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A Multi-Period Analysis of Two Common Livestock Management Strategies Given Fluctuating Precipitation and Variable Prices

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Many areas of the US recently endured a severe drought and management strategies to cope with the lack of forage production varied. A multi-period mathematical model is presented that estimates the outcomes of two common producer responses to changes in precipitation, partial liquidation and purchasing hay, given fluctuating cattle prices over a long term planning horizon. Results were further summarized with regression analysis and selected elasticities were calculated to reflect the sensitivity of outcomes to variability in precipitation and livestock prices. Although little impact was seen from utilizing additional hay as a strategy during drought, producers who follow this strategy are in a position to market more animals immediately post drought in general, resulting in better long run financial outcomes. Elasticity estimates suggest that profitability is more sensitive to variability in prices but that optimal choices of management strategies are more sensitive to variability in precipitation.

Key Words: Drought management, mathematical programming, herd liquidation, price cycle, cattle management

JEL Classifications: Q12, C61, D24

Recent droughts have had a major impact on cattle producers in the Intermountain West (Nagler et al., 2007). Drought negatively affects forage production, which can force ranchers to carry smaller herds, increase purchased feed, and/or increase acreage grazed. Although ranchers need not graze all available standing forage in any given year, available standing forage limits their grazing decisions. Moreover, these decisions are made in the face of variable market prices. Bastian et al. (2006) point out that path dependencies may exist when producers make drought management decisions coupled with cattle prices that may be relatively high or low. Producers must make management decisions given fluctuations in both natural and economic forces. Given the prevalence of drought, it is somewhat surprising that relatively little published research exists that examines long-term implications of drought management strategies coupled with variable cattle price environments.

How should a producer respond if the weather is favorable but the market is down, or conversely if prices are up but poor precipitation

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has negatively affected range condition? Both variable weather and cattle prices affect management decisions and ultimately profitability. It is obvious that producers must consider both weather and market forces when making grazing decisions. Yet these exogenous forces often do not move together. Thus, producers must consider their impacts jointly when making management decisions.

While information about the future states of these factors will be limited, some management strategies may be able to alleviate some of the impacts of poor forage production during drought, allowing producers the ability to take advantage of high prices. Bastian et al. (2006) found that Wyoming cattle producers most often utilized partial herd liquidation and feeding additional hay as strategies to cope with extended periods of drought. Yet the long-term economic consequences of these strategies are not well understood. The objective of this research is to determine if supplemental feeding may be able to improve the financial well being of the firm as a drought management strategy as compared with a more traditional approach of only partial liquidation given variable livestock prices. This paper also examines the relative impacts of variability in prices and weather on producers' optimal management decisions.

Review of Relevant Literature

Ramsey et al. (2005) analyzed Standardized Performance Analysis data from Texas, Oklahoma, and New Mexico for significant factors that impact cow herd production, costs, and profitability. The authors found that herd size positively impacted profit and reduced per unit costs but did not affect production as measured by pounds of weaned calf per female exposed to breeding. They also found that increased quantity of feed consumed increased costs but did not impact production, thus reduced profit. These results suggest that reducing herd size and increasing feed may negatively impact profit during a drought period, but these results offer little in terms of characterizing long-term firm financial well being.

Ward et al. (2008) analyzed extensive surveys of Oklahoma cattle producers to understand factors impacting technology and/or production practice adoption. They found that operations with smaller herd sizes and that were less dependent on cattle income were less likely to adopt a majority of recommended practices when compared with larger operations, including limiting the length of hay feeding seasons, stockpiling forages, and more intensive management practices such as using a computerized system of record keeping and creating long-term business plans and cash flow analyses. Their results might suggest that smaller operations dependent on outside income would be less constrained in variable market price environments. While these results offer some insights into production practices utilized, they offer little evidence of impacts on long-term profitability during changes in precipitation or prices.

Parsch, Popp, and Loewer (1997) show that when faced with fluctuating weather, increased stocking rates are associated with greater risks in both the frequency and severity of financial losses. Carande, Bartlett, and Gutierrez (1995) evaluated stocker operations in Colorado with differing rainfall and price scenarios, concluding that high stocking rates are profitable when rainfall is favorable, but lower stocking rates need to be utilized when rainfall is unfavorable. They also show that stocker operations can benefit by selling parts of the herd early if rainfall is low. When considering fluctuations in annual forage production, Garoian, Mjelde, and Conner (1990) found that cow-calf producers may be better off carrying smaller herds at all times and supplementing their herds with stockers during times of increased forage production. In a drought study of New Mexico cattle producers, Holecheck (1994) reports that producers who respond to high prices without regard to poor forage production levels tend to overgraze pastures, requiring that pastures be completely destocked for recovery. While these works offer useful insights regarding optimal herd management decisions in the face of weather and forage uncertainty, a systematic evaluation of long-term optimal management strategies for cow-calf production systems in the face of drought and variable prices would be a useful contribution to the literature.

This research has two objectives. First, we compare supplemental feeding during periods of reduced forage production to the more traditional strategy of partial herd liquidation. Second, we analyze the impacts of fluctuations in both livestock prices and weather on outcomes associated with these management strategies. Specifically, we examine the interactions of weather and price on optimal management decisions over long planning horizons. We accomplish the research objectives by first employing a multiperiod mathematical programming model with a base run of no precipitation fluctuation but with variable prices. We then incorporate fluctuating precipitation and analyze the two management strategies of partial liquidation and making purchased feed available to address forage shortages. We then analyze nearly 7,000 observations from these model runs econometrically to investigate the interactions of weather and price on management outcomes.

Theory

It is generally accepted that producers will choose a management strategy in a given year that they believe will maximize profit given their expectations of prices and precipitation. Our model maximizes the Net Present Value (NPV) of management decisions, namely the sum of discounted returns over time. Further, the model assumes that time paths of both precipitation and prices are known from the beginning of the planning horizon. While we recognize that decision makers without perfect information may deviate from our solutions, we feel our assumptions are warranted as they will help to show how management outcomes will be influenced by both weather and price effects.

