Ranch Decision-Making under Uncertainty—an Illustration

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Highlight: *Risk and uncertainty were explicitly included in a ranch decision model by the use of quadratic programming. Alternative ranch organizations are presented for a typical ranch firm in the Rolling Plains of Texas. These organizations illustrate the trade-offs between increasing net ranch income and the annual stability of income. To increase profits, the typical rancher was required to assume increasing amounts of risk. Incorporation of risk in the decision model improved understanding of the decision-making process of ranchers and the reasons why two similar ranchers could be "optimally" organized and operate with completely different ranch plans.*

Many of the production problems which confront agricultural firms stem from risk and uncertainty resulting from changing weather conditions, production techniques, demand or supply relationships, legal environment, institutional arrangements, etc. Just as growing plants evolve and adapt to changing environmental conditions, the firm manager responds, adapts or reacts to his continually changing environment so as to mitigate the adverse effects of risk and uncertainty.

This article illustrates a method to incorporate risk and uncertainty into a traditional economic analysis for improved decision-making by ranch managers (Whitson, 1974). Traditional economic analysis, as an example, linear programming, (Woodworth, 1973; D'Aquino, 1974; and Bartlett et al., 1974), provides a valuable means for evaluation of alternative production activities, the decision criteria normally related to maximizing profits (or minimizing costs in some examples) from a given set of resources. This function of economic analysis is important for improving resource allocation and thus economic efficiency. However, individual producers may not follow the "optimal" linear programming (LP) because the solution ignores sources and magnitude of risks. Decision models are needed which include considerations of risk and uncertainty as well as profits to better explain and/or predict managerial behavior.

Typical managerial responses to reduce and/or cope with adverse effects of a dynamic and uncertain environment include the following actions: (1) diversifying production, (2) maintaining flexibility so that needed changes may be recognized and production adjusted, (3) using marketing alternatives (futures market, forward contracting) to reduce price variation, (4) purchasing insurance, and (5) holding ready reserves of cash and credit (Hopkin, 1973). Diversification of production in ranching may result from the adoption of alternative grazing systems such as a deferred-rotational grazing program as opposed to a continuous year-long grazing program. Other examples might include adding stocker and feedlot activities to the traditional weaned calf phase of beef production.

These alternatives to reduce or cope with risk and uncertainty may be incorporated into a traditional economic analysis by a relatively new operations research technique, quadratic programming (QP). QP allows the tradeoffs between net income and stability of income to be quantified and has been used as a technique in investment analysis (Markowitz, 1959).

Risk Programming

Continued refinements in the theory of decision-making under uncertainty and greater capacity for computer application have prompted numerous applications of risk programming. In general, results illustrating the trade-offs between expected net income and stability of income have clearly indicated why ranch managers are not simply profit maximizers but are also concerned with risk (How and Hazell, 1968; Scott and Baker, 1972). This helps to explain why a ranch manager may not be fully receptive to a profit maximizing ranch plan developed, for example, by an LP analysis.

The quadratic program (QP) may be used for developing a series of "risk-efficient" ranch plans for a fixed quantity of ranch resources. This series of plans is considered "risk-efficient" in that each ranch plan yields minimum income variance for alternative levels of expected income. The graphing of expected net income derived from each plan in the series against each plan's respective variance of net income (usually presented as a standard deviation) may be expressed as an expected income-variance (E-V) boundary. The highest point on the E-V boundary is always the LP solution, which consequently is the plan which produces the greatest net income and variance of income.

Ranch resources may be utilized in many alternative ranch plans capable of producing a wide range in net income. The primary benefit of the QP analysis is that for a given set of ranch resources, many efficient income-variance ranch organizations may be derived. Given this efficient set of organizations, the ranch manager may then choose from

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among the "efficient" ranch organizations that specific one which most closely fits his risk-return preference. Thus, an "optimal" ranch organization or plan for one manager might not be the same as that for another manager with similar resources. The traditional LP analysis gives but one choice of ranch plans for a given resource situation, that plan which yields maximum income.

Data Requirements and Assumptions

To utilize a QP, the following data are required:

(1) Feasible production alternatives are identified by the ranch manager for inclusion in a ranch operating plan;

(2) Enterprise budgets are developed describing expected returns and costs for alternatives identified in (1);

(3) Resource use rates are established for the various alternatives identified in (1);

(4) Maximum resource levels are defined including maximum available credit, land, labor, etc.; and

(5) Variances and covariances of income are established for the group of alternatives established in (1) above.

