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Appendix A

KENYA AGRICULTURAL RESEARCH INSTITUTE NDFRC KATUMANI

Farming Systems Research Program

MAIZE PRODUCTION TECHNOLOGY - QUALITATIVE DATA SCHEDULE

SECTION A: FARM IDENTIFICATION

1. Farmer's Name...
2. Serial No..
3. Address ....
4. Enumerator ....
5. Location ....
6. Sub-location ....
7. Date ....

SECTION B: IMPROVED SEED VARIETIES AND RELATED ISSUES

8. Where is the nearest point at which you may purchase

   Local maize seed ....

   KCB seed ....

   Other maize seed ....

9. Are you usually able to obtain sufficient seed from these sources in time for planting?

   Yes = 1

   No = 2

10. How would you rank the following sources of seed?

Purchase..

Own farm ....

Local market ....

Other sources (specify) ....

11. How many seasons should KCB seed be grown before replacement with fresh seed?

_____________________ seasons.

12. What are the greatest obstacles to using more fresh seed (at most 3 seasons old)?

1 =

2 =

3 =

4 =

13. What is the best spacing for maize

Pure stand ....

Maize/beans/cow peas mixture ....

Maize pigeon peas mixture ....

14. What advantages does KCB have over local maize?

1. ....

2. ....

3. ....

4. ....

5. ....

15. What are the main advantages of local maize over KCB?

1. ....

2. ....

3. ....

16. How would you rank the following factors in order of contribution to maize yields?

Soil conservation ....

Well prepared seed-bed ....

Pedigree seed..

Planting on time ....

Optimum planting density ....

Fertilizer application .. ..

Weed control...

Others...

SECTION C: FIELD OPERATIONS

17. What are the advantages of planting

Before onset 1. ....

At onset 2. ....

After onset 3. ....

18. What are the disadvantages of sowing

Before onset 1. ....

At onset 2. ....

After onset 3. ....

19. What are the disadvantages of plough planting?

1. ....

2. ....

3. ....

20. What factors contribute to low final plant populations?

1. ....
2. ....
3. ....
4. ....

21. How many weeks after emergence do you commence weeding?

Number of weeks ....

22. How many weedings should one perform during

Poor season ....

Good season ....

Average season ....

SECTION D: SOIL FERTILITY AND PLANT NUTRITION

23. Do you practice

Fallowing = 1

Crop rotations? = 2

Neither = 3

24. What is your view of the fertility status of your fields?

High = 1

Adequate = 2

Low = 3

25. For the portion of your land that is low in soil fertility, do you take corrective action?

Apply fertilizers = 1

Apply manures = 2

Other (specify) ....

26. (If manure is applied) what is the most important source?

Own = 1

Neighbour = 2

Purchase = 3

27. On a given field, what frequency of application is aimed at?

Number..

28. How much is applied on the field in a season?

29. By what means is the manure applied?

Baskets = 1

Wheel barrow = 2

Ox-cart = 3

Others ....

30. Do you apply all available manure each season?

Yes = 1

No = 2

31. If not all manure is applied each season, why?

1...

2...

3...

4...

32. Do you apply manure to all the fields?

Yes = 1

No = 2

33. If not, how much crop land is usually covered

Less than 1/4 = 1

1/4 - 1/2 = 2

1/2 - 3/4 = 3

More than 3/4 = 4

34. What are the main factors that impede greater use of manure?

1. ....

2. ....

3. ....

4. ....

5. ....

6. ....

35. There are different types of fertilizers for maize. Which types do you know?

Planting (basal application) = 1 ....

2............................

3............................

4............................

Top dressing 1 ....

2............................

3............................

4............................

36. What is the best time for basal application of fertilizers?

At planting = 1

Before planting = 2

After planting = 3

37. What is the best time for top dressing?

1 =

2 =

3 =

38. Where would fertilizers be obtained?

Local shop = 1

KGGCU = 2

Other (specify) = 3

39. Would you always get fertilizer from these sources when needed?

Yes = 1

No = 2

40. How much fertilizers do you apply per hill?

gms basal ....

gms top dressing ....

41. What method of application do you use?

Direct placement = 1

Placement in furrow = 2

Other = 3

42. How would fertilizer be applied in order to minimize damage to seedling?

1...

2...

3...

43. Do you know about carry over of benefits to plants during different types of season?

Yes = 1

No = 2

44. Would you borrow money to finance purchase of fertilizers?

Yes = 1

No = 2

45. Is maize that is treated with fertilizer more or less likely to succeed during a poor season?

Yes = 1

No = 2

SECTION E: FARM FINANCE

46. What is the most important earner of cash for your household?

Activity	Rank
Non-farm	
Crops	

Livestock

Wage employment

Other

----

47. What is the highest number of cattle you have ever had?

Nos......................

48. What is the lowest number of cattle you have had?

Nos. ....

49. What is the most common cause of reductions in cattle numbers?

1 = drought 2 = sales 3 = disease

4 = other

50. What is the highest price for a mature cow?

Buying (Kshs.) .... Selling (Kshs). ....

51. What is the usual price of a cow?

Buying (Kshs). .... Selling (Kshs). ....

52. What is the lowest that you can get for a cow?

Buying (Kshs). .... Selling (Kshs). ....

53. What do you see as assuming more importance as an income earner? (circle)

Food crops

Cash crops

Non-farm

Livestock

Wage employment

Others (specify) ....

54. For money allocated to crop production how would you assign priority to expenditure on:

Seed ....

Fertilizers ....

Hire of extra labour ....

Hire of draft ....

Hire of machinery ....

Purchase of pesticides ....

Repair of equipment ....

55. Suppose that you have allocated a sum of money for land improvement. How would you assign priority to:

Terracing .... Fencing ....

Tree planting .... Bush clearing ....

Dam contraction ....

56. For money for household expenditure, how would you assign priority to:

Education of children --------------------------------

Purchase of food --------------------------------------

Purchase of consumer durables -------------------------

Purchase of consumer (including clothing) -------------------------------------

Purchase of appliances --------------------------------

Health --

Transportation --

Community affairs -------------------------------------

SECTION F: SOURCES AND USES OF CREDIT

57. One way to increase farm production is to use improved seeds and fertilizers. Would you borrow from an institution to finance purchase of farm inputs such as seeds and fertilizers?

Yes = 1

No = 2

58. Which institutions would a farmer such as yourself borrow from?

Commercial bank = 1

Commercial credit = 2

Co-op. = 3

59. Is a farmer like yourself likely to experience problems in attempting to borrow from such sources?

1. ....
2. ....
3. ....
4. ....

60. What are the advantages of borrowing funds to purchase crop production inputs?

1. ....
2. ....
3. ....
4. ....

61. What are the disadvantages of borrowing to finance purchase of crop production inputs?

1. ....
2. ....
3. ....
4. ....

62. Have you borrowed from such institutions to finance crop production activities?

Yes = 1

No = 2

SECTION G: LABOUR INFORMATION

63. What are the most labour demanding activities on the farm?

Crop production ....

Livestock activities ....

Farm maintenance ....

Non-farm activities ....

Household activities ....

Communal undertakings ....

64. Is household labour usually sufficient?

Yes = 1

No = 2

65. If No to 64, do you usually supplement family labour with off farm labour?

Yes = 1

No = 2

66. What sort of wage rate would the following categories of people seeking off farm employment expect to secure?

	Lowest	Highest
0-7 years of schooling	Kshs..........	Kshs. ....
8-11 years of schooling	Kshs.	Kshs. ....
12-14 years of schooling	Kshs.	Kshs ....
Over 14 years	Kshs.	Kshs. ....

SECTION H: LAND AND WATER MANAGEMENT

67. What are the principal systems of soil conservation

1. ....

2. ....

3. ....

4. ....

5. ....

68. What are the benefits from soil conservation?

Enhances sustained productivity

Maintains yields

Increases yields in subsequent seasons

Others

69. What is the cost of construction of terraces?

.... Kshs. per meter for ....

70. Approximately how long do terraces last before repair works are needed?

.... years.

SECTION I: SOURCES OF FARMING INFORMATION

71. How often are you visited by extension workers?

Ever = 1
Usually = 2
Occasionally = 3
Never = 4

72. What is the most common subject of advice?

Crops = 1
Livestock = 2
Soil conservation = 3
Other = 4

73. How often do you visit the extension staff?

Ever = 1
Usually = 2
Occasionally = 3
Never = 4

74. The purpose of your visit?

Crops	= 1
Livestock	= 2
Soil conservation	= 3
Other	= 4

75. Have you attended a course on farming?

Yes = 1

No = 2

76. (If yes) What was the course concerned with?

1. ....

2. ....

3. ....

