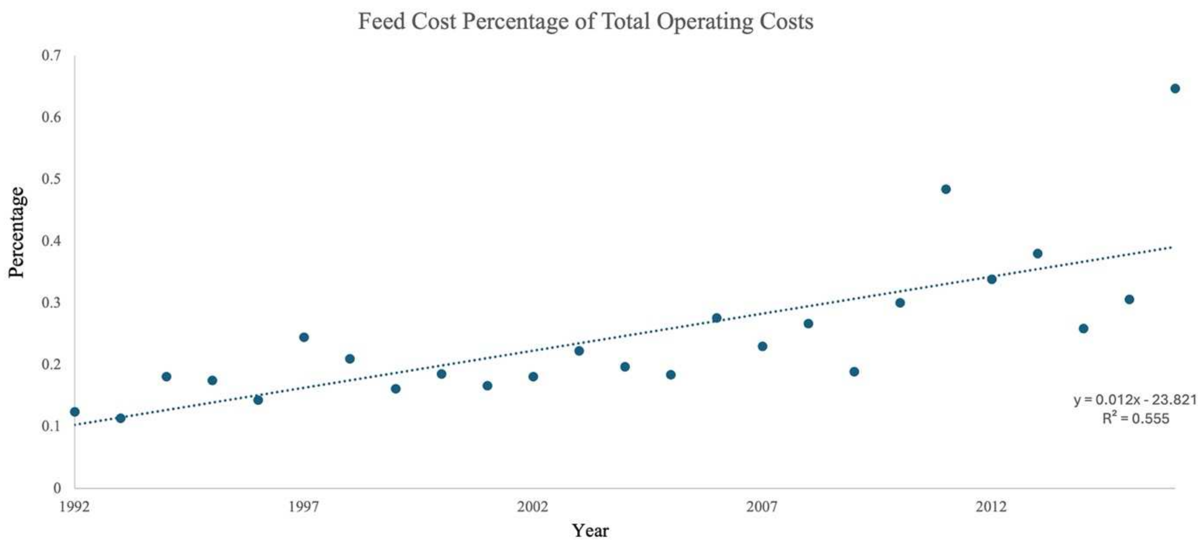

Figure 2.6 The average feed cost as a percentage of the total operating costs for producers in the southern U.S. indicates an upward trend from 1992 - 2016.

Total operating costs per cow includes but is not limited to managerial costs (machinery, equipment, and real-estate improvements), fuel, oil, other non-current asset costs, financial grazing cost per cow, and raised/purchased feed cost per cow. Gross revenue also varied largely ranging from $127 per head to $1,615 per head over the 25 years analyzed. The total operating costs per cow averaged $475 per year. Multiple reports showed that current cow costs range from approximately $850 to $1,000 in the United States (SDSU, 2023; AgUpdate, 2022) with feed, labor/equipment, and depreciation as the largest contributing factors (UNL, 2021). Figure 2.7 below shows the average total operating costs per year to provide context to how prices have changed over the two decades. On average, the total operating costs have increased ~12% each year for beef operators. However, some of that large increase was due to record prices in 2015. Therefore, 2015 was removed to evaluate costs from 1992-2014. Financial total operating costs increased more than 8% per year for beef operators. With inflation rate considered, operating costs increased >6% per year from 1992-2014 for beef producers.

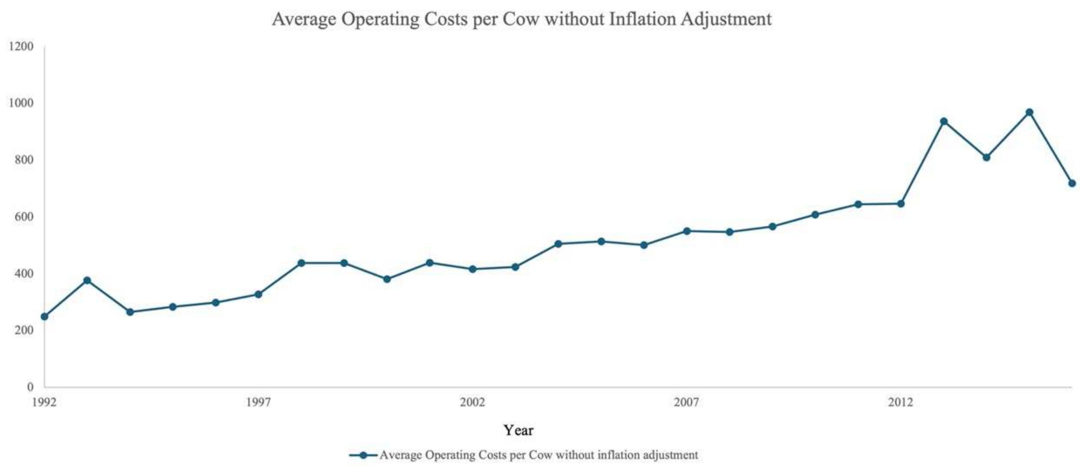

Figure 2.7 Average total operating costs per cow per year without inflation adjustment from 1992 - 2016.

Beef production and financial variables are informative in terms of comparing those benchmarks to other producers in a similar environment to identify potential areas of improvement or change. Percent ROA and UCOP are measures that offer a way for producers to evaluate the operation as a whole and to identify independent variables that may improve those values. To illustrate trends over the two decades analyzed, participant entries were averaged per year, with some years with more entries than others (see Fig. 2.1). The minimum ROA reported was -0.45 and maximum reported was 0.54. According to Bevers (2019), a healthy ROA is 1.5%

or greater. The average ROA in the data was -0.15%, which is categorized as economically unhealthy for a beef operation (Fig. 2.8; BCRC, 2023, accessed 9/1/2023)

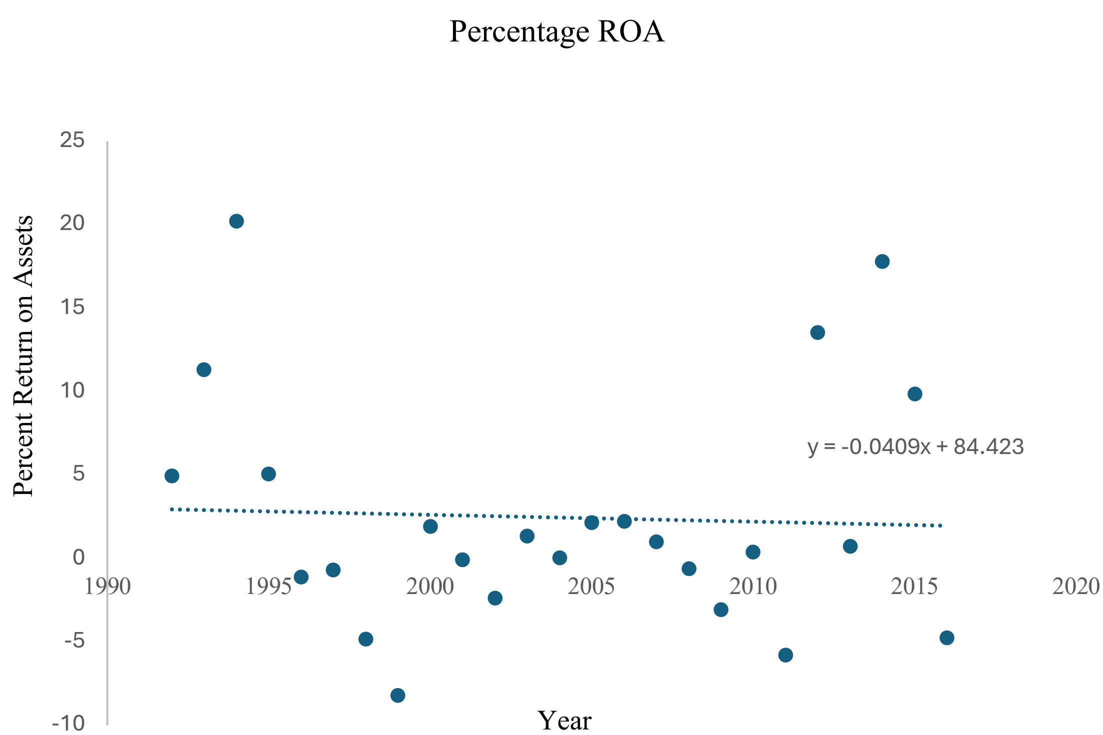

Figure 2.8 Percent return on assets over 25 years analyzed.

Unit Cost of Production is defined as the cost to produce one unit of output, which was weaning weight measured on per pound or per hundredth weight (CWT) basis. Comparisons among various costs of an operation to UCOP were examined to identify the level of contribution to operational cost per CWT. The first comparison showed feed costs vs UCOP (Fig. 2.9).

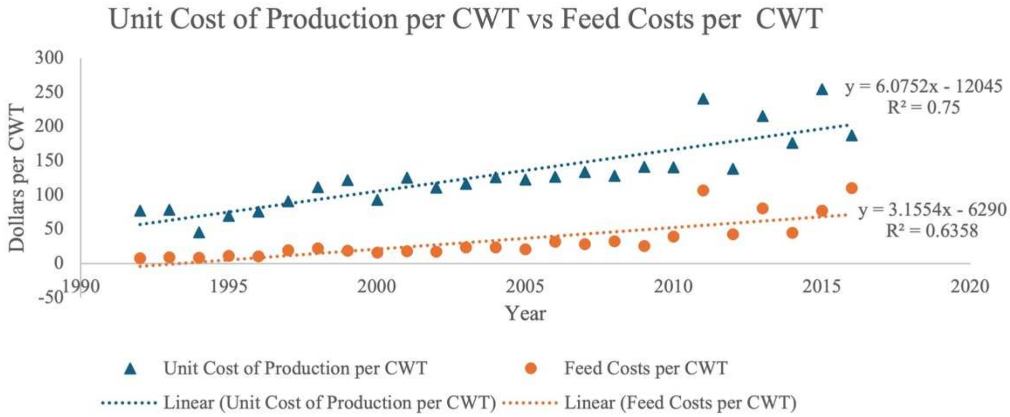

Figure 2.9 Feed Costs per CWT compared to the Unit Cost of Production (UCOP) per CWT.

Given the regression equation, UCOP increased twice the rate of feed costs over the two decades analyzed, indicating an increase in other operating costs (managerial costs, livestock, labor, etc.) concomitantly as feed costs. Hired labor management was also a large contributor to operational cost. Comparisons between UCOP and Labor are shown in Fig. 2.10. While the increase in labor cost has the greatest rate of change compared to all other costs, the increase is not steady, with frequent declines throughout the two decades, which may be indicative of inconsistent labor, ranches entering/exiting the industry, or the variation in hired labor costs within the industry.

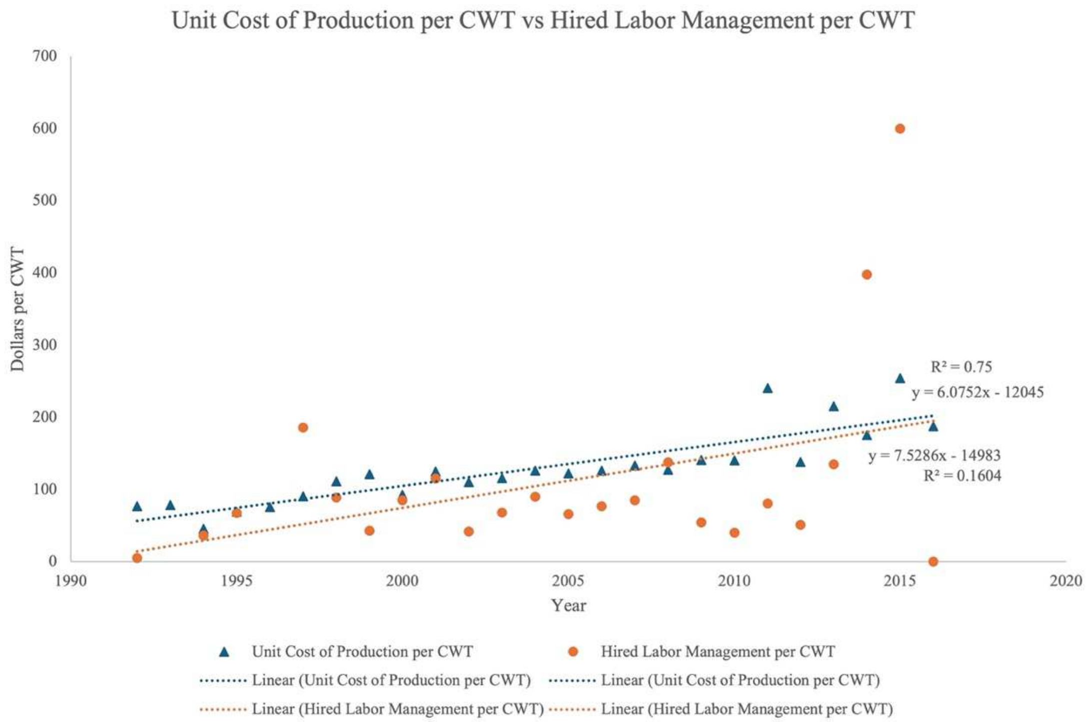

Figure 2.10 Comparison between the average Unit Cost of Production per CWT and Hired Labor Management per CWT.

