The Value of Seasonal Precipitation Forecasts in a Haying/Pasturing Problem in Western Oregon

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ABSTRACT

The economic value of current and hypothetically improved seasonal precipitation forecasts is estimated for a regionally important haying/pasturing problem in western Oregon by modeling and analyzing the problem in a decision-analytic framework. Although current forecasts are found to be of relatively little value in this decision-making problem, moderate increases in the quality of the forecasts would lead to substantial increases in their value. The quality/value relationship is sensitive to changes in various economic parameters, including the decision maker's attitude toward risk.

1. Introduction

A significant fraction of the agricultural land in western Oregon is devoted to forage crops for feeding sheep and cattle (Miles, 1983). Improved fields in this area are typically grass-legume mixtures. Cool temperatures and excessive soil moisture in winter, together with low summer rainfall, limit the utilization of these fields to spring and early summer. Successful preservation of the spring growth as a single cutting of sun-cured hay in June produces the maximum economic return from this land. However, the frequency of June rainfall in western Oregon is such that the hay crop, once cut, has a substantial probability of being damaged or completely ruined through leaching of nutrients and/or molding (e.g., Hall, 1980; Watson and Nash, 1960). A typical management alternative to haymaking is to use the fields for grazing. This alternative produces a lower but less variable income than haymaking.

The decision whether to attempt haymaking or to utilize growth for pasture must be made in early spring. As is the case in other agricultural decision-making situations, forecasts of future weather conditions may be of value in this haying/pasturing problem. Decision analysis (e.g., Keeney, 1982; Raiffa, 1968; Winkler and Murphy, 1985) represents an appropriate and useful framework within which to study this decision-making problem, and it also provides a sound methodology for assessing the *ex ante* value of information. This methodology has been used recently in a meteorological context to investigate the value of forecasts in the daily frost protection problem faced by orchardists (Katz *et al.*, 1982), as well as in the seasonal choice-of-crop (Winkler *et al.*, 1983) and fallowing/planting (Brown *et al.*, 1984) problems faced by small grains farmers.

The present study involves an application of decision analysis to the assessment of the economic value of seasonal precipitation forecasts in the haying/pasturing problem in western Oregon. Since the decision in a given year does not appear to be strongly influenced by decisions in previous or future years, the situation of interest here is modeled as a static problem. The approach taken is similar to that employed by Winkler *et al.* (1983), but the model is somewhat more complex in this case because of the uncertainty associated with successful haymaking. In addition, this study utilizes realistic values for the economic parameters in the decision-making model, and the analysis is extended to include the effects of the decision maker's attitude toward risk. A model of the basic decision-making problem is described in Section 2. Section 3 defines the forecasts of interest and provides expressions for their economic value. Numerical results are presented and discussed in Section 4, and Section 5 contains some concluding remarks and briefly considers several possible refinements to the analysis reported here.

2. Haying/pasturing problem: Components of the model

a. Actions and events

Three actions a_i (i = 1, 2, 3) are included in the haying/pasturing decision-making problem: 1) use forage growth as pasture (a_1); 2) attempt haymaking (a_2); and 3) attempt haymaking with supplemental fertilization (a_3). A set of three mutually exclusive and collectively exhaustive climate events θ_j (j = 1, 2, 3) is also considered. These events relate to total spring season (April–June) precipitation, and they are defined as follows: 1) below normal precipitation (θ_1); 2) near normal precipitation (θ_2); and 3) above normal precipitation (θ_3).

b. Economic returns

In order to use the decision-analytic framework, it is necessary to specify the net returns (to the farmer) associated with each of the nine pairs of actions and events. These returns will be represented by a returns function $R(a_i, \theta_j)$ $(i, j = 1, 2, 3)$. For pasturing (a_1), the numerical value of this function will simply be the net income over the pasture season. Since the success of a haymaking attempt is uncertain, the form of the returns function for a_2 and a_3 necessarily involves a statistical expectation with respect to hay quality.