77. Do you attend Barazas at which farming matters are discussed announced?

Yes = 1

No = 2

78. Do you attend farmers field days, Agricultural shows and demonstrations?

Yes = 1

No = 2

79. How much of what is demonstrated concerning maize production do you actually implement on return to your farm?

Less than 1/4 = 1

About 1/2 - 3/4 = 2

More than 3/4 = 3

80. Do you obtain comparable results with what you see at the demonstrations/field days?

About the same = 1

Less = 2

Far less = 3

81. What are your most important sources of information concerning farming?

Neighbour(s) = 1

Local market = 2

Extension officer = 3

Church organization = 4

The co-operative movement = 5

Radio broadcasts = 6

Barazas = 7

82. What does a farmer consider to be a poor season?

Start early and finishes early = 1

Start late and finishes early = 2

Start early, has dry spells and finish late = 3

Start late, is erratic, has dry spells and finishes early = 4

Other = 5

Appendix B

NON-ECONOMIC FACTORS AND SMALLHOLDER ADOPTION DECISIONS

B.1.1 Qualitative Dependent Variables Models

Probability models may be derived from underlying individual behaviour involving random elements. A firm's decision to adopt an innovation can be conceived of as being on a continuous scale, with actual adoption depending upon a stimulus (certain characteristics of the firm) to trigger the discrete response (adoption). Assume a continuous (unobservable) impact X^o which is a linear function of the stimulus X with a random disturbance, in the regression equation

$$X^* = \alpha_1 + \beta_1 X + \epsilon_1 \qquad \text{(B.1)}$$

and a threshold X^o given by

$$X^o = \alpha_2 + \beta_2 X + \epsilon_2 \qquad \text{(B.2)}$$

so that

$$Y = 1 \; if X^* > X^o$$

and

$$Y = 0 \quad \text{otherwise.}$$

An individual response of this type can be depicted graphically as in Figure B.1, where X^* would be at or somewhere to the right of X^o.

With the probability $Y_i = 1$ and not the value of Y itself regarded as a suitable function of the stimulus X, the i_{th} observation on Y may be regarded as a discrete random variable. The result would be a probability model which specifies the probability of the response as a function of the stimulus.

$$P(X) = P_r(Y=1) = P_r(X^o < X^*) \qquad \text{(B.3)}$$

From equations (B.2) and (B.3),

$$P_r(Y=1) = P_r ((\varepsilon_2 - \varepsilon_1) < (\alpha_1 - \alpha_2) + (\beta_1 - \beta_2) X$$

or

$$P(X) = F^* ((\alpha_1 - \alpha_2) + (\beta_1 - \beta_2) X$$

$$= F ((\alpha - \mu) / \sigma + (\beta / \sigma) X)$$

With $\alpha = \alpha_1 - \alpha_2$,
$\beta = \beta_1 - \beta_2$,

and $\mu = \mu_1 - \mu_2$,
$\sigma^2 = \sigma_1^2 + \sigma_2^2$.

μ_1, μ_2 and σ_{12}, σ_2^2 denote the means and variances of the two disturbances which are assumed independent.

$F^*(.)$ is the distribution function of $\varepsilon = \varepsilon_2 - \varepsilon_1$, and $F(.)$ is the distribution function of the corresponding standard variate with zero mean and unit variance. The observed stimulus X itself is directly compared to a random threshold which represents the propensity of the individual firm to respond to the stimulus. With a suitable specification of the distribution of $_\varepsilon F^*(.)$, a logistic function can be obtained. The slope of F^* (.) is $1/\sigma_2$, and it reflects variability in propensity to respond among individuals as well as heterogeneity with respect to propensity to respond in the sample. Such a response function for a single observation is shown in Figure B.1.

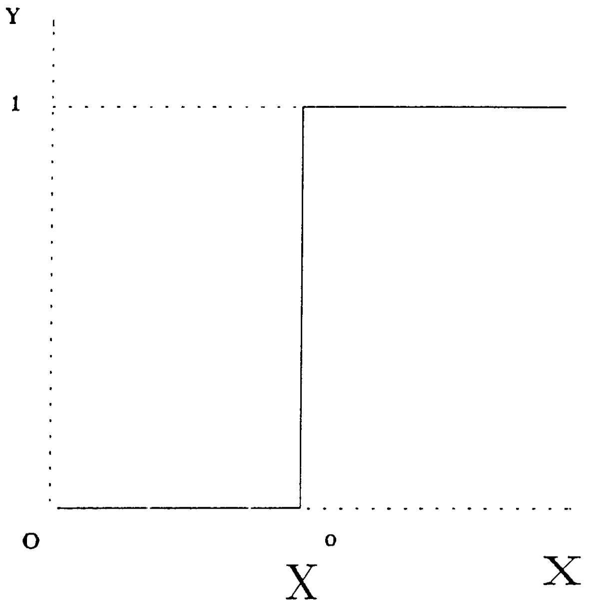

Fig. B.1. An individual response function of the QDVM model

The position of the critical level (threshold) is a random variable for each individual farm determined each time a random drawing is made from the sample. The threshold is usually assumed to be a determinate characteristic of the individual, which shows some dispersion in the population under consideration. The probability model arises because each individual constitutes a random drawing from this population. These behavioral models presuppose a causal relationship between the original stimulus X (or external determinants) some intermediate latent variable like an impact and the ultimate effect Y. The logistic function offers greater analytical convenience. It has desired properties such as:

- analytical convenience
- monotonically increasing from zero to one as X ranges over its domain as shown in Figure B.2, and
- symmetry of this representation that places alternatives $Y = 1$ and $Y = 0$ on an equal footing.

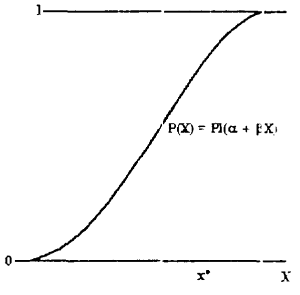

Fig. B.2. The CDF of the logit model

The *CDF F*(.) of any random variable with a symmetric *pdf* that can allow a linear transformation of its argument can also have these properties. In practice, two types of density function are used for this purpose. Of these two, the logistic function (yields the logit model) and the normal density function (leads to the probit model) are commonly used. The *pdf* of the logistic function can be written as equation (B.4).

$$f(Z) = \exp Z / (1 + \exp Z)^2 \tag{B.4}$$

which has mean zero and variance $\pi^2/3$. The standardized logistic distribution with zero mean and unit variance is

$$F_l(X) = \pi / \sqrt{3} \exp \pi / \sqrt{3} X / (1 + \exp \pi / \sqrt{3} X)^2 \tag{B.5}$$

and its *CDF* is

$$F_l(X) = \exp \pi / sqrt3X / (1 + \exp \pi / \sqrt{3} X \tag{B.6}$$

On the other hand, the distribution of the normal probability function is specified as

$$\phi(X) = 1/\sqrt{2}\pi\int_{-\infty}^{X}\exp^{(-1/2t^2)}dt \tag{B.7}$$

and its *CDF* is

$$Z(X) = 1/\sqrt{(2\pi)}\exp^{-1/2x^2} \tag{B.8}$$

If fitted to the same set of data, both the logit and probit specifications yield results that bear similarity in many respects. The normal density function is a common specification for any residual or unknown random variable, and has a direct intuitive appeal. Both the probit and logit models are similar in shape. The logit density has a higher peak in the middle than the probit density. At first, it declines faster than the normal, and then it slows down to the thicker tails. Over a relevant range of the probabilities, the logit is, symmetrically, somewhat steeper than the probit. With judicious adjustment of the linear transformation of the argument (X) , the logit and probit probability functions can be made to coincide over a fairly wide range (Cramer 1991). It is not easy to distinguish between the two on empirical grounds. However, the probit specification is less analytically tractable (Cramer 1991). Survey data of this study were fitted to the logit model.

B.1.1.2 Implementation

The principal aim behind this type of analysis is to estimate a vector of unknown parameters β . If repeated observations on a particular decision maker are available, P_i can be estimated using the sample proportion of occurrences that option one was chosen. This can then be used to compute β. Where repeated observations on the individual decision maker are not available, one has to resort to the Maximum Likelihood Estimation (MLE) methods to facilitate estimation of β. The latter is the most practical approach to the estimation of the parameters of a probit or logit model from survey data. This method yields estimates that are consistent and asymptotically efficient and, in addition, provides ready estimates of their asymptotic co-variance matrix.

Data from a sample survey would consist of i observations (i = 1, 2,..., n) on adoption of an innovation denoted by the (0,1) variable Y_i and a number for characteristics of each individual of the form X_i arranged in the vector x_i. The probability that observation i has $Y_i = 1$ is $P_i = P(X_i, \theta)$ with a given specification of the function $P(.)$. Since successive observations are assumed independently distributed, the sample density function of a vector can be written as

$$f(Y,X,\theta) = P(X_1,\theta) . Q(X_2,\theta) . P(X_3,\theta) . P(X_4,\theta)... \tag{B.9}$$

The probability that $Y_i = 0$ is

$$Q_i = Q(X_i,\theta) = 1-P(X_i,\theta) \tag{B.10}$$

where X is a matrix of the regressor vectors x_i.The argument θ, is a vector of unknown parameters and X_i are known constants. The likelihood function of the sample, designated L, has the same form, but now the sequence of zeros and ones is fixed as given by the sample observations and θ is the argument. The character of X does not change. Because L is a product, the log likelihood function log L is a sum.

$$logL(\theta) = \sum_{i\epsilon A1} \log P(X_i,\theta) + \Sigma \log Q \sum_{i\epsilon Ao} \log Q(X,\theta) \tag{B.11}$$

where $_{A1}$ and $_{A0}$ are observations with $Y = 1$ and $Y = 0$ respectively.