Three years show that hired labor was higher than operational cost. That is due to summarizing by averaging the datapoints on a yearly basis. It is possible that some participant's hired labor costs were higher than the average operational cost of other producers. Other costs increased over time but were nominal compared to feed and labor costs (Fig. 2.11). In 2013, 2014, and 2015 costs varied widely compared to historic costs.

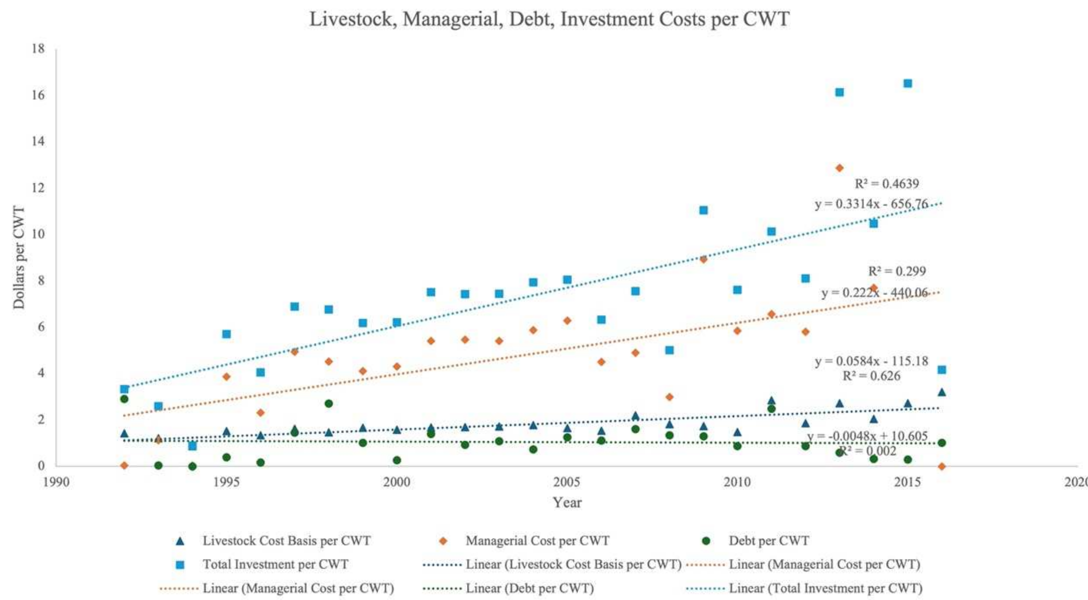

Figure 2.11 Livestock, Debt, Managerial and Investment per CWT were evaluated. All variables except Debt per CWT showed an upward trend over time.

Costs were compared to weaned calf pay weight and price. The extreme differences (regardless of year in which they occurred) between cost and price were examined. The lowest total operating costs per CWT occurred in 1994 at ~$45/CWT, while the highest operating costs occurred in 2015 at ~$250/CWT representing a 452% percent change. Given the time-span in which that occurred, that is on average a 21% increase in total operating costs per year (1994 – 2015). Conversely, pay weight price was examined where the least price occurred in 1998 at ~$74/CWT. The highest price occurred in 2014 at ~$252/CWT. That is a 243% overall increase during that time span, averaging a 14% increase in price each year (1998-2014). While the extremes examined in 2014-2015 were unprecedented market prices and costs, the data reflects costs have increased at a higher rate than what producers are being paid for beef on a CWT basis according to the trendlines (Fig. 2.12).

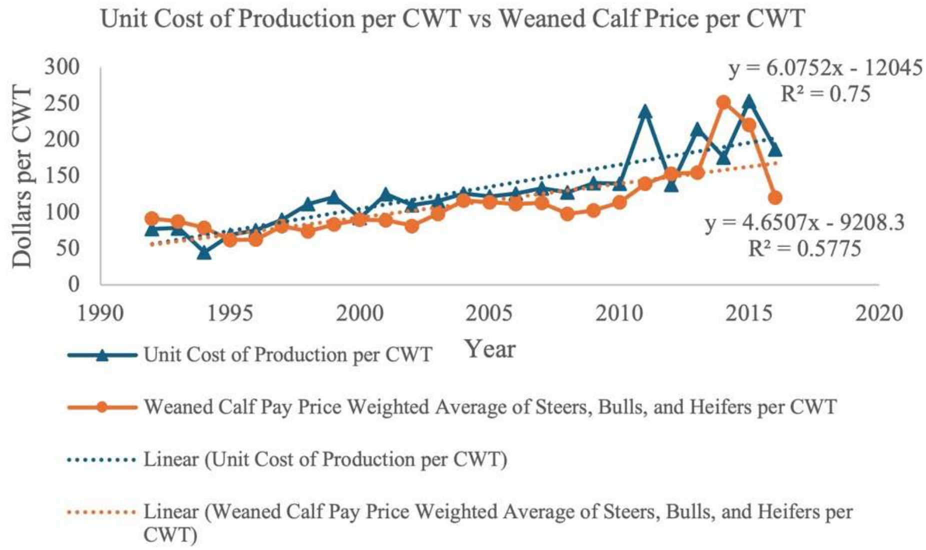

Figure 2.12 Weaned calf pay weight price (weight average of steers, bulls, and heifers) compared to the Unit Cost of Production (UCOP) of producers in the southwestern U.S.

Moreover, less than half the time are producers in a healthy status of ROA on average (Fig. 2.5). Figure 2.9 showed that only 5 of 25 years producer's profit from the weaned calf enterprise when compared to operating costs of only the weaned calves.

Discussion

The SPA data has been analyzed in a variety of ways which have addressed the economies of scale, short-term evaluations, and economic performance of beef cattle herds (Ramsey et al., 2005; Parker et al., 2004). Other SPA-type analyses have reported current benchmarks which are useful for farmers and ranchers to compare herd information with themselves to improve production and profitability (NDSU, 2022). Participant entries were averaged per year to understand and evaluate trends that have occurred over the two decades. The 25 years of data examined here covers multiple eras of markets, cattle cycles, and stressful environmental events.

A cattle cycle illustrates the relationship among the number of cows, harvest numbers, and market price usually in a 10–12-year period. In short, two cattle cycles occurred through 1992-2016; a record long cycle which started in the early 1990s and ended in 2004, and the second which was from 2005-2015. However, from 2006-2013, there was no typical cattle cycle pattern as ethanol was introduced which increased corn prices and decreased calf prices (Beef Magazine, 2015). Paired with drought, cattle reached a decade's low number in 2014. Historically, drought was most impactful during 1996, early 2000's, 2011, and 2012 (NOAA, 2023). The national herd decreased soon after those weather events which facilitated the contraction of cattle numbers and progression through the cattle cycle (Fig. 2.13).

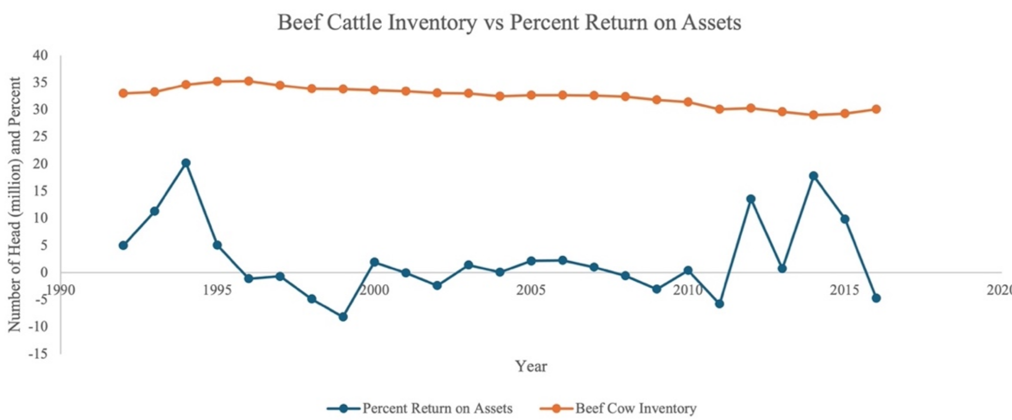

Figure 2.13 Cattle numbers reflective of the cattle cycle and Percent Return on Assets of producers from 1992 - 2016 (USDA-NASS, 2023).

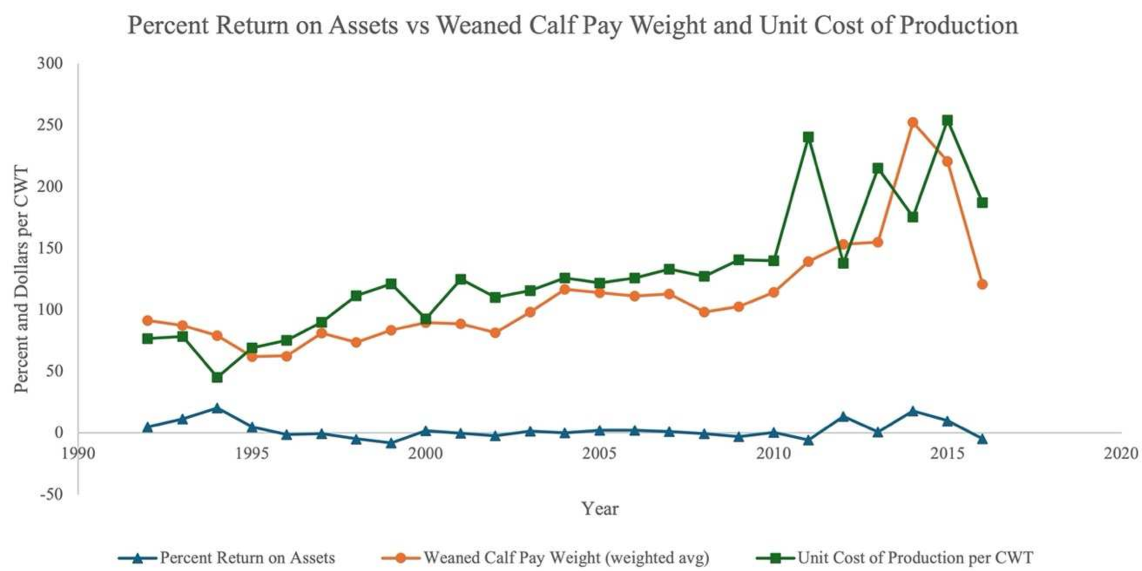

Figure 2.14 Percent Return on Assets compared to Weaned Calf Pay Weight and Unit Cost of Production for beef cattle industry from 1992 – 2016.

Therefore, understanding the cycle and market from 1992-2016 aides in following the current dataset. When the SPA data was overlapped with cattle cycles, it appeared that as cow numbers decreased (Fig. 2.13 and Fig. 2.14), UCOP and market prices increased. Generally, a decrease in cattle numbers creates an increase in market prices because inventory does not match demand. During this time-period, UCOP simultaneously increased which was most likely attributed to increases in feed costs because of drought.

Production variables largely remained stagnant, with some deviation for weaning weight in 2011 – on record as the driest year in Texas (Nielson-Gammon, 2012). It is a likely scenario during this time that producers weaned calves early to maintain their cow herd by decreasing forage requirements on the cow. The average weaning weight over the 25-year period largely remained at or below 530 pounds. Similarly, Pounds Weaned per Exposed female largely remained less than 430 pounds. Additionally, the trendlines illustrated positive but shallow slopes indicating little to no improvement of the two measurements. While growth genetics appear to be improving with average weaning weight and yearling EPD's increasing every year (AAA, 2024), producer data indicated in this area that weight traits are mostly stagnant.