In the case of pasturing, it is assumed that fences and livestock watering facilities are in place, so that no additional expenses are incurred when action a_1 is taken. Pasture rental is approximately \$0.35 per acre per day for the duration of the pasture season. The pasture season in western Oregon begins in early to mid-April, and it ends when stored soil moisture is insufficient to support good plant growth. This date may be as early as the latter part of June in dry years, or as late as the end of July in wet years. Net income depends on the length of the pasture season N_j $(j = 1, 2, 3)$, which may reasonably be regarded as completely determined by spring season precipitation. Typically, $N_1 = 75$, $N_2 = 100$, and $N_3 = 115$ days, corresponding to years with dry, near normal, and wet springs, respectively.

Precipitation in the spring is sufficient not to limit the growth of a hay crop. As a result, hay yield may be considered to be a function of fertility level. When haymaking is attempted, the yield is approximately 2 tons per acre without supplemental fertilization (a_2) and 3 tons per acre with the application of supplemental fertilizer (a_3). The expense of hay processing is approximately \$25 per ton in each case, and the expense of supplemental fertilization is approximately \$20 per acre. Income from haymaking depends on the quality of the hay. Although much of the hay produced in western Oregon is consumed on-farm, the trade in this commodity is sufficient for a market price to be well-established. The price of first-quality hay is \$60 per ton, the price of second-quality (damaged) hay is \$35 per ton, and ruined hay is essentially unsalable. Income (i.e., actual net income) as a function of hay quality, $I(a_i, \theta_k^*)$ $(i = 2, 3; k = 1, 2, 3)$, is presented in Table 1. Here θ_1^* represents first-quality hay, θ_2^* represents second-quality hay, and θ_3^* represents ruined hay.

Since the timing of precipitation events is uncertain relative to a hay cutting date, it is possible that a haying attempt may result in good, damaged, or ruined hay regardless of total spring precipitation. However, the probability of successful haymaking should be a decreasing function of seasonal precipitation amount. Haymaking income may thus be regarded as a random variable, conditional on spring precipitation amount. In order to calculate the returns $R(a_i, \theta_j)$ $(i = 2, 3; j = 1, 2, 3)$, it is necessary to estimate the conditional probabilities of hay quality given total spring precipitation, $P_{\Theta^*|\Theta}(\theta_k^*|\theta_j)$ $(j, k = 1, 2, 3)$. These probabilities were obtained using actual meteorological data and a simplified haymaking model. The model is similar to that used by Smith *et al.* (1971), although it more accurately reflects conditions in western Oregon and explicitly includes the effect of temperature on drying rate.

TABLE 1. Income function $I(a_i, \theta_k^*)$ $(i = 2, 3; k = 1, 2, 3)$ for haymaking (dollars per acre).

Action	Hay quality		
	First-quality (θ_1^*)	Second-quality (θ_2^*)	Ruined (θ_3^*)
Hay (a2)	70	20	−50
Hay with fertilization (a3)	85	10	−95

Briefly, the model begins its annual haymaking attempt subsequent to 1 June on the first rainless day which immediately follows a rainless day with a maximum temperature greater than 26°C. Once the hay has been cut, the (cumulative) progress of the drying process is estimated from the daily maximum temperatures; specifically, the hay is half dried during days where $T_{max} \geqslant 35°C$, one-third dried for $30°C \leqslant T_{max} < 35°C$, one-fourth dried for $24°C \leqslant T_{max} < 30°C$, and one-fifth dried for $19°C \leqslant T_{max} < 24°C$. If no measurable rain occurs before drying is completed, then the hay is considered to be first quality. If more than one inch of rain occurs before drying is completed, or if two consecutive wet days occur and more than 2.54 mm of rain has accumulated, then the hay is assumed to be ruined. Otherwise the hay is considered to be second quality.

Daily records of precipitation and maximum temperature (April through July, 1890–1983) for Corvallis, Oregon, were used as input to the haymaking model. July data were included only in wet or cool years, when the model haymaking process extended into that month. The conditional distribution $P_{\Theta^*|\Theta}(\theta_k^*|\theta_j)$ was estimated by grouping the 94 years according to spring precipitation amount (i.e., θ_j as defined in Section 3a) and computing conditional relative frequencies of the hay quality categories. This distribution is presented in Table 2.