The maximum likelihood estimate (MLE) of θ is θ^. MLE maximizes the likelihood of its logarithm. To find the values of θ^, the derivatives of L are found, set equal to zero and then solved simultaneously. In general such systems of equations have no analytical solution. θ^ is usually found by successive approximations. For this study, parameter values were computed by the SHAZAM computer software (White 1988; White, Wong, Whistler and Haun 1990).

Appendix C

STOCHASTIC DOMINANCE THEORY

C.1.1 Stochastic efficiency rules

Stochastic efficiency rules have been the subject of extensive coverage in the literature in recent years. The literature on stochastic efficiency theory varies greatly in complexity and sophistication. Anderson (1974) presents a compact discussion of the first, second, third and fourth degree stochastic (FSD, SSD, TSD and QSD) dominance criteria via relevant theorems and proofs. The basic structure of the theory is now outlined, following his scheme.

Stochastic dominance theory makes extensive use of the Arrow-Pratt measure of local risk aversion defined as

$$r(x) = -U''(x) / U'(x) \tag{C.1}$$

U' is the first derivative of the utility function $U(x)$, and, U'' is the second derivative of $U(x)$. For a random variable x which may only take values in the range $[a,b]$ probability density functions $f(x)$ and $g(x)$ can be specified. With x assumed to vary over its entire range so that f and g are continuous, cumulative density functions F and G can be written as

$$F_1(R) = \int_a^R f(x)\,dx \tag{C.2}$$

and

$$G_1(R) = \int_a^R g(x)\,dx \tag{C.3}$$

so that R varies continuously on the interval $[a,b]$. The procedure for accumulating areas under $f(x)$ to define $F_1(R)$ can be applied to $F_1(R)$ to accumulate area under the CDF and thus define $F_2(R)$ that is,

$$F_2(R) = \int_a^R F_1(x)dx, \quad G_2(R) = \int_a^R G_1(x)dx \tag{C.4}$$

and in general,

$$F_n(R) = \int_a^R F_{(n-1)}(x) \qquad \text{(C.5)}$$

A decision maker's preferences for x are encoded in a utility function $U(x)$ which is defined for all x in $[a,b]$. Several increasingly restrictive assumptions concerning $U(x)$ can be introduced. These involve derivatives of $U(x)$.

C.1.2 First degree stochastic dominance (FSD)

The utility function is assumed to be monotonically increasing over the relevant range and its first derivative is positive such that the range is from r_1 (x) = - ∞ r_2 (x) = + ∞.

First degree stochastic dominance (FSD), due to Quirk and Saposnik (1962), Hadar and Russell (1969) and Hanoch and Levy (1969), is the simplest and most universally applicable efficiency criterion (King and Robison 1981).

The distribution f dominates g by first-degree stochastic dominance (f *FSD* g) if, and only if, $F_1(R) \leq G_1(R)$ for all R in $[a,b]$ with strict inequality for at least one value of R .

The behavioral assumption concerning decision makers is that they all prefer more to less of x. This wide generality tends to restrict the practical usefulness of FSD, since this criterion can only eliminate few alternatives from consideration.

C.1.3 Second degree stochastic dominance (SSD)

Second degree stochastic dominance (SSD), due to Hadar and Russell (1969) and Hanoch and Levy (1969), holds for risk averse decision makers. In this case, the range of the function is from $r_1(x) = 0$ to $r_2(x) = +\infty$ (all risk averse agents). Distribution f is preferred to distribution g by second degree stochastic dominance (f *SSD* g) if and only if $F_2(R) \leq G_2(R)$ for all possible R with strict inequality for at least one value of R. This ordering proceeds on the basis of comparison of accumulated areas under alternative CDFs. Depicted on the same graph, accumulated area under $F(x)$ must be less or equal to the area under $G(x)$, for all values x.

If additional restrictions are imposed so that x is normally distributed or that the utility functions for the decision makers under consideration are quadratic, the ranking of x under SSD and the mean-variance criterion is identical. The behavioral assumption is that as well as preferring more to less, decision makers in this category are also risk averse.

These assumptions imply diminishing marginal utility of x (a concave utility function). Restated algebraically, $U'(x) > 0$ and $U''(x) < 0$. These assumptions imply that SSD has greater discriminatory power than FSD. For this reason, SSD has seen wider application in empirical work. However, the criterion is not discriminating enough, and SSD often leaves large numbers of alternatives in the efficient set.

C.1.4 Third degree stochastic efficiency (TSD)

In the TSD case, further restrictions are placed on utility functions for decision makers. Distribution *f* dominates distribution *g* in the third degree stochastic dominance sense (*f SSD g*) if and only if $F_3(R) \leq G_3(R)$ for all *R* in $[a,b]$ with strict inequality for at least one value of *R*. There is an additional requirement that $F_2(b) \leq G_2(b)$.

Graphically, for *f* to dominate *g*, $F_3(x)$ must never be to the left of $G_3(x)$ curve, and the top of F_2 curve must not be to the left of the top of G_2 curve. The TSD criterion is consistent (it does not require) with preference for positive skewness in the distribution of *x*.

The utility function is assumed to have a third derivative that is positive so that $U'(x) > 0$; $U''(x) < 0$; $U'''(x) > 0$. These additional restrictions on the preference function suggest that decision makers become decreasing risk averse as they become wealthier. It is a necessary but not sufficient condition for decreasingly risk aversion.

C.1.5 Stochastic efficiency criteria higher than TSD (HSD)

In principle, it is possible to develop efficiency criteria that are weaker than TSD by adding restrictions and assumptions about the utility function and relationships among distributions to construct, for example, fourth degree stochastic dominance criteria (QSD). However, such criteria are likely to encounter plausibility problems arising from lack of either intuitive or theoretical justification for the restrictions imposed on derivatives of the utility function beyond the third.

C.1.6 Generalized stochastic dominance (GSD)

The search for extensions which incorporate efficiency criteria that are both more flexible and more discriminating than the first, second and third degree criteria has yielded several important extensions. Of these, the most significant has been stochastic dominance with respect to a function (SDWRTAF) (King and Robison 1981). This procedure orders uncertain choices for decision makers whose absolute risk aversion functions lie within specified bounds on the Arrow-Pratt coefficient of absolute risk aversion:

$$r(x) = -U''(x)/U'(x) \tag{C.6}$$

where $U'(x)$ and $U''(x)$ are the first and second derivatives of a Von Neumann-Morgenstern utility function, and $U(x)$ is as already defined. The expression in equation (C.6) is equivalent to the difference between the expected utilities of outcome distributions $F(x)$ and $G(x)$. If for a given class of decision makers, the minimum of this difference is positive, $F(x)$ is unanimously preferred to $G(x)$ since this implies that the expected utility of $F(x)$ is always greater than that of $G(x)$. If the minimum is zero, it is possible for an individual in the relevant class of decision makers to be indifferent between the two alternatives.

$$[G(x) - F(x)]U'(x)dx \tag{C.7}$$

subject to the constraint

$$r_1(x) < -U''(x)/U'(x) < R_2(X) \tag{C.8}$$

If the minimum of the difference is negative, then the test is repeated replacing $G(x)$ with $F(x)$ to determine whether $G(x)$ is unanimously preferred to $F(x)$. It is possible that neither distribution is unanimously preferred and, in such a case, complete ordering cannot be achieved. The approach in this study was to find r such that on either side of that value, a different distribution dominates. For two distributions with n observations and associated probabilities, r is found such that the utility difference (UD) is effectively zero.

The main strengths of this particular approach in relation to smallholder farming are that detailed specification of utility functions or probability distributions is not required. This is in addition to availability of an efficient algorithm along with computer code to implement it (e.g., McCarl 1987; Raskin and Cochran 1986).

C.1.7 Evaluation of the stochastic dominance framework

As a framework for decision making under uncertainty, stochastic dominance theory draws strength from the fact that risky choices can be ranked without requiring exact specification of utility functions. For this reason, the concepts can be applied to larger numbers of decision makers, thereby reducing the problem of application of the Bernoullian utility theory to elicit actual utility functions. To take advantage of flexibility that the approach offers, seemingly, there has been a proliferation of applications of SD since the appearance of the first paper on the subject in 1962. The nature of problems to which SD concepts have been applied have been as varied as the subject areas. The most significant subject areas to see large-scale application of SD are finance, economics, mathematics, operations research, statistics, mathematical physics, mathematical psychology and engineering, to list but a few. By 1982, Bawa (1982) was able to publish an 'extensive but by no means exhaustive' listing of not less than 400 bibliographic items on the subject. A wide variety of problems in farming, in general, and smallholder farming in particular, involve analysis of choice from among uncertain prospects. SD criteria are particularly suited as analytical tools, given the large numbers of decision makers involved. For this reason, there have been a number of applications in agricultural economics. Analysis of control of a maize insect pest; selection of wheat varieties; adoption decision concerning a package of new maize technology (Anderson 1974) and assessment of varietal performance (Barah, Binswanger, Rana and Rao 1981) are among the earlier applications of SD to agricultural problems. Use of these criteria as predictors of reduced tillage (Lee, Brown and Lovejoy 1985), and in comparison of water conserving irrigation strategies (Harris and Mapp 1986) are examples of more recent applications.

