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RISK AVERSION AND THE FAMILY FARM

C.P.J. Burger

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Risk aversion and the family farm

Kees Burger
Economic and Social Institute
Free University, Amsterdam

Summary

Within the framework of expected utility maximisation a high degree of risk aversion may lead farmers to put more effort to the production of the risky crop. If risk is 'manageable', i.e. if they can adjust inputs to the weather conditions then the resulting set of optima reflects the risk attitude of the farmer and uncertainty in one argument of the utility function can be diminished by increasing uncertainty in another. This provides a more general framework for risk analysis including safety-first models.

1. Introduction

In the past ten years, a great number of articles have been published that deal with the importance of risk in farmers' decisions. Most of the empirical work has focussed on the extent to which behaviour towards risk influences the crop mix, treating land allocation similar to a portfolio problem, in which the objective is to maximise a function with both expected returns and its variance as arguments. Such studies employ linear, quadratic or MOTAD programming (see Hazell's survey,1982) or use an econometric profit or utility maximising approach (cf. Pope's survey,1982). Another strand of research has focussed on the elicitation of farmers' preferences regarding expected income vs. income variance by experiments, in which farmers were offered a choice between lotteries (Binswanger,1980) or were interviewed about their expectations and 'degree of surprise' at various outcomes and the equivalent certain income (e.g. Scandizzo & Dillon,1979 or Hamal & Anderson,1982).

Many authors, particularly those dealing with risks facing farmers in poor regions, have stressed the importance of subsistence risk. A widely held belief is that first and foremost farmer's behaviour toward risk is that the amount of food (or occasionally money) required for the subsistence of the family needs to be assured. Only then will he consider other activities, such as cash crops, other technologies etc. in which he often shows no marked risk aversion (Kunreuther & Wright,1979 and Shahabuddin & Mestelman,1986 for jute in Bangladesh; Ortiz,1979). Risk, in these studies, however, is considered more or less homogeneous and no explicit distinction is made within a utility frame work between food, grown and consumed on the farm, and cash crops, sold for money, used to purchase urban goods and services.

As far as utility functions are employed, they mostly have but one argument (income) or two related arguments (expected income and income variance, e.g. Wolgin,1975). When markets for family labour or for the food crop are not well developed, as is the case in many LDCs, no perfect substitution between money income and food and 'leisure' can be assumed.

This paper considers a family farm in such an environment. The basic model distinguishes food and 'leisure' as arguments in the utility function, where food can be produced by employing family labour (the complement of leisure).

Mutatis mutandis, this model also represents the trade off between home produced food and a cash crop, if instead of leisure, production of a composite good, consisting of leisure and food is taken, and instead of food, consumption of an urban good, c.q. production of a cash crop is considered. In this case, the arguments of the utility function would be the consumption of 'home goods' and of a good, purchased with the proceeds of cash crop sales. Putting consumption of the 'home good' equal to its production would lead to a similar type of analysis.

The next section introduces and applies Arrow's (1965) and Pratt's (1964) concept of risk aversion and risk premium. Section 3 extends the application to the more realistic case where, to a certain extent, risk is 'manageable' and adjustments can be made after the uncertainty is resolved. Some concluding comments are given in section 4.

2. Risk and expected utility

Risk analysis starts with how uncertainty about arguments of the utility function is evaluated. Only then can the implications be derived for the allocation of resources, such as family labour. The common approach to risk behaviour is the Arrow-Pratt measure of absolute risk aversion.

Consider a utility function u(x) where x is uncertain, with expected value $E[x] = \mu$ and variance σ^2.

What amount, to be called the risk premium , would the individual be prepared to pay to have a certain μ instead of the uncertain x?

Or, for what value of the premium π would

$$u(\mu-\pi) = u(x)?$$

Taking a first-order Taylor expansion of the left-hand-side (LHS) and a second-order expansion of the RHS, both around μ:

$$u(\mu) - \pi\, u'(\mu) = u(\mu) + \epsilon\, u'(\mu) + \tfrac{1}{2}\, \epsilon^2\, u''(\mu),$$

where ϵ is the (stochastic) difference between x and μ.

Taking expectations of the RHS, with $E\,\epsilon = 0$ and $E\,\epsilon^2 = \sigma^2$, we have

$$-\pi\, u'(\mu) = \tfrac{1}{2}\, \sigma^2\, u''(\mu)$$

or

$$\pi = -\tfrac{1}{2}\, \sigma^2\, u''(\mu)/u'(\mu).$$

For normal (concave) utility functions, this expression is positive and a certain amount lower than μ will have a utility equal to that of the uncertain amount with expected value of μ. The ratio u''/u' can be seen to be proportional to the risk premium (π) per unit of variance.