The returns function is then given by

$$R(a_i, \theta_j) = \begin{cases} 0.35N_j, \quad i = 1; j = 1, 2, 3 \\ E_{\Theta^*|\Theta}[I(a_i, \theta_k^*)] = \sum_{k=1}^{3} [P_{\Theta^*|\Theta}(\theta_k^*|\theta_j) I(a_i, \theta_k^*)], \\ \qquad i = 2, 3; j, k = 1, 2, 3. \end{cases} \quad (1)$$

TABLE 2. Conditional distribution of hay quality given seasonal precipitation amount category, $P_{\Theta^*|\Theta}(\theta_k^*|\theta_j)$, and associated marginal distributions $P_\Theta(\theta_j)$ and $P_{\Theta^*}(\theta_k^*)$ ($j, k = 1, 2, 3$).

	Hay quality			
	First-quality (θ_1^*)	Second-quality (θ_2^*)	Ruined (θ_3^*)	$P_\Theta(\theta_1)$
Below normal precipitation (θ_1)	0.7500	0.1071	0.1429	0.3000
Near normal precipitation (θ_2)	0.6579	0.1579	0.1842	0.4000
Above normal precipitation (θ_3)	0.5357	0.1429	0.3214	0.3000
$P_{\Theta^*}(\theta_k^*)$	0.6489	0.1383	0.2128	1.0000

Thus, for a_1 (decision to pasture), the returns are given by the product of the length of the pasture season and the daily pasture rental income. When haymaking is attempted, the returns will be the average income, probability weighted according to hay quality and spring precipitation. The numerical values of $R(a_i, \theta_j)$ in (1) are presented in Table 3, in dollars per acre per year.

c. Utilities

The returns in Table 3 are appropriate for a decision maker who is risk neutral (i.e., whose utility function for monetary returns is linear; for example, see Winkler and Murphy, 1985). The sensitivity of the value of forecasts to departures from the assumption of risk neutrality will be investigated by defining a utility function $U(a_i, \theta_j)$ over the range of returns in $R(a_i, \theta_j)$. This utility is given by

$$U(a_i, \theta_j) = \{[R(a_i, \theta_j) - 16.43]/34.82\}^\beta, \quad (\beta > 0;\ i, j = 1, 2, 3). \quad (2)$$

The numerical scaling constants in (2) are arbitrary, and they have been chosen such that $0 \leqslant U(a_i, \theta_j) \leqslant 1$ for convenience. Risk-averse utility functions are represented when the "risk attitude" parameter β is less than unity, and risk-seeking utility functions are represented when β is greater than unity. Thus, the marginal "worth" of monetary returns is a decreasing function of the returns for a risk-averse decision maker, an increasing function of the returns for a risk-seeking decision maker, and constant for a risk-neutral decision maker (e.g., see Keeney, 1982; Winkler and Murphy, 1985).

TABLE 3. Returns function $R(a_i, \theta_j)$ ($i, j = 1, 2, 3$) (dollars per acre-year).

	Precipitation		
Action	Below normal (θ_1)	Near normal (θ_2)	Above normal (θ_3)
Pasture (a1)	26.25	35.00	40.25
Hay (a2)	47.50	40.00	24.29
Hay with fertilization (a3)	51.25	40.00	16.43

3. Nature and value of forecasts

a. Definition and quality of forecasts

The forecasts of interest in the present context are the seasonal precipitation forecasts issued by the National Weather Service (NWS) (Gilman, 1983). These forecasts indicate the probability of below normal, near normal, and above normal precipitation, and currently assign a constant probability of 0.40 to near normal precipitation. Thus, each forecast is completely specified by a single probability. Let $Z = z$ be the forecast probability that spring precipitation will be below normal. The conditional distribution of spring precipitation, given the forecast, is then

$$\left.\begin{aligned} P_{\Theta|Z}(\theta_1|z) &= z \\ P_{\Theta|Z}(\theta_2|z) &= 0.40 \\ P_{\Theta|Z}(\theta_3|z) &= 0.60 - z \end{aligned}\right\}, \quad (3)$$

for completely reliable forecasts. The assumption of perfect reliability has been made since the number of probabilistic seasonal precipitation forecasts issued to date is insufficient to allow reasonable assessment of their actual reliability.