Steps 1 through 4 are identical to requirements involving the use of an LP analysis (Richmond, 1968). Variances and covariances of the income-producing activities are usually developed from historical time series data relating to each activity (estimates may require adjustments for time trends or other related statistical problems, Halter and Dean, 1971). Once variances and covariances have been developed, there is also the question of whether these data form a proper basis for projections of future variance estimates. An underlying assumption is that factors which are important in causing income variance in the past will also be important in the future. This assumption appears reasonable for the range livestock industry.

The principal assumptions associated with the development of optimal ranch plans illustrating expected net income (E) and associated minimum net income variances (V) are as follows (Hazell, 1971):

(a) A rancher develops a preference between alternative ranch plans solely on the expected income and associated income variance of the plans;

(b) A producer is a risk-averter in that given two plans that produce equal average income, the producer prefers that one with less income variability;

(c) The net income values used for calculating variances are normally distributed around a mean; and

(d) Net income from the production alternatives are independent from one time period to another.

QP Analysis—An Illustration

A typical ranch firm was modeled to evaluate the effects of alternative managerial actions on risk and returns for a fixed resource base of land and capital. The typical ranch was located in the Rolling Plains of Texas and was composed of 4800 acres of native rangeland composed of Deep Upland, Rolling Hills and Rocky Hills range sites in fair to good range condition. The ranch received 20 to 24 inches of rainfall annually. Past data indicated 25% of the years had less than 17 inches of rainfall. Fifty-six percent of the years had been below average (Hildreth and Thomas, 1956).

Included in ranch resources were 600 acres of cropland which could be utilized for dryland wheat production and/or for cash leasing to others. Additionally, there was $150,000 non-real estate credit available to the ranch manager as determined from equity in cows and machinery. The ranch manager had a primary objective of firm survival and a secondary objective of maximizing net income.

The alternatives being considered by the ranch manager included weaned calf production for moderate stocking rates (approximately 16 acres/animal unit [AU]) in combination with continuous stocking (no supplemental feed) and four pasture deferred-rotation (with and without supplemental feed) grazing programs. Heavier stocking rates (approximately 12 acres/AU) were also considered in combination with continuous stocking (without supplemental feed) and a two pasture deferred-rotation grazing program (alternatives selected from research in the Texas Rolling Plains, Kothmann, 1970). Also, the ranch manager was assumed to be considering the use of wheat pasture and/or fattening retained weaned and purchased steers in a custom feedlot as additional livestock production phases to increase and/or stabilize ranch income.

Average budgets reflecting the gross margins (gross sales less variable costs of production) were developed for each production alternative in the model. These budgets were based on data which had been collected during the past 5 years (1969 through 1973) from research results obtained from the Texas Experimental Ranch at Throckmorton, Texas; monthly livestock market reports; and additional information obtained from Texas Agricultural Extension personnel in the area. This average budget became the "estimate" for the future in the decision-model. The annual budgets (gross margins) for each activity were utilized to develop estimates of variances and covariances. For example, the weaned steers retained from a moderately stocked four-pasture deferred-rotation system with supplemental feed and further grazed on wheat pasture added $13.92, $19.64, $29.15, $7.09, and -$41.87 per head when placed in a feedlot for the years 1969 through 1973, respectively. This budgeting procedure was accomplished for each income-producing activity in the model. Standard statistical techniques were then utilized to obtain variance and covariance estimates from the annual gross margins.

Results and Discussion

The results from using a QP program (Cutler and Pass, 1971) for analysis are illustrated by Figure 1. A range of plans, X1 through X6, are presented producing from $41,000 to $76,000 average net income, respectively. The respective standard deviation of income (variance) ranges from $3,300 to $45,500 (Fig. 1).[1]

Plan X6 (Fig. 1) represents the traditional LP solution. The ranch plan producing maximum net income also produces the maximum quantity of net income variation. Thus, efforts to increase the expected income will always be accomplished by a relatively larger increase in variability of that income for a fixed resource base and given production alternatives.

Alternative ranch plans (X1 through X6) are described in Table 1. Each plan is organized differently, depending on the

[1] Weaned calf price variation was not allowed to influence the optimal choice of grazing systems because grazing systems are long-term considerations; it was allowed to influence additional phases of livestock production since this choice may be made annually.