The coefficient of absolute risk aversion A is defined as

$$A(x) = -\, u''(x)/u'(x)$$

For $u(x) = x^{\alpha}$, A equals $(1-\alpha)/x$; for $u(x) = -e^{-\alpha x}$, $A = \alpha$.

Another derivation of a risk premium would answer the question: What relative premium π^r would an agent pay to have

$$u(\mu(1-\pi^r)) = u(x)?$$

Again taking first and second order Taylor approximations, but now assuming that $x = \mu(1+\epsilon)$, and taking expectations, we find

$$\pi^r = -\tfrac{1}{2}\, \sigma^2 \mu\, u''(\mu)/u'(\mu).$$

This yields the **coefficient of relative risk aversion**,

$$R(x) = -\, x\, u''(x)/u'(x),$$

so that

$$R(x) = x\, A(x).$$

R(x) is proportional to the relative risk premium per unit of variance of ϵ, where $\epsilon = (x-\mu)/\mu$. Note, however, that the assumptions on ϵ in this derivation differ from those in deriving the expression for A(x). For $u(x) = x^\alpha$, $R(x) = 1-\alpha$; for $u(x) = x^{1-a}/(1-a)$, $R(x) = a$.
R(x) can also be considered as the elasticity of marginal utility (see Newbery & Stiglitz,1981,p.72) and it is, therefore, dimensionless. Other interpretations of R(x) are given by Hanoch(1977).

To give an example, suppose x has a coefficient of variation of 0.25, i.e. ϵ has a standard deviation of 0.25, and the utility function is characterised by constant relative risk aversion of 2, then the agent would be willing to sacrifice 6.25 % in order to eliminate uncertainty. If in our derivation, we would have taken the second-order approximation of both sides of the equality-sign, we would have found

$$R.\pi^r = -1 + (1+\sigma^2 R^2)^{\frac{1}{2}}$$

and

$$A.\pi = -1 + (1+\sigma^2 A^2)^{\frac{1}{2}}$$

and in our example the agent would be willing to sacrifice only 5.9 %. The difference between the two orders of approximation becomes particularly clear for $R \to \infty$ (or $A \to \infty$) when the first-order premiums would tend to infinity, whereas the second-order premiums would tend to σ. As the premiums are increasing functions of the aversion coefficients, σ forms an upperbound for them.

Important applications of expected utility maximisation can be found in agriculture. They pertain to land use planning under uncertainty about yields and/or prices, to adoption of innovations and to the use of risk-changing inputs such as fertilizers and pesticides. In these application the farmer is assumed to maximise the expected value of the utility, derived from income earned by allocating resources to activities, yielding uncertain returns.

The basic model for a family farm, deciding on how much effort to invest in a risky crop would be as follows.

$$\max E\,[u(f,\ t-\ell)]$$
$$\text{s.t. } f = f(\ell, \epsilon),$$

where ℓ stands for hours of work, yielding an uncertain production of f, e.g. food, that enters the utility function jointly with leisure, represented by $t-\ell$, t being total time available.

First-order condition for a maximum is that

$$E[u_1 f_1 - u_2] = 0$$

and the second-order condition is that

$$E[u_{11} f_1^2 + u_1 f_{11} - f_1(u_{12}+u_{21}) + u_{22}] < 0,$$

where the subscripts denote partial derivatives to the first and/or second arguments. For u to describe a normal consumer's utility function, we require u to be strictly concave with positive first-order derivatives, or

$$u_1,\ u_2 > 0 > u_{11},\ u_{22}$$

and

$$\begin{vmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \end{vmatrix} > 0$$

Now assume the impact of ϵ on f to be as $f = g(\ell)(1+r\epsilon)$, where r is a measure for the degree of uncertainty (r>0), and $E\,\epsilon = 0$, $E\,\epsilon^2 = \sigma^2$.

The first-order condition is

$$E\,u_\ell = E[u_1 g_\ell (1+r\epsilon) - u_2] = 0,$$

which can be written as

$$g_\ell = \frac{E\, u_2}{E[u_1(1+r\epsilon)]}.$$

How would ℓ react to an increase of r, i.e. to a 'mean-preserving' spread of the return to labour?

Since $\frac{d\ell}{dr} = -E(\frac{\partial u_\ell}{\partial r})/E(\frac{\partial u_\ell}{\partial \ell})$, where u_ℓ is the derivative of u with respect to ℓ after substituting the function f() for the first argument in the utility function, the sign of the relationship between ℓ and r is the same as that of $E[\partial u_\ell/\partial r]$, by virtue of the second-order condition.

