AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Calf Retention and Production Decisions over Time

David K. Lambert

Ranch production and marketing decisions occur sequentially over time as uncertainty regarding future events is resolved. The model developed in this paper explicitly considers the sequential nature of ranch decision making in determining optimal strategies for calf retention and production. A number of optimal decisions are reported for each period, conditional upon the state of nature and expected future events at that decision node. Solutions are found to be dependent on observed and expected output prices.

Key words: stochastic programming, ranch economics, beef cattle growth models, marketing, risk.

Cow/calf producers face several decisions in the fall of the year when weaner calves traditionally are marketed. The calves may be sold in the fall or retained over the winter. If the animals are retained, optimal rates of gain over the winter months must be determined. Sales can occur at any time over the period, either during the winter or in the spring following the feeding period. Animals fed through the winter and not sold in the spring may be placed on grass for additional weight gains over the summer.

Important considerations in these decisions include current and expected future input and output prices, the relationship between price and weight, and animal performance on winter feed and subsequent summer range. Production and marketing decisions are made throughout the period, are conditional upon past actions, and must be made in light of current and expected future prices and animal performance. This paper presents a model in which optimal feeding and marketing decisions are determined sequentially over the interval following the traditional sales period. The discrete stochastic programming approach employed (Rae 1971a, b) provides an optimal decision for the present period and a variety of future actions, each of which is optimal for the resulting future event. Each state of the process at each stage is conditional upon past actions and events and upon expected future events.

Although calves born in spring traditionally are marketed in the fall in much of the western United States (Gilliam), this strategy may not always be optimal. Cow/calf production and marketing strategies have been explored extensively in the literature. Contrary to traditional ranch practice, however, most authors have concluded that retention of calves beyond weaning improves ranch financial performance. Stokes, Farris, and Cartwright examined the marketing problem in a deterministic framework. Their results indicated that net returns were higher when weaned calves were retained and custom fed rather than being sold outright at weaning. A multiperiod risk programming approach was used by Whitson, Barry, and Lacewell to evaluate the risk-return effects of selling calves at weaning versus holding them through subsequent stages of the production process. Outcomes were improved when calves were retained.

Olson and Mikesell used a sequential programming model to determine optimal calf

---

David K. Lambert is an assistant professor in the Department of Agricultural Economics and Rural Sociology, The Pennsylvania State University. This work was conducted while the author was at the University of Nevada–Reno.

The author acknowledges the background work provided by Daniel G. Fleming and Theodore K. Wood in conducting this study. Use of Cornell University's IBM 3090-600E supercomputer was made possible through a noncompetitive grant from the National Science Foundation.

Comments on an earlier draft of this paper by three anonymous reviewers are greatly appreciated.

Copyright 1989 Western Agricultural Economics Association

marketing strategies in California under different forage production scenarios. Calves were sold at weaning in their model only when fall rainfall amounts, and hence forage supplies, were below normal. Similar results were obtained by Gebremeskel and Shumway. In their MOTAD model of the marketing problem, larger numbers of calves were sold at weaning only when poor weather resulted in below-average forage production. Some calves were retained beyond weaning, however, under all weather outcomes considered.

All of these earlier studies evaluated the retained ownership question assuming the availability of relatively low-cost grazing land. However, producers in areas facing severe winter weather must feed their animals over the winter rather than graze the retained animals. This paper examines the problem when feeding is the most feasible option for those animals not sold at weaning.

Many models addressing management problems facing the cow/calf producer have been static, in which optimal decisions were derived without the possibility of revision as uncertainty regarding the future was resolved over time (Gebremeskel and Shumway; Rodriguez and Roath). Exceptions have included dynamic programming approaches with both forward- (Rodriguez and Taylor) and backward-chaining equations (Yager, Greer, and Burt; Burt) and multiperiod risk programming models (Whitson, Barry, and Lacewell; Olson and Mikesell). This paper employs the latter approach, in which decisions are made sequentially over time as previously uncertain parameters become known.

The Discrete Stochastic Programming Model

Discrete stochastic programming models determine optimal activity levels in light of the sequential resolution of parameter uncertainty. These models are a class of the stochastic linear programming problem developed by Tintner and called the "wait and see approach" by Madansky.

First model development generally is attributed to Cocks in 1968. Cocks described a multistage model in which the values of some or all coefficients within each stage acquire modified probabilities as a result of past events or actions within the model. The multistage model discussed by Cocks allocates resources to activities within a period and then, whatever event is observed over the period, optimizes allocation over the next period. Allocation over succeeding stages continues based on past decisions and observed outcomes of the initially uncertain events.

Rae (1971a, b) expanded the discussion of Cocks' model and described in detail the construction, solution, and interpretation of results of a discrete stochastic programming model (DSPM) applied to a vegetable farm.

Although few applications of the DSPM to agricultural decision problems have appeared since Rae's articles, there has been a recent increase in interest in the approach. Lambert and McCarl developed marketing strategies for white wheat producers over the postharvest marketing period. Kaiser and Apland assessed alternative levels of farmer participation in farm programs. Olson and Mikesell investigated optimal livestock stocking levels on California annual rangelands under alternative precipitation regimes. Garoian, Conner, and Scifres analyzed brush clearing strategies for Texas ranches under different responses to treatment.