The southwest U.S. has vastly different climate environments in which to produce cattle. Stagnation of weaning weights and pounds weaned per exposed female given climatic limitations of the area may be an indication for producers to focus on other facets of their beef operation, such as, operating costs, rather than purchasing and focusing on extreme or above average growth genetics to improve performance.

As noted in other research, feed and labor costs were the largest contributors to overall costs of a beef operation (UNL, 2021; Short, 2001). Depreciation was incorporated into the cost basis of variables but has been determined as the third biggest contributor to costs (UNL, 2021). Interestingly, while feed costs have risen, they have not increased at the same rate of total financial operating costs, indicating an increase in all other costs (labor, managerial costs, etc.). While other costs are expectedly increasing, they increased at a much lower rate than feed and labor.

We compared one of the largest contributors to beef production profits (weaned calf pay weight) to all costs accrued to produce a weaned calf to understand if and how much profit margins exist. When evaluating producers on average, it appeared that ~20% of the time producers are profitable, with largest profit margins occurring in 2014 during herd expansion. Conversely, 2015 showed high profits from weaned calf pay weights but even higher costs, most likely associated with some producers replacing cattle they liquidated during the drought. Figure 2.5 showed similar results where ROA in 2014 and 2015 was relatively high compared to previous years. Additionally, Fig. 2.8 showed 11 of 25 years producers are in healthy status of ROA on average.

Interestingly, the data showed from SPA's inception to 2016, costs increased at a higher rate than weaned calf market price, on average. This is not to say that producers cannot be profitable given the circumstances in which they are operating and selling weaned calves. However, like any other industry, it is useful to diversify and investigate various revenue streams while simultaneously producing weaned calves. For example, creating value in the herd such as retaining and developing heifers rather than selling at weaning may be an option. Acquiring stockers may be another option to improve the overall revenue and assist cash flow as shown and suggested in Rhoades et al. (2014). Management practices such as a preconditioning weaning program before sale could also improve market price. Given adequate feed resources, adjusting calving dates and therefore sale time may be a realistic option to add value to calves when the market has slowed. There are many options to increase profit margins. Multiple revenue streams surrounding weaned calf production lessens the risk of a calf crop that may not be profitable some years.

All costs have risen and the more difficult to control costs (feed and labor) are rising at faster rates than remaining costs. Multiple events have led to rise in costs, making the need to analyze one's operation even more imperative. Profit margins are small and oftentimes inexistent when evaluating profit and costs associated with weaned calves. Stressful times are often costly to beef producers, and if decisions are made at the stressful time (e.g. no drought plan, etc.) there may be a need for real-time decision-making tool to assist producers to capture some profit that may otherwise be lost.

Industry emphasis has largely focused on growth genetics. The higher the growth of a calf, the more pounds of weaned sold and ultimately the higher the pay weight. However, the SPA dataset showed little to no increase in weaning weight or pounds weaned per exposed female over a 25-year period, paired with stagnant pregnant, calving, and weaning percentage. Additionally, the variables discussed above were derived from calves of more than 500 exposed females per year on average - a large gamut of producers, practices, environments, and type of cattle illustrating regional trends. Therefore, changes or focus upon growth in weaned calves or other beef production measures may not be as beneficial to the health of a beef operation as tracking, knowing, and controlling financial costs of the beef operation. Any negative deviation of beef production measurements always needs addressed, however, UCOP addresses the failure or success of those beef production measures by incorporating pounds of calves in its calculation.

All facets of a beef operation have a level of importance and contribute to the success of an operation. However, it appears that focus upon cost levels and specifically UCOP may be a holistic way to analyze and improve the success of an operation. The potential to change beef production measures is limited compared to the potential to improve cost measures. This comparison is especially important during low market times of the cattle cycle. Having "good" beef production measures are more limited in low market times than controlling the costs associated with beef production.

Conclusion

The objective of this research was to perform a comprehensive analysis over a large beef cattle production dataset to understand beef production and cost trends in the industry through multiple decades. We evaluated beef and financial production measures and determined that most production variables have largely remained stagnant over the 25-year period (e.g. pregnancy percentage, pounds weaned per exposed female). Additionally, financial variables such as feed and labor have increased and are the two most costly variables examined in this research. Additionally, most years producers have a negative ROA. Lastly, UCOP has increased over time. Analyzing UCOP as a means of success may be the most holistic way to improve facets within a producer's operation.

CHAPTER 3: USING MACHINE LEARNING TO DEVELOP A FINANCIAL RANCH HEALTH INDEX

Introduction

The environment, local and global markets, and the cattle cycle all have varying and wide effects on animal agriculture which creates complex situations for beef producers that result in long-term consequences for production and profits. For producers, this can be challenging to navigate a "moving target" in which plans for production (e.g. purchasing feed, marketing cattle) may be decided at a point in time which could be vastly different from the time in which the action occurs. Generally, knowing, controlling, and managing costs is a way to decrease risk in cattle production as markets, environment and demand are all variable and largely unpredictable.

Beef production and financial metrics have been used for decades to assist producers to benchmark and improve overall success of their beef operations. In its simplest form, producers have tracked records using a Redbook (AgriNews, 2022; NCBA, 2023), a pocket size book, to record calving activity, cattle inventory, Artificial Insemination (AI) date and information, and more. The Standardized Performance Program (SPA; a standardized beef performance and financial program for beef producers) and other similar programs have utilized and enhanced this type of record keeping for national standardization and benchmarking to compare producer's production output and identify aspects of the operation that could be improved.

Ultimately, these variables of an operation are useful individually which can enhance overall profits. However, there is limited research in how multiple variables are used to determine an overall financial health of an operation using beef production and financial metrics. Parker et al. (2004) described various models to determine significant beef production and financial variables predicting Cost, Pounds Weaned per exposed Female, and Return on Assets of the SPA data from 1991 – 2001. Independent variables (operating costs, weaning weight, etc.) were evaluated for a negative or positive relationship with the three dependent variables. However, Parker et al. (2004) research only spanned 10 years.

Bowman et al. (2019) recently evaluated High-, Medium-, and Low-Profit cattle producers during the years 2014 – 2018 from the Kansas Farm Management Association. Bowman et al. (2019) concluded that High-profit producers typically have lower feed costs ranging from $125-150 per cow compared to the Low-profit producers. Additionally, High-profit groups also had the lowest depreciation, machinery, and labor costs.

There is flexibility in decreasing costs in cattle production. There are multiple variables that may be focused on to improve overall production and profits as shown in Chapter 2 of this dissertation. Bowman et al. (2019) and UNL (2021) have shown the importance of managing feed costs, overhead costs (labor and equipment), and depreciation costs while Parker et al., (2004) investigated variables indicative of success.

Because of limited previous research and the ability to examine 25 years of beef operation data, the objective of this research was to identify Key Performance Indicators (KPI) that influence Unit Cost of Production (UCOP) to create a financial health index also known as Ranch Health Index (RHI). Subsequently, Systems Dynamics modeling was used to test for sensitivity of the KPI. Systems Dynamics is one way to investigate multiple holistic processes at one time to delve into these factors impacting beef cattle production. The sensitivity analysis was examined by a Ranch Health Index to assess and determine overall health of a beef operation to assist in extending longevity and future success of beef operations.

Materials and Methods

Data overview

Beef performance and financial data was obtained from the Standard Performance Analysis program conducted by Texas A&M AgriLife Extension (Bevers, 2016). This program had entries from three states including Oklahoma, Texas, and New Mexico. It contained 25 years of beef financial and production metrics from 1992 – 2016. The complete dataset contained nearly 600 data entries from 319 unique producers. Quality control and other filtering procedures were performed to obtain the most accurate data. Manual curation was conducted wherein 14 individual producer entries were removed due to inability to distinguish between dependable data and artifacts of the survey process. One producer was removed due to lack of information on multiple variables. Fall calving herds were removed from the dataset to remove seasonal effects on production year analysis. For duplicate entries, the second observation was removed (n = 3). One observation was removed due to unknown location. The final data frame consisted of 270 entries (139 unique producers) and 64 datapoints per producer (including financial and beef production data).

Data Cleaning and preparation

The dataset had 64 variables, this was parsed to 40 variables with the removal of metadata (like operation name), intermediate results from the original data source (such as grazing types [e.g. crop aftermath] as a percent of total grazing acres, categorical variables that have non-standard responses (such as dominate grazing rotation), and multicollinear variables (such as financial grazing cost per cow and financial grazing cost per CWT, in this specific case financial grazing cost per CWT was retained while the other removed). The success of an operation was based on the performance of the 'Financial Pretax Cost Before Non-Calf

Revenue,' here renamed Unit Cost of Production (UCOP). After a seed was set for reproducibility, prior to model generation, missing values (e.g. NA) were removed. Next, the data was split into and training and testing datasets (with the training dataset being 75% of the total data frame) with no strata. Cross-validation folds were also created. All variables were normalized to have a standard deviation of one and a mean of zero and imputed missing data using the nearest neighbor while removing variable with no variance.

Model creation, evaluation, and variable selection

Three models were investigated to determine the Key Performance Indicators (KPI) of UCOP and ultimately develop the Ranch Health Index (RHI). These models included Step-wise, Multiple Linear Regression (MLR), and a machine learning algorithm Random Forest (RF). These three specific models were chosen because of their differences in calculating predictor variables. The Step-wise model was constructed using the stepwise_model from the MASS package (v 7.3-60) in R (2021) using both directions, the critical limit was established at 0.05. The Random Forest model was constructed using the Ranger package (v 0.16.0) with tidymodels (2.0.0) and parsnip (1.2.1) for workflow (2021). The number of trees at each split when creating the tree models was set to 4 and importance = "impurity." When setting ranger engine for variable importance scores, 500 trees were constructed. The Multiple Linear Regression model was created with a set_mode to "regression" and an engine to "lm" within tidy models. In all cases, the model was described as y = UCOP and all other variables as predictors.

Models were all evaluated within the tidymodel workflow. The last_fit function was used to determine the best model and test performance and data collected with collect_metrics (RMSE and R squared). Collection_predictions was used to generate predictions from the test set. The final model was fit with parsnip's fit function and important features were extracted with extract_fit_parsnip.

Final model variable selection

When all models were complete, their coefficients or importance based on the specific model were aggregated into one data frame. R-squared values and RMSE were evaluated to determine which model was the most accurate with the most explanatory power. From there, the final model selected was used to determine weights of the most impactful factors predicting UCOP which were used to develop the Ranch Health Index.

Model concordance

Once the final model was determined and used for RHI development, the RHI model was tested against the SPA data with UCOP as the dependent variable for consistency and agreement to determine RHI usefulness and potential deployment to other producers interested in assessing their financial health of a beef operation.

First, SPA producers were sorted into three categories based on UCOP. Tier 1 included $1/3^{rd}$ of the producers with the lowest UCOP (n = 90); Tier 2 included the middle third of producers with moderate UCOP (n = 90); and Tier 3 included $1/3^{rd}$ of producers with the highest UCOP (n = 90).

Next, producers were examined in each category for consecutive data entry into the SPA program (e.g. 3 years or longer; n = 26). Once those producers were identified, the years in which they submitted data into the SPA program was evaluated. Three producers were selected with consistent data entry: 5 consecutive years of SPA data entry from 2004 – 2008. Producer 1 (AAG) had an average herd size of 560 head and was in Texas. This producer had UCOP values in all 3 tiers over the 5-year time-period. Producer 2 (AAN) had an average herd size of 458 head and was in New Mexico. This producer had SPA UCOP entries present in Tiers 2 and 3. Lastly, Producer 3 (FAD) had an average herd size of 120 and was in Texas. This producer had SPA UCOP values present in Tiers 2 and 3. Using the RHI developed and discussed previously, the three producers' raw data included in the SPA program was compared to the RHI predicted data.