Conceptually this can be represented as follows:

$$MaxNPV = \sum_t \pi_t(m_t;\, w_t,\, p_t),$$

where profit (π_t) in period t is a function of management strategy (m_t) subject to the state of the weather (w_t) and prices (p_t) in period t.

We also assume that the best strategy for the producer is one that maximizes the sum of the discounted returns over time. Discussion about how this is modeled follows.

Methodology

Mathematical Programming Model

May et al. (1998) state that unlike physical experiments, a mathematical programming model (MPM) allows researchers to alter important variables such as weather conditions to determine the effects on model outcomes given constrained resources. Another frequently used approach is that of simulation. Stockton and Wilson (2007) utilized a simulation model to determine the viability of grazing crop residues as a tool to mitigate the negative impacts of drought on forage production in Nebraska. However, in these simulations, herd sizes were fixed, and outcomes were not necessarily based on optimal response to drought. This approach allowed comparisons over a potentially large number of varying interactions on the economic impacts of alternative grazing strategies. The use of a multiperiod MPM can combine some of the advantages of both simulation and MPM techniques to determine the economic consequences of alternative practices given the optimal response to fluctuating conditions. This type of approach (a multiperiod MPM) allows us to vary both weather conditions and cattle prices, and compare the NPV of each strategy over a long-term planning horizon, while also determining how optimal management decisions may differ under alternative scenarios.

Due to the nature of the problem, a multiperiod linear programming model is utilized. The mathematical programming model is designed to capture optimal producer behavior in the face of fluctuating forage production and output prices. This model represents a livestock production system where herd decisions are based on an explicit objective of profit maximization. When faced with drought situations, physical resources (specifically forage availability) are generally more limiting than during normal weather conditions. The mathematical model incorporates the profit-maximizing objective of producers while limiting decisions to those that fit the resources available to the producer, including cattle prices faced in that period. This approach allows us to achieve our research objectives.

While the problem of proper herd management during drought situations is common for many types of cattle operations, this paper will utilize a representative ranch in central Wyoming to demonstrate the effects of different management strategies. Wyoming has over 5,800 cattle producers carrying over 1 million total head of cattle, with 2,800 of these having at least 100 head of cattle (Wyoming Agricultural Statistics Service, 2007). Cow-calf production systems are the most common type of livestock production system in Wyoming (Nagler et al., 2006); thus, the model is structured to represent a cow-calf production system. Nagler et al. (2006) document that the traditional strategies of partial and full herd liquidation and feeding supplemental hay during summer months were the most common practices used by producers during a prolonged drought. This research focuses on these two management strategies.[1]

The multiperiod linear programming model is based on previous work by Torell et al. (2001) and subsequently updated for Fremont County, Wyoming, by Taylor, Coupal, and Foulke (2004). In order to account for variability in prices, the model is solved using Generalized Algebraic Modeling System (GAMS) repeatedly over the entire planning horizon with each iteration beginning at a different point in the price series.

The model is solved to maximize NPV over a T year planning horizon. NPV is defined as the sum of yearly discounted gross revenues from both cattle (R_{cattle}) and crop (R_{crop}) operations, less associated forage (C_{forage}), animal (C_{cattle}), and crop (C_{crop}) costs, as well as fixed (C_{fixed}) and borrowing costs ($C_{financial}$) associated with the operation (see Equation 1).

$$MaxNPV = \sum_{t=0}^{T} (1+r)^{-t} (R_{cattle,t} + R_{crop,t} - C_{forage,t} - C_{cattle,t} - C_{crop,t} - C_{fixed,t} - C_{financial,t}) \quad (1)$$

Revenues can be obtained from cattle and/or crops. However, all crop sales consist of the sale of hay, which results in less hay available to feed the herd. The annual net returns are maximized each year over the planning horizon subject to equations relating to fixed land base used for grazing and harvest, animal transfer (accommodating herd evolution across years), and cash constraints. For further explanations about these constraints, see Torell et al. (2001).

The model represents a 600-head ranch, so initial breeding stock numbers are set to 600, but the model is free to adjust herd size in order to maximize net returns in each subsequent year subject to the block of herd transfer equations. When determining forage supply and demand, seasonal requirements and availability of forage are also determined. The year is divided into six separate seasons, each with limitations on type and amount of feed/forage available. For example, the majority of summer grazing occurs on public land, while private land is used primarily for raising hay to be fed in winter months. For further description of grazing seasons and allowed use, see Taylor, Coupal, and Foulke (2004).

The model is parameterized to represent a typical cow-calf operation in Fremont County, Wyoming able to support a herd of 600 cows. The model assumes an annual off-ranch income of $24,000, which is offset by a family expense allowance of $24,000, so returns represent only those from the ranching operations. The assumption that all ranch income is retained and available to be utilized in subsequent periods may not be representative of most livestock operations. Conclusions drawn subsequently could vary given a less frugal assumption (see for example Murugan, 2007). We assumed family needs were fully met by off-ranch income in order to better understand how the alternative strategies potentially employed by the ranch

[1] Leasing additional forage (although the regional nature of drought circumstances may limit this option) or incorporation of a stocker enterprise that can be liquidated in times of poor forage production (see for example Hart and Carpenter, 2005) may also be viable management strategies to cope with drought. However, work by Nagler et al. (2007) and Bastian et al. (2006) cite the most common responses to the most recent drought in this area as either liquidation or feeding. Also, as Nagler et al. (2006) state, the majority of Wyoming cattle producers are classified as cow-calf operations, with very few cow/yearling operations; therefore, our model utilizes this production system and compares these alternatives.

enterprise would compare across weather and price fluctuations, without regard to how family spending would affect the outcomes.