The decision tree in figure 1 illustrates the DSPM. The decision maker initially is faced with several possible future events in period A. He makes a decision, X_A, in light of his expectations of these future events. Event E_{B1} or E_{B2} then occurs. Assume E_{B1} occurs. The decision maker must now reach an optimal decision, X_{B1}, conditioned on X_A, the occurrence of E_{B1}, and future uncertain events, E_{C11} and E_{C12}.

The decision maker observes one of four possible events in period C (E_{C11}, E_{C12}, E_{C21}, or E_{C22}). The optimal decision, given E_{C11} is observed, for example, would be a function of all past decisions (X_A and X_{B1}) and events (E_{B1} and E_{C11}). The discrete stochastic programming model is formulated such that optimal decisions are reported for each node of the decision tree based on prior decisions and events and on the expected distribution of future events. Optimal activity levels for X_A, X_{B1}, X_{B2}, X_{C11}, X_{C12}, X_{C21}, and X_{C22} are reported in the results of the model.

Assume that the objective in figure 1 is the maximization of expected utility over the three periods. This can be represented:

$$\max EU(Y) = \sum \Pr(\Theta_i)U(y_i);$$

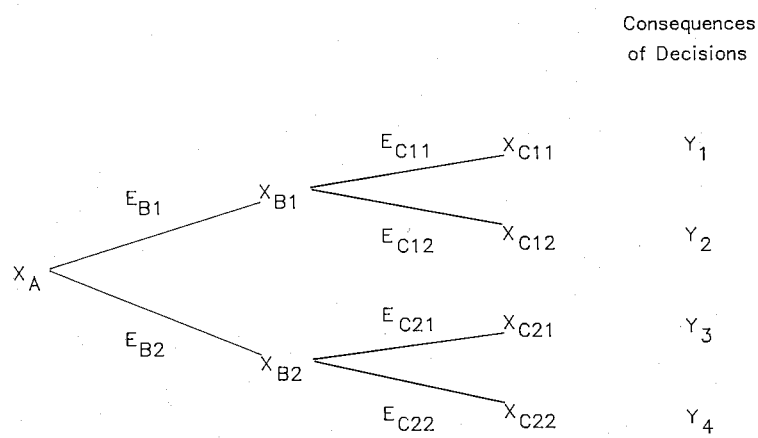

Figure 1. Discrete formulation of the sequential decision problem

subject to:

$$Q^1(X_A, X_{B1}, X_{C11}) - y_1 = 0;$$
$$Q^2(X_A, X_{B1}, X_{C12}) - y_2 = 0;$$
$$Q^3(X_A, X_{B2}, X_{C21}) - y_3 = 0;$$
$$Q^4(X_A, X_{B2}, X_{C22}) - y_4 = 0;$$

and

$$g^1(X_A, X_{B1}, X_{C11}) \leq 0;$$
$$g^2(X_A, X_{B1}, X_{C12}) \leq 0;$$
$$g^3(X_A, X_{B2}, X_{C21}) \leq 0;$$
$$g^4(X_A, X_{B2}, X_{C22}) \leq 0;$$
$$\text{all } X \geq 0.$$

As an illustration of the ranch decision problem, four income levels, y_i, will be determined by functions Q^i as a result of the different price events and production and marketing decisions made in periods *A, B,* and *C*. Functions g^i will represent ranch constraints as well as biological performance of the animals resulting from decisions X.

The sequential nature of the model and the divergence of events over time is apparent in the above formulation. For example, decisions made in period *A*, X_A, impact incomes and constraints in all states of nature since X_A is common to all income rows, Q^1–Q^4, and constraint rows, g^1–g^4. Decisions made in period *B*, X_{B1} or X_{B2}, depend on the occurrence of either E_{B1} or E_{B2}. Decision X_{B1} has no influence on the outcome of decisions given E_{B2} occurred. Finally, decisions made in period *C*, such as X_{C11}, only influence income along that branch of the event tree. The past determines the state existing at each distinct decision node, while decisions made at each node influence all nodes emanating from that point.

These characteristics of the DSPM conform to Antle's three criteria for the dynamic multiperiod sequential problem. Specifically, decisions are sequentially dependent, there is information feedback to the decision maker as time unfolds, and earlier decisions can be revised as more information becomes available.

The Ranch Decision Model

The components of the rancher's problem are described in this section. Production decisions are based on animal performance, costs and availabilities of different feeds, and expectations of future prices. Marketing decisions are based on current and expected future prices, past marketing decisions, and animal performance. The rancher is faced with marketing and production decisions throughout the one-year period considered in the model so long as some cattle remain. Past decisions and events continue to determine current states. Current states and expectations of future events influence current decisions.

Feeding decisions are made on a monthly basis over the five-month winter period. Optimal rations and subsequent rates of gain are determined for each monthly period. Animals not sold by the end of the winter feeding period (May) are placed on rangeland. Any animals not previously sold are sold at the end of the summer grazing period.

Four alternative formulations of the model are specified. In the first, all animals are sold in May following the winter feeding period. Solutions thus obtained indicate optimal win-

ter feeding rations when the a priori decision of selling the animals in the spring was made. The second formulation constrained the model to feed all animals over the winter and then place them on rangeland for summer grazing. Sales occurred in October following the grazing period.

