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Simplified Risk Analysis in Agricultural Extension

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Abstract

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Attention is given to the major methods of assessing risk in order to make choices. The literature frequently reports studies on mean-variance (E-V) analysis and stochastic dominance rules. Both of these methods are compared, in an agricultural application, with the approach outlined by Hanoch and Levy. The empirical results suggests that Hanoch and Levy's criterion appear to reduce the size of the risk-efficient set, and that the sets of recommendations from the methods under comparison were consistent. The two recommendations generated by Hanoch and Levy's rule were found to be reasonable for this particular decision process.

Introduction

Agricultural research results based solely on profit-maximizing assumptions may not be adopted by farmers who have other concerns in mind. Adoption would be more assured if the recommendations were to cover information about likely yields under unfavourable weather conditions and other sources of risk. For that reason, many studies are reported in which a set of risk-efficient alternatives is selected by risk models, and the choice of a given course of action is left to the farmer, according to his (usually unknown) risk preferences.

This is usually the case with the two most-utilized methods of decision-making under risk, namely mean-variance (E–V) analysis, and stochastic dominance rules.

A possible problem with these approaches is that, in many cases in agricul-

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tural applications, the risk-efficient set is sometimes very large (Hazell, 1970; Anderson, 1974). While it is accepted that, for business finance applications, the investor usually makes his investment decisions based on a wide choice of portfolios (Markowitz, 1959), farmers may not feel very confident with an efficient set of recommendations which is large enough to take into account all risk preferences. In applications where too many input combinations are possible, alternative models should be compared, so that the one which narrows down the number of risky choices may be advantageously used, if results are consistent. Among examples of such situations are experiments with fertilizer levels and other chemicals. In order to obtain response curves, a wide range of input levels may be used in the experiments; as result, too many input combinations may occur. With a limited set of options, farmers may make up their minds more readily, and at the same time research and extension organizations need not restrict themselves to a single (profit-maximizing) recommendation.

The objectives of this paper are twofold. First, attention will be given to the major methods of incorporating risk in decision models, so as to explain, in a theoretical context, the methods used in the empirical results. The second objective is to compare the results of these methods for the case of irrigated rice in southern Brazil. This comparison will illustrate the number of choices selected by the methods analyzed. With these results, other extension and research institutions will have more information about the ability of each model to select recommendations under risk.

Methods

Generalized decision models: Bernoulli's Principle

Bernoullian decision theory is a generalized approach to decision making under risk. It is a normative theory, based on subjective probabilities, to the decision maker, of the occurrence of uncertain events, and on the individual's perceptions as to the outcomes of these events (Dillon, 1971). Bernoulli's Principle, stated in terms of a single objective (e.g. to maximize expected utility of returns), implies the axioms of ordering, continuity and independence (Borch, 1968; Intrilligator, 1971). The Bernoulli Principle, also known as Expected Utility Theorem or the Fundamental Theorem of Expected Utility (Anderson et al., 1977), states that, if the axioms are not violated, there exists a utility function U for a decision maker which associates a single utility index with each uncertain course of action faced by the decision maker.

The properties of this function U are:

(1) If action X_1 is preferred to X_2, then:

$$U(X_1) > U(X_2)$$

(2) If $U(X_1) > U(X_2)$, then X_1 will be preferred to X_2 (hence transitivity is ensured).

(3) $U(X_1) = \mathrm{E}\, U(X_1)$

(4) $U(X_1) = a\, U(X_1) + b \qquad (a > 0)$

The ordering of uncertain events is ensured by (1) and (2). The axiom of continuity permits the measurement of probability levels P_j for given outcomes X_j or, alternatively, makes possible the elicitation of outcomes X_j for given levels of probability P_j.

Despite the overall consistency of Bernoulli's Principle, it must be emphasized that this approach is too general. More specifically, the axioms and properties of U give no indication whether or not the individual is risk-averse. Koch (1974) attempted to show that Bernoulli's Principle implies risk aversion; however, Bitz and Rogusch (1976) showed that Koch's results are based on an erroneous interpretation of the axioms of the Expected Utility Theorem. On the other hand, nothing can be inferred about either the format of U or about the relevant moments of the probability distributions of X_j.

Approaches restricting the Bernoulli Principle

Given the excessive degree of generality of the Expected Utility Theorem which complicates its empirical usefulness, a number of studies (e.g. Markowitz, 1959; Porter, 1973) have been designed to make this approach operational. Each alternative necessitates specific assumptions about the decision-making process.