Now

$$\frac{\partial u_\ell}{\partial r} = g_\ell(u_1\epsilon + u_{11}g\epsilon(1+r\epsilon)) - u_{21}g\epsilon$$

which is positive when the covariance of $g_\ell(u_1 + u_{11}g(1+r\epsilon)) - u_{12}g$ and ϵ is positive. At the margin this is so when the first derivative of the former expression with respect to ϵ is positive, i.e. when

$$g_\ell(2u_{11}gr + u_{111}g^2r(1+r\epsilon)) - u_{211}g^2r > 0$$

Sufficient conditions for this inequality to hold are that

$$u_{211} < 0$$
$$\partial R_f/\partial f < 0$$
$$R_f > 1,$$

where R_f is the coefficient of relative risk aversion of food consumption, $R_f = -(1+r\epsilon)gu_{11}/u_1$. This can be seen by considering, that if R_f is decreasing in $(1+r\epsilon)g$, then $\partial R_f/\partial\epsilon$ must be negative. Hence,

$$-g\{(1+r\epsilon)[u_{111}gru_1 - u_{11}u_{11}gr]/u_1^2 + ru_{11}/u_1\} < 0$$

which implies that

$$g(1+r\epsilon)u_{111} + u_{11}(1+R_f) > 0.$$

For $R_f > 1$, this implies that $g(1+r\epsilon)u_{111} + 2u_{11} > 0$, because $u_{11}<0$.

If the utility function is of the CES type, then $u_{211} < 0$, when the substitution elasticity is less than unity (Rothschild & Stiglitz, 1971).

Thus we find that under certain circumstances, when the farmer is sufficiently food-risk averse, has a relative food-risk aversion coefficient that is decreasing in f, and for whom ℓ and f are not

easily substitutable, more food will be produced the more risky is its production.
Conversely, a more food-risk averse producer would allocate more labour to food production. This can be shown by considering a second-order approximation of the expression for u_ℓ, regarded as a function of ϵ.

We had as first-order condition that

$$E\, u_\ell = 0$$

With a second-order approximation around ϵ=0, $E\, u_\ell$ can be written

$$E\, u_\ell = u_\ell^* + \sigma^2 g_\ell g r^2 (2u_{11} + u_{111} g) - u_{211} g^2 r^2$$

which has a positive derivative with respect to u_{11}. Here, u_ℓ^* denotes the value of u_ℓ for ϵ=0. Hence, if u_{11} would become more negative, and the farmer more food-risk averse, $E\, u_\ell$ would decrease, which would be compensated by an increase in ℓ, to meet the original first-order condition.
Summarising, for a farm family that operates outside the market, and is therefore characterised by an internal equilibrium as to the trade off between leisure and food production, under specific circumstances, more food will be produced when food production is more risky, and more food is produced when the family is more averse to risk in food production.
For families that operate within the market, and that therefore equate expected marginal utilities to market prices, these effects do not occur. Such families would tend toward less food production, and more wage labour, if food production would be more risky, as follows from the normal portfolio approach to allocation of labour.

3. Manageable risk and expected utility

Above, a subscript f was attached to the coefficient of relative risk aversion to indicate that only the aversion in the f-direction of the domain of the utility function was relevant. The other argument in the utility function, leisure, was not affected by the random term, as it is considered an instrument in the decision process. First a decision is made on how much labour to allocate (and how much leisure to take), then a random production and a random utility results from the process. Changes in ℓ bring about changes in f and its variance.

In the real world, production of a crop takes time, and the uncertainty about yields is not just resolved after the labour decision is made. During the growing season labour input can be adjusted to partly compensate for the vagaries of nature. In practice the cropping pattern itself can be adjusted by intercropping or resowing.

To incorporate such effects, a distinction needs to be made between the initial allocation of resources, to be made before anything is known about ϵ, and the allocation made later, partly in response to one of the sequential realisations of ϵ.

Suppose the initial allocation of resources refers to land and the ϵ-dependent realisation refers to labour. Thus, at the beginning of the growing season, land is allocated to food production and sown. Later in the season, more labour needs to be used for weeding, harvesting etc., but the allocation of this labour is made subject to weather conditions. If weather is fine, less labour may be required per unit of food, than when the weather conditions are worse.

The initial land allocation problem then needs to take two types of uncertainty into account. One type has to do with uncertainty about the resulting amount of food, the other type with the amount of labour to be allocated to the crop during the growing season. As the farmer knows how he will respond to all sorts of weather, he takes this into consideration in his initial land allocation. When his utility and production function are known, and the probability distribution of ϵ is known, a probability distribution can be derived of the labour he will allocate during the growing season. The initial land allocation then maximises the expected value of a utility function which incorporates the ϵ-dependent labour allocation.