Several efficiency criteria of differing discriminating power and ease of application have come into existence. In general, discriminating power depends on the nature of restrictions that are placed upon particular classes of utility functions for specified groups of decision makers. However, the number of decision makers for whom an efficiency criterion applies would vary inversely with the number of restrictions on their utility functions. At one extreme, FSD places no restrictions beyond the requirement that decision makers prefer more to less, but it has little discriminating power. By contrast, GSD can be applied with the required level of discriminating power, at the cost of more information about the decision makers utility function (exact specification of utility function should lead to exact prediction of choice).

While SD is widely used as a tool for empirical analysis doubts have been raised concerning the requirement that decision makers be risk averse. In cases of risk preference, clearly, SD concepts higher than FSD are not applicable. The concepts are also difficult to apply in situations where non-linear interactions among stochastic factors, non-linear constraints, discreet choice variables and adaptive strategies apply (King and Robison 1981). Particular care also needs to be taken when the alternatives to be compared are not mutually exclusive or they are not perfectly correlated ρ,= 0 (ρ is the coefficient of correlation).

It has also been pointed out that SD performs well when there is a finite and small number of choices (Kramer and Pope 1981). Groups of smallholders for whom analyses are required tend to be composed of large numbers. They also tend to operate fairly diverse portfolios.

The SD method operates on probability distributions. For prescriptive analyses, 'objective' probability distributions, perhaps obtained from historical data would be sufficient. If, on the other hand, descriptive or predictive use is intended, subjective probability distributions should be elicited from decision makers. Quite apart from the well known difficulties of specification of probability density functions that are appropriate to particular situations, elicitation of subjective probabilities is likely to encounter similar problems as would elicitation of utility functions. In such cases compromises are usually made.

Despite the problems that have been pointed out in this section, SD is still one of the dominant conceptual tools for characterizing choice within the expected utility theory framework. The position of SD in this regard is likely to remain unchallenged into the near future, and on-going research on theoretical and empirical fronts can be expected to provide resolutions to some of the concerns raised.

Appendix D

PROGRAMS FOR THE COMPUTATIONS OF MEASURES OF LIVESTOCK ENTERPRISE

Estimates of the performance measures for the livestock enterprise that were presented in chapter 5 and used in the risk programming matrix in chapter 8 were computed by three Fortran programs. These programs were used in conjunction with the dBASE III PLUS data base management system. The source files of the three Fortran programs are listed in this appendix. Portions of the code which performed input/output operations originated from sources whose identity the author was not able to ascertain. The author fully acknowledges his debt of gratitude to the authors of the segments of code he adopted.

```
            PROGRAM LIV1
C
C      Program to read daily rainfall data for case study farm
C      locations and write daily amounts arrays to enable
C      calculation of numbers of decades per year as required
C      by the Potter (1985) formulation.
C
C      ****************************************************
C      *                                                  *
C      *          Data Identification                     *
C      *                                                  *
C      ****************************************************
C
       CHARACTER INFILE*12, OUTFILE*12, STN*7
       DIMENSION DAILY(12,32),RAIN(365),MONTH(12)
       DATA MONTH/31,28,31,30,31,30,31,31,30,31,30,31/

C
C      ******************  Input/Output Section ***********
C
C
       OPEN (4, FILE = 'CON:')

C       ********** Site identificaion *********************
C
C
C
       WRITE (4, '(A)') ' Input rainfall file name ?:'
       READ (4, '(A)') INFILE
       I = LEN(INFILE)
       WRITE(4,*)I
       OPEN (1, FILE = INFILE (1:I), STATUS = 'OLD')
       WRITE (4,50)
50     FORMAT (' Found the file')
```

```
C
       N = INDEX(INFILE,'.')
       STN = INFILE(1:N-1)
C
C
      WRITE (4,'(A)') ' Start year = '
C
      READ (4,*) IYEAR1
C
      WRITE (4,'(A)') 'Start day = '
      READ (4,*) IDAY1
C
      WRITE (4,'(A)') 'End year = '
C
      READ (4,*) IYEAR2
C
      WRITE (4,'(A)') 'Last day = '
      READ (4,*) IDAY2
C
       WRITE (4,'(A)') ' Output file name? :'
C
C      ---------------IO?---------------
C
       READ (4,'(A)') OUTFILE
100    OPEN (2, FILE = OUTFILE, STATUS = 'NEW', IOSTAT = IOS)
c
       IF (IOS .NE. 0) THEN
          WRITE (4, '(A)') ' Cannot open output file', OUTFILE
C
          PAUSE "PRESS CTRL-C AND RE-ENTER OUTPUT FILE NAME"
          GO TO 100
       END IF
C
C                     Find start year in rainfall file
C
140    READ (1,*, END = 999)ISTAT, IYR
       IF (IYR.NE.IYEAR1) THEN
          READ(1,'(32(/))')
          GOTO 140
       ENDIF
C
       BACKSPACE 1
150    K = 0
C
C                     Read first line of annual rainfall data
C
       READ (1,*, END = 999)ISTAT,IYR
       FORMAT(2I9)
C
C                      Data read
C
       DO 300 J = 1,32
```

```
          READ (1,290) (DAILY (I,J), I = 1,12)
290       FORMAT(12F5.1)
C
300    CONTINUE
C
       LEAP = 0
       IF (MOD(IYR,4).EQ.0) LEAP = 1
       NDAY = 0
       ISTART = 0
C
C
       DO 600 I = 1, 12
          K = MONTH(I)
C
C
          IF (I .EQ. 2) THEN
              IF (LEAP .EQ. 1) K = K + 1
          ENDIF
C
C                    Now, take each day in turn
C
          DO 500 J = 1, K
             NDAY = NDAY + 1
C
C
C                     If missing data then report
C
                IF (DAILY(I,J).GT.900) THEN
                   WRITE (3,'(A,I3,A,I4)')
     &                     'Data missing on day ', NDAY, '
                            year',IYEAR

                ENDIF
C
                    WRITE(2,
                 '(1X,I4,1X,I3,4X,F5.1)')iyr,nday,daily(i,j)
C
C
             IF (IDAY2.EQ.NDAY .AND. IYEAR2.EQ.IYR) GOTO 999
500       CONTINUE
600    CONTINUE
C
C
       GO TO 150
999    CLOSE(1)
       CLOSE(2)
       STOP
       END


          PROGRAM RAINFALL
C
```

```
C
C*******************************************************
C
C
C              Program to sort rainfall data into arrays
C
C              as required by the Potter (1985) formulation
C
C
C
C
C*******************************************************
C
C                 DATA IDENTIFICATION BLOCK
C********************************************************
C
      CHARACTER INFILE*12, OUTFILE*12, STN*7
      DIMENSION DAILY(12,32),RAIN(365),MONTH(12)
      DATA MONTH/31,28,31,30,31,30,31,31,30,31,30,31/

C
C
C       Screen and keyboard
C
      OPEN (3, FILE = 'CON:')

C
C
      WRITE (3, '(A)') ' Input rainfall file name ?:'
      READ (3, '(A)') INFILE
      I = LEN(INFILE)
      WRITE(3,*)I
      OPEN (1, FILE = INFILE (1:I), STATUS = 'OLD')
      WRITE (3,50)
50    FORMAT (' Found the file')
C
C
      N = INDEX(INFILE,'.')
      STN = INFILE(1:N-1)
C
C
     WRITE (3,'(A)') ' Start year = '
C
      READ (3,*) IYEAR1
C
      WRITE (3,'(A)')  'Start day = '
C
C                     This may be non-standard
C
     READ (3,*) IDAY1
C
     WRITE (3,'(A)') ' Last  year = '
```

```
C
      READ (3,*) IYEAR2
C                    This may be non-standard
C
C
       WRITE (3,'(A)') 'Last day = '
C
      READ (3,*) IDAY2
C
       WRITE (3,'(A)') ' Output file name? :'
C
C      ---------------Open Data file---------------
C
       READ (3,'(A)') OUTFILE
100    OPEN (2, FILE = OUTFILE, STATUS = 'NEW', IOSTAT =
     &  ios)
       IF (IOS .NE. 0) THEN
          WRITE (3, '(A)') ' Cannot open output file',OUTFILE
C
          GO TO 100
       END IF
C
C                 Find start year in radiation/min-max temp
C
140    READ (1,*, END = 999)ISTAT, IYR
       IF (IYR.NE.IYEAR1) THEN
          READ(1,'(32(/))')
          GOTO 140
       ENDIF
C
       BACKSPACE 1
150    K = 0
C
C                 Read first line of annual rainfall data
C
       READ (1,*, END = 999)ISTAT,IYR
       FORMAT(2I9)
C
C                  Now, read one annual data set
C
       DO 300 J = 1,32
          READ (1,290) (DAILY (I,J), I = 1,12)
290       FORMAT(12F5.1)
C
300    CONTINUE
C
C                   Is this set in a leap year?
C
       LEAP = 0
       IF (MOD(IYR,4).EQ.0) LEAP = 1
       NDAY = 0
       ISTART = 0
```

```
C
C    -------------- Transfer annual matrix (day x month) to
C
C                   Take each month in turn
C
       DO 600 I = 1, 12
          K = MONTH(I)
C
C                   Fix February if leap year
C
          IF (I .EQ. 2) THEN
              IF (LEAP .EQ. 1) K = K + 1
          ENDIF
C
C                   Now, take each day in turn
C
          DO 500 J = 1, K
             NDAY = NDAY + 1
C
C
C
          WRITE(2,(1X,I4,1X,I3,4X,F5.1)')iyr,nday,daily(i,j)
C
C
C
C                   Check if end has been reached
C
             IF (IDAY2.EQ.NDAY .AND. IYEAR2.EQ.IYR) GOTO 999
500       CONTINUE
600    CONTINUE
C
C
       GO TO 150
999    CLOSE(1)
       CLOSE(2)
       STOP
       END


       PROGRAM DECADE
C
C      Program to calculate decades, i.e., the number of
C      10 day periods within which 20mm of rain or more
C      is received.
C
C      ************* Data identification block ************
C
       CHARACTER INFILE*12, OUTFILE*12
C
       OPEN (3, FILE = 'CON:')
```

```
C
C
       WRITE (3, '(A)') ' Input rainfall file name ?:'
       READ (3, '(A)') INFILE
       I = LEN(INFILE)
       WRITE(3,*)I
       OPEN (11, FILE = INFILE (1:I), STATUS = 'OLD')
       WRITE (3,50)
  50     FORMAT (' Found the file')
C
C
         write (3, '(a)') 'output file name?:'
         READ (3,'(A)') OUTFILE
C
  100    OPEN (12,FILE=outfile, STATUS= 'NEW', IOSTAT =IOS)

         IF (IOS .NE. 0) THEN
         WRITE (3, '(A)') ' Cannot open output file',OUTFILE

            PAUSE "PRESS CTRL-C AND RE-ENTER NEW NAME"
            GO TO 100
         END IF
C
C***********VARIABLE DECLARATIONS****************************
C
       WRITE(3,'(A)') ' Start year = '
       READ(3,*) IYEAR1
C
       WRITE(3,'(A)') ' End year = '
       READ(3,*) IYEAR2
C
C
       WRITE(12,65)
       DO 200 IY = IYEAR1,IYEAR2
       IDAY = 1
       KOUNT = 0
       TRAIN = 0.0
       DECA = 0.0
       LDAY = 10
C
C************READ IN RAINFALL DATA *************************
C
125      JK=0
130      IF(IDAY .LT. LDAY) THEN
             READ(11, 135) IYR,NDAY,RAIN
135          FORMAT(1X,I4,1X,I3,4X,F5.1)
C
                 SRAIN = 0.0
C**********************************************************
C               ACCUMULATE RAIN, CHECK FOR MIN
C**********************************************************
                      IF(RAIN .LT. 900.0) THEN
```

```
                            SRAIN = SRAIN + RAIN
                            TRAIN = TRAIN + RAIN
                        ENDIF
                    IDAY  =IDAY + 1
                       GO TO 130
          ENDIF
           IF(IDAY .EQ. LDAY) THEN
                DECA = DECA + SRAIN
                  IF(DECA .GE. 20.0) THEN
                      KOUNT = KOUNT + 1
                    ENDIF
           ENDIF
         IF(LDAY .LE. 361) THEN
                 LDAY = LDAY - 10
                 GO TO 125
         ENDIF
                  WRITE(12,150)IYR,KOUNT,TRAIN
150               FORMAT(1X,I4,3X,I3,3X,F7.1)

200   CONTINUE
C
999    CLOSE(11)
       CLOSE(12)
       STOP
       END
```