In the present study, a near normal spring will be defined as one in which the precipitation total falls within the central 40% of the probability distribution. Wet or dry springs are characterized by precipitation totals in the upper or lower 30% tail regions, respectively. Thus, climatological information (i.e., a climatological forecast) for seasonal precipitation is defined by

$$\left.\begin{aligned} P_\Theta(\theta_1) &= 0.30 \\ P_\Theta(\theta_2) &= 0.40 \\ P_\Theta(\theta_3) &= 0.30 \end{aligned}\right\}. \quad (4)$$

Current forecasts will be represented by the simplified predictive distribution $P_Z(z)$ derived by Brown *et al.* (1984) from data made available by the NWS. This distribution specifies the relative frequencies with which particular forecasts are made, and it is presented in Table 4. In addition, this table contains predictive distributions for forecasts based on climatological information, perfect information, and five levels of hypothetically improved forecasts. The latter represent idealized future improvements in the NWS seasonal precipitation forecasts. For example, Improvement 1 represents a situation in which a probability of below normal spring precipitation of 0.20 is issued on one-half of the occasions and a probability of below normal precipitation of 0.40 is issued on the remaining one-half of the occasions. Note that Improvement 5 represents the most accurate information possible within the current framework of NWS seasonal forecasts (with a 0.40 probability assigned to near normal precipitation), and it is thus "pseudo-perfect." Finally, Table 4 includes the variance σ_z^2 for each type of forecast, which is an indicator of forecast quality (larger variances indicate more accurate forecasts).

b. *Expressions for expected returns*

It will be assumed here that the decision maker chooses the action that maximizes expected return,

TABLE 4. Predictive distributions $P_Z\{z\}$ and forecast variances σ_z^2 of probability forecasts for below normal seasonal precipitation (z) associated with currently available forecasts, five hypothetical forecast improvements, climatological information, and perfect information.

Type of information	z	$P_Z\{z\}$	σ_z^2
Current forecasts	0.20	0.05	0.0022
	0.25	0.24	
	0.30	0.42	
	0.35	0.24	
	0.40	0.05	
Improvement 1	0.20	0.50	0.0100
	0.40	0.50	
Improvement 2	0.15	0.50	0.0225
	0.45	0.50	
Improvement 3	0.10	0.50	0.0400
	0.50	0.50	
Improvement 4	0.05	0.50	0.0625
	0.55	0.50	
Improvement 5	0.00	0.50	0.0900
	0.60	0.50	
Climatological information	0.30	1.00	0.0000
Perfect information	0.00	0.70	0.4500
	1.00	0.30	

where returns are defined in terms of utilities in the cases of risk-aversion or risk-seeking. The expected return for a particular action is defined as the probability weighted average of the returns (or utilities) associated with that action, where the probabilities are specified by the available information (i.e., climatological information, imperfect forecasts, or perfect information). The action that leads to the maximum expected return with respect to a given piece of information will be referred to as the optimal action for that information.

If only the (constant) climatological probabilities are available, then the optimal action is always the same, and the expected return for climatological information (ERCI) is given by

$$\begin{aligned}\mathrm{ERCI} &= \max_i E_\Theta[R(a_i, \theta_j)] \\ &= \max_i \{\sum_{j=1}^{3} [P_\Theta(\theta_j) R(a_i, \theta_j)]\}. \end{aligned} \tag{5}$$

In contrast, if perfect information were available, then the optimal action would be the action which maximizes $R(a_i, \theta_j)$ for each (known) outcome. Since the relative frequencies of the possible outcomes are specified by their climatological probabilities, the expected return for perfect information (ERPI) is given by

$$\begin{aligned}\mathrm{ERPI} &= E_\Theta[\max_i R(a_i, \theta_j)] \\ &= \sum_{j=1}^{3} [P_\Theta(\theta_j) \max_i R(a_i, \theta_j)]. \end{aligned} \tag{6}$$

Although perfect information is generally not available, it provides an upper bound on the quality and expected return of any imperfect forecast.