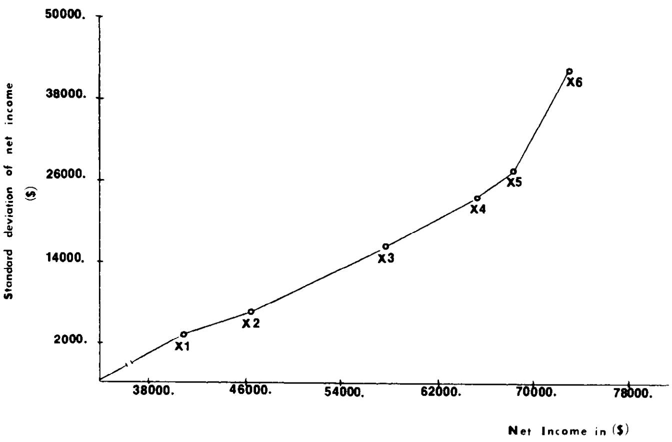

Fig. 1. *Relationship between level of net income and standard deviation of net income for alternative ranch organizations (X1–X6), Texas Rolling Plains.*

following: 1) the choice of grazing system and stocking rates for producing weaned calves, 2) weaned calves which may be sold, grazed on wheat pasture, fattened in a custom feedlot or grazed on wheat pasture followed by finishing in a feedlot, 3) the purchase of additional steers for use on wheat pasture, feedlots or both, and 4) use of cropland.

The composition of each plan (X1–X6) is presented in Table 1. For a given enterprise, such as the sale of weaned calves, the degree of risk may be observed by comparing alternative plans. For example, Plan X1 requires that all weaned calves produced from a moderately stocked, four-pasture deferred-rotational grazing system be sold at weaning. Additionally, all cropland is cash leased to another producer.

There are several alternatives to increase net income beyond $41,000. However, there is one optimal combination (risk-efficient) of enterprises to produce $46,000 (Plan X2) of income with minimum variance. Basic changes from Plan X1 include the following: (1) 11% of the weaned steers are retained and placed in a custom feedlot, (2) the stocking rate is increased and a two-pasture deferred-rotational grazing system selected, and (3) 6% of the cropland is farmed rather than being leased.

Since the QP analysis provides a means to select combinations of enterprises that produce minimum income variability at selected income levels, it is possible to rank the order that individual production enterprises will enter "risk efficient" solutions. As an example, the placement of retained weaned steers on wheat pasture and subsequently into a custom feedlot generates more expected profit than selling the retained steers following wheat grazing or custom feeding. However, from a variance standpoint, wheat grazing is relatively more "risky" for this study than is custom feeding. Thus, all means of expanding net ranch income are utilized (illustrated by composition of Ranch Plans X1 through X5) before grazing of wheat is selected as a means to increase income. The optimal LP solution would include wheat grazing in an optimal plan with no organizational alternatives provided the decision maker.

Each enterprise listed in Table 1 may be compared for Ranch Plans X1–X6 to better understand relative differences of income stability. Enterprises entered the optimal "risk efficient" plans on the basis of variance per dollar of net income produced.

A logical question might be, "Which of the six alternative ranch plans should the typical rancher select?" This question cannot be answered as easily for the rancher as it can be from models which have the single objective of maximization of profits. Thus, before the typical rancher can select an operating plan, he must establish *his* risk-return preference between income and stability of income. One way to establish the risk-return preference is to use a multiple objective function. This criterion for selection requires that (1) managerial goals or objectives be ordered and (2) priorities for satisfactory attainment be established. Then the first objective must be met or satisfied before the second is turned to and so

Table 1. Ranch organizations to minimize income variance for alternative net income levels in the Texas Rolling Plains.

Measurement	Unit	Ranch organizations[1]					
		X1	X2	X3	X4	X5	X6
Production alternatives							
Grazing system utilized[2]	N/A	M4PS	H2P	H2P	H2P	H2P	HC
Breeding herd size	Head	265	328	328	328	328	364
Raised livestock sold as:[3]							
(1) Weaned calves	%	100	89	0	0	0	0
(2) Wheat pasture (WP) steers	%	0	0	0	0	0	0
(3) Feedlot (FL) steers	%	0	11	100	100	100	0
(4) (WP) and (FL) steers	%	0	0	0	0	0	100
Purchased steers sold from:[4]	Head	0	0	0	69	208	426
(1) Wheat pasture (WP)	%	0	0	0	0	0	100
(2) Feedlot (FL)	%	0	0	0	100	100	0
Cropland farmed	%	0	6	61	100	100	100
Capital required (000)	$	11	15	42	73	123	150
Expected net income[5] (000)	$	41	46	58	65	68	74
Standard deviation (000)	$	3.3	6.2	15.6	22.7	26.7	45.5

