

UC Davis

UC Davis Previously Published Works

Title

Risk and decision-making

Permalink

<https://escholarship.org/uc/item/9c53s03t>

ISBN

9780191743658

Author

Winterhalder, Bruce

Publication Date

2007-04-05

DOI

10.1093/oxfordhb/9780198568308.013.0029

Peer reviewed

CHAPTER 29

Risk and decision-making

Bruce Winterhalder

29.1. Introduction

Risk is about unpredictable outcomes of behaviour and decisions, and their consequences for fitness or utility. We are interested particularly in decisions, conscious or not, which lead to actions based on the expectation of a certain result. We presume the outcome is unpredictable to some degree and, for simplicity, characterize it by a probability distribution, such as the normal distribution. This formalizes the outcome expectation as the mean value and alerts us to the chance that the actual result may fall significantly above or below it, with ascertainable odds but without surety. In subsistence studies, outcome risk is usually evaluated as a shortfall, the one-tailed chance of falling below a minimum outcome. There is no reason, however, that it might not instead or also be evaluated as an attempt to avoid a surfeit, say of a toxin found at varying levels in an otherwise essential food source.

Risk, then, is unpredictable variation in an outcome with consequences that matter. Because colloquial use of the term confounds several definitions, we must distinguish outcome risk from exposure to danger or hazards (He engages in risky—read hazardous—behaviour) and from simple chance or odds (He has some risk—read chance or odds—of catching the flu). Risk is distinct from uncertainty or incomplete knowledge, which by definition can be overcome by gathering information. Thus I can alleviate uncertainty about the day's weather forecast by reading the meteorology section of

the newspaper, but there is no escaping the unpredictability implied in the statement that there is a 40% chance of rain. The outcome—precipitation—can be assigned odds, but otherwise is not known in advance. These distinctions and the narrowing of the meaning of risk may be somewhat artificial, something to overcome with a more mature and integrated theory (Daly and Wilson, 2002), but for the moment they are essential.

Outcome risk is ubiquitous. It may be present in any behaviour in which choice can result in more than one outcome, unpredictable to some degree, and for which the outcomes have non-linear effects on a measure of value such as fitness or utility. Its importance will vary by the range of possible outcomes and the degree of their unpredictability, along with the extent to which they affect welfare. Where outcome risk is significant we expect that organisms will evolve to avoid harmful outcomes, whether shortfalls or surfeits, minimizing their occurrence to the extent that they can; we expect organisms to have risk-sensitive adaptations. In making this assumption we invoke various conceptual tools of behavioural ecology (Winterhalder and Smith, 2000), microeconomics (Landa and Wang, 2002) and cultural evolution (Henrich and McElreath, 2003).

This essay provides a brief survey of the analysis of outcome risk: what it is, in what circumstance it is important, what analytical tools we have for describing and analysing it, what examples demonstrate the utility of these tools, and what inferences we can draw from a risk-sensitive

approach to behaviour. Because risk analysis is based on well-developed mathematical theory, it is necessary to sketch in the first two sections some of technical details. The final sections summarize empirical evidence bearing on these ideas. Those who find the mathematics daunting may wish to begin with the examples in Section 29.4.

29.2. Risk in concurrent outcomes

A risk-sensitive analysis of a particular behaviour entails two steps: first, each possible option for the behaviour must be associated with a frequency distribution of its odds. A particular choice of cultivars for one particular field will result in a certain frequency distribution of yields, say of barley. Then each outcome, or in this case each yield, must be assigned a value which might be measured as fitness, utility or some other currency of relevance. Each yield of barley has a certain fitness value to the peasant family engaged in subsistence endeavour. The summed product of the distribution of outcomes times their individual values gives the overall or expected value of the option. We might find, for instance, that inter-cropping two varieties of barley yields more expected value than one or three varieties.

The algorithm that distinguishes between a probability distribution of outcomes and a matched distribution of values has its roots in Pascal's Wager. About 1660 the French mathematician, Blaise Pascal, reasoned that the probability of there being or not being a Christian God as described in the Old Testament was 50:50. He then decided that the eternal reward of heaven set against the damnation of hell, should God exist, tipped the equation decidedly in favour of belief. In Pascal's view, the value function established a decisive rebuttal to agnosticism even though the outcome distribution was inconclusive. Bernoulli (1954; first published 1738) and much later Friedman and Savage (1948) developed the mathematical formalities of this insight through the instrument of concave and convex utility functions.

Risk assessment entails sums over the product of frequency-weighted outcomes and

their associated values. Mathematically, for the continuous case:

$$E_i[V(x)] = \int f_i(x)V(x)dx$$

This reads: the expected value of option i , $E_i[V(x)]$, equals the integral (continuous summation) of the product of the outcome distribution for i , $f_i(x)$, and the value function for each outcome, $V(x)$, summed of all possible outcomes, x . In the discontinuous case we replace the integral form, $\int dx$, with simple summation, \sum .