Appendix E

RULES FOR DECISION ANALYSIS UNDER UNCERTAINTY

E.1.1 The expected utility model

The expected utility model (EUM) is one of the most significant developments in the economic theory of decision making uncertainty to date. It provides a framework for evaluating choices among risky prospects whose outcomes may be single or multiple dimensioned. Basically, for n prospective outcomes designated as x_j, ($j = 1, 2, ...n$) associated with probability of occurrence p_i ($i = 1,2, ... , m$) such that $\Sigma_{i=1}^{n} p_j = 1$, agents whose dispositions accord with the behavioral axioms underlying the EUM make their choices so as to maximize

$$E[U(.)] = \sum_{i=1}^{n} pj(Ux_j) \qquad \text{(E.1)}$$

The model is based on holistic evaluation of prospects; separable transformations on probabilities and outcomes and expectation operations that combine probabilities and outcomes multiplicatively. Development of the mathematical form of EUM appears to have had its early origins in the need to explain gambling related phenomena in the eighteenth century. Cramer (1728) and Bernoulli (1738) were among the first to concern themselves with what appeared to be anomalous gambling behaviour (Schoemaker 1982). At issue was the question of why gamblers, who were presumed to be maximizing expected monetary value, would pay only small amounts for gambles of infinite mathematical expectation (the St. Petersburg paradox). To illustrate, consider a gamble involving the tossing of a fair coin for as many times as is necessary to get 'heads' for the first time. For a $ 2 bet the expected pay-off for n tosses is 2^n. Hence, the gamble can have many outcomes, e.g., $ 2, 4, 8 ..., 2^n, with probabilities 1/2, 1/4, 1/8, ..., $(1/2)^n$. The expected money value (EMV) for this gamble

$$\sum_{n=1}^{\infty} (1/2)^n 2^n \qquad \text{(E.2)}$$

is infinite. However, gamblers are usually prepared to pay far less for such gambles. Bernoulli (1738) proposed that *expected utility* rather than *expected money value* is the quantitative index that is maximized by gamblers. He demonstrated that expected utility can be represented by a logarithmic function exhibiting diminishing likelihood for equal increments in wealth $U(x) = b \log [(a + x)/a]$.

A sound axiomatic foundation for the Bernoulli formulation was provided by von Neumann and Morgenstern (1944). Five axioms implying the existence of numerical utility indices for outcomes whose expectations for lotteries preserve the preference order over lotteries were spelt out. These are indices with direction and order of magnitude in the sense that a greater expected utility index corresponds to higher preference. Such utility functions are unique up to a positive linear transformation, such that if $U(x)$ is a person's utility function, then, so will be $U^*(x)$, and

$$U^*(x) = aU(x) + ba \geq 0 \tag{E.3}$$

E.1.2 Axioms of rational choice under uncertainty

- *Ordering and transitivity.*[16] An agent prefers lottery A to lottery B, or lottery B to A, or is indifferent between the two. If A is preferred to B, and B is preferred to C, then A would be preferred to C.

- *Continuity of preferences.* If A, a standard lottery ticket, is preferred to some prize B when P(A) = 1, and if on the other hand, B is preferred to A when P(A) = 0, then there exists some value of P for which the agent would be indifferent between A and B.

- *Independence.* An agent who expresses indifference between A and B should be indifferent between two lotteries which are identical in every respect except that one offers A and the other offers B.

- *Preference for higher probability of success.* Given two lotteries of equal size, agents will prefer the one with higher probability of success.

- *Compound probability assessment.* For a lottery whose prize is a set of other lotteries, an agent's attitude to such a compound lottery should be the same as it should have been if the odds of winning and losing had been assessed on individual components.

These postulates provide a psychological basis for the assessment of strength and direction of an agent's attitudes to risk. As $U(x)$ is unique up to a positive linear transformation, construction of a utility scale can be greatly aided by this fact. In general, elicitation procedures entail determination of certainty equivalents for gambles. The direction of attitude to risk (risk aversion, risk neutrality and risk preference) is determined on the basis of whether the expected money value of the gamble is less than, equal to or greater that its certainty equivalent. Strength of preference is indicated by the negative ratio of the first to the second derivative of the utility function (Pratt 1964).

E.1.3 Probability concepts

At the core of models of decision making under uncertainty is the concept of probability. For this reason, many significant extensions to the theory of probability have come into existence. Over the years, the concept has been represented in a variety of definitions. Four of these definitions are now outlined.

---

[16] The enumeration scheme adopted here is that of Baumol (1977 pp. 429-30).

(a) Probability as the number of elementary outcomes favourable to some event divided by the total number of possible elementary outcomes (La Place 1812).

(b) As a degree of confidence which for a given event may vary from person to person. This view, attributable to Bernoulli (1713), Venn (1866) and, more recently, Reichenbach (1935), takes probability as the limiting value of the percentage of favourable outcomes in an infinite sequence of independent replications.

(c) As a given set of evidence which bears a logical, objective relationship to some hypothesis, probability may be considered as a measure of the strength of this relationship (Keynes 1921, Jeffreys 1948).