The third and fourth specifications of the model allowed both optimal feeding and marketing decisions to be solved endogenously. Marketing and ration decisions are made each month over the winter. Any animals not sold by May, following the winter feeding period, are either sold or placed on summer range. The objective of the third model was the maximization of expected net returns. The fourth specification sought the minimization of total absolute deviation of net returns subject to parameterized values of expected returns.

Constraints in the model included the animal performance equations for the five-month feeding period, animal performance on summer range, and marketing activities. Steer prices are adjusted endogenously as animal weight changes.

The different components of the model are discussed individually below.

Animal Performance

Production activities for retained animals are a sequence of linked decisions over time. Input decisions are made on a periodic (daily, weekly) basis and may rely on prior input decisions and subsequent animal weight gain as well as on expectations or realizations of input and output prices.

The periodic production process employed in the feeding model is based on Fox and Black's (1977, 1984) net energy model for medium-frame steer calf performance:[1]

$$
\begin{aligned}
VFI_t &= [.1493(Ne_m)_t - .0460(Ne_m)^2_t \\
&\quad - .0196]W_t^{0.75} \\
(1) \qquad Ne_{mt} &= .077W_t^{0.75} \\
Ne_{gt} &= [VFI_t - Ne_{mt}/(Ne_m)_t]\,(Ne_g)_t \\
ADG_t &= 13.91\ Ne_{gt}^{0.9116}\ W_t^{-0.6837} \\
W_{t+1} &= W_t + ADG_t.
\end{aligned}
$$

[1] The net energy equations were reported on a daily basis. In order to reduce model size, the equations were used to approximate monthly feed requirements. Thus, the final equation was actually specified in the model as $W_{t+1} = W_t + 30.5ADG_t$.

VFI is voluntary feed intake, determined by both the beginning live weight of the animal and the net energy concentration (Mcal/kg) of the ration available for maintenance (Ne_m). The maintenance energy requirement, Ne_m, of the animal is a function of animal weight. The total amount of energy available for animal gain, Ne_g, is composed of excess energy after maintenance requirements have been met and the gain energy concentration of the ration, (Ne_g). Actual daily gain, *ADG*, is a function of animal weight and the total amount of energy available in the ration for gain. Decisions made during period *t* with respect to ration and, consequently, animal gain are then embodied in W_{t+1}.

Weight gains on summer range have been found to be influenced by production decisions made over the previous winter. Rogers and Malone gathered data from 72 steers over two Nevada growing seasons in the early 1960s and estimated the following rate of gain during the summer (the equation has been adjusted to reflect *ADG* in kilograms per day):

$$
\begin{aligned}
(2) \quad ADG_{summer} &= 1.0591 - \underset{(.0006)}{.0014W_{winter}} - \underset{(.0755)}{.6182ADG_{winter}}
\end{aligned}
$$

$R^2 = .50$,
Standard errors in parentheses.

Average daily gain over the entire summer period, ADG_{summer}, was found to be negatively related to W_{winter}, the weight of the steers at the beginning of the winter feeding season, and ADG_{winter}, the average daily gain of the animals over the winter period.

Although the R^2 value is relatively low, suggesting production uncertainty might be appropriate in the model for at least summer performance, production is considered deterministic in the current model.

Animal protein requirements were determined by calculating a linear relationship among protein required and animal weight and rate of gain reported in *Nutrient Requirements of Beef Cattle*. The following constraints to calculate required protein were added (protein, average daily gain, and animal weight are all in kilograms):

$$PROTEIN_t = .5090ADG_t + .0015W_t - .0411.$$

Simulation of Steer Calf Prices for the Model

Two characteristics of steer prices had to be considered in simulating expected future prices

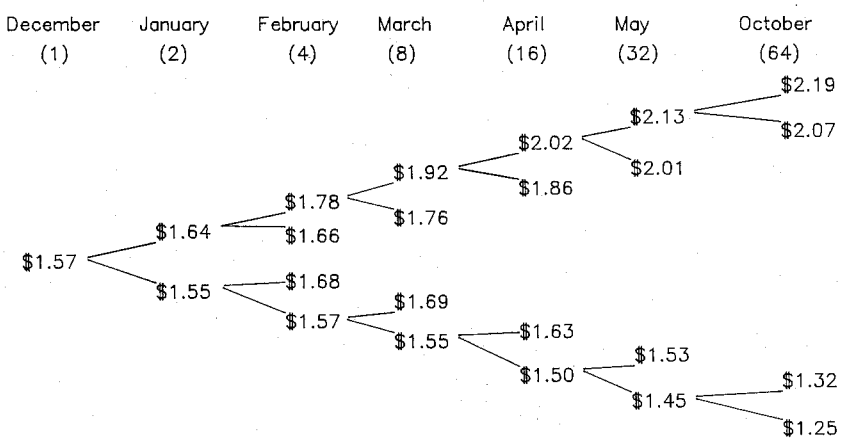

Figure 2. Portion of price event tree (dollars per kg for 181-227 kg (400-500 lb.) steer). Number of price states are listed below each month

for the model. First, prices vary over time. Second, steer prices are negatively related to animal weight.