Value here is a gloss for fitness and utility, the central metrics of neo-Darwinian and microeconomic theory, respectively. A value function might take many forms, but in the general case it can be visualized as a sigmoid, or convex-concave, curve (Figure 29.1). This formulation is prized for its versatility. Value accelerates with quantity when the outcome resource is in short supply; it decelerates with quantity as the outcome resource grows abundant. This non-linear form represents the changing marginal value of the resource as a function of its abundance.

In the convex portion of this curve, if an organism is given a choice between a fixed reward and even odds of that fixed reward plus or minus a small increment, it should opt for the even odds. Because the curve is accelerating in slope, the weighted upside gain more than offsets the weighted downside loss to beat the sure average. The organism should elect to be risk-prone in the sense of seeking the less predictable option. In the concave portion, the reverse is true: the sure average beats the weighted probability of the odds multiplied by their values. The organism is said to be risk-averse. The formal statement of this result is known as Jensen's inequality; refinements can be found in Kuznar *et al.* (2002).

Because the designations *risk-prone* and *risk-averse* run somewhat counter to common usage, it is important to emphasize that they mean only variance-prone or variance-averse. Note also that this example carries out the two-step procedure introduced earlier: sum over outcome frequency times value. It demonstrates that it may be in the organism's best interests—that is, may maximize its expected reward—to elect the less certain choice.

The example just given is a highly simplified comparison of two outcomes of equal probability,

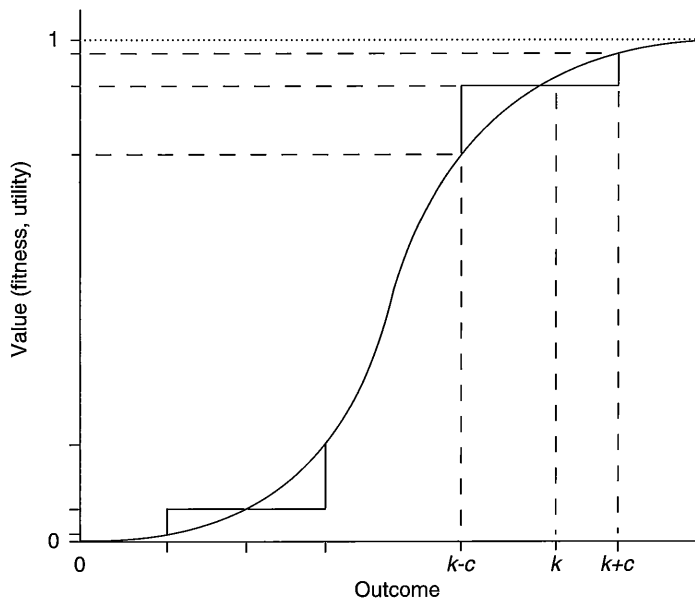


Fig. 29.1 The sigmoid value function. The curve shows the relationship between outcome and value, expressed as fitness or utility. In the concave portion of the curve, downward marginal returns are decreasing and the organism will prefer a constant return k to an equal probability of a variable outcome, $(k + c, k - c)$. The value associated with k is above the mid-point or average value for $k + c$ and $k - c$; the organism is risk-averse. In the convex portion of the curve, the segment with increasing marginal returns, the average of the unpredictable, variable outcomes is higher and the organism is predicted to be risk-prone.

equally distant from the fixed case, against the certain reward of that fixed case. Each possibility is confined to a limited portion of the value function falling on either the convex or concave segments. All other kinds of risk-sensitive analysis are variations on this procedure which complicate the outcome distribution, the value function, or both.

A risk-sensitive analysis requires certain assumptions. We assume the organism is capable of assessing and acting on the outcome distribution and value function, a premise that entails its having acquired significant information about the environment. The organism's choices need not be conscious, rational enactments of college mathematics. They might be entirely unconscious, coded by evolution in cognitive mechanisms, cultural decision heuristics or rules of thumb (Henrich and McElreath, 2002). We assume the environment is well behaved, at least to the degree that the parameters of the

outcome distribution are stable over time periods encompassing action and result. We assume that there is a single, unique value function guiding choice and that it is similarly well-behaved. Finally, we assume that the resource in question is divisible in increments small enough to make comparison of sigmoid positions meaningful (Henrich and McElreath, 2002).

While this list may appear to be highly restrictive, and perhaps decidedly unrealistic, evolutionary ecology studies show a variety of non-human organisms to be capable of risk-sensitive, adaptive behaviour (citations in Winterhalder *et al.*, 1999). Experiments have shown, for instance, that yellow-eyed juncos (*Junco phaeonotus*) have a sigmoid value function for food (Caraco *et al.*, 1980). Small, temperate-zone endotherms which generally are solitary feeding specialists, with low endogenous food reserves and high metabolic requirements, appear to be more risk sensitive than tropical

omnivores with more forgiving environments and metabolic characteristics (Winterhalder *et al.*, 1999, pp. 316–25). The taxonomic diversity of risk sensitivity highlights its general evolutionary significance.