(d) In the fourth definitional category, probability is viewed as degrees of belief, applicable to both repetitive and unique events. Foremost among the leading exponents of this approach were Ramsey (1931), de Finetti (1937, 1974) and Savage (1954). Within this scheme, probability of random events sum up to one, that is, $\Sigma_{i=1}^{n} p_i f(x_i) = 1$. Second, conjunctive and disjunctive rules follow the product and addition rules respectively. Thus, for mutually exclusive events,

$$P(AandB) = P(A) + P(B) \tag{E.4}$$

$$P(AorB) = P(A)P(B) \tag{E.5}$$

Formalization into Bayes (1763) theorem of the notion that many everyday decisions are reached on the basis of personal assessment of the likelihood of occurrence in the light of all available information pertaining to that particular decision was a major milestone in the development of decision theory. Formal presentation of Bayes theorem may be summarized in equations E.6 and E.7.

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \tag{E.6}$$

where

$$P(A),P(B), \geq 0 \tag{E.7}$$

E.1.4 Applications of EUM

Fully implemented, several results can be pursued within the EUM theoretical framework. A utility index can be obtained for an agent and used to order action choices for that particular individual. Out of this general framework, some of the classes of application are highlighted in this section.

(a) Gaining insights into an agent's risk preferences and beliefs concerning the likelihood of uncertain actions and modelling decision making under uncertainty.

(b) Prediction of possible courses of action that particular agents are likely to take.

(c) Hypothesis testing in the development of the theory of decision making. Examples of specific areas of this type of application are in the field of hypothesis testing in the theory of individual behaviour. Applications in the theory of consumer demand, investment and savings decisions are immediate possible areas of application of EUM.

(d) As a normative tool, EUM is often used in an advisory role for management to prescribe the lines of action that are most consistent with the decision maker's beliefs and preferences. This is a class of applications of EUM in managerial and or advisory contexts. Particular areas of analysis that can benefit from this analytical framework are in the fields of production and pricing decisions.

E.1.5 Assessment of EUM

Few subject areas in economic theory have attracted greater controversy than the EUM. Basically, if EUM indices are to correctly order action choices, several conditions must be met. The nominated measure of preference should, as well as facilitating assessments that accurately reflect the preference ordering of the agent in question, also have the property that they can be empirically assessed at reasonable cost. Validity of the axioms which underlie the scheme should be sustainable in the situations of application.

The question that arises persistently is, does the EUM framework qualify as an adequate paradigm for the analysis of choice under uncertainty? To which there is no unambiguous and categorical answer. However, there seems to be some consensus about desirable attributes of a theory of choice under uncertainty (Quiggin 1988).

(a) A theory of behaviour should not exclude patterns of behaviour which frequently obtain in real life.
(b) Such a theory should not permit or require behavioral patterns which violate basic tenets of rationality.
(c) A theory of choice under uncertainty should at least respect the axioms of transitivity of preferences and preservation of dominance.

E.1.5.1 Criticisms of EUM

The model has been criticized on the grounds that it is based on personalized decision making, and that the cost of applying it to the multiperson situations is likely to be high. In traditional agriculture, typified by numerous agents responding to wide ranging stimuli in a multiplicity of ways, attempts to find useful applications of EUM represent an analytical challenge of enormous proportions. A related consideration is that of the human tendency to seek simplifications and mental shortcuts. It is frequently argued that assessment procedures that are implied by the EUM would make very substantial demands upon human cognitive capacity. Taken at face value, these observations suggest weaknesses in the empirical application of EUM especially to smallholder problems. Problems associated with empirical estimation in a realistic fashion and at reasonable cost are likely to continue to restrict the usefulness of advances that are likely to be made within the EUM framework.

Criticism of EUM is by no means restricted to the difficulties associated with empirical estimation. Much of the controversy surrounding EUM stems from nonconformity of observed behaviour with at least some of the axioms which underpin the model. The Allais (1953) and Ellsberg (1961) phenomena fall within this category. The former involves the observation that outcomes obtained with certainty tend to loom larger than those which are uncertain. The latter concerns the discovery by Ellsberg (1961) that for lotteries involving high probability events, agents tend to dislike ambiguity, while for low probability events, they tend to prefer it. Both phenomena entail violation of the independence axiom, and, implicitly, the compound lotteries axiom.

E.1.6 Evaluation of EUM

In a survey of the EUM, Schoemaker (1982) arrived at a number of conclusions. At least for the type of decisions he examined, he appears to have taken the view that:

- As a descriptive model seeking insights into how decisions are made, EUM fails on at least three counts.
    - People do not generally structure problems as EUM suggests.
    - Information, especially, probability information is not usually processed as EUM suggests.

    - On the basis that it predicts choice behaviour in experimental situations poorly, it may not be regarded as a robust tool to aid in prediction.

- The view that hypothetical experiments have limited implications for theory is not unanimously held. Binswanger (1979, 1981) and Grisley and Kellogg (1987) are examples of applications in which advantages over experiments based on purely hypothetical situations were gained. However, see for example Hardaker and Ghodake (1984) who point to the overall usefulness of the Binswanger (1980, 1981) approach but regard the value of the method used to derive risk aversion measures as not proven. By contrast, empirical studies by Kogan and Wallach (1967) and Slovic (1966) on the effects of hypothetical versus real pay-offs suggested that cognitive process and decisions do not differ appreciably between these two situations. They apportioned much of the failure of the hypothetical experimental approach to cognitive (i.e., the way problems are structured) rather than motivational (i.e., the amount of mental effort exerted).

- Even if EUM were to predict well while it's assumptions are inconsistent, the idea that only prediction matters is epistemologically unappealing.

- Normative or prescriptive aspects of EUM introduce the difficulty of constructing utility indices. Some of these difficulties arise, not least, from the fact that changes in the context or framing of a problem may lead to different preferences (Hershey and

> Schoemaker 1982; Tversky and Kahneman 1981). The question arises as to which context measures the true risk taking attitude?

Schoemaker (1982) took the extreme view that EUM may not be a very useful model for representing real world problems. However, despite the criticisms, it has yielded useful insights and stimulated a body of research and in turn highlighted important areas of decision theory. It seems that until a richer model of decision analysis comes into existence, EUM will continue to provide a useful basis for research into decision making and related phenomena. It is a useful though far from perfect tool for analysis of choice (Robison 1982).

E.1.7 Extensions to EUM

Motivated by shortcomings of the EUM structure which have come to light, attempts have been made to develop alternative theoretical schemes. Most of the new developments recognize that EUM is basically sound and proceed to devise and extend features that would mitigate the effects of observed anomalies. A summary of four of these 'alternatives' is included in the following sections.

E.1.7.1 Certainty equivalent theory

First proposed by Allais (1953) and formalized by Handa (1977), this approach employs the concept of probability weighting. The essence of the theory is that 'low probability' events tend to be unduly over-weighted. Hence, the existence of insurance concurrently with gambling. In this formulation a continuous probability weighting function replaces the EUM. The continuity, completeness and transitivity axioms are retained while the independence axiom is replaced with two other axioms.

E.1.7.2 Prospect theory

The subjective expected utility functional form is extended so as to incorporate features from the domain of psychological analysis of decision problems (Kahneman and Tversky 1979). The main feature of this extension is that 'the carriers of value or utility are changes in wealth rather than final asset positions that include current wealth'. Risk seeking in the domain of losses is incorporated into the analysis by allowing for convexity in the utility functions for negative values.

E.1.7.3 Expected utility without the independence axiom

Proposed by Machina (1982), this approach dispenses with the independence axiom altogether. Instead of the standard EUM, a general preference function $V(F) = \int_0^M, U[w\, d\, F\,(W)]$ is used. It includes the standard EUM but with the special property of being linear in probabilities.

E.1.7.4 Anticipated utility theory

Most of the alternatives to EUM do not seem to meet the minimum requirements for a theory of choice under uncertainty, namely, avoidance of systematic intransitivities and violations of dominance (Quiggin 1988). Anticipated utility theory (AU) meets some of these shortcomings. The following quotation from Quiggin (1988 ch. 5) is intended to summarize the main elements of AU.

> ... The name AU [sic] derives from the fact that, like EU theory, this approach is based on the derivation of a point estimate of a utility function defined over outcomes. In AU theory, however, this estimate is not, in general, an expectation in the statistical sense....
>
> ... AU theory is consistent with transitivity and preservation of dominance, and that is the only extension of probability weighting approaches beyond the two-outcome case which has this property.

AU theory deals with individual preferences over a set W of outcomes and an associated set Y of prospects or random variables taking values in W. It is assumed that W is a subset of $\Re$ which may be interpreted in terms of level of wealth, income, or consumption. W will always be assumed to be connected and will always be assumed to be bounded from below.

A random variable $y \in Y$, may be regarded as a measurable function from some σ-field of events, S over a set ω of states of the world, and characterized by its cumulative distribution function $F\ y{:}w \rightarrow {:}Pr\{y \leq w\}$. The theory assumes state-independence, in the sense that two random variables with the same cumulative distribution function will be regarded as identical. Thus, there is a one-to-one mapping between Y and a subset of Dw. the spaces of CDFs taking values in W.