Model sensitivity and testing

From the final RHI, sensitivity of each variable was tested using R and Systems Dynamics Modeling using Stella® (Forrester, 2009). Modeling is a multidisciplinary approach that utilizes causal loops, feedback, mental models, and quantitative models to describe nonlinear relationships (Forrester, 2009). First, R was used to calculate the simple linear regression line of each variable predicting RHI to determine the slope of each variable impacting UCOP. Systems Dynamics Modeling (SDM) was used to perform a sensitivity analysis on Key Performance Indicators (KPI) of the three beef operations. The SPA data was integrated into the SDM that included 5 core modules: Cows, Calves, Feed, Financials, and Results (Appendix A). Each of these modules consist of multiple mathematical equations that describe the production and movement of cattle throughout a production year. For purposes of this study, the sensitivity analysis was performed in the Results module which incorporated the RHI index.

Each producer had 5 years of data. Each of their KPI's were averaged to perform a sensitivity analysis to determine overall changes that could be implemented to improve financial health. The model was performed from year 2004 to year 2008. Each KPI was tested at ± 5% and ± 10% from the original value to determine sensitivity of each variable. Finally, the models were investigated for maximum and minimum RHI values to provide realistic comparison of what good operational decisions vs. poor operational decisions could result in.

Results

Model creation, evaluation, and variable selection

Step-wise, Multiple Linear Regression, and Random Forest were all used to construct three different models for comparison of the variables predictive of UCOP (Table 3.1). Step-wise had the highest R-squared value, indicating the most explanatory power of the model but was paired with a higher RMSE indicating a less accurate prediction ability.

Table 3.1 Model parameters of the three models tested for Ranch Health Index (RHI) development: Linear Regression, Random Forest, and Step-wise regression model.

Model	RMSE	R-squared
Multiple Linear Regression	0.563	0.407
Random Forest	0.474	0.525
Stepwise Regression	25.93	0.7715

The models compared weighted the importance of variables differently and in the case of Step-wise removed non-significant variables (Table 3.2). Livestock Cost basis per CWT was weighted the heaviest in the Random Forest model and Step-wise regression model. Financial Raised/Purchased Feed per CWT and Number of Adjusted Exposed Females were the heaviest weighted variables in the Linear Regression model.

Table 3.2 Three models used to test for significant variables in predicting Unit Cost of Production (UCOP).

Variable	**MLR Coefficient**	**Random Forest Importance**	**Stepwise Coefficient**
CalvingPercentage	0.001355	8.07211148	-2.67466
numberofadjustedexposedfemal	-0.647622	14.6187511	-0.16837
HiredLaborManagementperCWT	0.287394	7.34010075	0.11773
beginningfiscalyearbreedingc	0.156723	11.77903	0.1552
Nativeunimprovedgrazingacres	0.129961	5.90190164	0.36503
FinancialRasiedPurchasedFeedPerCWT	0.427996	42.718788	1.22307
FinancialGrazingperCWT	0.344914	23.8546602	1.27822
ManagerialCostperCWT	0.250743	5.45828631	1.31609
PregnancyPercentage	0.099948	3.14418808	2.00405
DebtperbreedcowperCWT	0.167118	9.81375971	3.27999
LivestockCostBasisperCWT	0.120019	29.125491	14.17975
(Intercept)	0.003941	--	89.6747
Weanedcalfpaywtweightav2	0.041762	21.8912312	Not selected
lbsofweanedcalves	0.192806	18.6082891	Not selected
Poundsweanedperexposedfemale	-0.391466	9.78647675	Not selected
Averageweaningweight	0.233989	9.70013995	Not selected
TotalInvestmentbreedingcowperCWT	-0.138143	6.6553563	Not selected
CalfCroporweaningpercentage	-0.029018	6.02776121	Not selected
Improvedperennialgrazingacres	0.054793	5.30212762	Not selected
Poundsofraisedpurchasedfeed	0.047977	4.71185957	Not selected
Averageageatweaningmonths	-0.075186	4.10130541	Not selected
BreedingSeasonLength	-0.010637	3.62095345	Not selected
FemaleReplacementRate	0.006708	3.49578174	Not selected
ofcalvesbornduringfirst21	-0.036443	2.41167886	Not selected
ofcalvesbornduring42days	-0.047426	1.97188905	Not selected
Grazableforestgrazingperhead	0.036081	1.78242808	Not selected
ImprovedPerennialRaisedfeeda	-0.072043	1.49420984	Not selected
Annualorforagecropgrazingac	0.018865	1.42640275	Not selected
Nativeimprovedgrazingacrespe	0.036843	0.90033596	Not selected
CropAftermathgrazingperhead	0.034772	0.72467754	Not selected
Annualorforagecropraisedfee	-0.036608	0.60389906	Not selected
cropaftermathacresperexpose	-0.031233	0.24079632	Not selected
Nativeimprovedraisedfeedacre	-0.021174	0.17737034	Not selected
CropAftermathraisedfeedacres	-0.032514	0.07701798	Not selected
Nativeunimprovedraisedfeedac	-0.066424	0.02969512	Not selected

After comparison of the three models, Random Forest was chosen as the final model as it had low error and moderately high prediction ability. Additionally, machine learning Random Forest models account for collinearity (Lindner et al., 2022) which the other methods did not. The Random Forest method also prevents overfitting the model which enhances accuracy. Six variables were highly impactful with importance factors of > 15. These included: Number of Adjusted Exposed Females, Financial Raised Purchased Feed per CWT, Financial Grazing per CWT, Livestock Cost Basis per CWT, Weaned Calf Pay Weight, and Pounds of Weaned Calves. From there, the six variables selected in the machine learning Random Forest model were weighted on their importance factor to develop a Ranch Health Index (Table 3.3). This entailed converting the importance factors into a weighted percentage. The variables were compared in a network analysis where line thickness indicated similarity (Fig. 3.1).

Table 3.3 The six variables determined as Key Performance Indicators (KPI) of a beef operation that were included in the Ranch Health Index (RHI).

Variable	Weight
Number of Adjusted Exposed Females	0.09693026
Financial Raised Purchased Feed per CWT	0.28324876
Financial Grazing per CWT	0.15816935
Livestock Cost Basis per CWT	0.19311782
Weaned Calf Pay Weight	0.14515075
Pounds of weaned calves	0.12338306

The most similar variables included in the RHI were Number of Adjusted Exposed Females and Pounds of Weaned Calves.

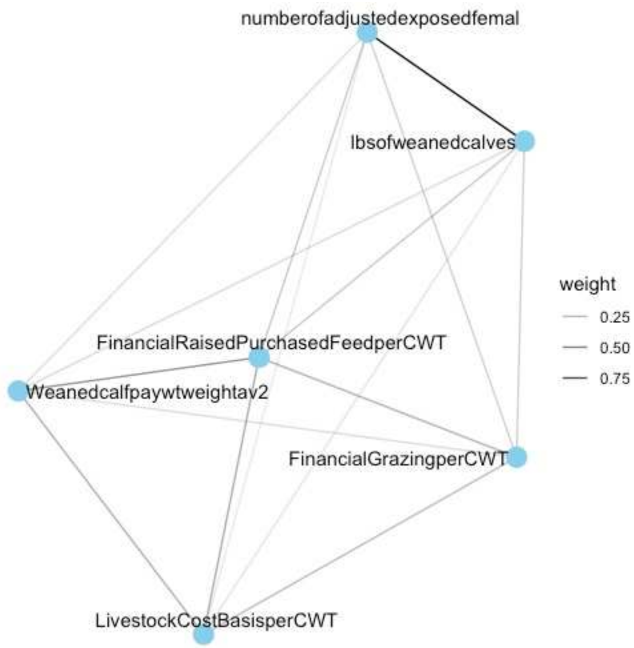

Figure 3.1 A network analysis was performed on the six Ranch Health Index (RHI) variables.

Model concordance

The RHI Index was developed with the six variables and their corresponding coefficients used as weighting factors. Three producers' complete SPA information with UCOP as a financial measure was compared to the developed RHI using the six selected KPI. The RHI considered a positive or negative impact on UCOP and was reflected using a positive or negative sign as shown below:

$UCOP =$ (-0.28* Financial Raised Purchased Feed per CWT) + (-0.16* Financial Grazing per CWT) + (-0.19* Livestock Cost Basis per CWT) + (0.15* Weaned Calf Pay Weight) + (0.12* Pounds of Weaned Calves) + (0.10*Number of Adjusted Exposed Females)

Because of this, results showed an inverse relationship between the predicted RHI results and the actual UCOP results showing utility in the model developed (Fig. 3.2).

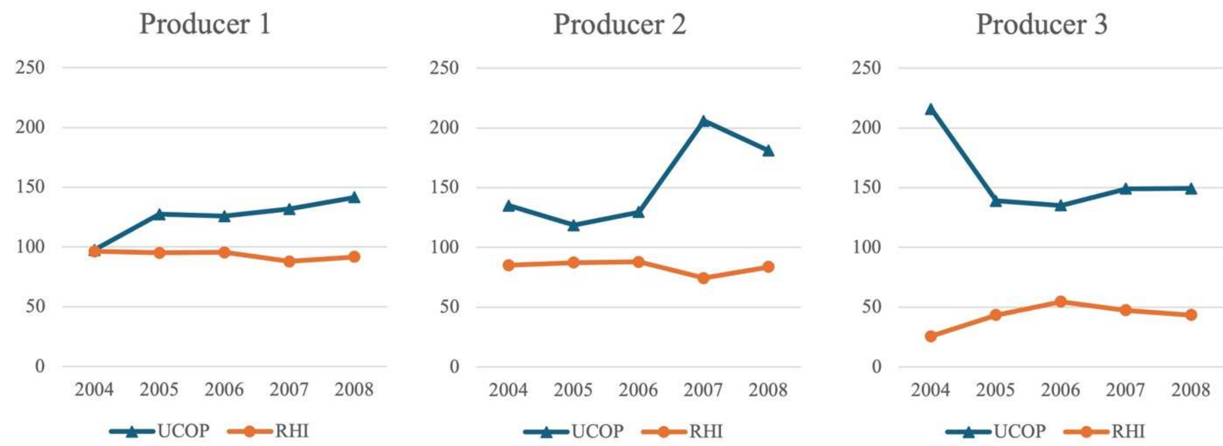

Figure 3.2 Model comparison between the Ranch Health Index (RHI) results and the Unit Cost of Production (UCOP) results from three producers which showed an inverse relationship.

Model sensitivity and testing

Sensitivity among the final KPI variables were tested from the SPA dataset to determine to what degree changes need to improve financial health of a producers' operation (Fig. 3.3) As expected, as each cost variable increases, UCOP also increases. However, it appeared that changes to Weaned Calf Pay Weight had the largest impact on RHI with a coefficient of 67.95 predicting UCOP (Table 3.4). Therefore, for every unit increase in pay weight, the UCOP increased by 67.95 dollars. Additionally, Livestock Cost per CWT had the second largest coefficient at 39.08. For every unit increase in Livestock Cost per CWT, UCOP increased by 39.08 dollars.

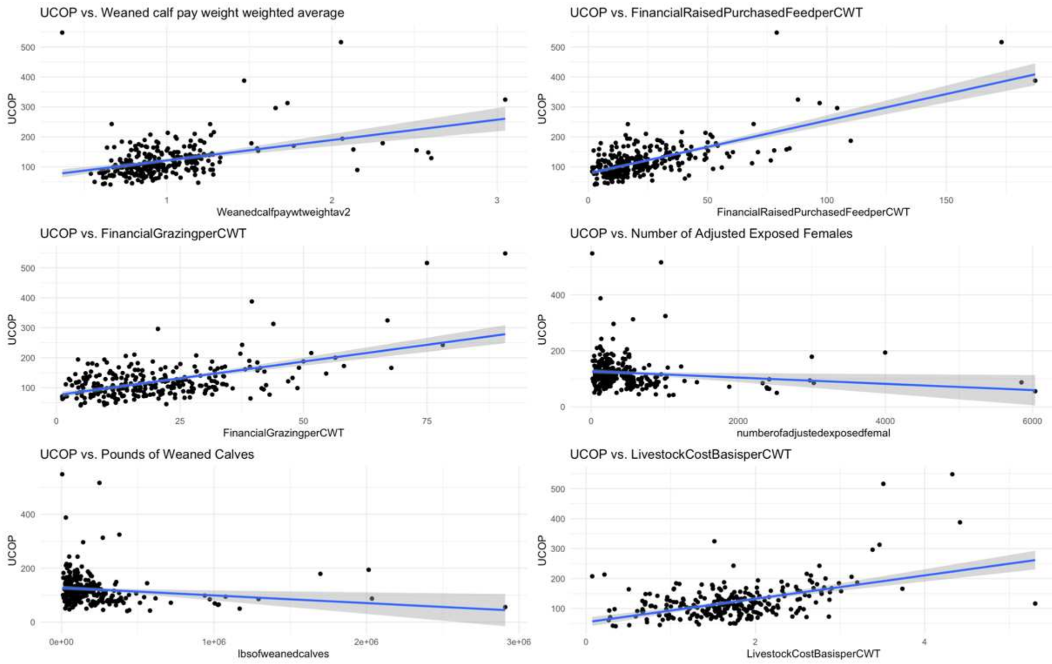

Figure 3.3 The six variables from the SPA dataset were used to predict UCOP.