Optimal actions given imperfect forecasts depend on the forecast z, and the expected return for forecast information will depend on the possible values of z and the frequencies with which they are used. Thus, the expected return for imperfect forecasts is given by

$$\begin{aligned}\mathrm{ERFI} &= E_Z\{\max_i E_{\Theta|Z}[R(a_i, \theta_j)]\} \\ &= \sum_{m=1}^{M} \{P_Z(z_m) \max_i \sum_{j=1}^{3} [P_{\Theta|Z}(\theta_j|z_m) R(a_i, \theta_j)]\} \end{aligned} \tag{7}$$

in which M is the number of distinct forecasts to be considered. Similar expressions can be written for the expected utilities of climatological, perfect, and imperfect information in terms of the utility function $U(a_i, \theta_j)$ [see (2)].

c. *Value of information expressions*

The value of forecast information is typically measured as the net increase in expected return over that associated with climatological information. Thus, the expected value of perfect information is given by

$$\text{EVPI} = \text{ERPI} - \text{ERCI}, \tag{8}$$

and the expected value of imperfect forecasts is given by

$$\text{EVFI} = \text{ERFI} - \text{ERCI}. \tag{9}$$

Imperfect forecasts can have nonzero value only if the optimal action associated with some of the forecasts differs from the (single) optimal action dictated by the climatological information. Moreover, $0 \leqslant \text{EVFI} \leqslant \text{EVPI}$ (Katz *et al.*, 1981), and EVPI will be used to scale the values of EVFI on the unit interval [0, 1].

4. Some results

a. Linear utility

The expected value of current, hypothetically improved, and perfect forecasts (dollars per acre per year) is presented in Table 5 for a risk-neutral decision maker, and for current pasture rental income (represented by \$0.35 per acre per day) as well as for a range of rental incomes around this representative value. It is clear that current forecasts are of relatively little value—\$0.01 per acre per year for this decision-making problem. However, the value would increase substantially given moderate forecast improvements. The quality/value relationship appears to be quite sensitive to relative incomes, since an increase in income for pasturing relative to haymaking (represented by an increase in the pasture price) strongly amplifies the response of forecast value to increases in forecast quality, whereas a corresponding decrease in income has the opposite effect.

TABLE 5. EVFI (expected value of forecast information in dollars per acre-year) as a function of daily pasture price for currently available forecasts, five hypothetical forecast improvements, and perfect information.

Type of information	Pasture return (dollars per acre-day)				
	0.31	0.33	0.35*	0.37	0.39
Current forecasts	0.00	0.00	0.01	0.17	0.57
Improvement 1	0.00	0.00	0.07	1.08	1.79
Improvement 2	0.25	0.25	1.25	2.28	3.02
Improvement 3	0.54	1.42	2.47	3.52	4.28
Improvement 4	1.55	2.62	3.69	4.76	5.54
Improvement 5	2.73	3.82	4.91	6.00	6.80
Perfect information	4.53	5.22	5.91	6.60	7.00

* Current typical price.

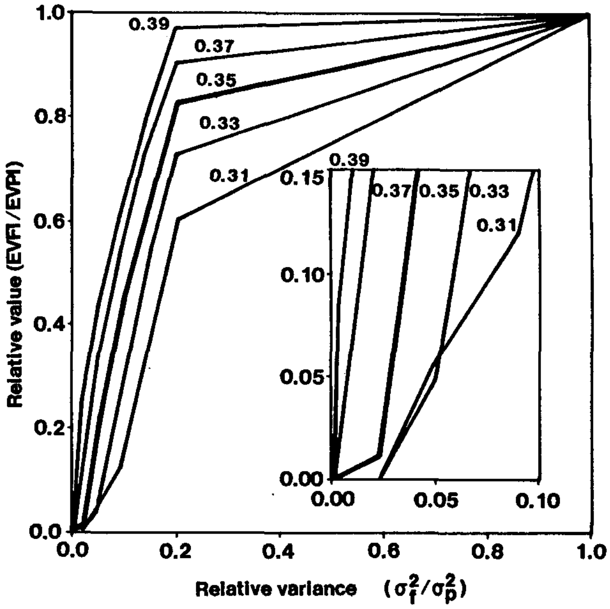

FIG. 1. Quality/value curves for five levels of pasture rental price (in dollars per acre-day). Current conditions are represented by the bold line.

These results are presented graphically in the form of quality/value curves in Fig. 1. In this figure, relative forecast value (EVFI/EVPI) is plotted against relative forecast quality (ratio of forecast variance σ_f^2 to variance of perfect forecasts σ_p^2). These curves indicate that the monetary value of the forecasts approximates a logistic function of forecast quality.