Expected prices needed to be simulated for each of the six feeding-period months (December through May), as well as for the October following the summer grazing season. Price indices were calculated in a manner similar to King and Lybecker.

Indices were calculated from monthly Kansas City prices for 400–500-pound steers from December 1962 to October 1987. Monthly price indices (*PI*) were calculated as follows:

$$PI_{it} = \frac{PRICE_{it}}{PRICE_{i-1,t}}, \quad \begin{array}{l} i = 1, \ldots, 12 \\ t = 1, \ldots, 25 \end{array}$$

where $PRICE_{it}$ is price in month i for year t. The actual December 1986 price of $71.00 per hundredweight was used for the initial month in the model. Two prices were generated for January, $P_{JAN,k}$:

$$P_{JAN,k} = P_{DEC} \times (\mu_{PI,JAN} \pm \sigma_{PI,JAN}),$$

or prices in January equaled December price times the mean index value, $\mu_{PI,JAN}$, plus (or minus) the standard deviation of the January index, $\sigma_{PI,JAN}$.

Four February prices were calculated conditional upon January's prices:

$$P_{FEB,km} = P_{JAN,K} \times (\mu_{PI,FEB} \pm \sigma_{PI,FEB}).$$

The procedure was repeated to simulate March through May prices and to represent simulated price predictions for the following October. A total of 64 (2^6) price states were generated (i.e., one price in December, two prices in January, 2^2 prices in February, etc.). A portion of the price event tree is depicted in figure 2.

Price discounts resulting from higher calf weights were calculated using average prices over the period for 400–500-, 500–600-, 600–700-, and 700–800-pound animals. The following price-weight relationship was found:

$$P_{Discount,w} = -.003478(W_{400\text{-}500} - W_w) \quad (3)$$
$$(.0021)$$
$$R^2 = .93,$$

where $P_{Discount,w}$ is the price discount from the 400–500-pound animal price for steers of weight W_w. The regression equation was added as a constraint to the programming model to adjust simulated prices by animal weights resulting from production decisions.

Input Costs

The model assumed all feedstuffs were purchased. Nevada prices quoted by local feed and supply stores were used where possible. Prices reported in *California Farmer,* a trade magazine, were used when local prices for particular feeds were not available. A list of feeds available in the model and their nutritional contents and costs appear in table 1.

An annual discount rate of 10% was applied to the monthly net return values to reflect opportunity costs of capital and variable costs resulting from continued animal retention. No opportunity cost was ascribed to the physical facilities in which the 100 steers were held over the winter.

Table 1. Feeds and Feed Characteristics Used

	CALCI	PHOSH	PROTN	NEGKG	NEMKG	COST/kg
Alfalfa	1.41	0.24	17.0	0.68	1.24	0.10
Alfalfa—Silage	1.61	0.38	17.0	0.74	1.31	0.11
Fescue—Hay	0.30	0.26	9.5	0.35	0.90	0.05
Oat—Hay	0.24	0.22	9.3	0.58	1.14	0.07
Barley—Straw	0.30	0.07	4.3	0.08	0.60	0.04
Barley	0.05	0.38	13.5	1.40	2.06	0.13
Corn	0.02	0.35	10.1	1.55	2.24	0.12
Beet—Pulp	0.69	0.10	9.7	1.14	1.76	0.12
Beet—Molasses	0.61	0.10	10.1	1.19	1.82	0.10
Cotton Seed Meal	0.19	1.24	54.0	1.16	1.79	0.21
Soy—Meal	0.33	0.71	49.9	1.40	2.06	0.32
Rice—Bran	0.08	1.70	14.1	1.03	1.63	0.07
Dical	22.00	19.30	0.0	0.00	0.00	0.33
Potassium-Chlor	0.05	0.00	0.0	0.00	0.00	0.26
Disodium	0.00	22.50	0.0	0.00	0.00	0.26
MON-NH_4	0.28	24.74	70.9	0.00	0.00	0.53
Limestone	34.00	0.02	0.0	0.00	0.00	0.05

Notes: CALCI—Calcium percentage of the feed; PHOSH—Phosphorous percentage of the feed; PROTN—Protein percentage of the feed; NEGKG—Net energy for gain concentration of the feed in Mcal per kg; NEMKG—Net energy for maintenance concentration of the feed in Mcal per kg; COST/kg—Cost of the feed in dollars per kg (dry matter basis).

The Marketing Decision

The ranch model was initially run under two predetermined marketing plans. In the first, optimal rates of gain were determined when all of the animals were retained over the winter and sold in the spring. The second model specified assumed that calves would be held over the winter and placed on range for five months prior to a fall sale. The final set of model runs expanded the decision variables in the model by determining optimal sales patterns endogenously.

Seven selling points were available to the producer in this final formulation of the model. Sell versus hold decisions were made monthly over the winter (December–May). The final selling point for any animals not previously sold was in October following the summer grazing season. Net returns at any one of these points under output price state of nature i will be a function of animal weight under state i, feed costs incurred in obtaining that weight, and number of animals sold. Animal weight has been determined by a succession of past production decisions. The number of animals sold in the period under state of nature i depends upon the number of animals sold in earlier periods along this branch of the decision tree, the total number of animals initially available, and future marketing expectations, which in turn depend on animal performance and expectations of future prices.

