

Optimization of rangeland management strategies under rainfall and price risks

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Abstract

Dynamic programming was used to obtain optimal management and marketing policies for stocker operations in Southeastern Colorado under different stocking rates, rainfall, and price scenarios. Simulated steer liveweights at low, moderate, and high stocking rates were incorporated with simulated steer prices to maximize the present value of net returns from the sale of 0, 50, and 100% of the steer inventory in July, August, September, or October. Two low-risk, 1 moderate-risk, and 2 high-risk scenarios were considered. The 2 low-risk scenarios were *favorable rainfall-optimistic price* and *favorable rainfall-pessimistic price*. The moderate-risk scenario was *average rainfall-average price*. The 2 high-risk scenarios were *unfavorable rainfall-optimistic price* and *unfavorable rainfall-pessimistic price*. The highest net returns from the low-risk and moderate-risk scenarios were obtained at the high stocking rate with sales in September and October. The highest net returns from the high-risk scenarios were obtained at the moderate stocking rate with sales in September and October. Risk-averse operators who are not prepared to handle sales before October will be better off using a low stocking rate. Risk-taker operators will obtain higher net returns than risk-averse operators using a high stocking rate providing they are prepared to sell half of the herd in July if cumulative rainfall up to June is below 149 mm. If this high stocking rate is maintained beyond July, operators should sell in September independently of the amount of rainfall or the level of prices in August.

Key Words: rangeland resource economics, risk analysis, dynamic programming.

Rangeland livestock producers face the challenge of managing in the present and planning for the future under ever-changing production, marketing, and financial conditions. Surveys conducted by Walker and Mapp (1984) and Patrick et al. (1985) showed that livestock price fluctuations, erratic weather, and

uncertain input costs were ranked by ranchers and farmers as the leading sources of net-return variability. Early proceedings from the Committee on Economics of Range Use and Development of the Western Agricultural Economic Research Council (1966) indicated high expectations from potential applications of risk management research. However, a survey conducted by Walker and Nelson (1980) among teaching and extension faculty across the nation reflected only modest levels of instruction on risk and decision theory.

A renewed interest in risk analysis has developed in the last 10 years. Most of the models developed in this period have treated risk within a static, risk-averse framework. A static approach may not be consistent with the way decision-makers behave under risk. Rangeland production is a dynamic process in which rainfall and price uncertainty compromise biological efficiency and expected income throughout. Management flexibility is extremely important to counteract negative rainfall and price influences. Moreover, risk influences farmers and ranchers' decisions, whether they are risk-neutral or risk-averse. Consequently, dynamic, risk-neutral optimization models may be more useful than static, risk-averse optimization models in obtaining management and marketing policies for rangeland livestock operations.

Dynamic optimization models have a recursive structure and can incorporate non-linear production functions. In these type of models, the optimal solution depends on the level of control applied to the system level of production, input costs, and price variability. Fisher (1985), Rodríguez and Taylor (1988), Lambert (1989), Garoian et al. (1990), and Schroeder and Featherstone (1990) incorporated production and price variability into dynamic optimization models. Most of these previous efforts concentrated in obtaining optimal marketing policies for cow-calf and cow-calf/yearling operations. With the exception of Rodríguez and Taylor (1988), no research efforts have looked into the development of intra-seasonal optimal marketing policies for stocker operations in the presence of rainfall and price risks at different stocking rates.

This paper addresses:

- a) The need to model marketing and management decisions in rangeland stocker operations in a dynamic rather than static setting. A dynamic approach is more reflective of how decision-makers operate.
- b) The demand for a spectrum of optimal alternatives for stocker operations instead of an unique solution. The alternative cho-

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sen by the operator depends on his/her own degree of risk aversion relative to the degree of rainfall and price risks present in each situation.

In a stocker operation, the producer either buys 160-kg calves in October/November expecting to sell them at 340 kg in October/November of the next year, or buys 227-kg steers in May and expects to sell them at 340 kg in October/November of the same year. The study presented here incorporated the means of simulated steer live weight for low (5.6 ha/steer), moderate (3.8 ha/steer), and high (2.5 ha/steer) stocking rates with the means of simulated steer prices to maximize the present value of net returns (NPV) from the total or partial sale of the steer inventory in July, August, September, or October.