Optimal actions as a function of forecast probabilities z are depicted in Fig. 2 for various levels of the pasture rental price. This figure reveals that, for the given range of pasture prices, a_3 (haymaking with supplemental fertilization) is the optimal action whenever the forecast probability for a dry spring equals or exceeds 0.45. As would be expected, increasing pasture price expands the range of forecast probabilities for which pasturing is the optimal action.

For all except the highest pasture price, the optimal action based on climatological information (i.e., $z = 0.30$) is a_2 (attempt haymaking), so that ERCI is \$37.54 per acre per year. When the pasture price is very high (\$0.39 per acre per day) the climatologically optimum action is a_1 (pasture), and ERCI is \$37.83 per acre per year. As noted in Section 3c and substantiated by the results presented in Table 5 and Fig. 1, nonzero value for imperfect forecasts is realized only when the optimal action for some forecast probability differs from that for climatological information ($z = 0.30$). For current forecasts or Improvement 1, for which $0.20 \leqslant z \leqslant 0.40$, Fig. 2 reveals that deviations from the climatologically optimal action do not occur

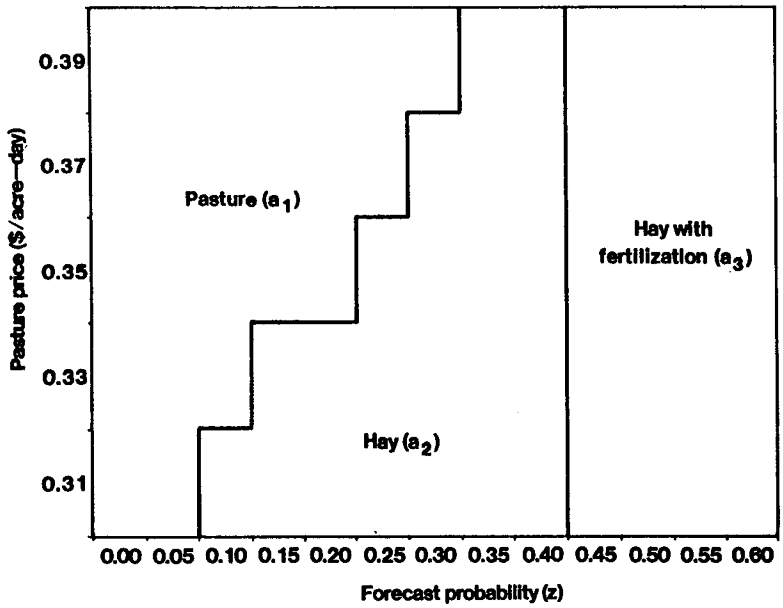

FIG. 2. Optimal actions for a risk-neutral decision maker as a function of pasture rental price (dollars per acre-day) and forecast probability of a dry spring (z).

until pasture price is at least \$0.35. Accordingly, Table 5 and Fig. 1 indicate that forecasts of this quality are of no value for low pasture price. As forecast quality improves, differences between forecast and climatological probabilities become larger (and increase in frequency) and the value of the forecasts increases.

b. Nonlinear utility

The effect on the quality/value relationship of deviations from linear utility for monetary return is illustrated in Fig. 3. Once again, value appears to be a logistic function of quality. For this haying/pasturing problem, forecasts are more valuable for risk-averse decision makers than for risk-seeking decision makers, although the quality/value relationship appears not to be as sensitive to risk attitude as it is to relative income. We note that most real-world decision makers, including farmers, are expected to be risk averse to some extent.

Figure 4 shows optimal actions as a function of the forecast probabilities for various values of the risk attitude parameter β. The figure indicates that a_3 (haymaking with fertilization) is optimal for a wider range of forecast probabilities as β increases. Risk-averse decision makers are not inclined to risk the large loss in income associated with a_3 and θ_1^* (cf. Table 1) unless the probability of a dry spring is quite high, despite the fact that the income from successful haymaking with this action, $I(a_3, \theta_1^*)$, is substantial. As in the case of linear utilities, nonzero forecast value occurs only when optimal actions differ from that for $z = 0.30$ for at least some forecast probabilities. Thus, the lower quality forecasts are of no value for $\beta = 2.0$. On the other hand, although the optimal action when $\beta = 0.2$ differs from the climatologically optimal action only for the (currently relatively rare) forecast of $z = 0.20$, the income loss associated with a failed hay crop has a substantial impact on the risk-averse decision maker. As

