An Evaluation of Expected Value and Expected Value-Variance Criteria in Achieving Risk Efficiency in Crop Selection

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This article evaluates the performance of expected value and expected value-variance criteria in achieving risk efficiency in crop selection. Results indicate that the expected returns criterion achieves risk efficiency in many situations because of constraints. However, in the absence of many constraints the expected returns criterion performs poorly except when highly mean-dominant activities are present. The expected value-variance criterion achieves a high degree of risk efficiency for all situations examined. This result implies that criteria more complex than expected value-variance are not necessary for crop selection analysis, given empirical returns distributions. Key words: expected returns, expected value-variance, risk efficiency, risk aversion

The importance and methods of analyzing farming decisions in a risk framework have been discussed in the agricultural economics literature since Head-y's article on minimizing income variability through farm production diversification. Yet, two relatively recent studies suggest that risk may not be a very important consideration in such decisions. Brink and McCarl compare linear programming and risk programming results in explaining actual farmer decisions and conclude that, in general, risk aversion is not important in farmers' choices among acreages of corn, soybeans, wheat, and double-crop soybeans. Lee et al. consider both "objective" and "subjective" income distributions in analyzing farmers' choices between conventional and reduced tillage methods, concluding that the expected value decision criterion does as well predicting actual farmer choices as either the expected value-variance criterion or stochastic efficiency criteria.

Two concerns occur in generalizing results of these studies. First, rich constraint specifications, such as the one used by Brink and McCarl, may cause crop mix decisions to be similar over a wide range of risk aversion because of the complex resource allocation problem. Thus, situations requiring few constraints, such as the existence of near complete labor and capital services markets, may better reflect the effect risk has on decisions. The second concern is the presence of activities with strongly mean-dominant returns which may cause "plunging behavior." This situation also masks the importance of risk because the same decision is made by virtually all decision makers. The Lee et al. study apparently reflects this situation as indicated by the incidence of first-degree stochastic dominant solutions.

In contrast to the two foregoing studies, most studies accept risk as an important aspect of decision making. Furthermore, many of these studies take the view that good empirical analyses require methods other than the expected value-variance (E-V) model because of its theoretical restrictions (Lehman; Quirk and Saposnik; Fishburn). These restrictions have led to the development of alternative criteria, including various types of stochastic dominance (Hanoch and Levy; Meyer; Hadar and Russell), the exponential utility moment-generating function approach (Yassour et al.; Collender and Zilberman) and direct expected utility function maximization (Lambert and McCarl).

Day's study of Mississippi crop yield distributions, which indicates that yields are nonnormal, at least in part has been the impetus for choosing methods other than the E-V criterion for empirical studies of farm situations. For example, Yassour et al. cite Day's article in justifying the need for

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the exponential utility moment-generating function (EUMGF) method. Then by assuming gamma distributed yields and constant prices, they show that the E—V criterion may lead to incorrect decisions in choosing among four rice production technologies. Similarly, Coilender and Zilberman cite Day's article in justifying the extension of the EUMGF approach to crop selection and land allocation for cotton and corn in Mississippi. Again, gamma yields and constant prices are used in showing that crop selection with the EUMGF and E—V methods may differ. Although Lambert and McCarl do not cite Day, they use several nonnormal probability distributions along with Monte Carlo data experiments to demonstrate that inconsistencies may exist between E—V and direct expected utility solutions.