Two low-risk, 1 moderate-risk, and 2 high-risk scenarios were considered. The 2 low-risk scenarios were *favorable rainfall-optimistic price* and *favorable rainfall-pessimistic price*. The moderate-risk scenario was *average rainfall-average price*. The 2 high-risk scenarios were *unfavorable rainfall-optimistic price* and *unfavorable rainfall-pessimistic price*.

A Dynamic Programming Model for Stocker Operations

Dynamic programming was used to maximize the present value of net returns in July, August, September, and October. Net return was a function of the state variable *inventory of stocker steers on hand* (IN) and 2 dependent variables, *steer liveweight* (LWT) and *steer price* (PR). The state variable *inventory of stocker steers on hand* was represented by initial values of 34, 50, and 75 steers in a 190-ha pasture for low (5.6 ha/steer), moderate (3.8 ha/steer), and high (2.5 ha/steer) stocking rates (SR), respectively. The optimal value function was obtained with the following recurrence relationship:

$$f_t(IN_t) = \max\{[(PR_t^k * LWT_{t,1} * CS(u)) - (COM * CS(u)) - (VCH_t * IN_t)] + B_t * f_{t+1}(IN_{t+1})\} - f_0 \quad (1)$$

where:

$f_t(IN_t)$ = the present value of net returns from following an optimal policy with t stages remaining in the planning horizon, given a specific inventory at hand IN_t .

LWT_t = the mean of steer live weight in time t .

PR_t^k = the mean of steer price of the k weight-class in time t . The weight-class is determined by LWT_t .

$CS_t(u)$ = number of steers sold in time t according to the control applied u .

u = applied control represented by the sale of 0, 50, or 100 percent of the steer inventory (IN) in July, August, September, or October.

COM = the value of sales commission estimated at \$8/steer.

VCH_t = the variable costs comprising labor, minerals, and veterinary expenses in stage t . These costs were estimated at \$0.40/head/day.

B_t = discount factor based on the annual nominal inflation.

$f_{t+1}(IN_{t+1})$ = the maximum net present value from allocating IN steers from stage $t+1$ to the end of the process.

f_0 = initial outlay of buying steers in May which is a function of $IN_1 * PR_1^k$. Initial outlay also included the interest paid for borrowing the initial amount of money to purchase the steers. Interest on borrowed capital was estimated at 11.5% annually.

Equation (1) was numerically solved by backward enumeration

subject to the following transition equation for the state variable:

$$IN_t = IN_{t-1} - CS_t \quad (2)$$

where the *inventory of steers on hand* (IN) at stage t was a function of the *inventory of steers on hand* (IN_{t-1}) in the previous stage minus the *number of steers sold* (CS) in stage t . The value for the *number of steers sold* depended on the control u applied. Changes in the *inventory of steers on hand* affected the stocking rate. This in turn made *steer liveweight* fall into a different weight-class and consequently into a different *steer price* value.

The model algorithm was built into subroutines of the dynamic programming software CSUDP (Labadie 1990). The subroutines were enumerated in Carande (1992). The simulation model RANGES (Carande 1992) was used to obtain the values of steer liveweight under the 5 different scenarios. The model was calibrated for Southeastern Colorado conditions using historical rainfall and production data. Afterwards, RANGES was customized with a Gamma-distributed rainfall generator (Carande 1992). The model was set for 300-year iterations obtaining a frequency distribution of steer liveweight under stochastic rainfall.

For the *average rainfall* scenario, the means of *steer liveweight* for each grazing period were obtained from a complete frequency distribution generated with the 300-year simulation run. For the *unfavorable rainfall* scenario, the means of *steer liveweight* were selected from those years with rainfall values falling in the lower quartile of the frequency distribution. The lower quartile contained cumulative values of rainfall below 107 mm in the first, 149 mm in the second, 196 mm in the third, 241 mm in the fourth, 268 mm in the fifth, and 287 mm in the sixth grazing period. For the *favorable rainfall* scenario, the means of *steer liveweight* were selected from those years with rainfall values falling in the upper quartile of the frequency distribution. The upper quartile contained cumulative values of rainfall above 175 mm in the first, 229 mm in the second, 285 mm in the third, 339 mm in the fourth, 373 mm in the fifth, and 398 mm in the sixth grazing period.