[1] The respective plans are presented on Figure 1.
[2] H=heavy stocking, M=moderate stocking, C=continuous grazing, 4P and 2P refer to four and two pasture deferred-rotational grazing systems, S=supplemental feed.
[3] All heifers were sold as weaned calves or were used as replacement cows.
[4] The use of wheat pasture followed by finishing in a feedlot was also an available alternative. However, it was not selected as a component of any of the plans presented.
[5] Expected net income refers to expected gross sales less variable costs of production.

on until all objectives are maximized or at least met.

For this analysis it was assumed that the first goal of the manager was to ensure the survival of the ranch firm. The survival level depends on (1) what constitutes a "disaster" level of net income and (2) with what degree of probability the rancher is willing to accept less than this "disaster" level. The second goal, once the first goal was satisfied, was assumed to be maximization of net income.

To illustrate the use of this decision criterion, assume the rancher has a fixed cash requirement of $30,000 per year. The rancher considers annual income of less than this amount as a disaster because he would not be able to meet annual land payments, cow payments, and minimum consumption requirements. Further, assume the typical rancher requires that a selected operating plan provide at least $30,000 annual "disaster" income 90% of the time.

By the use of a standard *t* table, and utilizing the standard deviation of net income determined from the QP analysis, the lower boundary of the net income confidence interval may be derived for each ranch plan (Table 2). Ranch Plans X1 through X4 satisfy the typical rancher's first priority; i.e., the typical rancher could expect Ranch Plans X1 through X4 to produce at least $30,000 net income requirement and also produces maximum net income of the four plans.

Given the risk-return objectives (increases in net income versus stability of net income) of the typical rancher, the "optimal" ranch plan to maximize the typical rancher's objective produced $65,000 net income (versus the traditional optimal ranch plan of $76,000). Thus, the typical rancher in this example was willing to give up $11,000 of average net income in return for an increase in ranch income stability of $26,000 at the 90% level of confidence.

Ranch Plan X4 differed considerably from Plan X6 (Table 1). An important distinction is that resources are not allocated to maximize net income with Ranch Plan X4; rather they are allocated to maximize the ranch manager's objectives. These objectives include risk and return components.

Limitations of the Model

There are several problems associated with the use of risk programming models such as quadratic programming. The major ones are as follows: 1) overcoming computational difficulties associated with the use of available computer programs (Batterham, 1971), 2) determining the most important components of risk (Dillon and Anderson, 1971), 3) measuring risk (Hazell, 1971), and 4) considering input-output coefficients in the model as deterministic (Rae, 1970).

Table 2. Ninety percent confidence level for production of minimum net income ($) from alternative ranch organizations in the Texas Rolling Plains.

Ranch[1] organization	Lower net income[2] boundary-90% level (000) ($)	Meets the minimum[3] income requirement
X1	36	Yes
X2	37	Yes
X3	34	Yes
X4	30	Yes
X5	27	No
X6	4	No

[1] See Table 1 for a description of the ranch organizations.
[2] These values represent the lower quantity of net income which would be expected 90% of the time. This value is determined by subtracting the standard deviation times the appropriate 90% *t* value from the expected net income.
[3] Plan X4 maximizes expected income while meeting the minimum income requirement of $30,000.

Despite the above limitations, it appears the analysis greatly improves the traditional economic model's approximation of "real world" decision making by ranch managers and stands as a valuable tool to improve ranch managers' decision making under uncertainty.

Summary and Conclusions

An analytical model was proposed to incorporate risk and uncertainty faced by ranch managers into a traditional economic analysis for improved decision making. A typical ranch situation was developed for the Texas Rolling Plains to evaluate alternative risk reducing managerial responses by evaluating the trade-offs between net income and uncertainty.

In order to increase profits, the typical rancher was required to assume increasing amounts of risk. Thus, given different risk-return preferences of ranchers, it becomes apparent why the higher level of risk associated with profit-maximizing plans may not be acceptable to all ranchers. The incorporation of risk and uncertainty in a decision model improves the understanding of the decision-making process of ranchers and explains why two ranchers might be "optimally" organized with completely different ranch plans, depending on their individual risk-return preferences.

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