These examples are not an exhaustive list of studies criticizing the E—V criterion for empirical analysis, but they demonstrate situations in which the theoretical limitations of E—V can become apparent. A substantial weakness of these arguments is that the settings and data with which the results are obtained do not conform to empirical situations. In theory, decision making is based on income (wealth) attributes of all obtainable variables with which income is associated (Tsiang). Therefore, empirical incremental decisions that maximize expected utility should be made within the portfolio context of the opportunity set, not as an independent decision. The Yassour et al. study imposes incremental, discrete choice independent of the larger portfolio context, thereby eliminating the influence of covariance or higher comoments with other investments and/or production opportunities. Although Coilender and Zilberman, and Lambert and McCarl use a portfolio framework, the settings for their studies still lack generality because the opportunity sets are limited to only two activities. The realism of the data of each study also can be questioned. The Yassour et al. and Coilender and Zilberman studies impose gamma distributed yields and assume constant prices. Even if gamma distributed yields appropriately represent empirical distributions, the constant price assumption probably causes the variance and skewness of the returns distributions to be too large (Buccola). Lambert and McCarl's study may imply even less about the empirical validity of the E-V model for crop selection, because no apparent relationship exists between their experimental data and empirical crop returns. Thus, neither these nor similar studies provide good empirical tests of the E—V model for crop selection because of opportunity set and data limitations.

The two foregoing perspectives on empirical decision criteria are extremes. One perspective holds that risk aversion is of limited importance ar)(i thus, expected returns are sufficient for decisi0' making. The other perspective is that risk is ven, important, but information contained in the mea and variance of returns is insufficient for good de cision making. The purpose of this study is to nro vide additional information regarding situations \vhen the expected returns (ER) criterion is acceptable for selecting risky crops and if stochastic analysis beyond the E-V criterion is warranted. The ex-pected utility hypothesis is used to represent stochastic efficient behavior, with various utility functions representing a wide range of risk aver- * sion. Decisions based on the ER and E-V criteria are compared to the maximum expected utility (EU) solution. Comparisons for each utility function are based on an empirical situation and various other opportunity set situations using farm-level empirical data. These analyses give insight as to the i degree of risk-efficiency loss resulting from cropping decisions based on the ER or E—V criteria.

Analytical Procedure

The procedure for comparing activity selections of ER and E-V criteria with those of EU requires three steps. Consider the comparison of ER and EU. The first step is to find a portfolio of activities that maximizes expected utility for each utility function considered. Second, the choice that maximizes expected returns is found. Then, the effectiveness of the ER criterion with respect to EU is measured by an efficiency index. Procedures for comparing E—V and EU choices are similar. Step one remains unchanged. Because the E-V criterion gives a set of portfolio choices, the next step is determining the E-V set and the single E-V portfolio with the highest expected utility (E*U). The third step determines the efficiency of the E*U choice relative to the EU choice by an efficiency index measure. These procedures closely follow analytical methods of Kroll et al.

Direct Maximization of Expected Utility

Four different utility functions are used in selecting portfolios consistent with maximum expected utility. The specific forms of the utility functions are:

where R is the return obtained from a portfolio of agricultural production activities. These utility functions include all functional forms posited by Tsaing, and Lin and Moore. These functions represent ranges of absolute risk aversion from very risk averse ($U_1 = -e^{-0.0001R}$), to not very risk averse ($U_3 = R^{0.90}$). The highest absolute risk aversion represented corresponds to the highest risk aversion elicited by King and Oamek for similar levels of income for a sample of Colorado wheat farmers.

The portfolio of productive activities that maximizes expected utility (EU) is found by Goldfarb's generalized nonlinear programming algorithm as modined by Buckley. This algorithm is a gradient-reduction procedure that uses first and second derivative information to form Lagrangian multipliers and determine search directions.

Expected utility functions are formed and valued in the programming model as follows:

(i) EU = -ti; u(R_k>]
n k=i

where U(R_k) is the utility function value of the portfolio return for observation k; R_k is the annual ' portfolio return for observation k; and n is the number of annual observations on portfolio returns. Furthermore, because equation (1) is maximized with respect to productive activities, the portfolio return is included in the form:

m
(2) R_k = S ^{r}jk Xj
j=i

Where r_{jk} is the gross return per unit of activity j for observation k; X, is the level of activity j; and m is the number of activities from which a portfolio is selected. Therefore, optimal portfolios are selected by a model of the following form:

. n m
(3a) maximize: - [^ ^{u} (2 ^{r}jk X;)] n k=i
j=i
m
(3b) subject to: ^ Xj *a*^ =£ *b*
j=i
(3c) *X* ^ *0*

where U(-), ij$_k$ ^{an}d Xj are as previously defined, Oj is the q-dimensional column vector of constraint coefficients of the variable Xj, for j— 1,2, . . .m, where q is the number of such constraints; *b* is the q-dimensional column vector of constraint restriction levels; *X* is the m-dimensional column vector of Xj's; and *0* is a m-dimensional column vector of zeros.

Expected Return Analysis

A standard linear programming formulation of the problem is solved to determine the ER solution for comparing with EU solutions. This model incorporates the same linear constraints as the model for maximizing expected utility. The general specification for this problem is:

(4a) maximize: *r' X*
(4b) subject to: AX =£ *b*

X ^ 0

where *r* is a (mxl) vector of expected returns and A is a (qxm) linear constraint matrix of nonsto-chastic input-output coefficients.

The expected utility of the ER choice (E'U) is calculated using equation (1) to allow the efficiency evaluation of the ER choice.

Expected Value-Variance Analysis

A quadratic programming formulation of the problem is solved for comparing E—V solutions with maximum expected utility solutions of the various utility functions. The quadratic programming problem is specified as:

(5a) minimize: *X' Q X*
(5b) subject to: *r' X* = C
(5c) A *X**= *b*
(5d) *X* 5= *0*

where Q is the variance-covariance matrix of gross returns for *X.* This model incorporates the same linear constraints as the model for solving maximum expected utility. The additional constraint (5b) is used to set the expected returns level, C, for minimizing variance. The E—V set considered in the analysis is found by parameterizing C at $100 intervals. The expected utility of each portfolio in the E-V set is calculated by equation (1). A simple search procedure selects the E-V portfolio yielding the highest expected utility (E*U) for each utility function.

Determining Relative Risk Efficiency

Several methods have been used for measuring the relative stochastic efficiency of a portfolio. Pulley compares E-V portfolios to expected utility maximizing portfolios by forming a ratio of their expected utility values as follows:

E*U
(6) ^{P} - EU

where E*U is the expected utility of the E-V portfolio and EU is the expected utility of the maximum expected utility solution. This measure represents the fraction of the maximum utility captured by the E-V approximation. The problem with this measure is that it can be made arbitrarily close to 1.0 by adding constants to the utility function.

Kroll et al. circumvents the utility function transformation problem by using a "naive" portfolio as a reference point from which to measure utility gain of the E—V and utility maximizing solutions. The Kross et al. measure is:

$$KLM = \frac{E^*U - E_nU}{EU - E_nU} \tag{7}$$

where E_nU is the expected utility of the naive equally weighted portfolio. The Kroll et al. measure represents the utility gain of the E-V portfolio (over the naive portfolio) as a fraction of the utility gain of the expected utility maximizing portfolio. This measure is invariant to scaling and additive transformations of the utility function, but is not invariant to the choice of naive portfolio. A relative risk efficiency measure presented in Reid and Tew which is free of the limitations of the foregoing measures is the method used in this study. Reid and Tew formed their measure as a ratio of certainty equivalents and, as such, it is invariant to linear transformations of the utility function and has the most straightforward interpretation. Measures for evaluating the risk efficiency achieved by the ER and E—V criteria are formed as follows:

$$IER = \frac{CE(E'U)}{CE(EU)} \tag{8a}$$

(8b) CE(E*U)

'- = -Ei^ur

where CE(E'U) is the certain income yielding the same expected utility as the maximum expected return solution; CE(E*U) is the certain income yielding the same expected utility as the best E— V solution; and CE(EU) is the certain income producing the same expected utility as the maximum expected utility solution. An expected utility value is calculated with respect to each specified utility function and decision criterion. Certainty equivalent ratios are calculated to measure the relative risk efficiency achieved by each decision criterion for each utility function.