The model was run for 12 different stocking rates. These stocking rates were the result of differences in initial stocking rates and changes in steer inventory due to partial sales in July, August, September, or October. Table 1 lists the end-of-season means of steer liveweight at each stocking rate from the average, favorable, and unfavorable rainfall scenarios. As previously reported in

Table 1. End-of-season steer liveweight as influenced by stocking rate and rainfall.

Stocking Rate	Rainfall Scenarios		
	Favorable	Average	Unfavorable
(ha/steer)	(kg)		
2.5	350	334	304
3.8	352	346	333
5.0	353	347	338
5.6	353	348	339
7.6	353	349	341
10.0	354	349	342
11.2	354	350	343
14.6	354	351	343
19.0	354	350	344
21.1	354	350	344
37.1	354	350	344
38.0	354	350	344

Table. 2 Average simulated real prices of stocker steers for different weight classes from July to October for each scenario considered.

Weight Class	Price Scenario	July	August	Sept.	Oct.
----- (\$/100 kg) -----					
363-Kg	optimistic	181.72	182.60	183.26	184.14
	average	164.34	165.66	167.20	168.74
	pessimistic	147.62	148.72	151.36	152.90
317-Kg	optimistic	185.46	186.78	187.88	189.20
	average	167.86	169.62	171.38	173.36
	pessimistic	150.26	152.02	155.10	156.86
272-Kg	optimistic	192.28	193.38	194.48	195.36
	average	174.02	175.34	176.88	178.64
	pessimistic	154.66	156.20	159.06	160.82
227-Kg	optimistic	205.26	204.82	204.16	203.50
	average	185.24	185.02	184.80	185.02
	pessimistic	163.24	163.24	164.56	164.78

weight classes. It uses coefficients from a harmonic regression model combined with a set of serially independent residuals obtained with a Markov-chain procedure using a set of random deviates. This set of random deviates was drawn from a Weibull distribution and multiplied by a variance-covariance upper-right triangular matrix. For the *average price* scenario, means of steer price were obtained from a frequency distribution including all values generated with a 200-year simulation run. For the *pessimistic price* scenario, means were obtained from the lower quartile of the frequency distribution. For the *optimistic price* scenario, means were obtained from the upper quartile of the frequency distribution. Table 2 lists the means of *steer price* for all weight-classes from July to October for the pessimistic, average, and optimistic price scenarios.

Optimal Intraseasonal Marketing Decision for Stocker Operations

Carande (1984), the effect of stocking rate on steer liveweight increases as rainfall decreases.

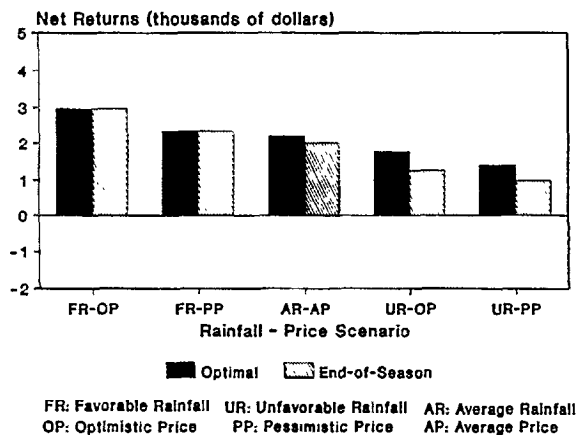
The means of *steer price* were obtained from monthly distributions of cross-correlated prices generated with the simulation model PRIGEN (Carande 1992). The model generates cross-correlated steer prices with seasonal and cyclical components for 6

Table 3 presents a summary of the optimal policies chosen and present values of net returns obtained from following the optimal marketing strategy. Cases were listed by increasing level of risk and stocking rate. Steers were kept on the range until October in the *favorable rainfall-optimistic price* and *favorable rainfall-pes-*

Table. 3. Optimal policies and net present values (NVP) from stocker operations at 3 initial stocking rates and 5 rainfall-prices scenarios.