Table 3.4 The regression equations of the six most impactful variables predicting Unit Cost of Production (UCOP).

Variable	Equation
Number of Adjusted Exposed Females	y = 126.95 + -0.01 x
Financial Raised Purchased Feed per CWT	y = 78.22 + 1.77 x
Financial Grazing per CWT	y = 75.45 + 2.24 x
Livestock Cost Basis per CWT	y = 54.29 + 39.08 x
Weaned Calf Pay Weight	y = 53.55 + 67.95 x
Pounds of Weaned Calves	y = 127.43 + 0 x

Moreover, Systems Dynamics Modeling (SDM) was used to perform a sensitivity analysis on Key Performance Indicators (KPI) of the three beef operation's RHI. Additionally, average values of each tier group of the SPA data are shown in Table 3.5 for comparison to the producers analyzed. Producer values of each KPI are shown in Table 3.6 and were tested for sensitivity. Since each of these producers had 5 years of data entry into the SPA program, the values for each KPI were averaged and tested. However, yearly data entries of the three producers into the SPA program had UCOP values present in the top tier, middle tier, and lowest tier of the entire dataset.

Table 3.5 The average value of each variable for the complete Standardized Performance Analysis (SPA) data split into tiers based on ascending order of the Unit Cost of Production (UCOP) measure.

Averages	Financial/Raised Purchased Feed per CWT	Financial Grazing per CWT	Livestock Cost Basis per CWT	Weaned Calf Pay Weight per CWT	Number of Adjusted Exposed Females	Pounds of Weaned Calves per Exposed Females	UCOP	RHI
Tier 1	14.08	15.93	1.48	87.05	762.62	432.07	75.87	134.40
Tier 2	20.89	19.69	1.62	94.25	362.96	421.40	110.66	91.70
Tier 3	38.00	25.88	2.05	117.80	360.57	421.04	175.92	89.08

Table 3.6 The average value of each variable included in the Ranch Health Index (RHI) calculation from the three producers with at least 5 years of data entry into SPA.

Averages	Financial/Raised Purchased Feed per CWT	Financial Grazing per CWT	Livestock Cost Basis per CWT	Weaned Calf Pay Weight per CWT	Number of Adjusted Exposed Females	Pounds of Weaned Calves per Exposed Females	UCOP	RHI
Producer 1	32.34	19.90	1.91	108.37	534.00	434.71	124.87	109.22
Producer 2	19.08	7.61	2.46	119.11	475.60	357.08	153.99	101.25
Producer 3	47.96	26.76	2.20	115.60	123.40	403.42	157.66	59.96

Each producer's sensitivity results are shown in Tables 3.7, 3.8, and 3.9. Ranch Health Index (RHI) sensitivity results showed similar results to the original RHI results when testing the variables independently of each other at ± 5% and ± 10%. However, when testing all combinations, there was more than ~8,000 various options to improve financial health. Ultimately, the minimum and maximum financial health consequences were compared to illustrate the extent to which financial health could change or improve at ± 10% (Fig. 3.4).

Table 3.7 Sensitivity analysis of Producer 1 testing the six variables included in the Ranch Health Index (RHI) at -10%, -5%, +5%, and +10% from the original value.

	-10%			**-5%**			**5%**			**10%**		
Producer 1	-10% Observed Value	% Change	Ranch Health	-5% Observed Value	% Change	Ranch Health	+5% Observed Value	% Change	Ranch Health	+10% Observed Value	% Change	Ranch Health
Financial Raised/Purchased Feed Cost per CWT	29.12	-272.80	110.3	30.72	-5.27	109.83	33.96	4.77	108.92	35.58	9.11	108.47
Financial Grazing Cost per CWT	17.91	-11.11	109.7	18.90	-5.29	109.53	20.90	4.78	109.21	21.90	9.13	109.05
Livestock Cost Basis per CWT	1.72	-11.05	109.4	1.81	-5.52	109.39	2.00	4.50	109.34	2.10	9.05	109.34
Weaned Calf Pay Weight per CWT	97.533	-11.11	107.8	102.952	-5.26	108.56	113.79	4.76	110.19	119.21	9.09	111.00
Pounds of weaned calves per exposed female	392.4	-11.11	104.1	414.2	-5.26	111.99	457.80	4.76	111.99	479.60	9.09	114.61
Number of Adjusted Exposed Females	480.6	-11.11	104	507.3	-5.26	112.04	560.70	4.76	112.04	2.10	9.05	114.71

Producer 1

Table 3.8 Sensitivity analysis of Producer 2 testing the six variables included in the Ranch Resiliency Index (RHI) at -10%, -5%, +5%, and +10% from the original value.

	-10%			**-5%**			**5%**			**10%**		
Producer 2	-10% Observed Value	Percent Change	Ranch Health	-5% Observed Value	Percent Change	Ranch Health	+5% Observed Value	Percent Change	Ranch Health	+10% Observed Value	Percent Change	Ranch Health
					-5.26	101.69	20.03	4.76	101.16	20.99	9.09	100.88
Financial Raised/Purchased Feed Cost per CWT	17.17	-11.11	102	18.13								
Financial Grazing Cost per CWT	24.08	-11.11	101.5	25.42	-5.26	101.48	28.10	4.76	101.36	29.44	9.09	101.30
Livestock Cost Basis per CWT	2.21	-11.11	101.5	2.34	-5.26	101.45	2.58	4.76	101.40	2.71	9.09	101.38
Weaned Calf Pay Weight per CWT	107.199	-11.11	99.64	102.952	-5.26	100.53	113.79	4.76	102.32	131.02	9.09	103.21
Pounds of weaned calves per exposed female	322.38	-11.11	97.12	414.2	-5.26	99.27	457.80	4.76	103.57	479.60	9.09	105.72
Number of Adjusted Exposed Females	428.4	-11.11	96.66	507.3	-5.26	99.04	560.70	4.76	103.72	2.10	9.05	106.17

Producer 2

Table 3.9 Sensitivity analysis of Producer 3 testing the six variables included in the Ranch Resiliency Index (RHI) at -10%, -5%, +5%, and +10% from the original value.

	-10%			**-5%**			**5%**			**10%**		
Producer 3	-10% Observed Value	Percent Change	Ranch Health	-5% Observed Value	Percent Change	Ranch Health	+5% Observed Value	Percent Change	Ranch Health	+10% Observed Value	Percent Change	Ranch Health
					-5.26	59.86	50.36	4.76	58.52	52.76	9.09	57.85
Financial Raised/Purchased Feed Cost per CWT	43.16	-11.11	60.53	45.56								
Financial Grazing Cost per CWT	24.08	-11.11	59.62	25.42	-5.26	59.40	28.10	4.76	58.98	29.44	9.09	58.76
Livestock Cost Basis per CWT	1.99	-11.11	59.23	2.10	-5.26	59.21	2.32	4.76	59.17	2.43	9.09	59.15
Weaned Calf Pay Weight per CWT	104.04	-11.11	57.46	109.82	-5.26	58.32	121.38	4.76	60.06	127.16	9.09	60.92
Pounds of weaned calves per exposed female	357.3	-11.11	54.43	377.15	-5.26	56.81	416.85	4.76	61.57	436.70	9.09	63.95
Number of Adjusted Exposed Females	111.06	-11.11	57.96	117.23	-5.26	58.57	129.57	4.76	59.78	135.74	9.09	60.42

Producer 3

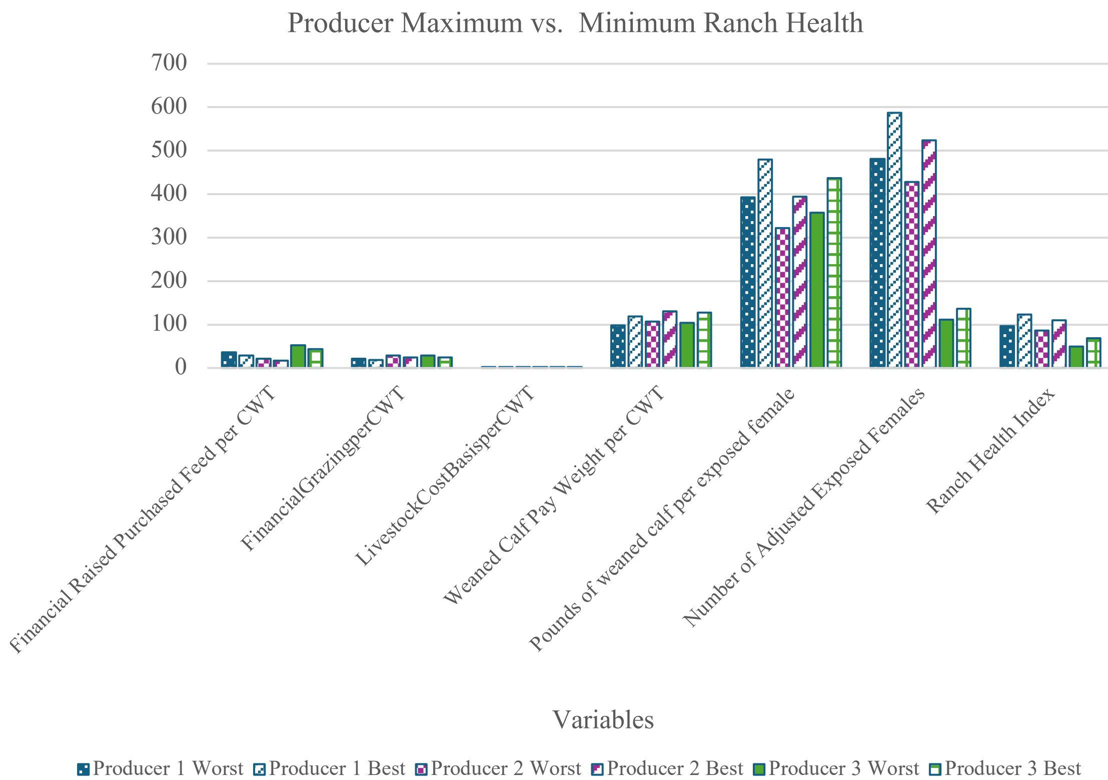

Figure 3.4 The maximum Ranch Health Index (RHI) compared to the minimum RHI using the six variables indicative of Unit Cost of Production (e.g. best vs. worse case scenarios given the sensitivity analysis parameters of the three producers tested).

Producer 1 had approximately 560 head of cattle. In the 5 years examined, Producer 1 retained 11% females for replacements and had an average weaning weight of 516 pounds. The average total pounds sold was 232,133 over the 5 years and averaged at $1.08 per pound. Therefore, Producer 1 made approximately $250,703.64 on cattle sales annually. If Producer 1 costs were to improve at 10% for feed and livestock costs, cattle sales would improve to $1.134 per pound, which improves the producer's overall profit to ~$13,000. Producer 2 had approximately 458 head of cattle with an average weaning weight of 453. If Producer 2 costs were improved by 10%, their overall profit would improve by more than $8,000. Lastly, Producer 3 had about 120 head of cattle that weaned at 492 pounds. This producer's profit would improve by nearly $4,000 if they were to improve grazing, purchased/raised feed, and livestock costs by 10%.

As stated previously, there are multiple ways to improve ranch health. Therefore, there are multiple facets of an operation that could represent financial health. However, after review of the complete SPA dataset and the 3 individual producers, the RHI was separated into scores of financial health, where a score of > 100 was excellent health, a score 80 – 100 was good financial health, and < 80 was poor operational health. When comparing the three selected producers and their KPI averages compared to the entire SPA dataset RHI, Producers 1 and 2 are in excellent financial health where Producer 3 falls in the poor financial health category based on the six most impactful variables of UCOP.

