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Choice of utility function form: its effect on classification of risk preferences and the prediction of farmer decisions

Sugu M.M. Zuhair [a,1], Daniel B. Taylor [b], and Randall A. Kramer [c]

[a] *Department of Agricultural Economics, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka*
[b] *Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0401, USA*
[c] *Department of Resource Economics, Center for Resource and Environmental Policy Research, Duke University, Durham, NC 27706, USA*

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ABSTRACT

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In applications of expected utility analysis, researchers are confronted with a choice among several utility functional forms. Subjective utility values and probability distributions for price and yield were elicited from Sri Lankan producers of minor export crops. Exponential quadratic and cubic utility functions were estimated. The choice of functional form was found to affect both the classification of risk attitudes and the prediction of harvesting strategy. The exponential function was the best predictor of harvesting strategy because it was the best predictor of mature harvesting. All three functions were equally poor predictors of premature harvesting.

INTRODUCTION

A critical step in many applications of decision analysis under the expected utility hypothesis is the specification and estimation of a suitable utility function. For this purpose, several functional forms have been used

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Correspondence to: D.B. Taylor, Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0401, USA. FAX (703)231-4163.
[1] Present address: Department of Applied Economics, Victoria University of Technology, Vic., Australia.

in empirical studies (Halter and Dean, 1971; Lin et al., 1974; Lin and Chang, 1978; Musser et al., 1984). Researchers generally agree that utility functions should possess some desirable properties such as continuity and decreasing absolute risk aversion. However, beyond that, there is little guidance for researchers to use in selecting functional forms. Using data collected from Sri Lankan farmers, this study first compares the risk attitudes implied by quadratic, exponential, and cubic utility functions. Then an investigation is made of whether or not the ranking of prospects is independent of the utility functional form.

Many studies have arbitrarily chosen a particular functional form and then proceeded with the analysis. In one evaluation of functional forms, Lin and Chang (1978) criticized the forms usually employed because all forms require certain restrictive a priori assumptions. These authors suggested a Box–Cox transformation as a means of determining the form of the function rather than assuming it. Despite the appeal of this approach, Buccola (1982a) later demonstrated that the Box–Cox transformation is not consistent with Bernoullian decision theory.

Musser et al. (1984) have shown that the choice of functional form is critical because it can affect the classification of decision makers based on their risk attitudes. Musser et al. (1984) classified twelve graduate students in their study using the second derivative of the utility function as a measure of risk aversion. The utility functions used were quadratic ($U = a + bx - cx^2$), semi-log ($U = a + b \ln x$), and non-linear ($U = a + bx^c$). The quadratic function classified three subjects as risk-preferring and the rest as risk-indifferent. The semi-log function classified all subjects as risk-averse, and the non-linear function classified all subjects as risk-indifferent.

Regardless of the specific functional form chosen, certain properties are desirable in a functional form. Important ones include: strictly positive marginal utility of income, the ease of estimating the parameters of the function, the ease with which the function can be mathematically manipulated to determine summary measures such as the mean and variance, and the behavior of the measures of the risk aversion. Ideally, a utility function also should exhibit decreasing absolute risk aversion with respect to increasing wealth. Of the functional forms suggested in the literature, the quadratic and the exponential seem to be the most popular.

Analyzing a California farmer's marketing problem, Buccola (1982b), assuming a normal distribution of returns, reported that quadratic and exponential functions gave the same optimal portfolio if and only if there was no more than one linear constraint influencing the decision making and both functions had the same absolute risk aversion coefficients at the optimal solution. Hanoch and Levy (1970), in a theoretical comparison of quadratic and cubic functions, concluded that the cubic function has certain properties which are preferred to those of the quadratic function. These properties are: (1) expected utility depends on the third moment of the distribution, skewness; (2) this added parameter results in greater flexibility and better approximates the general utility function; (3) within certain restrictions on the coefficient, it is monotonically increasing; (4) it exhibits a decreasing degree of risk aversion at certain intermediate levels; and (5) it allows for risk preference (convexity) at certain intervals of high returns. The arguments for the cubic utility function, therefore, rest on the assumption of non-normal returns or non-zero skewness.