Stocking Rate	Rainfall and Price Scenario	Optimal Marketing Policy	NPV
(ha/steer)			(\$)
Low (5.6)	Favorable Rainfall - Optimistic Price	Sell in October	\$2,052
	Favorable Rainfall - Pessimistic Price	Sell in October	\$1,630
	Average Rainfall - Average Prices	Sell 1/2 in September - 1/2 September - 1/2 in October	\$1,579
	Unfavorable Rainfall - Optimistic Price	Sell 1/2 in September - 1/2 in October	\$1,398
	Unfavorable Rainfall - Pessimistic Price	Sell in October	\$1,125
	Favorable Rainfall - Optimistic Price	Sell in October	\$2,974
	Favorable Rainfall - Pessimistic Price	Sell in October \$2,361	
	Average Rainfall - Average Price	Sell 1/2 in September - 1/2 in October	\$2,221
	Unfavorable Rainfall - Optimistic Price	Sell 1/2 in September - 1/2 in October	\$1,776
	Unfavorable Rainfall - Pessimistic Price	Sell 1/2 in September - 1/2 in October	\$1,412
Moderate (3.8)	Favorable Rainfall - Optimistic Price	Sell in September - 1/2 in October	\$4,419
	Favorable Rainfall - Pessimistic Price	Sell 1/2 in September - 1/2 in October	\$3,546
	Average Rainfall - Average Price	Sell 1/2 in September. - 1/2 in October	\$2,817
	Unfavorable Rainfall - Optimistic Price	Sell 1/2 in July - 1/4 in September - 1/4 in October	\$1,510
	Unfavorable Rainfall - Pessimistic Price	Sell 1/2 in July - 1/2 in September	\$931
	Favorable Rainfall - Optimistic Price	Sell in September - 1/2 in October	\$4,419
	Favorable Rainfall - Pessimistic Price	Sell 1/2 in September - 1/2 in October	\$3,546
	Average Rainfall - Average Price	Sell 1/2 in September. - 1/2 in October	\$2,817
High (2.5)	Unfavorable Rainfall - Optimistic Price	Sell 1/2 in July - 1/4 in September - 1/4 in October	\$1,510
	Unfavorable Rainfall - Pessimistic Price	Sell 1/2 in July - 1/2 in September	\$931
	Favorable Rainfall - Optimistic Price	Sell in September - 1/2 in October	\$4,419
	Favorable Rainfall - Pessimistic Price	Sell 1/2 in September - 1/2 in October	\$3,546

Moderate Stocking Rate



High Stocking Rate

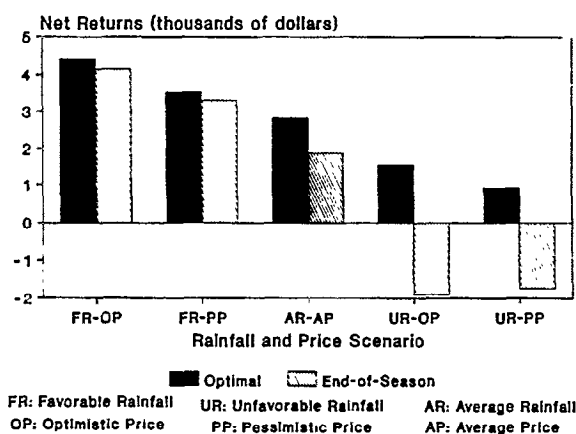


Fig 1. Net returns obtained under the optimal marketing policy vs. net returns from the traditional end-of-season marketing policy for 2 stocking rates.

simistic price scenarios at low and moderate stocking rates. Steers were also kept on the range until October in the unfavorable rainfall-pessimistic price scenario at the low stocking rate. Steers were sold half in September and half in October in the unfavorable rainfall-optimistic price scenario at the low and moderate stocking rate, in the average rainfall-average price scenario at the low, moderate, and high stocking rates, in the unfavorable rainfall-pessimistic price scenario at the moderate stocking rate, and in the favorable rainfall-optimistic price and favorable rainfall-pessimistic price scenarios at the high stocking rate. Steers were sold half in July, 1 quarter in September, and the remaining quarter in October in the case of the unfavorable rainfall-optimistic price scenario at the high stocking rate. Steers were sold half in July and half in September in the unfavorable rainfall-pessimistic price scenario at the high stocking rate.