Discussion

Beef producers are challenged to determine profitable cattle production and plan for future success in sometimes limiting climatic environments, variable operation situations (e.g. owned or leased land, available feed resources) and volatile markets. Therefore, each producer has a unique beef operation that is operated with knowledge mostly from a variety of experiences.

Unlike most professions, beef operators must be knowledgeable in many fields: herd health, beef nutrition, genetics, financial planning and management, mechanics, farming, marketing, and many aspects of each. Because of this breadth of subject base, operators tend to use prior generations practices as a form of management because it has historically been a proven way for success and limits investigation into a potentially nonprofitable way to manage their beef operation. In a sense, it is "easier" to do "what has always been done" compared to risking an already risky livelihood on the unknown or wasting time/money investigating a different management practice that previous generations and/or experiences have possibly shown to not be successful.

The industry has recently provided indexes to enhance production using a more effective method while simplifying the process to get there. For example, most beef breed associations and some seedstock breeders developed selection indexes that involve multiple trait selection that equates to enhanced traits including profitability, maternal ability, terminal ability, etc. (AAA, 2020; AHA, 2023; ASA, 2023, Leachman, 2024). Additionally, Spangler et al. (2022) recently developed an index called iGENDEC to simplify bull buying for commercial breeders. While the above indexes do concern genetic selection in a beef operation, Oklahoma State University

(2018) has been one of the few who developed a financial health assessment of a beef operation but includes multiple financial health outputs to select from.

Here, we show an alternative approach to assessing financial health of beef operators. Knowing that most beef producer operations are unique, the index developed here does not concern specific management practices, climate environments, or genetic selection – an advantage. The variables identified as important to determine financial health are robust in which each producer's management practice can vary widely but results can still be informative to gauge financial health and long-term success for the operator. The most useful way to utilize this index would be to compare results year after year. Therefore, producers can evaluate their specific situation given known constraints or events from year to year that may have altered production and consider those factors when possibly changing practices to ultimately enhance success of the operation.

RHI Tiers and percentile ranking

Three tiers were described in the SPA dataset that separated producers based on their UCOP measure. Subsequently, the RHI was applied to the dataset to determine the range of the RHI scale for the top tier (1/3rd of producers), middle tier (2/3rd of producers), and third tier (3/3rd of producers).

As shown in Table 3.5, the 3rd tier had the highest feed costs. More specifically, the Financial Raised/Purchased Feed per CWT for the 3rd tier group was more than double the 1st tier group. Financial Grazing per CWT showed similar results. The RHI weighted these two variables at 0.28 and 0.16, respectively. We see large variations among all 3 tier groups which reinforces the fact that feed cost is one of the biggest components to long-term success of an operation and a leverage point for cost savings.

Livestock Cost Basis per CWT was considered one of the main influencers of UCOP and RHI. As shown in table 3.4, Livestock Cost Basis per CWT increases from Tier 1 to Tier 3. One way to decrease this cost would be to expand heifer replacement during years in which the market is low. Therefore, when the market is higher the heifers and their potential production (e.g. calves) are higher. Interestingly, pay weight was highest for the 3rd tier group. However, the fact the other five variables were lower for tier 3 than for tiers 1 and 2 reinforces the necessity to control costs despite pay price of weaned calves sold. To some degree all costs are necessary to decrease to observe large improvements in financial health.

The RHI average values were as follows: Tier 1 – 134.40; Tier 2 – 91.70; and Tier 3 – 89.08. Producer values can differ widely for the specific KPI variables which ultimately creates potential outliers within each tier. However, a general score measure was decided where an RHI score of 100 and above was considered excellent. A score of 80-100 was considered good, and a score below 80 was considered poor.

RHI and Sensitivity with 3 Producers

The top variables determined as most indicative of success as determined in this study include Financial Grazing per CWT, Financial Raised/Purchased Feed per CWT, Livestock Cost Basis per CWT, Weaned Calf Pay Weight per CWT, Number of Adjusted Exposed Females, and Pounds Weaned.

Financial Grazing per CWT and Financial Raised/Purchased Feed per CWT have been reported multiple times as one of the largest contributors to cost of an operation (Becker, 2012; UNL, 2021). Feed cost has been reported to account for 70% of total costs which includes purchased feed, leased ground, or harvested feed. In the current dataset feed costs ranged from 35% to 67% of total operating costs. Therefore, the results identified in the Step-wise, Linear

Regression, and Random Forest are consistent with other research findings despite the vast range in costs associated with feed in the dataset. Additionally, feed costs are an area of great variability and creativity of the operator. All aspects of a beef operation hinge on the quality, amount, and type of feed in terms of nutritional value aiding in reproduction, growth, health, and overall appearance of beef cattle. Additionally, the cost associated with feed and the profits also associated with feed are vital to predicting success of a beef operation and were determined as important factors in the RHI.

Number of adjusted exposed females was the smallest weighted variable impacting UCOP. The 2nd and 3rd tier groups had a similar number of exposed females but the first tier group had nearly double the number of exposed females. This variable could be considered an impactful factor of UCOP because other costs are spread out over more units (e.g. equipment costs, fences, etc.).

The non-current asset Livestock Cost Basis per CWT was considered one of the most impactful variables for UCOP in the Step-wise and RF models. Livestock Cost Basis per CWT is the cost basis for the asset values based on the price paid for the asset without the accumulated depreciation. Where producers raise their own replacements, the Livestock Cost Basis is the cost of raising the breeding animal (Bevers, 2016). Here, the three producers averaged ~$1.85 per CWT. This variable was weighted the second highest out of the six variables determined as impactful factors of UCOP. However, because the magnitude of Livestock Cost Basis is smaller than other variables, it may not be the best leverage point to improve financial health.

Pounds of weaned calves was the second lowest weighted variable. However, this variable may be more of an optimum as there could be diminishing returns to attempting to improve the number of pounds weaned. For example, the cost to increase the type or quantity of feed to improve weights may outweigh the pay out from the additional pounds gained. Additionally, purchasing high growth genetics for potentially higher price may not be the appropriate action when producing in harsh climate environments that need more feed resources to produce.

RHI Utility and Deployment

Various tools have been developed to assist beef operators in decision making and ultimately improve success such as benchmarking databases like FINBIN (2019), SPA (Bevers, 2016), UCOP measure, and CHAPS (NDSU, 2019) to name a few. However, this study aimed to use multiple procedures to ensure simplicity and usefulness of a scientific model to help producers determine ways to enhance their overall health of an operation.

By using three distinct models classical multiple linear regression (MLR), machine learning Random Forest Modeling (RF), and Step-wise regression model, an index was developed to analyze the health of a beef operation using a diverse set of variables. While not all variables examined in the SPA dataset were considered significant to assessing success of an operation through operational costs, the six variables selected for the RHI are indicative of many aspects of a beef operation and account for most of all costs of a beef operation.

Ultimately, this method of assessing beef operator's financial health is a simple and quick way to aide producers in improving their overall success and assessing their current operational state. Additionally, previous analyses to gauge and benchmark producers beef operation are often cumbersome and challenging to obtain consistent and consecutive data from producers to learn trends and/or gaps in the operation. While some of the variables identified for use in the RHI do need additional information to gain accurate measures, such as Livestock Cost Basis per CWT (e.g. need to calculate costs and feed it takes to develop the animals), using the RHI largely relies on a few main variables to serve as a basis for the six variables selected. For example, the number of head, pounds sold, price sold of weaned cattle, hired labor costs, feed costs and debt largely cover the necessary information to analyze a producer's operation and cost points. Other factors in a beef operation are important and must not be ignored (e.g. calving percentage). However, to gauge how costly an operation is compared to other producers or the producer themselves year after year, the RHI may be the most useful and easily deployable for producers to examine on their own. Additionally, producers that are inquisitive and do want to test various scenarios, the complete Systems Dynamics model could be used to ask more complex questions (Appendix A Fig. A.1 – Fig A.5). The RHI, for now, can serve as a gateway for producers to analyze their operations in other ways.

The benefit to utilizing RHI rather than single variables to analyze the health of a beef production system is that we can use an all-encompassing value to assess the whole system. As shown in Figure 3.1, the variables determined as significant predictors for UCOP represent diverse aspects of a beef operation. Since beef operational success is determined on holistic processes, the diversity in variables used in the RHI create a robust measure to assess and improve success.

Sensitivity analysis of the three producers illustrated the vast differences producers can enhance their financial state. The best way to improve financial health status would be to improve all six variables by 10% in this scenario tested. However, realistically, producers can focus on 2-3 variables to help overall profits.

Future Directions and Conclusion

Ranch management decisions are made daily, however, quantitative values that demonstrate the magnitude of these decisions can be useful to inform producers how one management change has favorable or unfavorable results that impacts unit cost of production. Therefore, an impactful way to use the RHI would be to incorporate other operational questions into the sensitivity of the index. Determining KPI's relevant to beef operational costs and performing a sensitivity of three producers using Systems Dynamics modeling provides a strong foundation to answering more complex questions regarding beef operational systems.

The objective of this research was to identify Key Performance Indicators (KPI) that influence Unit Cost of Production (UCOP) to create a financial health index also known as Ranch Health Index (RHI). Based on development of the RHI, model validation, and sensitivity analysis of the three producers, we determined the RHI using the six KPI shows utility in addressing financial health concerns for producers and may provide a way to assist producers in improving their UCOP.