His problem should be formulated as

$$\max_{a} E \max_{\ell} u(f(a,\ell,\epsilon), t-\ell(a)),$$

where a stands for acreage allocated to food crops. We now consider the first part of this optimisation problem. How are food consumption (and production) and labour adjusted to ϵ, when maximising u, with land predetermined? Or, deleting a, what is

$$\max_{\ell} u(f(\ell,\epsilon),t-\ell)$$

An optimum requires

$$u_1 f_1 - u_2 = 0$$

and

$$f = f(\ell,\epsilon)$$

for all values of ϵ and we have

$$\frac{d\ell}{d\epsilon} = \frac{u_1 f_{12} + f_1 f_2 u_{11} - f_2 u_{21}}{N}$$

where N is equal to $-u_{\ell\ell}$:

$$N = -(u_1 f_{11} + u_{11} f_1 f_1 - f_1(u_{21}+u_{12}) + u_{22}) > 0$$

$d\ell/d\epsilon$ now measures the change in the optimal ℓ per unit change in ϵ. The corresponding change in f follows from

$$\frac{df}{d\epsilon} = f_1\frac{d\ell}{d\epsilon} + f_2 = \frac{u_1(f_1 f_{12} - f_{11} f_2) + f_1 f_2 u_{12} - f_2 u_{22}}{N}$$

By convention f_2 can be set to positive values, f_1 naturally is positive and f_{11} negative.
Using the first-order conditions we have

$$\frac{df}{d\epsilon} > 0 \text{ for } \frac{f_{11}}{f_1} - \frac{f_{12}}{f_2} < \frac{u_{12}}{u_1} - \frac{u_{22}}{u_2}$$

and

$$\frac{d\ell}{d\epsilon} < 0 \quad \text{for} \quad \frac{f_{12}}{f_1 f_2} < \frac{u_{21}}{u_2} - \frac{u_{11}}{u_1},$$

thus allowing 'technical' characteristics, the derivatives of f, to be separated from 'behavioural' characteristics, reflected in u and its derivatives.
A positive change in ϵ increases f initially by $f_2 d\epsilon$ but this change can be reduced by adjustment of the labour input.
Suppose that at average levels of ϵ, $df/d\epsilon$ is positive and, therefore, that $d\ell/d\epsilon > -f_2/f_1$, and that such a positive 'change of nature' makes some reduction in effort possible, so that $-f_2/f_1 < d\ell/d\epsilon < 0$.
How would these changes respond to changes in the extent of risk aversion? In what variable would more risk-averse decision makers make

the larger adjustment? As in the previous section, the impact of changing risk aversion is measured here by the response of $d\ell/d\epsilon$ and $df/d\epsilon$ to a change in u_{11} and u_{22}. We have

$$\frac{\partial(d\ell/d\epsilon)}{\partial u_{11}} = \frac{f_1 f_2}{N} + \frac{f_1 f_1}{N}\cdot\frac{d\ell}{d\epsilon} = \frac{f_1}{N}(f_2+f_1\frac{d\ell}{d\epsilon}) = \frac{f_1}{N}\cdot\frac{df}{d\epsilon};$$

$$\frac{\partial(df/d\epsilon)}{\partial u_{11}} = \frac{f_1^2}{N}\cdot\frac{df}{d\epsilon};$$

$$\frac{\partial(d\ell/d\epsilon)}{\partial u_{22}} = \frac{1}{N}\cdot\frac{d\ell}{d\epsilon}; \qquad \frac{\partial(df/d\epsilon)}{\partial u_{22}} = \frac{f_1}{N}\cdot\frac{d\ell}{d\epsilon};$$

so that for $df/d\epsilon > 0$ and $-(f_2/f_1) < d\ell/d\epsilon < 0$, we have

$$\partial(d\ell/d\epsilon)/\partial u_{11} > 0 \quad \text{and} \quad \partial(df/d\epsilon)/\partial u_{11} > 0 \quad \text{and}$$

$$\partial(d\ell/d\epsilon)/\partial u_{22} < 0 \quad \text{and} \quad \partial(df/d\epsilon)/\partial u_{22} < 0.$$

Thus, a lower u_{11}, i.e. more aversion to food-risks will decrease the change in f per unit change of ϵ and reduce the absolute size of df, whereas $d\ell/d\epsilon$ will also be lower, thus increasing the absolute size of $d\ell$. A household that is more averse to random changes in leisure will show the opposite, i.e. the absolute size of $d\ell$ will decrease and that of df will increase per unit change in ϵ.