Data and Situations Analyzed

The empirical setting for this research is a representative farm situation for the Coastal Plain region of Georgia as identified by Chou et al. from information collected by the Farm Information Center of the University of Georgia. The representative farm resource and constraint situation includes 660 acres of total cropland, 100 acres of irrigation capacity, 60 acres of peanut allotment, monthly family labor based on average available working hours, and a rotational constraint which allows up to two-thirds of cropland to be planted to legume crops. A series of farm-level yields and corresponding prices for 1975-82 is used to represent the probability distribution of returns per acre for each of nine production activities suitable for the region (Moss and Saunders; Perry and Saunders).[1] These nine activities include irrigated and nonirrigated corn, soybeans, and peanuts; and nonirrigated wheat, oats, and double crop wheat-soybeans. Table 1 presents descriptive statistics for the gross returns of each production activity. These statistics indicate that sample means and variances differ widely

Table 1. Descriptive Statistics of Gross Returns for Production Activities in the Coastal Plain Region of Georgia, 1975-82

Crop	Mean $ / acre	Variance $ / acre	Coefficient of variation[3]	Skewness[h]	Kurtosis[c]
Irrig. Corn	470.27	9,834.44	0.21	-0.66	2.39
Nonirrig. Corn	139.33	2,267.04	0.34	-1.12	3.49
Irrig. Soybeans	231.90	3,611.41	0.26	-0.08	1.94
Nonirrig. Soybeans	137.25	811.94	0.21	0.09	2.70
Nonirrig. Wheat	96.98	643.38	0.26	0.64	2.32
Nonirrig. Oats	82.08	212.1 1	0.17	0.96	2.65
Nonirrig. Wheat/ Soybeans	188.53	6,988.78	0.44	-0.48	2.32
Irrig. Peanuts	501.51	7,969.76	0.18	0.43	2.34
Nonirrig. Peanuts	411.75	1,618.50	0.10	0.11	1.34

[a] The coefficient of variation is computed by dividing the standard deviation by the mean.

[h] Skewness is computed by dividing the third central moment) by the cubed standard deviation. A value of zero indicates no skewness.

*•' Kurtosis is computed by dividing the fourth central moment by the fourth power of the standard deviation. A value of three . indicates kurtosis of a normal distribution.

While the probability distributions can be represented in other ways (e.g. Bessler; McSweeney et al.). the overall conclusions of this study should be unaffected.

ong the activities. In addition, both positive and eative skewness and both more and less kurtosis n *L the normal distribution exist among sample 1 mms of the activities. Table 2 presents the cor- f lation coefficients among activity returns. Many fthese correlations are substantially less than one, . dicating that diversification opportunities exist for jgflincantly reducing portfolio variance. The representative situation described earlier and <-everal variations are analyzed with empirical data. Some variations may represent other common situations , while other situations demonstrate extremes. The variations are formed by reducing the numbers of activities and constraints. The specific situations are:

Situation la: The representative empirical situation with all nine production activities and all constraints;

Situation Ib: Includes nine production activities with the limited constraints of land, irrigation capacity, and peanut allotment;

Situation 2a: Includes six production activities (irrigated and nonirrigated peanuts and double crop wheat-soybeans excluded) with all (relevant) constraints.

Situation 2b: The same as Situation 2a with the limited (relevant) constraints of Situation Ib;

Situation 3a: Includes the three production activities of nonirrigated corn and soybeans and wheat with all (relevant) constraints;

Situation 3b: The same as Situation 3a with the limited (relevant) constraints;

Situation 4a: The same as Situation 3a, except nonirrigated peanuts replaces corn;

Situation 4b: The same as Situation 4a with the limited constraints.