ALTERNATIVE FUNCTIONAL FORMS FOR UTILITY

In all the utility functional forms discussed, U will refer to the utility index and x to the monetary measure. In this article income will be in Sri Lankan Rupees (Rs.). At the time of the study, US$1 was equal to 26.28 Rs. The quadratic utility function (QUF) can be represented as:

$$U = a + bx + cx^2 \tag{1}$$

where a, b, and c are parameters. If the second derivative of the function, $2c$, is less than zero then diminishing marginal utility is implied over the entire range of x, thus ruling out risk-preferring behavior. If it is positive, however, the individual would be classified as risk-preferring over the entire range of income. The Arrow–Pratt absolute risk aversion coefficient, R_a, for the QUF is given by:

$$R_a = \frac{2c}{b + 2cx} \tag{2}$$

Function (2) will remain positive for $x < (b/2c)$. Consequently, within this range of x, the quadratic function will exhibit increasing risk aversion, and for values of $x > (b/2c)$, the function will exhibit decreasing risk aversion.

The exponential utility function (EUF) can be represented as:

$$U = K - \theta e^{-\lambda x} \quad \text{for } K, \theta, \lambda > 0 \tag{3}$$

where, K and θ are parameters and e is the base of natural logarithms. The second derivative of the function is:

$$-\lambda^2 \theta e^{-\lambda x} < 0 \tag{4}$$

implying diminishing marginal utility. The Arrow–Pratt absolute risk aversion coefficient, R_a, is λ, which is positive and constant. The exponential utility function, therefore, exhibits constant risk aversion over all levels of net returns, which can be argued is one of its major limitations.

The cubic utility function (CUF) can be expressed as:

$$U = a + bx + cx^2 + dx^3 \tag{5}$$

where a, b, c, and d are parameters. The second derivative is given by $2c + 6dx$, the sign of which depends on the sign and the magnitude of the parameters c, d, and the level of income, x. Thus increasing and decreasing marginal utility are both possible. The Arrow–Pratt absolute risk aversion coefficient for the CUF is:

$$R_a = -\left[\frac{2c + 6dx}{b + 2cx + 3dx^2}\right] \tag{6}$$

The R_a thus can be positive or negative depending on the parameter values and income at which equation (6) is evaluated.

METHODS AND DATA

The data used in this paper were obtained as part of a comprehensive study of the decision making of Sri Lankan farmers who produce minor export crops (MEP). The minor export crops considered in this study were cocoa, coffee, pepper, cardamons, and nutmeg. Several other crops, primarily spices and vegetables, also are referred to as minor export crops in Sri Lanka, but were not considered in this study. The specific decision which the study examined was the harvesting behavior of these farmers. The farmers often harvest their crops prematurely due to fear of theft, damage by insects, cash needs, and other factors. The study developed methods to predict whether farmers would harvest maturely or prematurely. One of the methods used elicited utility functions to compare the income earned from premature harvesting with the income earned in a future period from mature harvesting.

The data were collected through two farm surveys in the districts of Kandy and Matale in the central province of Sri Lanka. The surveys were conducted between December 1985 and February 1986. The sample size of the first survey was 240, with an equal number from each district. The first survey was used to collect general information about farms in the two districts. Using the electoral voters' register as a sampling frame, farm households were sampled randomly.

A second survey was conducted among 30 farmers selected at random from the larger sample of 240 farmers. The second survey collected more detailed information about decision making activities on the farm, with the chief decision maker as the unit of inquiry. This survey included elicitation of subjective utility functions and probability distributions.