Objective Function

The objective of the expected return maximization model in its current form is the maximization of expected net returns over all price outcomes. Formally,

$$\text{(4)} \qquad \text{Max } ER = \sum_{i=1}^{64} \Pr(\Theta_i) \sum_{t=1}^{7} INCOME_{it}.$$

The subscript i refers to the marketing and production decisions made under the price conditions existing in state of nature i. Expected returns, ER, are obtained by summing net returns, $INCOME$, over all seven marketing periods under each state. Total income under state i is then weighted by the probability, $\Pr(\Theta_i)$, of that state's occurrence.[2]

The objective function for the final formulation, in which total absolute deviations of returns are minimized for differing values of expected returns, is

$$\text{(5)} \qquad \text{Min } TAD = \sum_{i=1}^{64} TAD_i,$$

where total absolute deviation is summed over all states and equals the difference between net returns averaged over all states and net returns under state of nature i.

[2] Each of the 64 states of nature in the model was given an equal chance of occurrence. Probabilities could, of course, be assigned different values if desired.

Table 2. Winter Feed Rations under Most and Least Favorable Price Events

	Dec.	Jan.	Feb.	Mar.	Apr.
Most Favorable Price Events					
Average Daily Gain (kg)	1.248	1.245	1.251	1.260	1.266
Daily Ration (Dry Matter Basis, kg)					
Alfalfa Silage	0.543	0.607	0.668	0.728	0.788
Corn	2.103	2.437	2.877	3.406	3.942
Cotton Seed Meal	0.491	0.437	0.409	0.400	0.390
Rice Bran	2.298	2.587	2.728	2.749	2.765
$[Ne_m]$	1.848	1.855	1.871	1.892	1.911
$[Ne_g]$	1.214	1.219	1.233	1.251	1.267
Least Favorable Price Events					
Average Daily Gain (kg)	1.248	1.178	1.100	1.060	1.081
Daily Ration (Dry Matter Basis, kg)					
Alfalfa Silage	0.543	0.615	0.681	0.000	0.000
Corn	2.103	1.766	1.262	1.217	1.600
Cotton Seed Meal	0.491	0.255	0.000	0.000	0.000
Rice Bran	2.298	3.514	4.871	5.448	5.555
Oat Hay	0.000	0.000	0.000	0.740	0.795
$[Ne_m]$	1.848	1.780	1.711	1.681	1.704
$[Ne_g]$	1.214	1.156	1.097	1.070	1.090

Results

Winter Feeding Followed by Spring Sale

The first situation examined determined optimal rates of animal gain over the winter when all animals were to be sold in spring. All sale activities were constrained to market cattle in May, the end of the winter feeding period.

Input demand levels varied depending upon price events over the winter period. In general, the higher the expected price, the higher was the optimal rate of gain. Higher rates of gain under favorable price outcomes resulted from feeding rations with higher energy contents. As an illustration, table 2 contrasts optimal daily rations in April under the highest and the lowest price events. Table 3 shows optimal animal weights in May under all price outcomes.

Although the results reported here are conditional upon the assumed feed and output prices, a summary function of the feeding decision can be estimated over the ranges of gain, prices, and animal weights observed in the solution.

Table 3. Optimal Animal Weights (kg) in May Following Winter Feeding for Animals Sold in Spring Given Various Seasonal Price Configurations

Price in		Jan. Price = High April Price		Jan. Price = Low April Price	
Feb.	Mar.	High	Low	High	Low
High	High	391.2	389.2	385.5	382.8
High	Low	386.8	383.9	379.9	378.0
Low	High	385.7	383.3	378.2	375.3
Low	Low	380.1	378.2	372.9	372.9

The cost function can be estimated from the optimal solution using simple curve-fitting procedures. The following relationship was found for cost of gain, rate of gain, and animal weight:[3]

$$COST_t = -.8442 + .9070ADG_t + .0015W_t.$$

Optimal daily gain in the model solution was found to be most influenced by expected future prices and animal weight:

$$ADG_t = .4339 + .5118EP_t - .0001W_t,$$

where EP is the weighted average of all future prices from the decision node at time t, and W is animal weight in kilograms. Optimal rates of gain are positively related to expected prices and negatively related to animal weight. The negative relationship between gain and weight derives from the positive influence of animal weight on the cost of gain and the negative relationship between animal weight and price.

Winter Feeding Followed by Summer Grazing

Rates of gain over the winter were much reduced when the model was constrained to feed all animals over the winter and sell them the following fall after a summer grazing period. Table 4 shows May weights following the winter feeding period. Table 5 shows market weights following summer grazing. The lower winter gain resulted from the compensatory gain phenomenon found in beef cattle placed on grass following a winter feeding period.

[3] Cost and average daily gain equations represent activity levels obtained in the model and should not be extrapolated beyond gains of between about 1.0 and 1.3 kilograms, expected prices between $1.25 and $2.20 per kilogram, and weights between 200 and 400 kilograms.