Results

Table 3 presents indices of relative risk efficiency for each situation, utility function, and decision criterion analyzed. First, consider indices associated with the ER criterion, 1_{ER}. As expected, the ER criterion does well for the less risk-averse utility functions, regardless of the activities or constraint situation. For functions representing more risk aversion, the loss in relative stochastic efficiency can be quite dramatic. The degree of loss depends on the degree of risk aversion and the situation. For the representative situation, la, a loss in risk efficiency occurs only for the utility function representing the most risk aversion. The index measure of 0.8578 indicates that the ER criterion achieves only 85.78 percent of the certain-dollar equivalent income achieved by the EU criterion. Other utility functions indicate no efficiency loss from the ER criterion because of the high mean returns from peanuts, double cropping, and irrigated corn. These functions all select the same crops because the utility of high expected returns outweighs the disutility associated with risk.

When the more mean-dominant activities are removed from the opportunity set, as in situations 2a and 3a, the loss in relative efficiency becomes greater, and functions with lower relative risk aversion now show losses in relative risk efficiency. A maximum expected utility decision in this situation raises utility by appropriate diversification strategies, while decisions made with the ER criterion do not.

When fewer constraints and activities specify the situation, the relative efficiency of ER usually declines as illustrated by comparisons of situations la, 2a, and 3a with their respective less constrained counterparts $1\mathrm{b}_r$ 2b, and 3b. Constraints cause diversification of activities which reduce the loss in relative risk efficiency caused by ER decisions. However, the addition of constraints causes the ER criterion to become more relatively efficient for another reason besides the diversification effect: constraints lower the absolute stochastic efficiency achievable, which is the base for measuring relative efficiency (the denominator of I).

Two phenomena occur in changing from situations 2 to 3 which can cause indices either to rise or fall. First the number of diversifiable alternatives is reduced, implying that potential efficiency gain from diversification becomes more limited. Second, a highly mean-dominant activity is removed, which lowers the absolute utility gain for all functions. In moving from situations 2 to 3, if a function places relatively more (less) value on risk than income, then the index for that function increases (decreases). This increase (decrease) occurs because the denominator of I, which is the base from which relative efficiency is measured, falls relatively more (less) than the numerator.

Situation 4 demonstrates what happens when few diversifiable alternatives exist and one alternative is strongly mean dominant. In this situation not enough utility gain can be derived through diversification to offset the utility loss of expected income for any function represented. Thus, no loss in efficiency occurs for any function from the use of the ER criterion.

In contrast to the ER criterion, the relative risk efficiency achieved from the E—V criterion is 100 percent or virtually 100 percent in every situation considered. The smallest index for the E—V criterion is 0.9997. These results indicate that the

Table 2. Correlation Coefficients Among Crop Returns

	Irrig. Corn	Nonirrig. Corn	Irrig. Soybeans	Nonirrig. Soybeans	Nonirrig. Wheat	Nonirrig. Oats	Nonirrig. Wheat/Soybeans	Irrig. Peanuts	Nonirrig. Peanuts
Irrig. Corn	1.0	-0.005	0.585	0.387	-0.101	-0.151	-0.267	-0.048	0.343
Nonirrig. Corn		1.0	0.47	0.530	0.002	0.466	0.637	0.540	-0.058
Irrig. Soybeans			1.0	0,477	0.429	0.425	-0.297	0.097	0.600
Nonirrig. Soybeans				1.0	-0.076	-0.022	0.341	0.468	-0.782
Nonirrig. Wheat					1.0	0.756	-0.676	0.367	0.315
Nonirrig. Oats						1.0	0.240	0.286	0.815
Nonirrig. Wheat/ Soybeans							1.0	0.155	-0.045
Irrig. Peanuts								1.0	-0.038
Nonirrig. Peanuts									1.0

Table 3. Relative Risk Efficiency Indices for the Expected Returns (I_{ER}) and Expected Value-Variance (I_{EV}) Criteria for Various