Direct elicitation of utility functions does have its critics, but direct elicitation has considerable appeal from an empirical perspective (Robinson et al., 1984). The two most widely used direct elicitation methods for utility are the Ramsey method and the modified Von Neumann–Morgenstern method (1953). The Ramsey method elicits certainty equivalents for several risky alternatives. The modified Von Neumann–Morgenstern method elicits certainty equivalents for a series of lotteries. The modified Von Neumann–Morgenstern method was deemed appropriate for this study in view of its ease of use (Anderson et al., 1977) and its proven effectiveness in Sri Lanka in a previous study (Herath et al., 1982).

Using the modified Von Neumann–Morgenstern method as outlined in Anderson et al. (1977, p. 72), utility values were elicited for a range of incomes. This range was established for each individual farmer to correspond to the possible farm income levels which could be experienced by that farmer. The upper value of the range was the net family income from farm and off-farm activities reported in the first survey. The lower value of the range was selected to be a negative 20% of the reported net family income. A negative value was selected for the lower range to allow utility estimation over losses as well as gains. Interviews were conducted by graduate students in agricultural economics at the University of Peradeniya, who were trained in interviewing techniques by the senior author. Binswanger (1980), in discussing the work of Dillon and Scandizzo (1978), argued that the elicitation of utility functions can be subject to interviewer bias. However, since the purpose of this paper is to compare the implications of different functional forms for the information obtained by one interviewer per farmer, this concern is not relevant to this analysis. That is, the comparisons in this study are across functional forms for a given farmer rather than across farmers.

Subjective probability distributions were elicited from 30 growers for prices and yields of the minor export crops. A modified triangular distribution method was used to elicit 5th, 50th and 95th percentiles of the distributions (Moskowitz and Bullers, 1979). The shortcomings of this limited information procedure are recognized (Spetzler and Stael Von Holstein, 1975), but the method was chosen because of the speed with which it can be administered. This was an important consideration given that 20 distributions were elicited from each farmer. Prices and yields were assessed independently because of the large number of growers and the small size of Sri Lankan production relative to the world market.

To compare the relative performance of the three utility functions in predicting behavior, a Monte Carlo simulation model was constructed. The model simulated net family income from farm and non-farm sources. Income from minor export crops was treated as stochastic using the elicited probability distributions of prices and yields. Means and variances were estimated by formulas given in Anderson et al. (1977), and a truncated normal distribution was used to generate 1000 random draws for each minor export crop for each farmer. The truncation was made to assure that no negative prices or yields were generated. The randomly generated income levels were then evaluated with the three fitted utility functions to estimate expected utility levels for the two harvesting options.

UTILITY FUNCTION ESTIMATION

The quadratic (QUF) and cubic functions (CUF) were estimated for each farmer by applying the method of ordinary least squares while the exponential functions (EUF) were estimated by the method of maximum likelihood. For the exponential functions, a set of parameters (K, θ, and λ) was determined for each function which minimized the sum of squares of the error terms. These estimates were used as the starting values in the maximum likelihood method. Space limitations preclude presentation of the estimated functions. The reader is referred to Zuhair (1986) for additional details on the estimation.

For the EUF, estimates of the Arrow–Pratt risk aversion coefficient, λ, were significant at least at the 0.05 level for all the farmers. For the QUF and CUF, the risk aversion coefficients are non-linear functions of the utility function's parameters; thus determination of the level of significance of the risk aversion coefficients for these functions was not possible.

For the QUF, the adjusted-R^2 ranged from 0.80 to 0.99. With the exception of one farmer's QUF, which was significant at 0.01 level, all the other farmers' QUFS were significant at the 0.001 level, based on an F-test. For the CUF, the adjusted-R^2 ranged from 0.86 to 0.99. Based on an F-test, the CUFS were significant at the 0.01 level for four farmers and at 0.001 for the rest of the farmers. For the EUF, the adjusted-R^2 ranged from 0.86 to 0.99. Comparing the adjusted-R^2 across functions, the CUF gave the highest adjusted-R^2 for 14 farmers, the EUF for three farmers and the QUF for two farmers. For four farmers, all three functions gave the same adjusted-R^2. Four farmers had the same adjusted-R^2 for the CUF and EUF, which was higher than for their QUF. The QUF and the CUF were tied for highest adjusted-R^2 for two farmers, while the QUF and the EUF had the same higher adjusted-R^2 than the CUF for the remaining farmer.