Because of this state independence property, it is possible for many purposes to confine attention to random variables which are co-motonic in the sense that they have the same rank-ordering over states of the world (Schmeidler 1984). It is then possible, without loss of generality, to define ω so that it can be ordered from worst to best states of the world. That is, if $\omega_1 \leq \omega_2$, then $y(w_1) \leq {:}y\ (w_2)$ for all random variables $y \in Y$. It is, therefore, possible to define a general function $F{:}S \rightarrow \Re$, such that $F(s_0) = P_r\{\omega \leq \omega_0\}$, and hence, for all y, $y(\omega = w) \Rightarrow F_y(w) = F\ (\omega)$. Special attention will be paid to discrete random variables or 'prospects'. These may be represented in the form

$$w;p = (w_1,w_2,\ldots w_n);(p_1,p_2,\ldots p_n) \tag{E.8}$$

where p_j is the probability of outcome w_i, $\Sigma\, p_i = 1$, and the w_i are ordered from worst to best, so that $w_1 \leq w_2, \leq \ldots \leq w_n$.

Given a preference relation P on Y, the problem for a cardinal utility theory is to construct a real-valued functional V on Y, such that $V(y) \leq V(y')$ if and only if, y P y'. EU theory involves constructing a utility function $U : W \rightarrow \Re$ and setting

$$v(y) = \int U(\omega)dF(\omega) \tag{E.9}$$

> or in the discrete case,
>
> $$V(w;p) = \sum_i p_i U(w_i) \tag{E.10}$$
>
> An appropriate function V, unique up to a linear transformation, may be constructed for any preference relation satisfying the EU axioms of transitivity, continuity, preservation of dominance and independence of irrelevant alternatives. The AU model includes EU as a special case. In addition to the utility function, it employs a weighting function $q : [0\ ,\ 1] \rightarrow [0\ ,\ 1]$. The function q is continuous, monotonically increasing such that $q(0) = 0$, $q(1) = 1$. This function may be composed with a cumulative distribution function F to yield a weighting function $H = q^\circ F$, which possesses the usual properties of a cumulative distribution function. Furthermore, in view of the ordering assumption on Ω, it is also possible to define a function $q^\circ : \Omega \rightarrow \Re$, such that $q^\circ(\omega) = q(F(\omega))$. The AU functional is defined as
>
> $$V(y) = \int U(w)\,dq(F_y(w)) \tag{E.11}$$
>
> The term 'anticipated utility' reflects the idea that the weighting function is integrated to yield an anticipated value of $U(w)$ which may be different from the mathematical expectation. Expected utility corresponds to the special case when q is the identity function, that is, when preferences are linear in probabilities....
>
> ... the major innovation in AU theory is the notion that 'intermediate' and 'outlying' events are weighted differently, and these notions are only meaningful for prospects with three or more possible outcomes....
>
> ... AU theory provides a straight forward explanation of the problems observed in the construction of utility functions by questionnaire. Any approach which uses different probabilities in the construction of the questionnaire is likely to confound the effects of probability weighting with those of utility of outcomes. This includes the case where fixed probabilities (not equal to 1/2) are used, but the low probability outcome is sometimes more desirable and sometimes less desirable than the high probability outcome so that the weighting on the less desirable outcome will sometimes be $q(p)$ and sometimes $q(1 - p)$. Since the ELCE procedure does not encounter this difficulty, it will always yield internally consistent results when applied to an AU maximizer.

E.1.8 Other schemes of choice under uncertainty

While EUM and extensions are well established as models of representing choice under uncertainty, they are not the only available approaches. Motivated by considerations of analytical convenience, mainly, a variety of approaches that can be applied to decision analysis have come into existence. One class of such models is based on methods in which it is assumed that the decision maker seeks to maximize utility while minimizing an appropriate measure of variability in performance. Another category is based on the assumption that the need to insure a minimum level of income necessary to sustain the farm family is an overriding concern for small farm operator. Some of these schemes are now listed, but this list is by no means exhaustive.

E.1.8.1 The mean-variance model

Decision makers are postulated as seeking to select a portfolio of activities based on a decision rule that minimizes variance of return for a given level of expected return (Markowitz 1959, 1991). This formulation allows incorporation of trade offs between expected profit and risk via the risk aversion parameter into the analysis. However, requirements that the algebraic form of the utility function be quadratic or that if the utility function is of the negative exponential, returns be normally distributed introduces some as yet unresolved theoretical and conceptual difficulties for the use of this formulation. Moreover, three considerations have tended to hinder wider application of the E-V model in agriculture. Data required for the construction of covariance matrices are usually beyond the reach of an average analyst. Lack of a general quadratic programming algorithms which can be implemented at reasonable cost has also tended to limit the use of the E-V model. Also, measures of the risk aversion parameter are required to enable location of optimal plans on efficiency frontiers and these are difficult to obtain.

E.1.8.2 Mean of total absolute deviation

The Mean of Total Absolute Deviation (MOTAD) is a popular analytical tool. Its popularity largely derives from the ease with which it can be implemented (MOTAD models can be solved by standard linear programming algorithms). Based on the absolute deviation of returns from the mean, this model represents risk as deviations from expected profit (Hazell 1971). Thus the criterion of selection depends on some trade off of expected returns and absolute deviations from the mean.

E.1.8.3 Mean-semivariance analysis

It is widely acknowledged that some decision makers may be concerned about criteria other than (or in addition to) mean performance and variance. The mean-semivariance rule allows for the incorporation of downside risk in the analysis. The main principle is that while it is reasonable to expect decision makers to be averse to making losses, it is not easy to justify an assumption that they will be averse to gains. The Mean-semivariance model employs as a criterion the semi-variance of profit below a target.

E.1.8.4 Safety-first rules

In the safety-first models, decisions are thought to regard risk as possibility of disaster or threat of survival. Risk is implicitly defined in terms of the lower left hand tail of the distribution of the variable of interest. A number of decision rules can be classified within this general framework. Telser's (1955) safety-first rule is based upon the maximization of expected return subject to the constraint that minimum return has to be attained at the desired probability. Kataoka's (1963) safety-fixed rule specifies that minimum return which can be attained should be maximized with a given probability level. Roy's (1952) rule requires minimization of the probability of return falling below a specified level. The target-semivariance rule (Porter 1974) assumes that risk is perceived as deviations below a critical level of return. Low's (1974) criterion entails selection of a plan which ensures income at a certain level in each state of nature. Target-MOTAD (Tauer 1983) is the linear approximation to the target-semivariance rule. The target-MOTAD decision rule is the minimization of probability weighted deviations below a specified target for a given level of expected return.

Most of the safety first-rules can be associated with a number of shortcomings. Unlike EUM, safety-first rules lack a sound axiomatic foundation. Like EUM, implementation of safety-first rules requires specification of parameters of the decision makers behaviour, a task that may well raise as many problems as does specification of utility functions. However, it may be better to apply safety-first rules in attempting to represent smallholder decision making. This is because survival considerations are likely to be important in smallholder decision making. Further discussion of safety-first models is deferred to Chapter 8.

Appendix F

PROPOSED SCHEME OF REPRESENTING SMALLHOLDER DECISION MAKING

F.1.1 Smallholder preferences

The smallholders interviewed for the present study have low capacities to absorb random shocks in production. The evidence supports the contention that these households seek to satisfy security goals before the income goals are attempted. This observation appears to be true for many farmers in the semi-arid tropics, where production risk is high and markets for subsistence requirements are not adequately developed (Anderson and Dillon 1989). In such cases, utility of an act can be expressed as priority ordered vectors showing the expected utility in each attribute dimension (Anderson *et al.* 1977). A hierarchical ordering of wants is defined for the goals of each agent.

A class of preferences of this type can be represented according to lexicographically ordered vectors of expected utility values. For the *i*th decision maker, utility in the *j*th goal U_{ij} (x_{ij}) can be attached to each x_{ij} in $X_{ij} = 1,2,\ldots, n$, so that x_1 and x_2 are two activities in the set X. If x_1 and x_2 have marginal distributions x_{i1} and x_{i2}, then, x_1 is only not preferred to x_2 if and only if

$$[u_1(x_{11}), u_2(x_{21}),\ldots, u_n(x_{n1})] \overset{L}{\leq} [u_1(x_{12}), u_2(x_{22}),\ldots, u_n(x_{n2})] \qquad \text{(F.1)}$$

The interpretation of the lexicographic order is that x_1 is not to be preferable to x_2 if and only if

$$u_1(x_{11}) < u_1(x_{12}) \qquad \text{(F.2)}$$

or

$$u(x_{11}) = u_1(x_{12}) \qquad \text{(F.3)}$$

and

$$u_2(x_{21}) < u_2(x_{22}) \ or \ \ldots \ or \ u_i(x_{i1}) = u_i(x_{i2}) \qquad \text{(F.4)}$$

for all $i < n$ and u_n (x_{n1}) $\leq$ u_n (x_{n2}) (Rae 1971a, p. 457).

An appropriate objective function in terms of a lexicographic utility function may take the form:

$$E[u(x)] = \sum_{i=1}^{n} \alpha_i (p' u_i) \tag{F.5}$$

where

α_i are trade-off weights and u_i are utility vectors.