The literature of portfolio selection gives a wide coverage of mean-variance (E–V) analysis as a model designed to restrict the generality of Bernoulli's Principle. In this approach, only the first two moments of the probability distributions of returns are considered. E–V analysis can be directly derived from the axioms of the Expected Utility Theorem under two assumptions (Tobin, 1958; Markowitz, 1959): (a) the decision makers' utility function is quadratic; and/or (b) the probability distributions of returns are normal.

Chipman (1973) and Baron (1977) extensively discuss the theoretical implications when each of the above assumptions is taken in turn. Basically, E–V analysis assumes that the decision maker chooses the course of action which shows smallest variance for a given level of income, or alternatively, the option which provides the highest mean for a given level of variance. When A shows a greater mean and also has a greater variance of returns than B, then both are said to be risk-efficient under the E–V criterion (Anderson et al., 1977). This characteristic of E–V analysis may produce undesirable results in some agricultural applications, because sometimes alternative A may be far more profitable than B, but a slight excess of variance over B will indicate that both alternatives are equally desirable under this criterion. Critics of E–V analysis (Borch, 1969; Feldstein, 1969) also pointed out some possible inconsistencies of the indifference curves of E–V analysis.

In order to overcome the shortcomings of E–V analysis (or E–S analysis, when V is replaced by the standard deviation), many authors introduced other criteria to decision-making under risk. Some analysts opposed the hypotheses of normality of returns and quadratic utility functions of the decision makers, but at the same time kept the axiomatic foundation of Bernoulli's Principle. In this line of study, the stochastic dominance (SD) rules were developed (Quirk and Saposnik, 1962; Hadar and Russell, 1969; Anderson, 1974). Stochastic dominance rules take into account entire cumulative distributions of returns, rather than only their means and variances. However, the SD rules do not appear to make any significant improvements in empirical analyses over the much simpler E–V approach (Porter, 1973; Porter and Bey, 1974; Porter and Carey, 1974). According to these authors, the efficient set of portfolios generated by E–V analysis does not differ too much from that generated by the SD rules, depending on the degree of aggregation of the data.

Later on, Perrakis and Zerbinis (1978) demonstrated theoretically that the results of E–V analysis are a subset of SD results. According to them, for distributions with finite returns empirically generated from observed data, E–V and SD-efficient sets may turn out to be similar. Meyer (1977) also criticized the SD rules on the grounds that the assumption of risk aversion, implicit in the second degree of dominance, is unnecessary. While the stochastic dominance criteria are being scrutinized and improved (Flood et al., 1983; Pope and Ziemer, 1984), analysts should also make more effort to compare these methods of risk analysis empirically.

Stochastic dominance can also restrict the number of eligible choices when it is defined with respect to a function (Meyer, 1977). If the degree of risk aversion is zero, then only one alternative is selected, namely the profit-maximizing option. However, in order to define the range of risk aversion a farm survey is often required, so as to measure farmers' preferences as to risk in a given sample (Crocomo, 1979). This process may be desirable, because risk-preference measures tend to be stable over time (Love and Robison, 1982). However, the desirable degree of expertise in risk analysis may not be readily available among extensionists or researchers in developing countries. Parametrization of the degree of risk aversion in a Monte Carlo routine is also possible (Herath et al., 1982), but the range of this measure should also be obtained from farm surveys.

Apart from E–V analysis and SD rules, other criteria to select choices under risk were considered in the literature. A simple method of dealing with risk (without the use of farm surveys) is Hanoch and Levy's (1970) rule, which is a criterion to incorporate risk based on the axioms of the Expected Utility Theorem, with the following additional assumptions: (a) the utility function of the decision maker is quadratic; (b) the probability distributions of returns are symmetric.

Under these assumptions their symmetric rule is a special case of the stochastic dominance rules, which do not impose any shape for the distributions of returns nor any specific type of utility function.

Despite some critics (e.g. Anderson, 1973, 1975) there exists an extensive body of literature which uses and justifies the hypothesis of quadratic utility functions as a reasonable approximation of a decision maker's behaviour, at least within a given range of returns (Tsiang, 1972).

The hypothesis of symmetric distributions of returns can, in some cases, be satisfied by a large variety of distributions, e.g. normal, uniform, triangular and beta. Empirical results reported by Da Cruz (1979) show that the symmetric assumption approximately holds for gross margins for rice producers in the central states of Brazil. On the other hand, the use of symmetric distributions of returns is more acceptable vis-a-vis the more restrictive normality hypothesis utilized by Freund (1956) and Wiens (1976) in agricultural studies.