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Appendix A

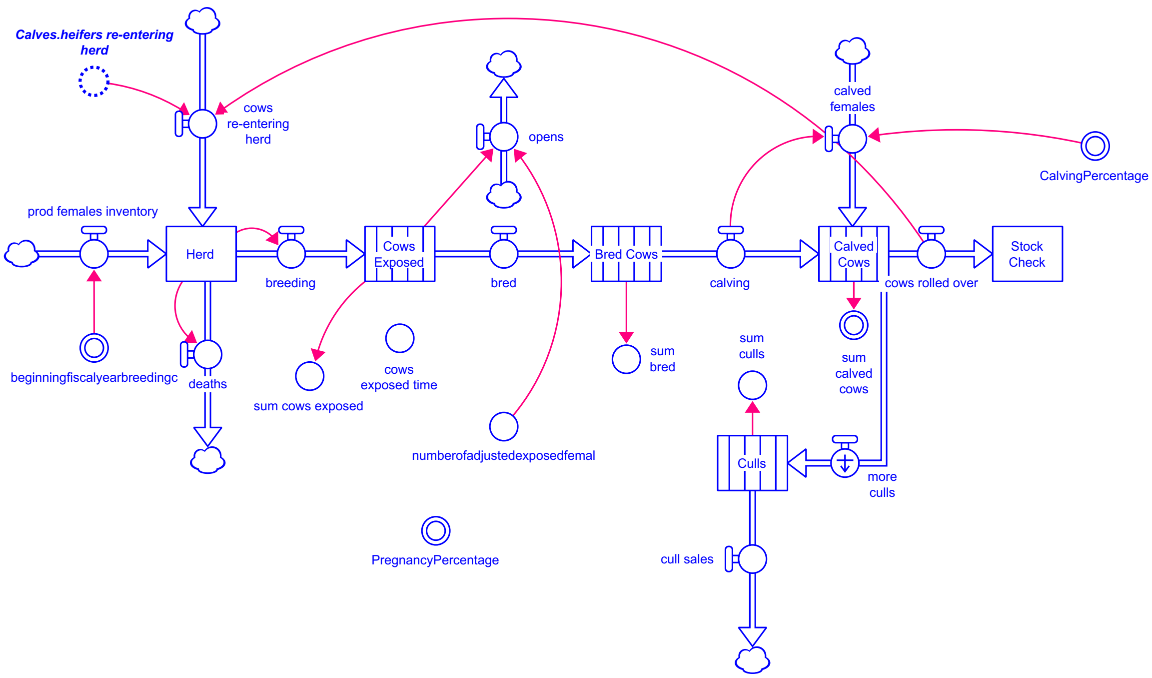

Figure A.1 Module 1 of Systems Dynamics model: Cow Herd

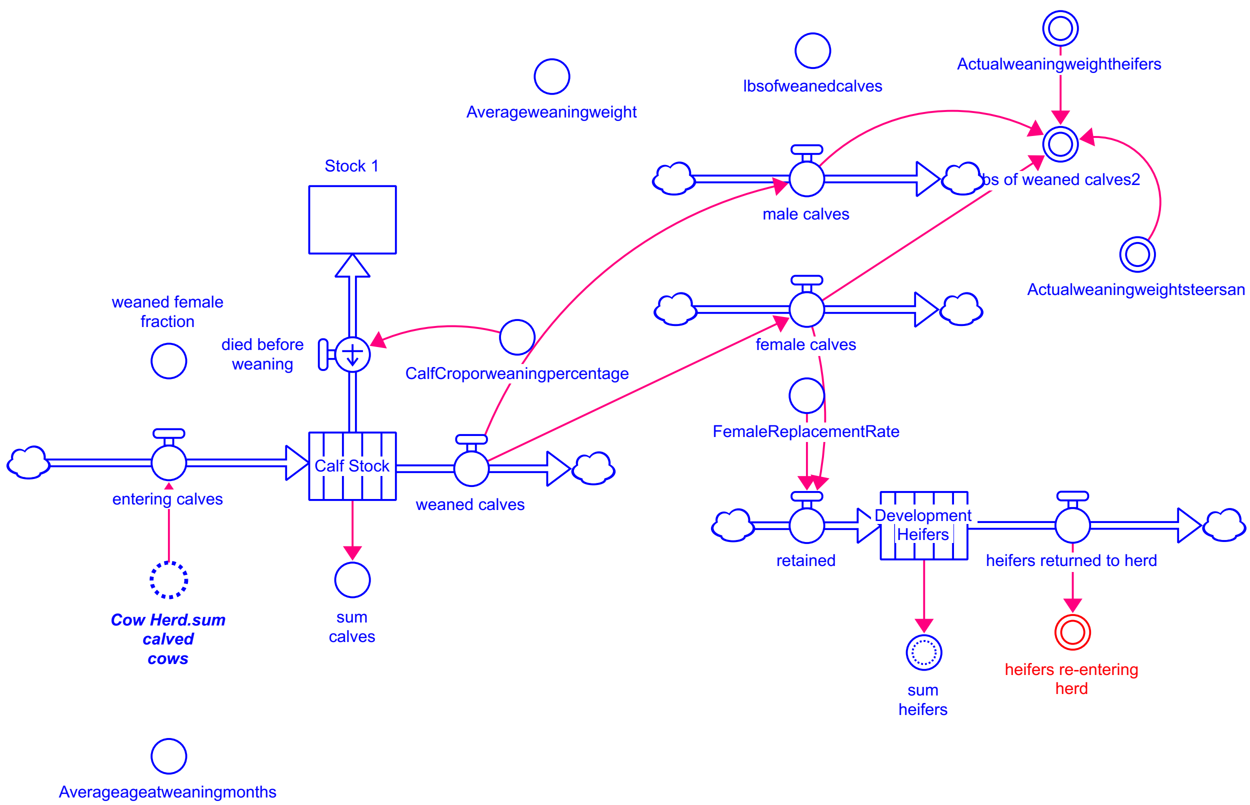

Figure A.2 Module 2 of Systems Dynamics model: Calves

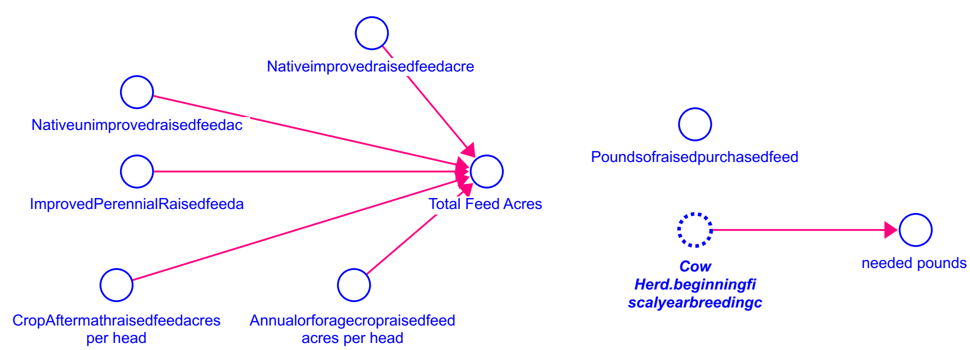

Figure A.3 Module 3 of Systems Dynamics model: Feed and Land

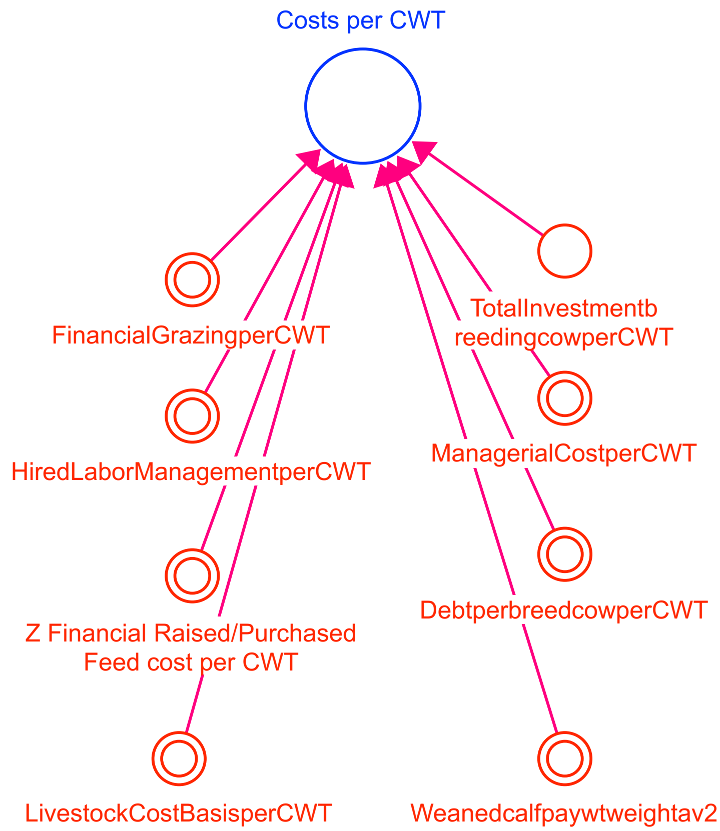

Figure A.4 Module 4 of Systems Dynamics model: Financials

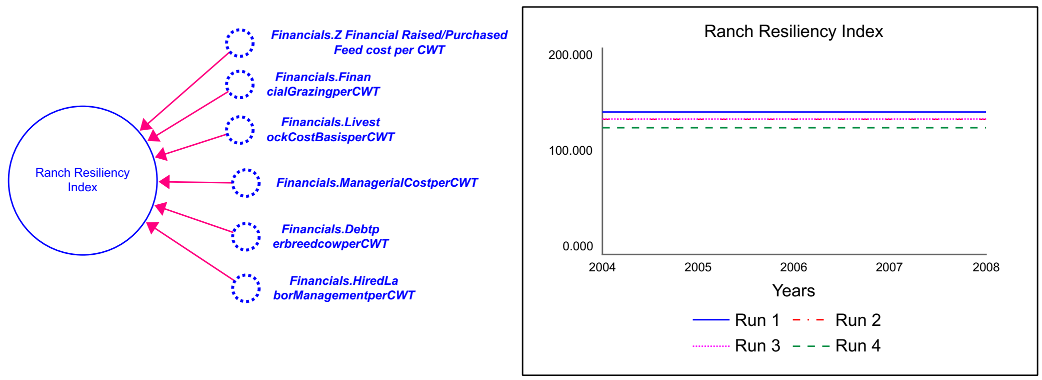

Figure A.5 Module 5 of Systems Dynamics model: Results

Appendix B

<u>R Code</u>

```
library(tidyverse)

library(readxl)

library(tidymodels)

library(ranger)

set.seed(032592)


beth1 <- read_excel("chapter2/PhD R Data Excel.xlsx", sheet = "beth1")


#filtered data based on correlations and catagorical values

UCOPperCWT.model <- beth1 %>%

  dplyr::select(c(FinancialPreTaxCostBeforeNon,

                 TotalCurrentAssetsCostBasi:FinancialGrazingperCWT,

                 BeginningDatefiscalYear:Weanedcalfpayweightsheifer,

                 lbsofweanedcalves:BreedingSeasonLength)) %>%

  dplyr::select(!c(DominantGrazingMethod))
```

```
UCOPperCWT.model <-beth1 %>%
    dplyr::select(c(FinancialPreTaxCostBeforeNon,
                    TotalCurrentAssetsCostBasi:Financialtotaloperatingcostp,
                    AX, BF,
                  Nativeunimprovedgrazingacres:RaisedFeedacresperexposedfe,
                  Poundsofraisedpurchasedfeed: BreedingSeasonLength))

#change names but after filter
UCOPperCWT.model <- UCOPperCWT.model %>%
  rename(FinancialNetPretaxIncomeAfterWithdrawalPerCwt = AX,
      FinancialPretacCostNonCalfRevAdjPerCwt = BF,
      FinancialRasiedPurchasedFeedPercwt = Z,
      UCOP = FinancialPreTaxCostBeforeNon)

UCOPperCWT.model <- UCOPperCWT.model %>%
  dplyr::select(-FinancialPretacCostNonCalfRevAdjPerCwt,
      -Financialtotaloperatingcostp,
      -FinancialGrossRevenueperCWT,
      -Weanedcalfweightweightedav,
      -GrazingfeedacresperExposedf,
      -poundweanedperacreutlizedby,
      -TotalCurrentAssetsCostBasi,
      -RaisedFeedacresperexposedfe,
```

```
    -OtherNonCurrentAssetsCost,
    -FinancialNetPretaxIncomeAfterWithdrawalPerCwt,
    -Weanedcalfpayweightsteerb,
    -Weanedcalfpayweightsheifer,
    -Actualweaningweightheifers,
    -Actualweaningweightsteersan)


###############pre-models#######################


#processing to get data in right format
#data.for.models <- na.omit(UCOPperCWT.model)


#split the data for training/testing
data.for.classifier.split <- initial_split(UCOPperCWT.model)


# extract training and testing sets and cv from training
UCOP_train <- training(data.for.classifier.split)
UCOP_test <- testing(data.for.classifier.split)
UCOP_cv <- vfold_cv(UCOP_train)


#define the recipe
UCOP_recipe <- recipe(UCOP ~ .,data = UCOP_train) %>%
```

```
  step_normalize(all_numeric()) %>%
  step_impute_knn(all_predictors())

############random forest########################

#Random Forest model
rf_model <- rand_forest() %>%
  set_args(set_args(mtry = 4)) %>% #don't want to tune later
  set_engine("ranger", importance = "impurity") %>% #need importance for later
  set_mode("regression")

rf_workflow <- workflow() %>%
  add_recipe(UCOP_recipe) %>%
  add_model(rf_model)

#evaluate model
rf_fit <- rf_workflow %>%
  last_fit(data.for.classifier.split)
test_performance <- rf_fit %>% collect_metrics()
test_performance

# generate predictions from the test set
test_predictions <- rf_fit %>% collect_predictions()
```

```
#final model
final_model_rf <- parsnip::fit(rf_workflow, UCOPperCWT.model)

#importance
ranger_obj <- extract_fit_parsnip(final_model_rf)$fit
important.features <- as.data.frame(ranger_obj$variable.importance) %>%
  rename(Importance = "ranger_obj$variable.importance") %>%
  dplyr::arrange(desc(Importance))

#####mlr################################

lm_model <- linear_reg() %>%
  set_mode("regression") %>%
  set_engine("lm")



lm_workflow <- workflow() %>%
  add_recipe(UCOP_recipe) %>%
  add_model(lm_model)

#evaluate model
lm_fit <- lm_workflow %>%
```

```
  last_fit(data.for.classifier.split)
test_performance <- lm_fit %>% collect_metrics()
test_performance

# generate predictions from the test set
test_predictions <- lm_fit %>% collect_predictions()

#final model
final_model_lm <- parsnip::fit(lm_workflow, UCOPperCWT.model)

#importance
ranger_obj <- extract_fit_parsnip(final_model_lm)$fit


##############

library(MASS)
normalized_data <- as.data.frame(scale(UCOP_train))
full_model <- lm(UCOP ~ ., data = normalized_data)
stepwise_model <- stepAIC(full_model, direction = "both")
summary(stepwise_model)

final_model_try <- lm(UCOP ~ CalvingPercentage +
```

```
              numberofadjustedexposedfemal +
              HiredLaborManagementperCWT +
              FinancialRasiedPurchasedFeedPercwt +
              FinancialGrazingperCWT +
              ManagerialCostperCWT +
              PregnancyPercentage +
              DebtperbreedcowperCWT +
              LivestockCostBasisperCWT +
              Weanedcalfpaywtweightav2 +
              lbsofweanedcalves +
              Poundsweanedperexposedfemale +
              Averageweaningweight,
              data = UCOPperCWT.model)
summary(final_model_try)


#final model with sig predictors
final_model <- lm(UCOP ~ HiredLaborManagementperCWT +
                FinancialRasiedPurchasedFeedPercwt +
                FinancialGrazingperCWT +
                ManagerialCostperCWT +
                DebtperbreedcowperCWT +
                LivestockCostBasisperCWT,
                data = UCOPperCWT.model)
```

```
summary(final_model)

##########figures
library(gridExtra)
library(plotly)

FinancialRaisedPurchasedFeedPercwt.p <- ggplot(UCOPperCWT.model, aes(y = UCOP,
x = FinancialRaisedPurchasedFeedPercwt)) +
  geom_point() +
  geom_smooth(method='lm') +
  theme_minimal() +
  ggtitle("UCOP vs. FinancialRaisedPurchasedFeedPercwt")

HiredLaborManagementperCWT.p <- ggplot(UCOPperCWT.model, aes(y = UCOP, x =
HiredLaborManagementperCWT)) +
geom_point() +
  geom_smooth(method='lm') +
  theme_minimal() +
  ggtitle("UCOP vs. HiredLaborManagementperCWT")


FinancialRasiedPurchasedFeedPercwt.p <- ggplot(UCOPperCWT.model, aes(y = UCOP,
x = FinancialRasiedPurchasedFeedPercwt)) +
```

```
    geom_point() +
    geom_smooth(method='lm') +
    theme_minimal() +
    ggtitle("UCOP vs. FinancialRasiedPurchasedFeedPercwt")


FinancialGrazingperCWT.p <- ggplot(UCOPperCWT.model, aes(y = UCOP, x = FinancialGrazingperCWT)) +
    geom_point() +
    geom_smooth(method='lm') +
    theme_minimal() +
    ggtitle("UCOP vs. FinancialGrazingperCWT")


ManagerialCostperCWT.p <- ggplot(UCOPperCWT.model, aes(y = UCOP, x = ManagerialCostperCWT)) +
    geom_point() +
    geom_smooth(method='lm') +
    theme_minimal() +
    ggtitle("UCOP vs. ManagerialCostperCWT")

DebtperbreedcowperCWT.p <-  ggplot(UCOPperCWT.model, aes(y = UCOP, x = DebtperbreedcowperCWT)) +
```

```
  geom_point() +
  geom_smooth(method='lm') +
  theme_minimal() +
  ggtitle("UCOP vs. DebtperbreedcowperCWT")

LivestockCostBasisperCWT.p <- ggplot(UCOPperCWT.model, aes(y = UCOP, x =