Table 4. Optimal Animal Weights (kg) in May Following Winter Feeding for Animals Sold in Fall after Summer Grazing Given Various Seasonal Price Configurations

Price in		Jan. Price = High April Price		Jan. Price = Low April Price	
Feb.	Mar.	High	Low	High	Low
High	High	318.2	318.2	304.8	304.8
High	Low	318.2	318.2	304.8	304.8
Low	High	318.2	318.2	297.2	297.2
Low	Low	314.4	305.0	288.3	278.0

Table 5. Optimal Animal Weights (kg) in October Following Winter Feeding for Animals Sold in Spring Given Various Seasonal Price Configurations

Price in		Jan. Price = High April Price[a]		Jan. Price = Low April Price[a]	
Feb.	Mar.	High	Low	High	Low
High	High	364.8	364.8	359.7	359.7
High	Low	364.8	364.8	359.7	359.7
Low	High	364.8	364.8	356.8	356.8
Low	Low	363.3	359.8	353.4	349.4

[a] Summer weight gains are completely determined by rates of gain over the winter and animal weight prior to the winter feeding period. Hence, animal weights in October are independent of final selling prices.

Conceptually, animals fed to high rates of gain on winter rations will suffer when placed on lower quality range grasses, whereas animals that have been fed a lower quality ration over the winter will perform better (Bohman and Torell; Bohman).

Optimal rates of gain over the winter feeding period were relatively insensitive to expected prices. Except for the first month's ration, which resulted in an average daily gain of .23 kilogram, optimal rates were between .9 and 1.0 kilogram for the winter period along most branches of the event tree. The exception was the lowest branch, representative of the worst price outcomes. Optimal rates under pessimistic price expectations fell to .47 kilogram in the second month of feeding, though gains did increase under all states through the feeding season. The optimal rate under the most pessimistic price event rose to .57 kilogram per day in the last month prior to placing the animals on grass for the summer.

However, the lower quality feed rations resulted in greater summer gain under these pessimistic price events. Summer gain ranged between .36 and .47 kilogram (average of .39) along the lower branches, compared to ranges from .31 to .36 kilogram (average of .31) along the upper branches of the event tree.

The final selling weight of the animals was greatest along the optimistic price events (364.8 kilograms). The apparent decision rule was to maximize ending weight by feeding to heavier rates of gain over the winter when output price was expected to be high. However, minimizing the cost of winter gain seemed to be more important under pessimistic price expectations relying on greater compensatory growth over the summer. Animals gained 78 kilograms over the winter period under the most pessimistic price outcome, compared to 118 kilograms under the highest expected prices. Summer growth somewhat compensated for this with ending weights being 349.4 kilograms under the pessimistic price outcomes versus 364.8 kilograms under the highest prices.

Simultaneous Production and Marketing Decisions

The previous two sections considered fixed marketing strategies and determined optimal rates of gain under different price events. This section describes model solutions when optimal marketing activities were determined endogenously. Thus, optimal sales strategies and feeding decisions were determined simultaneously at each period depending upon state of nature.

All animals under all states of nature were fed winter rations identical to those in the first model's solution (i.e., when sales were constrained to occur in May). In addition, all animals were sold in May following the feeding period. In other words, the solution attained when production and marketing activities were determined endogenously was identical to the solution when all sales were constrained to occur in May.[4]

The production and marketing activity levels obtained when both were determined endogenously ensued from the high returns to feeding resulting from the feed costs, animal per-

[4] Since the model is highly nonlinear in the constraints, a number of alternative starting points were specified to avoid the solution representing a local, rather than a global, optimum. In all cases, either the model converged to the all-sales-in-May solution, or the final value of the objective function was less than under the May-sales solution.

formance equations, and cattle prices used in the model. Costs of gain were generally about 50–60¢ per kilogram for most of the weights and gains resulting in the model. May steer prices, however, ranged between about $1.45 and $2.15 under the states of nature used in the model. The low marginal cost of gain relative to returns favored feeding the animals over the winter period.

Even when summer grazing was made costless, the optimal strategy was still to sell animals in May. This strategy resulted primarily from the behavior of steer prices over the year. Prices over the winter and spring generally trended upwards. However, the price index over the 25 years of prices used reflected an average October price that was over 5% lower than the preceding May's price. Given the relatively low cost of winter gain, net returns were highest by feeding to high rates of gain over the winter and selling the 373- to 391-kilogram animals at the end of the winter feeding period.

Risk Sensitive Production and Marketing Strategies

There was no diversification of sales over time in the sequential model when both production and marketing decisions were choice variables. Either no animals were sold at a marketing node or all animals were sold. This may be expected in the risk-neutral case. Reconsider figure 1. Assume decision X_A is to sell all animals in the first period and $X_{\bar{A}}$ is to sell no animals in the period. Assume further that A is the monetary outcome of X_A and $E\bar{A}$ is the expected outcome of $X_{\bar{A}}$. The marketing decision in period A then is to choose the action yielding the highest reward (or expected reward). Assuming no lumpiness or economies in sales of different lot sizes, there will be no value c $(0 \leq c \leq 1)$ such that $cA + E((1 - c)\bar{A})$ is greater than the maximum of A or $E\bar{A}$. The optimal action will thus be either X_A or $X_{\bar{A}}$.

In order to test the sensitivity of the model to risk considerations, the production and marketing problem was reformulated as a MOTAD (Minimization of Total Absolute Deviations) model (Hazell). Constraint rows were added to calculate total absolute deviation from the mean of income under all states of nature. Total absolute deviation was then minimized subject to increasingly lower bounds placed on expected net returns.