Herd Management

Model parameters are set to represent herd characteristics (e.g., birth rates, minimum replacement rates, maximum percentage of heifers kept, and bull ratios) typical of operations in the study area, but the producer is free to buy or sell animals given these parameters. Also under management control is the amount of land to be grazed and amount of feed to be purchased, restricted by typical resource constraints faced by producers within the study area. Land can be used for grazing or raising hay crops. Any unused hay crop can be sold. Land available to producers simulates a representative operation for Fremont County, and includes privately owned land, as well as the option to utilize public and private grazing leases. Seventy percent of available land is leased from federal agencies, with 20% being privately owned, and the remaining 10% being state owned. Producers are able to graze and/or feed animals as long as their nutritional requirements are met. In this setting, it is required that all animals maintained in the operation will be sufficiently fed in order to reach required weights. Differential nutritional requirements are accounted for within each season, as well as across years. Any alterations in herd size occur due to deeper culling rates in the case of liquidation or through retaining more heifer calves or purchasing of cows in the case of increases in breeding stock.

Forage Production

Annual variability in forage production due to weather impacts is modeled by altering the forage production constraint of each land type each year. In years experiencing poor precipitation, each land class produces lower amounts of forage. The scaling variable affecting forage production was estimated using a regression from Smith (2005) (Equation 2). Smith ascertained that spring precipitation, specifically precipitation from March 5 through May 25, is a good predictor of yearly forage production for this region of Wyoming.

$$\begin{aligned} &\textit{Predicted Forage}(lbs/ac) \\ &= 216.046 + 48.489\textit{PRECIP}(R^2 = 0.32), \end{aligned} \quad (2)$$

where PRECIP is total precipitation (inches) occurring from March 5 through May 25.

Given the model is parameterized to represent Fremont County, Wyoming, weather data from the Riverton Weather Station obtained from the National Climatic Data Center (NCDC, 2007) were used in the forage prediction regression equation. The precipitation data series represented 1921 through 2006 (86 years). Given these weather data, predicted forage response (based on Equation 2) is used to estimate yearly forage production as a percentage of mean production. This yearly percentage of mean predicted forage over the time horizon is used as a scalar to adjust the annual forage production across each land type in the model. The statistics regarding actual precipitation and estimated forage production are shown in Table 1. Over the 86-year horizon, 45 years exhibited below-average growing season precipitation. However, periods of consecutive years with subaverage precipitation only occurred nine times, with five instances of 2-year droughts, two 3-year droughts, and two 9-year droughts. The remaining drought years were mixed within periods of average to above-average growing season precipitation.

Hay price and availability for purchase does not vary with precipitation in the model as most hay production in the area is irrigated, and is therefore not highly impacted by drought (as defined by deficit spring precipitation). In fact, dry land hay production in the region has reached a maximum of only 1.27% of total annual hay production since 1959 (Wyoming

Table 1. Distribution of Actual Precipitation Data Used and Estimated Forage Production (in lbs/ac)

	Precipitation (inches)	Forage Production (lbs/ac)
Minimum	0.70	249.99
Average	2.93	358.00
Maximum	8.51	628.69
Standard Deviation	1.46	70.94

Agricultural Statistics Service, 2007). In a study performed in the same area, Bastian et al. (2009) concluded that drought had no significant effect on hay prices due to the fact that hay production relies almost entirely on irrigation, which can mitigate the effects of drought via water storage. Moreover, given that drought tends to be regional in nature, statewide hay markets did not show as much variability as expected. Hay prices were not highly correlated with spring precipitation (less than 0.23). Likewise Stockton and Wilson (2007) found no relationship between localized hay prices and precipitation in Nebraska.

Management strategies were modeled in the following manner. First, the model was solved for a constant annual average forage production under a given 86-year price series and planning horizon (labeled as No Drought scenario). Then the model was rerun with the forage constraints rescaled over the planning horizon from variable precipitation. The solution represented the standard herd liquidation strategy (labeled as Base scenario). The model was then reformulated to allow for the strategy of purchasing additional feed by allowing the model to feed purchased hay during summer months. Thus, for the purchased feed strategy, the model could choose to feed purchased hay and/or change herd size (labeled as Feed scenario).

To evaluate forage production impacts on herd decisions, the model also has been parameterized featuring three different starting points along the forage production path for the Base and Feed scenarios. These three distinct beginning points along the forage production path were chosen by looking at 10 year moving averages of forage production, and they represent the beginning of relatively good (Wet Start), poor (Dry Start), or average (Average Start) period of forage production. The Wet Start scenario had 3 years of below normal growing season precipitation in the first 10 years. However, no year was below 93% of normal. The Average Start scenario also had 3 years of below average precipitation, but all three were around 85% of normal, while in the Dry Start scenario all of the first 10 years had below average growing season precipitation. The weather data were looped so that regardless of starting point, the entire 86-year data set could be utilized.

Cattle Prices

Prices received from livestock sales are modeled to fluctuate over time. Actual prices received at the Torrington, Wyoming auction from 1968 through 2006 for various classes of livestock formed the basis for the price data. The majority of data were obtained from the Livestock Marketing Information Center (LMIC) (Jim Robb). Bred cow prices were not available from LMIC. They were obtained from Cattle-Fax (Cattle-Fax Inc.), and were based on West-wide, not Wyoming-specific, prices. The bull, cull, and bred cow price series had some missing observations. As cattle prices tended to move together, the missing values were extrapolated from the existing data available from the Torrington auction. Complete data sets for steer calf, heifer calf prices, and yearling prices were used to predict missing values for bull, cull, and bred cow prices using Ordinary Least Squares regression.

Livestock are sold on November 1 in the model. To reflect appropriate seasonal price levels, average prices from October 1 through November 30 were used in the model. Given the price data, the average November 1 prices were truncated to a data set of 1980–2006 (27 years with two complete price cycles existing within the data). As price cycle is expected to perpetuate in a similar manner, these 27 years were then looped over time. The model was then reconstructed to have 27 iterations per weather start, each starting at a different year of the price cycle. The model then has three runs (Average, Wet, and Dry starts) of 86 years, each with 27 iterations (different starting points on the price cycle). The result is a data set that includes optimal decisions and the resulting financial returns for all possible combinations of market and weather states for all three weather starting point scenarios for a total of 6,966 yearly observations for both the "Base" and "Feed" scenarios.