The specific objective would be to maximize *E [u(x)]* of the least important factor subject to the attainment of the least satisficing expected utility values of all other factors (Hillier 1967; Rae 1971b). For decision makers facing multiple goal situations for which trade-off between goals is not acceptable, decision weights between goals are not measurable. It is also possible, with additional simplifications, to represent such a hierarchical goal structure by a piece-wise linear step function as in Equations F.6-F.9.

$$u(x) = \begin{cases} h & if\, x < x_1 \\ (\frac{(l-h)}{(x_2-x_1)}) \cdot (x-x_1) + h & if\, x_2 \le x \le x_1 \\ \ell & if\, x < x_2 \end{cases} \tag{F.6}$$

The derivative of this preference function, $u'(x)$, exists

$$u' = \begin{cases} 0 & if\, x < x_1 \\ \frac{(l-h)}{(x_2-x_1)} & if\, x_1 < x < x_2 \\ 0 & if\, x > x_2 \end{cases} \tag{F.7}$$

- **Parameter definition**

  h = Value of $u(x)$ to the left of the step
  ℓ = Value of $u(x)$ to the right of the step
  x_1 = Value of x at the left end of the step
  x_2 = Value of x at the right end of the step.

Note that x is not defined at x_1 and x_2

Appropriate resource supply and risk constraints on $u(x)$ can be specified and represented as m real valued functions $g_j(x)$, $j = 1,2, \ldots, m$. Constrained optimization of $u(x)$ would be sought via the Lagrange-Euler formulation. A function $g(x,h,\ell)$ would be specified and set equal to zero. The next step would be, to multiply $g(x)$ by λ, a Lagrangian multiplier and then add the product to the preference function, $u(x)$ to obtain equation (F.6).

$$L = u(x,h,l,\lambda) = u(x,h,l) + \lambda g(x,h,l) \qquad \text{(F.8)}$$

Given an appropriate set of coefficients, the critical values (or gradient vectors) of x,h, ℓ and λ at which $u(x)$ is optimized may be found by setting the first order partial derivatives equal to zero and solving simultaneously.

$$du/dx = du/dh = du/dl = du/d\lambda = 0 \qquad \text{(F.9)}$$

The function $u(x)$ is nonlinear, and there is no reason why the constraint set $g(x)$ should not involve nonlinearities. The nonlinear programming problem of finding the optimum value of $u(x)$ subject to $g(x)$ can be considered as one of choosing x which maximizes $u(x)$ over some non-empty set C, the feasible set. Quite apart from considerations of an appropriate algorithm to implement such a formulation (which is not within the scope of this thesis), other issues need to be satisfactorily resolved. These relate to whether a point which maximizes $u(x)$ subject to $x \in C$ exists; whether the solution is unique and, what the characteristics of the solution are. A detailed treatment of the main theorems and proofs of the conditions that must be satisfied can be found in Takayama (1985). The essence of the theory that is being proposed is summarized in Figures F.1a-F.1d.

F.1.1.1 The effect of a parameter change on $u(x)$

Let $\mathbf{u}\ (\mathbf{x}_j)$ be a priority ordered vector of utilities of a prospect $\mathbf{x}$ in j dimensions reflecting a set of wants for a household. Then, for the jth dimension, which may be subsistence, purchase of consumer goods or education of children, over the range x_{j1} and x_{j2}, the household will not trade off across other dimensions. Thus x_{j1} can be considered as the minimum entry point for the particular goal, in this example, KShs. 1 500.00 for minimum subsistence. Extra income up to KShs. 2 500.00 will go towards meeting additional subsistence. Above that level of income, fulfillment of the next want in the hierarchy starts.

The effect of variation in x on $u(x)$ for three families is illustrated in Figure F.1a. The first family, which may have only a few people may require subsistence worth KShs. 1 500.00, to move to a higher goal. By contrast, families numbered 2 and 3 would need KShs. 2 000.00 and 2 500.00 respectively. Entry points are likely to be determined by factors such as household size, age distribution, educational attainment and occupation for individual members of the household. These factors are likely to influence the choice of least cost strategy that might enable the household to attain the desired levels of want fulfillment. While the first family may produce enough produce using traditional techniques, the other two may need to use improved practices in order to achieve the same level of goal attainment.

The way individual households move from a lower to a higher ranked want is illustrated in Figure F.1b. The highest rated goal $\ell 3$) is fully satisfied when income is KShs. 1 500.00. That particular farmer would require an additional KShs. 1000.00 to fulfil the needs of $\ell 2$, and KShs. 500.00 for $\ell 3$. A different household may order its preferences differently, depending on the preferences of the decision maker. Figure F.1c illustrates how inter-farm flexibility with which a household may move from one goal to the next can be assessed. Farm $h3$ clearly has greater flexibility than farmers $h1$ and $h2$. A household with more school age children may have reduced flexibility to move to higher goal fulfillment. It may not be in a position to invest in farm development even when income appears to be sufficient for this purpose.

It may be that once the wants that are considered to be basic by the household have been met in stage 1, trade-offs between attributes may now be attempted in stage 2 as shown in Figure F.1d. In the first stage, the basic wants are met (A-F in Figure F.1d). Thereafter, expected utility of income is maximized subject to appropriate restrictions (F-G in Figure F.1d). The highest rated goals are satisfied first (A-B). The second rated goals are satisfied next (B-C), followed by C-F. Beyond F, household income (X) is in excess of what is needed to support subsistence (X^*).

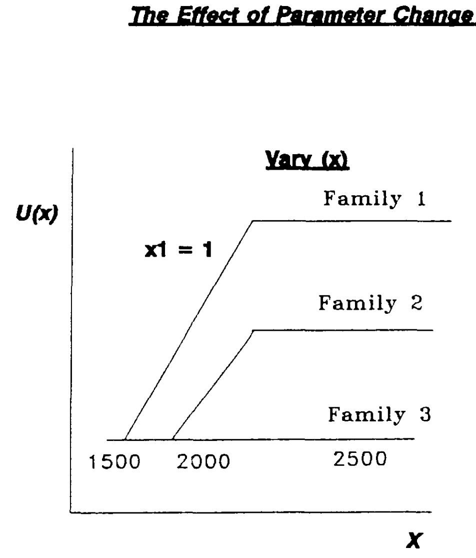

Fig. F.1a Effect of changes in family size on *u(x)*

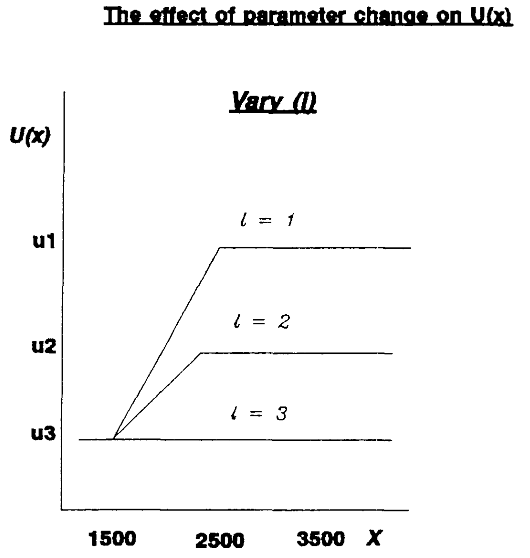

Fig. F.1b Change in *u(x)* as *x* is varied

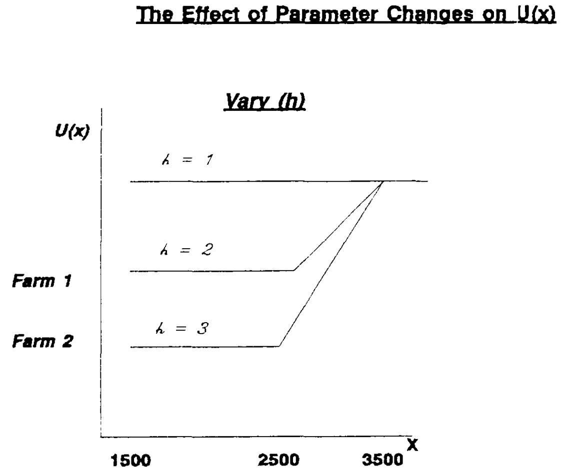

Fig. F.1c Change in *u(x)* as *x* is varied

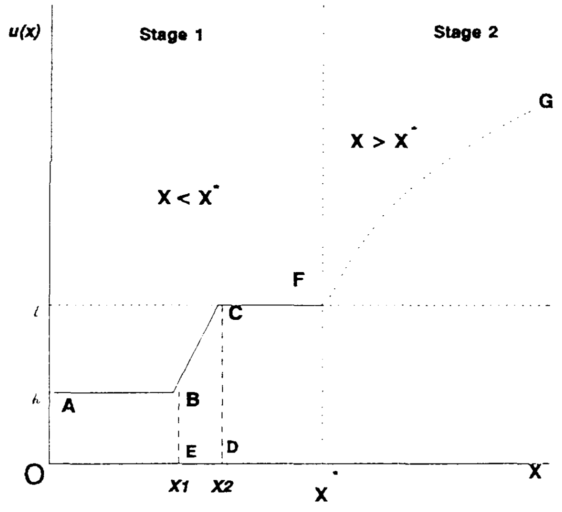

Fig. F.1d. Representation of hierarchical preference structure