Sales occurred earlier in the year and animal weights were lower as the expected net return was constrained to be smaller. In addition, calves were not always sold in lots of 100 animals. In some cases, smaller lots were sold at different times throughout the marketing period. However, as observed elsewhere (Lambert and McCarl), diversification along a particular branch of the decision tree was limited. The risk-return frontier is illustrated in figure 3.

Concluding Statements

The value of the discrete stochastic programming model as an approximation to the real-world decision environment is hard to refute. Discrete events represent the decision maker's expectations of the future. Alternative optimal strategies are derived in the model contingent upon an event's occurrence. The structure of the model allows a large number of alternative future states limited only by computational capabilities and the analyst's ability to interpret the results for the decision maker.

A decision problem common to many cow/calf producers was modeled in this paper: Given prevailing input costs and expected output prices, should some or all weaned calves be retained in the fall? If so, to what rate of gain should they be fed over the winter and should they then be sold or placed on rangeland for additional gains over the coming summer?

Rates of gain were highest over the winter when all animals were to be sold in the spring. Gain was found to be positively related with the decision maker's expected prices. Rates of gain were lower when the animals were to be placed on rangeland following the winter period. Advantage was taken of the compensatory gain available on the cheaper summer range.

Calves were retained through the winter under all states of nature in which both production and marketing activities were choice variables. Optimal rates of gain under favorable price expectations were about one kilogram per day. All calves were sold in spring under all states of nature with none of the animals being placed on range.

An interesting question still remains given the result of this and other conditional normative models of the cow/calf producer's decision problem. Namely, if models indicate

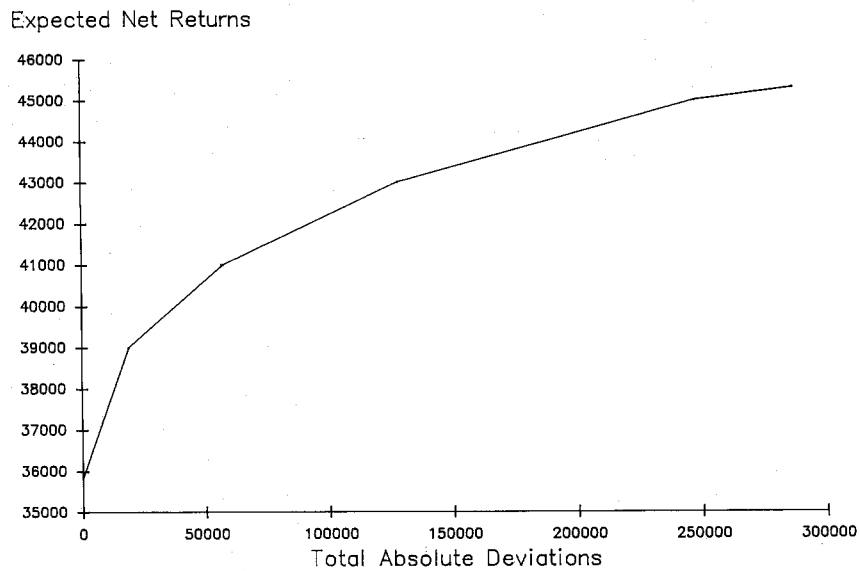

Figure 3. Expected net returns—total absolute deviation frontier

higher returns (even when adjusted by risk considerations) when calves are retained, why are fall sales of weaned calves the predominant sales strategy in the West? Several hypotheses can be offered for this behavior. Further research is needed to determine which hypothesis, or combination of hypotheses, best explains producer behavior.

First, perhaps producers are more averse to risk than elicitation measures generally predict. A recent survey of a small group of Nevada ranchers found only slight degrees of risk aversion (Wood, Lambert, and Torell), indicating that the increased price and production risk of feeding animals over the winter should be relatively unimportant. However, an extremely risk-averse producer would seem most likely to sell all animals in the fall thus avoiding all future risk.

Second, cash flow constraints may require many ranchers to sell animals in the fall. Even though a 10% discount rate was incorporated in the model, financial markets may not be perfect. Lender approval would be necessary to delay repayment of operating loans by six months. Such approval may not be forthcoming.

Third, ranchers' objectives may be characterized by satisficing behavior. There may be a limited search for marketing alternatives with fall sales resulting from observing prices that are "good enough." If traditional fall marketings result in returns that, in most years, satisfy producer financial goals, there may be no perceived reason for exploring alternative strategies.

Finally, ranchers may be faced with physical or labor constraints that prevent winter feeding of large numbers of animals. It is commonly observed that, even though the bulk of the sales occur in the fall, a cow/calf producer may hold a small number of lighter calves over the winter to put additional weight on them prior to a spring sale. With additional holding facilities, the availability of low-cost labor, and animal performance similar to that incorporated into the discrete stochastic programming model, perhaps a larger percentage of the calves would be retained.

All of these possibilities could be tested. Additional research linking rancher goals and conditional normative decision models would enhance the validation of models appearing in the literature.