FARMER RISK ATTITUDES

The Arrow–Pratt risk aversion coefficient, R_a, was computed for each farmer. The R_a, when computed with the EUF is independent of the level of income, while for the QUF and the CUF the R_a is a function of income. The R_a was computed at the midpoints of the income ranges used to elicit the utility functions (Table 1).

TABLE 1

Arrow–Pratt absolute risk aversion coefficients, R_a

Farmer number	Exponential (EUF)	Quadratic (QUF)	Cubic (CUF)
1	0.00005270	0.00006577	−0.0005469
2	0.00040450	0.00043294	−0.0003523
3	0.00019760	0.00018766	0.0002077
4	0.00033224	0.00034390	0.0002386
5	0.00036092	0.00041337	0.0001543
6	0.00011053	0.00012043	0.0000384
7	0.00029795	0.00034901	0.0000404
8	0.00001611	0.00000551	0.0000006
9	0.00012613	−0.00044156	−0.0007702
10	0.00010392	0.00004496	0.0001368
11	0.00009431	0.00010614	−0.0000184
12	0.00005919	0.00006931	−0.0000962
13	0.00047985	0.00054206	0.0000541
14	0.00001732	0.00001979	−0.0000130
15	0.00011673	0.00014056	−0.0000782
16	0.00022695	−0.00030186	−0.0001271
17	0.00005872	0.00071295	0.0004009
18	0.00027857	0.00033571	0.0000065
19	0.00062817	0.00069943	−0.0000285
20	0.00008684	0.00009609	−0.0000386
21	0.00356840	0.00407888	−0.0010882
22	0.00046407	0.00033893	0.0002905
23	0.00007983	0.00002191	0.0000292
24	0.00007236	0.00007536	0.0000191
25	0.00007145	−0.00050530	−0.0000495
26	0.00136620	0.00148119	0.0009055
27	0.00015313	0.00018857	−0.0000202
28	0.00033195	0.00036976	0.0001822
29	0.00017842	0.00021807	−0.0000639
30	0.00253540	0.00310520	−0.0019286

$R_a > 0$ means that the farmer is risk-averse at this level of income, while $R_a < 0$ means that the farmer is risk-preferring. The risk aversion coefficients were calculated for the quadratic and cubic functions at the midpoints of the ranges used for each farmer to elicit his utility function. For the exponential function, R_a is independent of the level of income.

The EUF classified all farmers as risk-averse, $R_a > 0$. The R_a, as given by λ, ranged from 0.00001611 (farmer 8) to 0.00356840 (farmer 21). The QUF classified 27 farmers as risk-averse and three farmers as risk preferring at the income midpoint. For the risk-averse farmers, the R_a ranged from 0.00000551 (farmer 8) to 0.00407888 (farmer 21). The risk-averse farmers with the lowest and the highest R_a with the QUF at the income midpoint also had the lowest and highest R_a with the EUF. For farmers classified as risk preferring by the QUF, the R_a at the income midpoint ranged from -0.00044156 (farmer 9) to -0.000050530 (farmer 25).

At the income midpoint, the CUF classified 15 farmers as risk-averse and 15 farmers as risk-preferring. The R_a for risk-averse farmers ranged from 0.0000006 (farmer 8) to 0.0009055 (farmer 26). Note that farmer number 8 had the lowest level of risk aversion with all three functions. For the risk-preferring farmers, the R_a ranged from -0.0000130 (farmer 14) to -0.0019286 (farmer 30). The three farmers classified as risk-preferring by the QUF were also classified as risk-preferring by the CUF at their income midpoint. Twelve of the farmers who were classified as risk-averse by the QUF were classified as risk-preferring by the CUF.