This means that the set of optima (given the initial land allocation) corresponding to the values that ϵ can possibly take reflects the risk attitude of the household. As an extreme case, consider the much discussed safety-first approach to food production. There it is assumed that households will 'always' satisfy their basic subsistence needs, before considering other activities. When cast in the term of our model, this amounts to assuming (1) that these household are highly averse to food risks at that point (an extremely low u_{11}) and (2) that obviously labour can be adjusted so as to (more or less) guarantee that this level is reached. From the above derivation it follows that at such high levels of food-risk aversion, the input of labour will bear most of the burden of the adjustment to unforeseen circumstances and that the set of optimal levels of food will be narrow. In the food-leisure space, this set of optima would then form a straight line at the subsistence level of food. This will, of course, have an influence on the acreage allocation. If the utility function and the production process are such, that by adjusting labour input, food crop yields can be stabilised, the acreage allocation can be made in an almost certain environment.

As $df/d\epsilon$ and $d\ell/d\epsilon$ are measures for the ex ante uncertainty about f and ℓ, the analysis shows that uncertainty in one argument of the utility function can be reduced by increasing the uncertainty in another argument. But this requires that the second-order derivatives of the utility function (u_{11} and u_{22}) are regarded as parameters, reflecting the local household attitude towards risk. Households with ample supply of family labour may have values of u_{22} close to zero, so that relatively big changes in labour supply can be made in response to realisations of ϵ resulting in relatively small changes in food produced. Thus, a sufficient labour capacity on the farm may contribute to reduced uncertainty about food production. When labour becomes scarce, as is the case when male workers leave the farm to work elsewhere, "agriculture suffers. It allows of no preparatory cultivation nor does it enable him to take advantage of favourable rainfalls" (Schapera, quoted in Low, 1986,p.52).

Production strategies, where crop mixes are adjusted to weather conditions prevailing during the growing season are widely reported (see e.g. Huijsman, 1986 or Just & Candler, 1985). When households are more averse to risks in food produced than to risks in cash crops and labour is adjustable to weather conditions, ceteris paribus one would expect to see the variance in food yields to be lower (relative to its 'natural' level) than that of cash crop yields. Yet, in most empirical and theoretical analyses of supply under risk, the time aspect and the possibilities this offers for risk reduction are mostly ignored. Just and Pope (1979), in their article on the formulation of supply equations under risk, emphasize the inclusion of a separate mechanism to account for risk-changing activities. In their view supply functions should at least be modeled as

$$y = f(x) + h(x)\epsilon,$$

so that the variables x have an impact on both the 'certain' part of y and on its 'uncertain' part. They do not, however, derive this result from a formal model.

The uncertainty about the returns of a cash crop consists of yield risk and of price risks, whereas the returns of the home-consumed food crop are governed by the yield only. Even if the farmer could control the yields of a cash crop, he would still face the price risk. Even this latter risk may be manageable to some extent, however. Akiyama (1985), for example, finds that jute yields in Bangladesh are positively influenced by current prices and if farmers can adjust to current prices, their uncertainty about the total returns should also be manageable to some extent.

4. Concluding comments

In the previous section it was shown that a high degree of aversion to food-risk may lead to more effort put into food production. In addition, when the risk is - more or less - manageable, such high relative risk aversion should lead to relatively certain yields. The derivation of the results rested on an analysis of effects of a lower second-order derivative in one direction. Models that are meant to reflect such extremely high degrees of risk aversion at some point should therefore not have constant second-order derivatives, as would be the case when using a second-order approximation of a utility function. Risk aversion being a 'second-order' phenomenon itself requires that the underlying model should at least provide a third-order approximation to the 'real' utility function. Changing second-order derivatives - extremely low at points close to the subsistence level but rapidly increasing at higher level of food or income - also explain the observed 'down-side risk aversion' (cf. Menezes et al.,1980) and 'focus loss' types of behaviour (cf. Boussard & Petit, 1967).

Risk aversion is measured in a certain direction. Risk aversion coefficients in the various directions of the domain of the utility function may show large differences. If the farm household would be fully integrated in the market, and hence would accommodate his input and output to the prevailing prices, the only risk left would be income risk and only the income-risk aversion would play a role. As soon as some inputs or outputs cannot be marketed at all, several risk aversion coefficients start to play a role. A farm family may be highly averse to food-risk at some point, but not to 'leisure'-risk or less to cash-risks. Measures for multivariate risk aversion have been developed by Kihlstrom & Mirman(1974), Hanoch(1977), Karni(1979) and others but no applications seem yet to have been made.

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ESI-VU
Postbus 7161
1007 MC Amsterdam