LivestockCostBasisperCWT)) +
  geom_point() +
  geom_smooth(method='lm') +
  theme_minimal() +
  ggtitle("UCOP vs. LivestockCostBasisperCWT")


grid.arrange(HiredLaborManagementperCWT.p,
FinancialRaisedPurchasedFeedPercwt.p,
         FinancialGrazingperCWT.p,
         ManagerialCostperCWT.p, DebtperbreedcowperCWT.p,
LivestockCostBasisperCWT.p)


# Fit the linear regression model
model <- lm(UCOP ~ LivestockCostBasisperCWT, data = UCOPperCWT.model)
coefficients <- coef(model)
```

```
intercept <- coefficients[1]
slope <- coefficients[2]
cat("y =", round(intercept, 2), "+", round(slope, 2), "x")

model <- lm(UCOP ~ HiredLaborManagementperCWT, data = UCOPperCWT.model)
coefficients <- coef(model)
intercept <- coefficients[1]
slope <- coefficients[2]
cat("y =", round(intercept, 2), "+", round(slope, 2), "x")

model <- lm(UCOP ~ FinancialRasiedPurchasedFeedPercwt, data =
UCOPperCWT.model)
coefficients <- coef(model)
intercept <- coefficients[1]
slope <- coefficients[2]
cat("y =", round(intercept, 2), "+", round(slope, 2), "x")

model <- lm(UCOP ~ FinancialGrazingperCWT, data = UCOPperCWT.model)
coefficients <- coef(model)
intercept <- coefficients[1]
slope <- coefficients[2]
cat("y =", round(intercept, 2), "+", round(slope, 2), "x")
```

```
model <- lm(UCOP ~ ManagerialCostperCWT, data = UCOPperCWT.model)
coefficients <- coef(model)
intercept <- coefficients[1]
slope <- coefficients[2]
cat("y =", round(intercept, 2), "+", round(slope, 2), "x")

model <- lm(UCOP ~ DebtperbreedcowperCWT, data = UCOPperCWT.model)
coefficients <- coef(model)
intercept <- coefficients[1]
slope <- coefficients[2]
cat("y =", round(intercept, 2), "+", round(slope, 2), "x")


######PCA
UCOPperCWT.model.pca <- na.omit(UCOPperCWT.model)
for (i in seq_along(UCOPperCWT.model.pca)) {
  UCOPperCWT.model.pca[[i]][is.infinite(UCOPperCWT.model.pca[[i]])] <- NA
}
pca_result <- prcomp(UCOPperCWT.model.pca, scale. = TRUE)
# Print summary of PCA
summary(pca_result)
loadings <- pca_result$rotation
transformed_data <- pca_result$x
```

```
# Scree plot
plot(pca_result, type = "l")

# Biplot (for first two principal components)
biplot(pca_result, scale = 0)

##########pca subset

######PCA
filtered.data <- UCOPperCWT.model %>%
  select(HiredLaborManagementperCWT,
         FinancialRasiedPurchasedFeedPercwt,
         FinancialGrazingperCWT,
         ManagerialCostperCWT,
         DebtperbreedcowperCWT,
         LivestockCostBasisperCWT)

UCOPperCWT.model.pca <- na.omit(filtered.data)
for (i in seq_along(UCOPperCWT.model.pca)) {
  UCOPperCWT.model.pca[[i]][is.infinite(UCOPperCWT.model.pca[[i]])] <- NA
}
pca_result <- prcomp(UCOPperCWT.model.pca, scale. = TRUE)
```

```
# Print summary of PCA
summary(pca_result)
loadings <- pca_result$rotation
transformed_data <- pca_result$x

# Scree plot
plot(pca_result, type = "l")

# Biplot (for first two principal components)
biplot(pca_result, scale = 0, arrow.len = 0)
biplot(pca_result, scale = 0, cex = 0)


pca_result <- prcomp(UCOPperCWT.model.pca, scale. = TRUE)
iris.pca <- prcomp(iris[, -5], scale.=TRUE)
biplot(pca_result, xlabs=rep("*", nrow(UCOPperCWT.model.pca)), cex=.75)
plot(pca_result, type = "l")


final_model <- lm(UCOP ~ HiredLaborManagementperCWT +
                  FinancialRasiedPurchasedFeedPercwt +
                  FinancialGrazingperCWT +
```

```
                ManagerialCostperCWT +
                DebtperbreedcowperCWT +
                LivestockCostBasisperCWT,
              data = UCOPperCWT.model)
summary(final_model)



###########predictions####################


df.to.predict <- read_excel("~/Downloads/beth1casestudies.xlsx", sheet = "Sheet1")
%>%
  rename(FinancialNetPretaxIncomeAfterWithdrawalPerCwt = AX,
         FinancialPretacCostNonCalfRevAdjPerCwt = BF,
         FinancialRaisedPurchasedFeedPercwt = Z,
         UCOP = FinancialPreTaxCostBeforeNon) %>%
  select(HiredLaborManagementperCWT,
         FinancialRasiedPurchasedFeedPercwt,
         FinancialGrazingperCWT,
         ManagerialCostperCWT,
         DebtperbreedcowperCWT,
         LivestockCostBasisperCWT,
         UCOP)
```

```
write_csv(df.to.predict, "~/Desktop/df.to.predict.csv")



# Make sure to replace new_data with your actual data for prediction


new_data <- data.frame(
  HiredLaborManagementperCWT = df.to.predict$HiredLaborManagementperCWT,
  FinancialRasiedPurchasedFeedPercwt =
df.to.predict$FinancialRasiedPurchasedFeedPercwt,
  FinancialGrazingperCWT = df.to.predict$FinancialGrazingperCWT,
  ManagerialCostperCWT = df.to.predict$ManagerialCostperCWT,
  DebtperbreedcowperCWT = df.to.predict$DebtperbreedcowperCWT,
  LivestockCostBasisperCWT = df.to.predict$LivestockCostBasisperCWT
)

# Predict using the final model
predictions <- predict(final_model, newdata = new_data)

# Print or use predictions
predictions <- as.data.frame(print(predictions))



########look at predictions
```

```
predictions <- read_excel("~/Downloads/beth1casestudies.xlsx", sheet = "predictors")

ggplot(predictions) +
  geom_point(aes(y = Value, x = FiscalYear, color = Type)) +
  geom_line(aes(y = Value, x = FiscalYear, group = Type, color = Type)) +
  facet_wrap(~ProID) +
  ylab("UCOP in Dollars")

#########lets predict everything

all_new_data <- data.frame(
  HiredLaborManagementperCWT =
UCOPperCWT.model$HiredLaborManagementperCWT,
  FinancialRasiedPurchasedFeedPercwt =
UCOPperCWT.model$FinancialRasiedPurchasedFeedPercwt,
  FinancialGrazingperCWT = UCOPperCWT.model$FinancialGrazingperCWT,
  ManagerialCostperCWT = UCOPperCWT.model$ManagerialCostperCWT,
  DebtperbreedcowperCWT = UCOPperCWT.model$DebtperbreedcowperCWT,
  LivestockCostBasisperCWT = UCOPperCWT.model$LivestockCostBasisperCWT)

# Predict using the final model
  predictions_all <- predict(final_model, newdata = all_new_data)
```

```
  # Print or use predictions
  predictions <- as.data.frame(predictions_all)

  all_new_data <- cbind(all_new_data, predictions, UCOPperCWT.model$UCOP) %>%
    rename(UCOP = "UCOPperCWT.model$UCOP")

  ggplot(all_new_data) +
    geom_point(aes(y = UCOP, x = predictions_all)) +
    geom_abline(color = "darkred")+
    ylab("UCOP Actual") + xlab("UCOP Predicted") +
    ggtitle("UCOP Predicted with Index vs. UCOP Actual")

na.omit.all_new.data <- na.omit(all_new_data)
cor(na.omit.all_new.data$UCOP, na.omit.all_new.data$predictions_all)^2*100

######network
library(igraph)
library(ggraph)

UCOPperCWT.model.noUCOP <- UCOPperCWT.model %>%
  select(-UCOP) %>%
  select(c(HiredLaborManagementperCWT,
       FinancialRasiedPurchasedFeedPercwt,
```

```
        FinancialGrazingperCWT,
        ManagerialCostperCWT,
        DebtperbreedcowperCWT,
        LivestockCostBasisperCWT)) %>%
  na.omit()

cor_matrix <- cor(UCOPperCWT.model.noUCOP)
# Convert correlation matrix to an adjacency matrix
adj_matrix <- as.matrix(cor_matrix)
# Create a graph object
graph <- graph_from_adjacency_matrix(adj_matrix, mode = "undirected", weighted =
TRUE)

E(graph)$weight <- abs(E(graph)$weight)

ggraph(graph, layout = "fr") +
  geom_edge_link(aes(alpha = weight)) +
  geom_node_point(color = "skyblue", size = 5) +
  geom_node_text(aes(label = name), repel = TRUE) +
  theme_void()
```