PREFERRED HARVESTING STRATEGIES

Table 2 gives indices of expected utility for the three utility functions analyzed with respect to income which could be earned from mature and premature harvesting decisions. The estimated utility functions were used to compute the expected utility of income under two harvesting strategies, mature harvesting (M) and premature harvesting (P). The income distribution from each alternative was computed using a Monte Carlo simulation model which sampled prices and yields from elicited subjective probability distributions (Zuhair, 1986). The expected income generated by the Monte Carlo simulation fell within the income range used to elicit the utility function for all but two farmers. In these two cases, the expected income levels were less than 10 percent above the upper limit of the range. The income range used to elicit the certainty equivalents for estimation of the utility functions thus was comparable with the income resulting from the Monte Carlo simulations.

For the EUF, the utility index for Strategy-M was higher than that of Strategy-P for 29 farmers. The QUF ranked Strategy-M higher for 25 farmers and lower for five farmers. The CUF ranked Strategy-M higher for 21 farmers and lower for nine farmers. The CUF, thus, favored the premature harvesting strategy for the largest number of farmers.

These results demonstrate that different utility functional forms can have a different preference ordering for the same set of prospects. Comparing the EUF and the QUF, four reversals in ranking of the prospects are observed. Between the EUF and CUF there are eight reversals in ranking, and between the QUF and CUF, six reversals occurred.

The ultimate test of functional form is how well the function predicts actual farmer behavior. In Table 3, 1985 observed farmer behavior is compared to the predicted behavior with respect to the mature versus

TABLE 2

Indices of expected utility for mature and premature harvesting strategy

Farmer number	Exponential (EUF)		Quadratic (QUF)		Cubic (CUF)	
	M	P	M	P	M	P
1	75.035 *	74.700	91.465 *	90.990	192.239 *	189.791
2	79.951 *	77.704	81.815 *	81.381	99.965	108.347 *
3	29.872 *	25.857	29.789 *	25.741	29.943 *	25.963
4	62.373 *	46.541	62.655 *	46.670	63.538 *	46.482
5	69.359 *	68.758	71.259 *	70.696	77.372 *	76.726
6	40.345 *	39.476	40.421 *	39.516	38.334 *	37.277
7	81.357 *	81.030	81.057 *	80.927	87.908	88.383 *
8	69.941 *	66.881	70.746 *	67.329	72.558 *	69.601
9	58.445 *	51.388	60.218 *	47.823	62.064 *	42.557
10	56.155 *	48.073	55.921 *	47.470	56.073 *	47.687
11	83.064 *	82.898	81.718	81.791 *	85.531	86.586 *
12	64.757 *	60.861	74.626 *	68.268	100.360 *	86.193
13	79.013 *	78.554	85.500	85.567 *	103.417	104.355 *
14	73.120 *	72.865	74.071 *	73.844	96.385 *	96.256
15	84.770 *	84.404	83.863 *	83.534	82.584	83.361 *
16	30.573 *	27.057	20.002 *	16.394	20.260 *	17.166
17	19.150 *	18.847	26.223 *	23.007	24.456 *	21.253
18	68.196 *	67.403	76.557 *	73.326	92.045 *	83.816
19	70.341 *	59.101	71.830 *	60.678	81.210 *	66.374
20	84.710 *	82.605	83.211 *	81.758	75.470	80.209 *
21	71.804 *	67.671	73.145 *	69.353	89.855 *	85.364
22	80.685 *	80.661	84.499	84.857 *	78.946 *	78.877
23	28.039 *	12.827	27.466 *	12.913	27.288 *	12.660
24	82.715	82.826 *	81.723	81.922 *	78.748	79.556 *
25	27.533 *	18.735	25.885 *	17.757	26.379 *	18.342
26	31.197 *	24.955	31.703 *	25.223	32.427 *	25.611
27	77.645 *	75.610	77.541 *	75.905	89.287	90.126 *
28	82.108 *	82.034	85.720	86.071 *	86.969	87.401 *
29	71.005 *	65.050	79.680 *	72.338	109.006 *	92.607
30	52.923 *	41.644	55.206 *	42.311	65.211 *	40.042