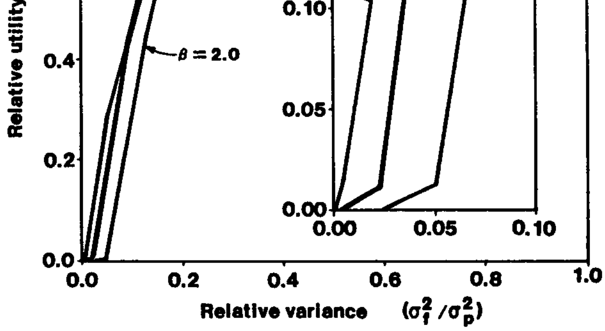

FIG. 3. Quality/utility curves for three values of the risk attitude parameter (β) and a fixed pasture rental price of \$0.35 per acre-day. Risk neutrality is represented by the bold line.

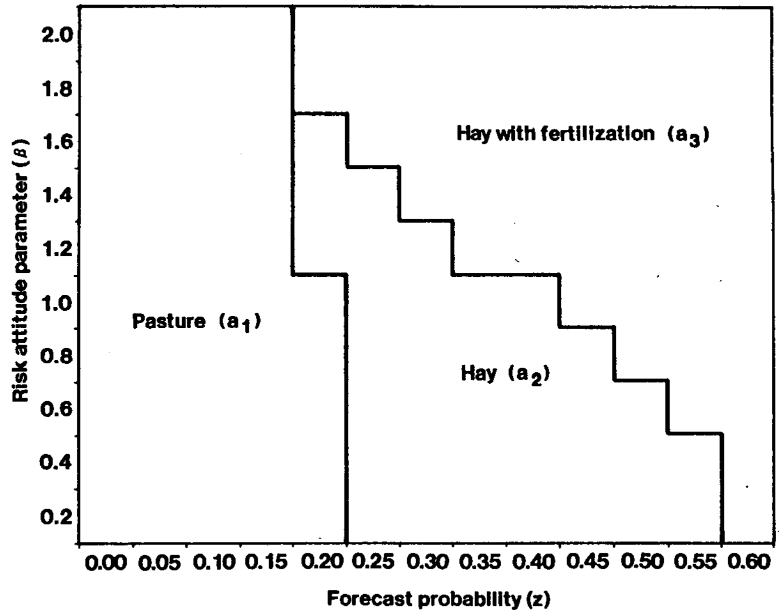

FIG. 4. Optimal actions as a function of risk attitude parameter (β) and forecast probability of a dry spring (z) for a fixed pasture rental price of \$0.35 per acre-day.

a result, even current forecasts are of appreciable value in this case.

5. Conclusion

This paper has presented a simplified analysis intended to illustrate the present and potential value of NWS seasonal precipitation forecasts in a particular, regionally important, decision-making problem. The analysis indicates that current forecasts are of small, but nonzero, value in this problem. Forecast value is quite sensitive to the relative incomes associated with the different actions, and to a lesser extent to deviations from risk-neutrality. The logistic form of the quality/value curves indicates that relatively modest improvements in forecast quality would produce substantial increases in forecast value.

Several refinements could be considered as a means of making the model of this haying/pasturing problem more realistic. For example, as additional probabilistic seasonal precipitation forecasts are issued by the NWS it will be possible to assess their actual reliability and to introduce this factor into the analysis. A longer record of forecasts would also allow use of a less idealized predictive distribution for current forecasts. Other actions could be included in the analysis as well. For example, strategies involving simultaneous use of haying and pasturing could be considered. In addition, an important but possibly underutilized alternative is the preservation of the spring growth as silage, a moist feed produced by partially fermenting the forage (e.g., see Watson and Nash, 1960). Silage-making involves a considerably shorter dry period than haymaking, but it requires additional capital expenditure.

Finally, the present analysis has treated pasture fertilization in a somewhat unrealistic manner, insofar as it would be possible under the current model to defer fertilization for many years when no dry springs were forecast. In reality, the effects of a fertilization extend several years beyond the year of application, and maintenance of productive yields requires fertilization at intervals of approximately 3–5 years. Incorporation of this factor would transform the decision-making situation from a static to a dynamic problem, since a given year's decision would then be influenced by actions taken in previous years.

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