Regression Analysis

Given all the combinations of weather and price realizations modeled, abundant data were available to determine how each of these factors affected management outcomes. To accomplish our second objective, the relationships between management strategies and selected outcome variables, such as financial returns given variation in weather and market prices, could be determined. Given the large amount of data generated, linear regression was utilized to analyze the yearly impacts of both weather and price variability on variables of interest. Equation 3 shows the standard regression model that was estimated for the financial returns and management decision variables.

$$(3) \qquad Y_t = \beta_0 + \beta_1 Market_t + \beta_2 Weather_t + \varepsilon_t$$

where Y_t is an outcome of the model in year t for variables such as *Net Yearly Returns*, *AUY* (herd size in animal unit years), *Cull* (both total number cull animals and as a percent of herd size), *Acres Grazed* (both total acres and acres per AUY), and *Feed* (both total feed and feed per AUY expressed in tons). $Market_t$ is steer calf price in year t, and $Weather_t$ is growing season precipitation in year t, and ε_t is an error term.

All of the independent and dependent variables were converted to a percentage of their associated means. Therefore, the coefficients can be directly interpreted as an elasticity that the independent variables (price and precipitation) have on the dependent variable of interest. Elasticities were estimated for all weather runs combined (the entire 6,966 observations generated in the GAMS output).

These elasticities serve as a measure of the sensitivity of production and financial variables to management strategies given changes in exogenous variables representing fluctuations in market prices and forage production due to changes in precipitation. In order to determine the impact that allowing summer hay had on producers' decisions, separate regression models were estimated for each of the "Base" and "Feed" scenarios.

Results

It was expected that droughts would negatively affect ranch income; however, it was unknown how management decisions might alleviate some of this impact. Depending on both length and severity of drought, various management decisions should be able to mitigate the negative impacts of extended periods of drought.

Financial Outcomes

As expected, model results reveal that drought affects ranch income unfavorably. Figure 1 shows the comparison of total discounted profits over the 86-year planning horizon for the "No Drought" case, as well as the "Base" and "Feed" scenarios given the three different starting points. The data shows that in all scenarios, with the exception of the one that started with good precipitation years and allowed producers to feed hay in summer months, inclusion of variable weather had a negative impact on the sum of discounted annual returns. Also of note, when comparisons are made across initial weather impacts, the ability to feed during summer months improved the financial outcomes over the standard practice of liquidation only as a way to overcome drought. Table 2 shows how individual discounted yearly returns compare across the "No Drought," "Base," and "Feed" scenarios. For the "Base" and "Feed" scenarios, yearly discounted returns include data from all three weather starting points. The case with constant average forage production in all years (No Drought) outperforms any of the scenarios that impose variable forage production as a result of variable precipitation. When forage production is modeled to be impacted by weather, in all three starting points, the ability to summer feed increased total discounted ranch income over the 86-year planning horizon when compared with the base model. The ability to feed had the greatest impact in the Average and Wet starting point scenarios.

Decision Variables

Results of the baseline drought model (Base) show that it is optimal to partially liquidate in the face of drought conditions. However, the model never fully liquidated the herd. On average, the ranch supported 697 animal unit years (AUY), ranging from 534 to 1,294 AUY in given years (Table 3). In the 'Feed' scenario, allowing the ranch the ability to purchase summer feed during these periods alleviated some of the

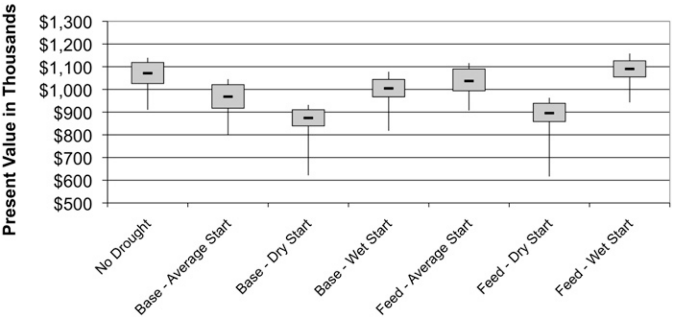

Figure 1. Distribution of Net Present Value of Ranch Income Across Scenarios and Weather Starting Points (Note: Vertical lines represent the range of distributions, shaded boxes represent the area between the first and third quartiles, and the heavy horizontal line represents the mean.)

negative financial impacts of drought over the entire planning horizon. When the model was allowed to feed during summer months, the case ranch averaged a slightly higher herd size (701 AU) over the planning horizon, but it also realized a wider range (483–1,917 AU). The ranch also averaged less feed (911 tons as compared with 1,017 tons fed in the "Base" scenario), but the maximum feed allowed in any year was much higher in the "Feed" scenario when compared with the "Base" scenario (3,190 tons as compared with 1,931 tons). These results suggest that producers who adjust both herd size and allow supplemental hay will generally have better long-term financial results when faced with fluctuating forage production. However, the size of the herd and the amount of additional feed purchased also depends on where the producer is in the price cycle. Therefore, there is no single "right" decision for a manager when faced with drought situations given variability in prices.

Whether or not summer hay is allowed, the model indicates that producers should generally graze most of the land they have access to. However, as seen in Table 3, when summer hay is allowed, the distribution of acres utilized is shifted upward from an average of 4,954 acres grazed up to 5,520 acres grazed when supplemental feeding was allowed. This implies that allowing producers the ability to summer feed results in more thorough utilization of rangeland. It is interesting to note that as summer feeding is allowed, on average, producers will feed slightly less in years of favorable forage production, selling more than under the "Base" scenario. During periods of poor forage production, the model indicated that it was optimal to feed significantly more than would have been the case under the "Base" scenario, as seen in Table 4.