	Utility Functions				
	$U_1 = -c^{-0.0001R}$	$U_2 = -R^{-0.001}$	$U_3 = -R^{-0.90}$	$U_4 = \text{In}(R)$	
			I_{ER}		
la	0.8578	1.0000		1.0000	1.0000
Ib	0.7153	1.0000		1.0000	1.0000
2a	0.8121	0.9740		I.0000	0.9881
2b	0.6308	0.9680		1.0000	0.9689
3a	0.7852	0.9809		1.0000	1.0000
3b	0.7099	0.9460		1.0000	0.9460
4a	1.0000	1.0000		1.0000	1.0000
4b	1.0000	1.0000		1.0000	1.0000
			- - IEV - -		
la	1.0000	1.0000		1.0000	1.0000
Ib	0.9997	1.0000		1.0000	1.0000
2a	0.9997	1,0000		1.0000	1.0000
2b	1.0000	1 .0000		1 .0000	0.9999
3a	0.9999	1.0000		1.0000	1.0000
3b	1.0000	0.9999		1.0000	0.9999
4a	1.0000	1.0000		1.0000	1.0000
4b	1.0000	1.0000		1.0000	1.0000

characteristics of the empirical data are such that portfolios formed using the E-V criterion are sufficient for achieving extremely high degrees of risk efficiency, even when the utility function represents a high level of risk aversion, when the opportunity set is very restricted, and/or when the number of constraints is very limited.

Concluding Comments

This paper assesses the relative stochastic efficiency loss that occurs from basing cropping decisions on the maximum expected returns criterion or the expected re turns-variance criterion. Several situations are analyzed using portfolio concepts and empirical farm-level returns. Significant losses in relative stochastic efficiency can result from using the expected returns criterion when a high degree of risk aversion exists, when the number of constraints is limited, when strongly mean-dominant activities are relatively few, and/or when the number of diversifiable alternatives is relatively large. Analysis of the representative empirical situation of this study (situation la) indicates that, given the characteristics of the returns distributions of the cropping choices, many decision makers would experience no loss in utility from basing cropping decisions on the maximum expected returns criterion. Hence, it is not surprising that the expected returns criterion performed well in predicting farmer behavior, given the situations in the Brink and McCarl, and Lee et al. studies. However, many decision makers may be very risk averse and/or face conditions in which the expected returns criterion is not suitable for achieving stochastic efficiency. Such conditions exist when few or no high-mean alternatives exist or when few constraints exist. Therefore, the conclusion that business risk is unimportant in crop production decisions is decision maker and/or situation specific and cannot be generalized.

In contrast, the E~V criterion is shown to achieve an extremely high degree of relative risk efficiency for every utility function and situation represented. Thus, the conclusion that the E-V criterion is an excellent risk efficiency criterion in cropping decisions is generalizable to the extent that the characteristics of the empirical observations on crop returns are representative of other empirical distributions. Because most of the crops analyzed (except peanuts) are fairly common over a wide geographic area, and situations without the regionally unique crop are included in the analyses, no reason exists for believing the results of this study are unique. Previous studies with results contrary to this one have occurred for two reasons. First the assumed returns data do not represent empirical data because of imposed yield distributions, a disregard for the interaction of price with yield in forming returns distributions, and/or the use of synthetic data merely to demonstrate a point. Second these studies either have ignored the effects diversification can have on the distributions of portfolio returns, or the diversifiable alternatives allowed in the opportunity set have been unrealistically limited. Limiting the effect of diversification for whatever reason potentially is a very serious omission, especially under conditions of skewed returns.

In conclusion, the views that risk aversion is unimportant or that all expected utility conditions are required for adequately capturing risk behavior are extreme for empirical crop selection criteria, given the range of empirical opportunities and data. Therefore, the expected value-variance criterion appears to be an excellent model for empirical analysis of crop selection without undue simplifications or complexities.

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