The highest net returns in the low-risk and moderate-risk scenarios were obtained at the high stocking rate with sales in September and October. The highest net returns from the high-risk scenarios were obtained at the moderate stocking rate with also sales in September and October. The difference between the net returns from the low and high-risk scenarios was \$927 at low

stocking rate. This difference climbed to \$1,562 at the moderate stocking rate, and \$3,488 at the high stocking rate. These differences in net returns, according the level of stocking rate level and the degree of risk, reaffirm the *higher return-higher risk* rule of financial analysis. The relativity of optimizing under "average conditions" was evidenced by the difference of \$1,886 between the net returns from the *average rainfall-average price* scenario and the net returns from the *unfavorable rainfall-pessimistic price* scenario at the high stocking rate.

The differences in net returns obtained from optimizing intervals (dynamic approach) rather than an end-of-season point (static approach) proved the importance of early sales when applying a high or moderate stocking rate under below-average rainfall conditions (Figure 1). Moreover, early sales when applying a high stocking rate saved the operation from losses of \$1,907 in the *unfavorable rainfall-optimistic price* scenario and \$1,725 in the *unfavorable rainfall-pessimistic price* scenario.

Conclusions

In making optimal decisions under rainfall and price variability, early sales was an important factor in whether the stocker operation was to avoid negative returns. These findings agreed with those of other authors such as Garoian et al. (1990), Schroeder and Featherstone (1990), and Rodriguez and Taylor (1988). When all 15 optimal policies were compared, rainfall had more effect on the timing of sales than price. Under favorable rainfall conditions, price level did not change the timing of sales at any of the stocking rates. Under unfavorable rainfall conditions, price level did change the timing of sales at the low and high stocking rates.

When using high stocking rates, flexible marketing strategies decreased the risk of obtaining negative net returns. This was specially true when rainfall and/or prices realized at lower levels than the long-term average. Conversely, inflexible marketing strategies called for lower stocking rates independently of the level of rainfall and/or prices. The resulting spectrum of policies according to the stocking rate applied and the rainfall and price levels reaffirmed the relevance of dynamic optimization as a procedure to obtain management and marketing policies under risk. Under price variability, alternatives that manipulate the purchase and/or selling price, such as future contracts or hedging, could be more important than the overall price level. Under rainfall variability, flexible rules of management will have a positive effect on the economic sustainability of the enterprise and the biological sustainability of rangelands.

Management Implications

When making decisions under rainfall and/or price variability, the strategy chosen by the operator will depend on his/her own degree of risk aversion and the flexibility allowed by the enterprise. A risk-averse stocker operator who is not prepared to handle early sales in September will be better off using a low stocking rate. If the same operator is prepared to handle early sales, higher profits will be obtained using a moderate stocking rate. He/she should sell in September unless the cumulative rainfall in August is above 339 mm.

A risk-taker operator will obtain higher profits than a risk-averse operator by using a high stocking rate, providing the cumulative rainfall up to the month of May is above 107 mm. The operator can apply a high stocking rate only if the range is in good or excellent condition, and be prepared to sell half of the herd in July if the cumulative rainfall through May is below 149 mm. The remaining steers should be sold in September regardless of the level of price or rainfall in this month. Stocker operators should avoid the temptation of running a higher than 3.8 ha/steer stocking rate in the presence of high seasonal prices under an inflexible marketing scheme. If below-average rainfall occurs while stocking at this stocking rate, the operation will register end-of-season losses of \$10.50/ha.

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