Driving Factors

The above-mentioned figures and tables suggest that drought does impact returns and that, long-term, purchasing feed may be the superior strategy. However, the voluminous results make it difficult to draw conclusions as to what is driving these results. Regression analysis was used to more clearly document systematic differences in outcomes in all of these individual

Table 2. Comparison of Discounted Yearly Returns Across Scenarios

	Discounted Yearly Returns		
	No Drought	Base	Feed
Minimum	−$8,548	−$22,769	−$32,593
Average	$12,163	$10,719	$11,350
Maximum	$139,042	$145,153	$150,907
Standard Deviation	$20,218	$19,688	$21,253

Table 3. Descriptive Statistics for Selected Outcomes Across the "Base" and "Feed" Scenarios

	Net Returns ($/year)[a]		Herd Size (Animal Units)[b]		Number Culled (Head)[c]		Grazing (Acres)[d]		Total Feed (Ton)[e]		Feeding Rate (Tons/AU)[f]		Stocking (Acres/AU)[g]		Culling Rate (Head/Herd Size)[h]	
	Base	Feed	Base	Feed	Base	Feed	Base	Feed	Base	Feed	Base	Feed	Base	Feed	Base	Feed
Minimum	−22,769	−32,593	534	483	60	56	1,682	1,743	768	356	1.40	0.64	2.92	3.07	0.10	0.09
Average	10,719	11,350	697	701	82	83	4,954	5,520	1,017	911	1.46	1.29	7.19	8.05	0.12	0.12
Maximum	145,153	150,907	1,294	1,917	125	184	5,879	6,917	1,931	3,190	1.51	3.15	10.36	13.18	0.14	0.14
Standard Deviation	19,688	21,253	96	139	10	15	887	930	144	426	0.02	0.41	1.46	1.67	0.01	0.01

[a] Net Returns are defined as individual discounted annual returns over the planning horizon.
[b] Herd Size is defined as annual number of animal units supported by the operation.
[c] Number Culled is defined as annual number of cows sold as cull cow by the operation.
[d] Grazing is total amount of range and pasture land utilized annually by the operation.
[e] Total Feed is the annual amount of hay fed in tons.
[f] Feeding Rate is defined by the annual amount of hay fed per animal in tons.
[g] Stocking is defined as numbers of acres grazed annually per animal unit.
[h] Culling Rate is defined as animals sold as cull cows as an annual percent of total animal units supported by the operation.

situations. The resulting estimates provide direct evidence of the degree of association between the production environment faced and the resulting outcomes through an elasticity measure. Tables 5 and 6 display results of these regressions for the "Base" and "Feed" scenarios, respectively.

In each table, the regression coefficients are represented in the "Market" and "Weather" columns, with associated t-statistics reported directly under the coefficients. The coefficient values are elasticities representing the sensitivity of the variables on the corresponding row to changes in the variable represented in the column. For example, for the "Base" scenario represented in Table 5, a 1% increase in "Market," or Steer Calf Price, caused the model to select decisions that increase acres grazed 0.300% on average. On the other hand, a 1% increase in "Weather," or growing season precipitation, resulted in a decrease of total acres grazed by 0.674% on average.

The elasticities presented in the first rows of Tables 5 and 6 show that yearly returns are more heavily impacted by variations in livestock prices than by variation in precipitation. The elasticities suggest that yearly returns are nearly four times more sensitive to proportionate change in calf price than precipitation across both scenarios. In the "Base" scenario (Table 5), the positive elasticities with respect to market illustrate that as producers face better market prices, it is optimal for them to respond by increasing herd size, acres grazed, and total feed provided. The results also suggest an increase in total culling activities, but culling percentage actually drops. This implies that even as the total number of culled cows increases, it increases less than overall herd numbers increase during favorable market conditions.

Table 4. Total Amount of Hay Fed (in tons) Across Scenarios for all Years and Years with Less than 85% of Average Precipitation (drought)

	All Years		Drought Years	
	Base	Feed	Base	Feed
Mean	1,017	911	925	1,113
Standard Deviation	144	426	50	402

Table 5. Market and Weather Elasticities of Production and Financial Returns for "Base" Scenario

	Base		
	Market	Weather	R Squared
Net Returns ($/year)[a]	4.018	1.009	0.632
	(103.113)	(36.226)	
Herd Size (Animal Units)[b]	0.254	0.326	0.286
	(25.707)	(46.133)	
Number Culled (Head)[c]	0.202	0.210	0.175
	(21.784)	(31.648)	
Grazing (Acres)[d]	0.300	−0.674	0.606
	(31.445)	(−98.684)	
Total Feed (Ton)[e]	0.233	0.326	0.261
	(22.493)	(44.157)	
Feeding Rate (Tons/AU)[f]	−0.022	−0.002	0.058
	(−20.572)	(−2.273)	
Stocking (Acres/AU)[g]	0.069	−0.997	0.942
	(16.602)	(−334.394)	
Culling Rate (Head/Herd Size)[h]	−0.049	−0.102	0.142
	(−11.000)	(−32.067)	

Notes: Values represent elasticities estimated using Ordinary Least Squares. Values under elasticities are associate t-stats. Also reported are associated R-Square Values.
[a] Net Returns are defined as individual discounted annual returns over the planning horizon.
[b] Herd Size is defined as annual number of animal units supported by the operation.
[c] Number Culled is defined as annual number of cows sold as cull cow by the operation.
[d] Grazing is total amount of range and pasture land utilized annually by the operation.
[e] Total Feed is the annual amount of hay fed in tons.
[f] Feeding Rate is defined by the annual amount of hay fed per animal in tons.
[g] Stocking is defined as numbers of acres grazed annually per animal unit.
[h] Culling Rate is defined as animals sold as cull cows as an annual percent of total animal units supported by the operation.