A quadratic utility function can be represented by:

$$U(X) = a + bX + cX^2 \tag{1}$$

where X is a random variable (e.g. returns per hectare). Assuming a positive marginal utility:

$$U'(X) + b + 2cX > 0 \qquad (c < 0) \tag{2}$$

Under the assumption of risk aversion (this assumption is empirically measured by Binswager, 1978, and Dillon and Scandizzo, 1978):

$$U''(X) = 2c < 0 \tag{3}$$

Equations (2) and (3) imply that X is restricted to the interval $X < K$, where $K = -b/2c > 0$.

In this way a quadratic utility function is represented by:

$$U(X) = 2\,KX - X^2 \qquad (K > 0;\ X < K) \tag{4}$$

In order to compare two symmetric distributions, Hanoch and Levy (1970) derived the symmetric rule:

X_1 will dominate X_2 if:

$$2(\mu_1 - \mu_2)\sigma_1 + (\mu_1 - \mu_2)^2 - (\sigma_1^2 - \sigma_2^2) > 0 \tag{5}$$

where

$\mu_1 = \mathrm{E}(X_1)$

$\mu_2 = \mathrm{E}(X_2)$

$\sigma_1 = \sqrt{\mathrm{var}(X_1)}$

$\sigma_2 = \sqrt{\mathrm{var}(X_2)}$

A computer package (PACTA) utilized by EMBRAPA, to compare technologies under risk, incorporates the above symmetric rule as one of its options (Da Cruz, 1980). It is a simulation program designed to compare gross margins and risk of alternative technologies. Explanations of the routines for gross-margin generation can be found in Anderson (1976). Basically, the program computes probability distributions of gross margins from data on prices, yields and costs supplied by the user under a variety of probability-distribution assumptions. The gross margins of each technological alternative are pairwise compared. When the utility function of the decision-maker is known, PACTA gives the expected utility of each alternative. The options of linear, quadratic and negative exponential utility functions can be used (Da Cruz, 1979).

Since prices and yields enter in a multiplicative way into the computation of gross margins under a variety of distributions (e.g. normal, triangular, beta), the shape of the resulting gross-margins distributions is usually indeterminate. The symmetric rule should be applied only in cases where these distributions are approximately symmetric. Following Anderson's (1976) approach, the twentiles of the cumulative density functions (cdf's) of the gross margins are output. Hence these cdf's can be easily plotted and the graphical method for establishing stochastic dominance can be used (Anderson et al., 1977).

Hanoch and Levy's (1970) rule will be compared with the stochastic dominance rules and the E–V criterion, for the purposes of this paper. Stochastic dominance rules and E–V analysis were selected because of their popularity in the literature. Hanoch and Levy's rule was chosen because of its simplicity and the availability of the PACTA program mentioned above.

Despite the fact that they were not included in the comparisons, mention should be made of the safety-first rules. Such rules usually consist of ad-hoc methods without axiomatic foundation, where the major goal of the decision maker is the avoidance of disaster rather than the maximization fo utility. Pyle and Turnovsky (1970) review some fo these rules. Given that their results are considered by many (e.g. McInerney, 1969) to be too conservative, their application should be considered only under very specific circumstances, in cases where avoidance of disaster is the major objective of farmers.

Data sources

The experimental data come from a study undertaken by EMBRAPA at the Pelotas experiment station, located in the state of Rio Grande do Sul. This experiment station has experience of more than 20 years in rice research. There were 20 technological alternatives *T*, as follows:

T1 = I14 N1 H1	T11 = I14 N2 H1
T2 = I21 N1 H1	T12 = I21 N2 H1
T3 = I28 N1 H1	T13 = I28 N2 H1

T4 =I35 N1 H1	T14=I35 N2 H1
T5 =I42 N1 H1	T15=I42 N2 H1
T6 =I14 N1 H2	T16=I14 N2 H2
T7 =I21 N1 H2	T17=I21 N2 H2
T8 =I28 N1 H2	T18=I28 N2 H2
T9 =I35 N1 H2	T19=I35 N2 H2
T10=I42 N1 H2	T20=I42 N2 H2

where I is irrigation, I14 14, I21 21, I28 28, I35 35, and I42 42 days after plant emergence, respectively; N is nitrogen, N1 before irrigation, and N2 at the period of plant flowering; and H is herbicide, H1 before plant emergence, and H2 after plant emergence.