M, Mature harvesting strategy; P, Premature harvesting strategy; *, Preferred strategy.

premature harvesting. For each utility function, the farmer's expected income from mature and premature harvesting of the MEC was employed (Zuhair, 1986). The EUF, with 23 correct predictions, did the best job of predicting actual behavior. The QUF was second with 19 correct predictions, while the CUF was last with 15 correct predictions. With only one correct prediction of premature harvesting by each utility function, all three functions did a better job of predicting mature harvesting than premature harvesting. That predictions were better for mature harvesting may, at least

TABLE 3

Observed (1985) versus predicted behavior of the three utility functions

Farmer number	Observed behavior	Predicted behavior		
		Exponential (EUF)	Quadratic (QUF)	Cubic (CUF)
1	M	M *	M *	M *
2	M	M *	M *	P
3	P	M	M	M
4	P	M	M	M
5	M	M *	M *	M *
6	M	M *	M *	M *
7	M	M *	M *	P
8	M	M *	M *	M *
9	M	M *	M *	M *
10	P	M	M	M
11	M	M *	P	P
12	M	M *	M *	M *
13	M	M *	P	P
14	M	M *	M *	M *
15	M	M *	M *	P
16	M	M *	M *	M *
17	M	M *	M *	M *
18	P	M	M	M
19	M	M *	M *	M *
20	M	M *	M *	P
21	M	M *	M *	M *
22	M	M *	P	M *
23	M	M *	M *	M *
24	P	P *	P *	P *
25	P	M	M	M
26	M	M *	M *	M *
27	M	M *	M *	P
28	M	M *	P	P
29	P	M	M	M
30	P	M	M	M
Total correct predictions out of 30 observations:		23	19	15
Correct predictions out of 22 observed mature harvesters:		22	18	14
Correct predictions out of 8 observed premature harvesters:		1	1	1

M, Mature harvesting; P, Premature harvesting; *, Correct prediction.

in part, be due to the sample containing only eight actual premature harvesters. Alternatively, since these three utility functions did not correctly predict behavior for seven of the premature harvesters, perhaps some other form of utility function would be more appropriate for these individuals.

It should be noted that a stronger test of these utility functions would have been to compare them to observed behavior in subsequent years since the predicted behavior represents a long term average behavior determined from the results of the Monte Carlo simulation. This test, however, was beyond the scope of the study.

CONCLUSIONS

This study has demonstrated that the choice of a utility function is an important aspect of the methodology of applying expected utility theory. The importance of choosing an appropriate utility function cannot be over emphasized. Depending on the functional form chosen by the researcher, farmers may be classified as risk averse or risk preferring. In contrast to the exponential utility function which imposes risk aversion on all farmers, the quadratic utility function classified 27 farmers as risk-averse and three as risk-preferring, while the cubic utility function classified half of the farmers as risk-averse and half as risk-preferring.

In addition to the risk attitudes classification issue, this study explored the effects of utility functional form on the ranking of risky prospects. It was found that there were numerous preference reversals when different functional forms were used to evaluate mature versus premature harvesting strategies. This study examined the simple choice of either mature or premature harvesting. The large number of preference reversals suggests that if the analysis was extended to the more complicated case of portfolio selection, portfolios also would be sensitive to choice of functional form.

In this study, the EUF performed better than other functions in predicting overall farmer behavior, but more research is needed to better predict premature harvesting behavior. The results do not suggest that the EUF will be the appropriate function in all cases. Rather, the results of this study suggest that when employing a utility function, several functions must be estimated and evaluated in terms of their power to predict actual situations. Only then can an appropriate function for further analysis be selected. Furthermore, it should be noted that since an individual's preferences and the utility function which will accurately reflect these preferences are unique to each individual, it is not likely that one form of utility function will correctly predict the behavior of all individuals. At best, a utility function which predicts behavior correctly for most individuals, such as the EUF in this study, may be identifiable.

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