While these outcome variables are all significantly affected by market fluctuations in a statistical sense, most are more responsive to fluctuations in weather as evidenced by the relative magnitude of elasticities for weather (Tables 5 and 6). The elasticities representing herd size, number of animals culled, acres grazed, total feed, acres per animal, and culling rate are all greater for "Weather" than they are for "Market." The elasticity of yearly returns is the notable exception where market prices are clearly more influential. What these elasticities imply is that if a producer faces a weather year that is 1% better than some other year, in the absence of the ability to provide supplemental feed in the summer, they respond on average by increasing herd size by 0.326% and total amount fed to their animals by 0.326%, including grown and purchased feed (Table 5). The producer would also reduce both total acres grazed (0.674%) and acres per animal (0.997%) because the land is more productive during these wetter years.

With respect to an increase in precipitation, the model indicates that a producer would increase total amount of hay fed, but less is offered to each animal. However, managers can partially liquidate a herd as a strategy to overcome unfavorable weather. The negative elasticity between "Weather" and culling rates (−0.102 and −0.107 in the "Base" and "Feed" scenarios, respectively) indicate that this is a useful strategy in the face of drought. Once the herd size is reduced, managers need less total feed. However, total numbers culled will be higher when faced with favorable weather because, while culling rates are lower, inventories tend to be higher (Tables 5 and 6). Producers can also alleviate some of the effects of poor forage production by increasing total acres grazed, but, more specifically, by increasing the allowable acreage per animal, which is accomplished by partial liquidation.

Table 6 reports the elasticities for the scenario where hay is allowed in traditionally

Table 6. Market and Weather Elasticities of Production and Financial Returns for "Feed" Scenario

	Feed		
	Market	Weather	R Squared
Net Returns ($/year)[a]	4.453	1.690	0.231
	(40.378)	(21.441)	
Herd Size (Animal Units)[b]	0.235	0.405	0.190
	(15.534)	(37.346)	
Number Culled (Head)[c]	0.198	0.271	0.117
	(14.031)	(26.863)	
Grazing (Acres)[d]	0.224	−0.559	0.595
	(27.840)	(−97.149)	
Total Feed (Ton)[e]	0.339	−0.608	0.076
	(8.882)	(−22.272)	
Feeding Rate (Tons/AU)[f]	0.139	−1.060	0.430
	(6.764)	(−72.115)	
Stocking (Acres/AU)[g]	0.004	−0.917	0.759
	(0.461)	(−148.073)	
Culling Rate (Head/Herd Size)[h]	−0.037	−0.107	0.148
	(−8.319)	(−33.713)	

Notes: Values represent elasticities estimated using Ordinary Least Squares. Values under elasticities are associate t-stats. Also reported are associated R-Square Values.
[a] Net Returns are defined as individual discounted annual returns over the planning horizon.
[b] Herd Size is defined as annual number of animal units supported by the operation.
[c] Number Culled is defined as annual number of cows sold as cull cow by the operation.
[d] Grazing is total amount of range and pasture land utilized annually by the operation.
[e] Total Feed is the annual amount of hay fed in tons.
[f] Feeding Rate is defined by the annual amount of hay fed per animal in tons.
[g] Stocking is defined as numbers of acres grazed annually per animal unit.
[h] Culling Rates is defined as animals sold as cull cows as an annual percent of total animal units supported by the operation.

"off-season" summer months. Again, proper management with regard to weather fluctuations allows producers to take advantage of favorable market conditions. The main differences are that when examining market impacts, more total feed and more feed per animal are allowed in response to favorable market years. Only the coefficient representing elasticity of "Market" on acres/AUY in the "Feed" scenario was not statistically significant at the 95% confidence level.

The major differences when comparing weather and precipitation impacts between the "Base" and "Feed" scenarios are that the sign on total feed has switched, indicating producers should actually provide less total feed during good weather years under the "Feed" scenario. When producers are allowed to summer feed, the weather is also the dominant driver related to total herd size (AUY) and both feed variables (total and per animal). The magnitudes of elasticities for these variables are much higher in the "Feed" scenario than in the "Base" scenario. This implies that supplemental feeding allows for management decisions that are able to respond more to weather impacts than they do market movements, even though their yearly returns are in fact more heavily impacted by market prices than precipitation changes under this scenario. Also, under the "Feed" scenario, elasticities associated with herd size, total feed, and feed/AUY with respect to weather impacts become statistically different (and greater in absolute value) than those with respect to market impacts. Allowing supplemental feed during summer months can place producers in a position to benefit greater from beneficial markets than relying solely on herd liquidation.

More Detailed Examination of Yearly Outcomes within Period of Drought

The model is designed to maximize the yearly incomes, and allowing supplemental feed during drought years will tend to increase the stream of discounted incomes. Discussion of results to this point has focused on total outcomes over the entire planning horizon. However, producers would also be interested in how the decision to allow supplemental feed impacts the yearly returns during the period of drought. Are there strategies that can alleviate adverse weather conditions allowing producers to take advantage of favorable markets? Model results for a 5-year drought in the beginning stages of the planning horizon were examined to specifically analyze differences in yearly decisions and outcomes during a drought across the different scenarios. In the Average Start scenario, a 5-year drought occurred in the 11th year of the planning horizon. The following analysis shows how yearly returns are impacted during a drought when supplemental feed is allowed.