These 20 alternatives, arranged on a pairwise basis, resulted in 190 combinations to be selected by the risk models.

In order to compute the gross margins of each alternative, average rice in the region of Pelotas prices for the May–November 1980 period were taken. Cost data for the corresponding agricultural year are published in IRGA (1980).

Results

Because yields and prices are based on several probability distributions, the resulting gross-margin distributions of each alternative are indeterminate. However, they showed extremely low levels of skewness, and for that reason Hanoch and Levy's symmetry rule could be used to select risk-efficient alternatives. Under Hanoch and Levy's criterion, 18 alternatives were discarded as inefficient under risk. This implies that only 10% of the alternatives (two out of 20) were chosen by Hanoch and Levy's rule as efficient under risk.

These results can be summarized as in Table 1.

The sets of risk-efficient alternatives tend to be consistent. Alternatives T12 and T15 selected by Hanoch and Levy's rule are also present in the set of nine options selected by the mean-variance criterion (T1, T2, T5, T6, T7, T8, T12, T15, and T19) and the seven alternatives chosen as risk-efficient by the stochastic dominance rules (these belong to the E–V set, excluding T5 and T6).

One question which may arise at this point is: are the technological alter-

TABLE 1

Number of risk efficient alternatives selected by alternative models

Risk criterion	Risk-efficient alternatives out of twenty	Percentage
Hanoch–Levy	2	10%
Mean-variance	9	45%
Stochastic dominance	7	35%

natives selected by such risk models relevant to farmers? For the case of the technological alternatives T12 and T15 selected by Hanoch and Levy's method, the answer is yes. From an agronomic point of view both alternatives are among the most appropriate for local conditions. Farmers with fields which can be irrigated by gravity, without mechanical power, are likely to adopt alternative T12 (it has a longer irrigation period). This fact is due to the low irrigation costs of the gravity system, so that a farmer may keep the crops for a longer period under water. However, almost 70% of the rice acreage in Rio Grande do Sul is irrigated with a mechanical system, based on fuel. For those farmers, system T15 seems to be the most appropriate due to the high irrigation costs, and bearing in mind the fact that the rice variety under investigation is of a long cropping-cycle type; thus it can endure a longer period without water.

Such a clear-cut interpretation is not available for the nine alternatives selected by the mean-variance criterion and the seven generated by the stochastic dominance rules. The agronomists would have some difficulty in explaining to farmers the circumstances under which they would fit. An easier way out of the problem, of course, is simply to show the farmers all the risk-efficient alternatives, and let them choose one among them. To the other extreme, a specific recommendation could be made individually by assessing the utility function of each farmer, and choosing the alternative which maximizes each expected utility. Obviously this course of action is not possible on a routine basis, due to the time involved in eliciting individual risk preferences.

Concluding remarks

Three methods of incorporating risk were utilized in this paper. Empirical results showed that Hanoch and Levy's (1970) criterion selected only two risk-efficient alternatives out of twenty. This fact suggests that the assumptions of symmetry of distributions, and the quadratic form of utility functions incorporated in the criterion, appear to reduce the size of the E–V set.

For this particular case, the use of such an approach was convenient because of the large number of options involved. The authors are not advocating the case where only a single (e.g. the profit-maximizing) recommendation should be given to farmers. Some allowance should be given to farmers' risk preferences, provided that the number of risk-efficient alternatives is not too large. When too many technological alternatives are risk-efficient, farmers may feel that the recommendations are not reliable, or that the extension service is not sure of which recommendations are the best.

Hanoch and Levy's rule incorporates two assumptions, both susceptible to criticism, as reported above. More effort should be made in the academic area to develop new and better methods of incorporating risk in decision models which do not need to rely on such assumptions, in cases where these prove to be too restrictive. The obvious implication is that the usefulness of any risk model will depend on the validity of its underlying hypotheses.

In this particular application, the three approaches utilized in the comparisons did not generate conflicting results. For other applications, these and other methods should be compared again, so that the resulting recommendations to farmers make sense. We are aware of the fact that research and extension organizations should consider the trade-off between simplicity and theoretical appeal. Future research in risk modelling should evaluate the effects of different hypotheses in alternative approaches to risk, bearing in mind at the same time the practical aspects of ease of use and cost.

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