The model can be used, in its present form, to formulate optimal production and marketing rules, conditional upon observed and expected price outcomes. The results can be used to assist decision makers when appropriate feed cost, output price events, and animal performance equations are inputted. Educational benefits derive as well from noting the sensitivity of the model to risk, expected compensatory gain, and optimal production levels under alternative future price events.

[*Received September 1988; final revision received February 1989.*]

References

Antle, John M. "Sequential Decision Making in Production Models." *Amer. J. Agr. Econ.* 65(1983):282–90.

Bohman, Verle R. "Compensatory Growth of Beef Cattle: The Effect of Hay Maturity." *J. Animal Sci.* 14(1955): 249–55.

Bohman, Verle R., and Clark Torell. "Compensatory Growth of Beef Cattle: The Effect of Protein Supplements." *J. Animal Sci.* 15(1956):1089–96.

Burt, Oscar R. "A Dynamic Economic Model of Pasture and Range Investments." *Amer. J. Agr. Econ.* 53(1971):197–205.

Cocks, K. D. "Discrete Stochastic Programming." *Manage. Sci.* 15(1968):72–79.

Fox, D. G., and J. R. Black. "A System for Predicting Performance of Growing and Finishing Cattle. 1. Development of a Model to Describe Energy and Protein Requirements and Feed Values." *Feedstuffs* 49(22-1977):21.

———. "A System for Predicting Body Composition and Performance of Growing Cattle." *J. Animal Sci.* 58(1984):725–39.

Garoian, L., J. R. Conner, and C. J. Scifres. "A Discrete Stochastic Programming Model to Estimate Optimal Burning Schedules on Rangeland." *S. J. Agr. Econ.* 19(December 1987):53–60.

Gebremeskel, T., and C. Richard Shumway. "Farm Planning and Calf Marketing Strategies for Risk Management: An Application of Linear Programming and Statistical Decision Theory." *Amer. J. Agr. Econ.* 61(1979):363–70.

Gilliam, Henry C. *The U.S. Beef Cow-Calf Industry.* U.S. Department of Agriculture, Economic Research Service, Econ. Rpt. No. 51, Washington DC, 1984.

Hazell, P. B. R. "A Linear Alternative to Quadratic and Semivariance Programming for Farm Planning under Uncertainty." *Amer. J. Agr. Econ.* 53(1971):53–62.

Kaiser, H. M., and J. Apland. "A Risk Analysis of Farm Program Participation." Minnesota Agr. Exp. Bul. No. 578, Dept. of Agr. and Applied Economics, University of Minnesota, 1987.

King, Robert, and D. Lybecker. "Flexible, Risk-Oriented Marketing Strategies for Pinto Bean Producers." *West. J. Agr. Econ.* 8(1983):124–33.

Lambert, David K., and B. A. McCarl. "Sequential Modeling of White Wheat Marketing Strategies." *N. Cent. J. Agr. Econ.* 11(1989):105–15.

Madansky, A. "Linear Programming under Uncertainty." *Recent Advances in Mathematical Programming,* eds., R. Graves and P. Wolfe, pp. 103–10. New York: McGraw-Hill, 1963.

National Research Council. *Nutrient Requirements of Beef Cattle,* 6th revised ed. Washington DC: National Academy Press, 1984.

Olson, K. D., and C. L. Mikesell. "The Range Stocking Decision and Stochastic Forage Production." Selected paper, Western Agricultural Economics Association Annual Meeting, July 1988.

Rae, Allan N. "Stochastic Programming, Utility, and Sequential Decision Problems in Farm Management." *Amer. J. Agr. Econ.* 53(1971a):448–60.

———. "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management." *Amer. J. Agr. Econ.* 53(1971b):625–38.

Rodriguez, Abelardo, and L. Roy Roath. "A Dynamic Programming Application for Short-Term Grazing Management Decisions." *J. Range Manage.* 40(1987): 294–98.

Rodriguez, Abelardo, and R. G. Taylor. "Stochastic Modeling of Short-Term Cattle Operations." *Amer. J. Agr. Econ.* 70(1988):121–32.

Rogers, LeRoy F., and John W. Malone, Jr. *Economics of Feeding Rates for Wintering Calves in Northern Nevada.* Max C. Fleischmann College of Agriculture, University of Nevada–Reno, Publication R-27, September 1966.

Stokes, Kenneth W., Donald E. Farris, and Thomas C. Cartwright. "Economics of Alternative Beef Cattle Genotype and Management/Marketing Systems." *S. J. Agr. Econ.* 13(December 1981):1–10.

Tintner, G. "Stochastic Linear Programming with Application to Agricultural Economics." *Second Symposium on Linear Programming,* pp. 197–228. National Bureau of Standards, Washington DC, 1955.

Whitson, Robert E., Peter J. Barry, and Ronald D. Lacewell. "Vertical Integration for Risk Management: An Application to a Cattle Ranch." *S. J. Agr. Econ.* 8(December 1976):45–50.

Wood, Theodore K., David K. Lambert, and Dave Torell. *Goals and Risk Attitudes of Mojave Desert Beef Cattle Producers.* College of Agriculture, University of Nevada–Reno (forthcoming).

Yager, W. A., R. C. Greer, and O. R. Burt. "Optimal Policies for Marketing Cull Beef Cows." *Amer. J. Agr. Econ.* 62(1980):456–67.