The distribution of returns for the different market iterations over this 5-year span across the "Base" and "Feed" scenarios is shown in Table 7. It appears that the ability to feed summer hay during a drought has little, if any, impact on average yearly returns. It would be difficult to show any producer the benefit of such a plan based on these results alone. However, during this window, a producer that allows summer hay is able to carry a larger herd, which will allow them the benefit of selling more animals immediately postdrought. A producer that does not allow summer feeding must rebuild their herd after more severe liquidation. This inventory effect of allowing summer feed is the main benefit of the summer hay strategy. The producer that allows summer hay has higher costs throughout the drought. However, these costs are at least partly off-set by having a more constant stream of calves to sell. A producer that does not allow supplemental feeding more aggressively liquidates their herd, reducing the costs of carrying animals during the drought while also benefiting in the short-term by increasing sales through liquidation. However, immediately following a drought, when forage conditions are again favorable, these producers must spend time and resources rebuilding the herd in order to produce a similar number of calves, while producers that allow summer hay have a larger

Table 7. Comparison of Distribution of Net Discounted Returns during 5-Year Drought Across "Base" and "Feed" Scenarios (Both Individual Net Yearly Returns, as well as Net Yearly Returns Summed over 5-Year Drought)

	Base	Feed
	Individual Discounted Yearly Returns	
Minimum	−$45,068	−$49,863
Average	$46,651	$46,932
Maximum	$136,012	$134,562
Standard Deviation	$42,447	$43,265
	Sum of Discounted Yearly Returns Over Drought	
Minimum	$14,059	−$7,123
Average	$233,255	$234,659
Maximum	$431,373	$425,593
Standard Deviation	$128,365	$121,617
	Difference Between "Feed" and "Base" Scenarios of Discounted Yearly Returns Over Drought[a]	
Minimum	−$25,693	
Average	$1,404	
Maximum	$27,902	

[a] Differences between the two scenarios is defined as the direct comparison of the two scenarios over each of the iterations utilized in the model.

herd intact. Table 8 shows the difference in returns over the 3 years immediately following the 5-year drought.

As stated above, the ability to feed summer hay can help a producer's financial standing; however, the benefit usually comes post-drought. This is due to the fact that a producer must increase costs in order to allow additional feed, but the benefit is realized after the drought, because they were able to carry a larger herd throughout the drought, resulting in more sales immediately following the drought. This inventory effect drives the difference in outcomes observed when summer feeding is allowed. Table 9 shows the impact summer feeding can have during the drought and that part of the planning horizon immediately following the drought. So, although summer feeding does impact producers' financial standing over the long run, when looking at individual drought occurrences, the true benefit of feeding summer hay during a drought is realized after the event by having larger inventories intact instead of having to rebuild herds. It is important to note that this result is at least partially dependent on the use of cash reserves to purchase additional feed. If excessive borrowed capital is required to purchase feed to maintain herd size, the positive impacts from additional sales later could be negated. Thus, the principle of financial leverage applies.

Discussion and Conclusion

Recent droughts have greatly impacted cattle producers through decreases in yearly forage production. Cattle prices also have a role in livestock operation outcomes. The objective of this paper has been to address the impacts that variations in weather conditions and variable prices have on livestock operation outcomes, giving attention to the possibility of alleviating some negative impacts of drought by allowing summer hay feeding.

As producers are expected to be driven by the motive of profit maximization and constrained both in terms of financial and physical resources, a multiperiod linear programming

Table 8. Comparison of Distribution of Net Discounted Returns over 3 Years Immediately Following 5-Year Drought Across "Base" and "Feed" Scenarios (Both Individual Net Yearly Returns, as well as Net Yearly Returns Summed over 3 Years Immediately PostDrought)

	Base	Feed
	Individual Discounted Yearly Returns	
Minimum	−$30,095	−$11,856
Average	$83,612	$94,648
Maximum	$161,212	$177,057
Standard Deviation	$48,937	$47,844
	Sum of Discounted Yearly Returns Immediately After Drought	
Minimum	$16,321	$58,776
Average	$250,837	$283,944
Maximum	$417,947	$444,627
Standard Deviation	$127,556	$121,702
	Difference Between "Feed" and "Base" Scenarios of Discounted Yearly Returns Immediately After Drought[a]	
Minimum	−$17,637	
Average	$33,107	
Maximum	$89,304	

[a] Differences between the two scenarios is defined as the direct comparison of the two scenarios over each of the iterations utilized in the model.

Table 9. Comparison of Distribution of Net Discounted Returns over 5-Year Drought and 3 Years Immediately Following Across "Base" and "Feed" Scenarios

	Base	Feed
	Sum of Discounted Yearly Returns	
Minimum	$305,576	$325,074
Average	$484,092	$518,603
Maximum	$709,791	$737,590
Standard Deviation	$135,806	$127,508

model maximizing NPV over a predetermined planning horizon was utilized to determine these impacts. Analyses focused on financial outcomes as well as management decisions, compared across precipitation and price scenarios, with management strategies including herd liquidation, as well as a strategy that allows feeding hay in traditionally off-season summer months. The model was solved iteratively starting at each of 27 potential years over a loop of market prices. An 86-year loop of weather data were used to estimate forage production, with the model being solved over three distinct starting weather patterns for each of the market iterations.

Results show that financial outcomes and management decisions are in fact influenced by both the current state of the weather (as measured by the impact of precipitation on forage) and the market. Yearly returns are much more sensitive to prices than weather, however. An interesting finding is that, independent of the state of the market, most management decisions are more influenced by growing season precipitation and, therefore, forage production. In order to reduce the negative impacts of drought situations, managers should partially liquidate their herd, increase acreage utilized (both in total and per animal), and increase amount fed (both total and per animal). The results also show that the ability to feed hay during summer months will ultimately help ranchers' financial standing in the long run.

The ability to summer feed will have a larger impact on financial status postdrought than during drought because the ability to carry larger inventories through the drought also requires additional costs as compared with a producer with a more aggressive liquidation strategy. However, the additional costs also allow more animals to be sold during drought as compared with a more drastically liquidated herd, offsetting some of the higher costs. It should be noted that producers must have the financial resources to withstand these added costs. More importantly, the strategy of allowing summer feeding allows more animals to be sold postdrought as opposed to requiring a period of herd build up associated with culling more aggressively during drought.

Ultimately, there is no single right decision for livestock operators when faced with fluctuating forage production. Proper strategies for producers must incorporate the current status of both weather and the market. The results show how movements in these two exogenous factors affect cattle management decisions and the resulting outcomes. The modeling efforts of this paper focus mainly on how allowing feeding summer hay can alleviate some of the pressures of reduced forage production in the face of unfavorable weather conditions. However, caution must be used, as this model does not fully account for forage dynamics across years. Another potential drawback of this model is the inability to fully account for risk aversion when managing cattle herds. A risk averse producer, or a producer with specific cash flow needs, may not be able to wait for the benefits associated with the strategy of allowing summer hay feeding during drought periods. Analyses of other management strategies beyond those studied here could make a contribution to the literature.

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References

Bastian, C.T., S. Mooney, A.M. Nagler, J.P. Hewlett, S.I. Paisley, M.A. Smith, W.M. Frasier, and W.J. Umberger. "Cattle Ranchers Diverse in Their Drought Management Strategies." *Western Economics Forum* 5(2006): 1–8.

Bastian, C.T., P. Ponnamanneni, S. Mooney, J.P. Ritten, W.M. Frasier, S.I. Paisley, M.A. Smith, and W.J. Umberger. "Range Livestock Strategies Given Extended Drought and Different

Price Cycles" Journal of the American Society of Farm Managers and Rural Appraisers 72,1(2009):153–63.

Carande, V.G., E.T. Bartlett, and P.H. Gutierrez. "Optimization of Rangeland Management Strategies under Rainfall and Price Risks." *Journal of Range Management* 48(1995):68–72.

Cattle-Fax Inc. Unpublished data. Centennial, CO. Internet site: http://www.cattlefax.com/ (Accessed August 21, 2007).

Garoian, L., J.W. Mjelde, and J.R. Conner. "Optimal Strategies for Marketing Calves and Yearlings from Rangeland." *American Journal of Agricultural Economics* 72,2(1990):604–13.

Hart, C.R., and B.B. Carpenter. "Stocking Rate and Grazing Management." Texas Agricultural Extension Service Publication E-64, 2005.

Holecheck, J.L. "Financial Returns from Grazing Different Management Systems in New Mexico." *Rangelands* 16(1994):237–40.

May, G.J., L.W. Van Tassell, M.A. Smith, and J.W. Waggoner. "Optimal Feed Cost Strategies Associated with Early and Late Calving Seasons." Paper presented at the conference of the American Agricultural Economics Association annual meetings, Salt Lake City, UT, August 2–5, 1998.

Murugan, S. "Profit Maximizing Livestock Production and Marketing Strategies to Manage Climate Variability." M.S. thesis. New Mexico State University, Las Cruces, NM, 2007.

Nagler, A., C. Bastian, J.P. Hewlett, S. Mooney, S.I. Paisley, M.A. Smith, M. Frasier, W. Umberger, and P. Ponnameneni. *Multiple Impacts, Multiple Strategies: How Wyoming Cattle Producers are Surviving in Prolonged Drought*. Laramie: University of Wyoming, Cooperative Extension Service, 2007.

Nagler, A., S. Mooney, C. Bastian, J.P. Hewlett, B. Aldridge, B.A. Sarchet, W. Umberger, M. Frasier, S.I. Paisley, M.A. Smith, P. Ponnameneni, D.T. Taylor, and T. Foulke. *Wyoming Beef Cattle Producers Survey – Final Report*. Laramie: Department of Agricultural and Applied Economics, University of Wyoming, June 2006. Internet site: http://agecon.uwyo.edu/WYLivestock/FINALReport.pdf (Accessed April 24, 2008).

National Climatic Data Center (NCDC). National Oceanic and Atmospheric administration (NOAA). Internet site: http://www.ncdc.noaa.gov/oa/ncdc.html (Accessed June 6, 2007).

Parsch, L.D., M.P. Popp, and O.J. Loewer. "Stocking Rate Risk for Pasture-Fed Steers Under Weather Uncertainty." *Journal of Range Management* 50(1997):541–49.

Ramsey, R., D. Doye, C. Ward, J. McGrann, L. Falconer, and S. Bevers. "Factors Affecting Beef Cow-Herd Costs, Production, and Profits." *Journal of Agricultural and Applied Economics* 37,1(2005):851–63.

Robb, J. Personal Communication. Livestock Marketing Information Center (LMIC), Lakewood, CO, June 2007.

Smith, M.A. *Drought Prediction Model Development and Dissemination in Wyoming*. Report for 2002WY7B, 2005. Internet site: http://water.usgs.gov/wrri/04grants/Progress%20Completion%20Reports/2002WY7B.pdf (Accessed April 24, 2008).

Stockton, M.C., and R.K. Wilson. "Simulated Analysis of Drought's Impact on Different Cow-Calf Production Systems." Paper presented at the Southern Agricultural Economics Association meetings, Mobile, AL, February 4–7, 2007.

Taylor, D., R. Coupal, and T. Foulke. "The Economic Importance of Livestock Grazing on BLM Land in Fremont County, Wyoming." Project Report. Department of Agricultural and Applied Economics, College of Agriculture, University of Wyoming, October 2004. Internet site: http://agecon.uwyo.edu/Econdev/PubStorage/Fremont%20County%20final26Oct04.pdf (Accessed June 17, 2009).

Torell, L.A., J.A. Tanaka, N. Rimbey, T. Darden, L. Van Tassell, and A. Harp. *Ranch-Level Impacts of Changing Grazing Policies on BLM Land to Protect the Greater Sage-Grouse: Evidence from Idaho, Nevada and Oregon*. PACWPL Policy Paper SG-01-02. Caldwell, Idaho: Policy Analysis Center for Western Public Lands, 2001.

Ward, C.E., M.K. Vestal, D.G. Doye, and D.L. Lalman. "Factors Affecting Adoption of Cow-Calf Production Practices in Oklahoma." *Journal of Agricultural and Applied Economics* 40,3(2008):851–63.

Wyoming Agricultural Statistics Service (WASS). Internet site: http://www.nass.usda.gov/Statistics_by_State/Wyoming/index.asp (Accessed May 30, 2007).