The z -score model (Figure 29.2) for risk-sensitive analysis has proved to be particularly useful (Stephens and Charnov, 1982). It adopts a normal distribution for characterizing outcomes and a step function to represent value. A step function is a limiting form of the sigmoid curve: below the threshold, R_{min} (defined as a resource minimum) value is zero; above the threshold, its value is one. A risk-sensitive organism will do its best to minimize the one-tail chance of falling below R_{min} , equivalent to maximizing the odds of being above it.

If μ and σ represent the mean and standard deviation of the normal distribution, respectively,

we can express these relationships using the equation for the standard normal deviate, $z = (\mu - R_{min})/\sigma$ rearranged as the slope-intercept equation, $\mu = (R_{min} + \sigma z)$. This positions μ as the y -axis coordinate, σ as the x -axis coordinate, and R_{min} as the intercept. z is the slope of the line segment extending from R_{min} . Each possible behavioural option is associated with an outcome which has a unique mean (μ) and standard deviation (σ). The best option is that intersected by the intercept line of maximum slope (or maximum z).

The z -score model produces two simple rules and a more complex graphical or mathematical solution. The *expected energy-budget rule* says that organisms whose expected or average outcome is below R_{min} will always prefer a variable (unpredictable) to a constant (certain) reward, if their means are equal. The reverse is true of organisms

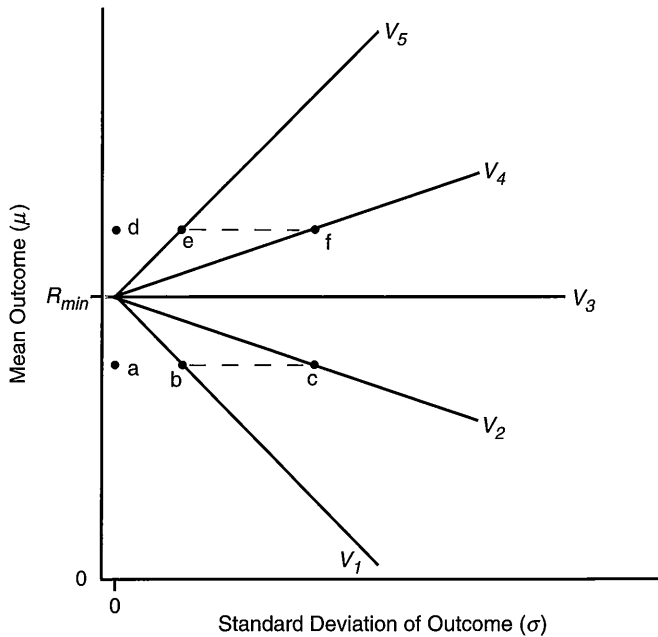


Fig. 29.2 z -Score model. σ is the standard deviation and μ is the mean of the normal distribution of outcomes. R_{min} is defined by using a step-function for assessing the values of these outcomes; it is the minimum threshold the organism must meet. The best risk-minimizing option is found via the highest slope line connecting R_{min} and a (σ, μ) pair. The option associated with that particular combination of mean and standard deviation of outcome is optimal. Options along the line have the same value, making the set of such lines (e.g. v_1 through v_5) a risk indifference or iso-value map. The expected energy-budget rule is illustrated by comparing points a–b to d–e; the extreme variance rule by comparing b–c to e–f (see text).

whose expected outcome is above R_{\min} . The *extreme variance rule* says that organisms whose expected outcome is below R_{\min} will elect outcomes with greater over lesser unpredictable variance at the same mean, whereas those above the R_{\min} threshold will do the reverse. More generally, the z -score model allows us to compare the expected value of any set options, each characterized by a mean and standard deviation, as a function of R_{\min} (Figure 29.2).

Winterhalder *et al.* (1999, pp. 310–13) show that the z -score model and an alternative risk-sensitive formulation, the linear discounting function, are specific instances of the general sigmoid model of Figure 29.1, drawing attention again to its versatility. They describe the circumstances in which the more specific conceptualization should give robust results.

We also can treat R_{\min} or the sigmoid inflection point not as a starvation threshold but rather as an aspiration level. In a stratified society, we might predict that individuals will be alternately risk-prone and, then risk-averse, followed by another such cycle as they advance up the class-differentiated income scale (Friedman and Savage, 1948). Those who have moved solidly into the next higher class will be intent on consolidating their gains and not slipping backward, hence risk-averse. Those who may be positioned to make a socially attractive leap into the next higher class may, by contrast, adopt more risk-prone options. Kuznar (2002) provides a mathematical function to represent stacked sigmoid-shaped curves, along with an interpretation of its parameters and description of how to apply and test it with field data.

29.3. Temporal discounting and risk

So far we have been examining coincident outcomes, those occurring in the same time frame. Neither the frequency distribution of outcomes nor the value function incorporates the effects of delay. However, it is possible that outcome rewards are spread unpredictably over time and, if the reward for a decision is delayed, it may be subject to temporal discounting. Discounting is evident when an organism decides for a small reward immediately rather than a larger one at a

later time; it assesses the effect of time delay on preference. For instance, pigeons that are risk-averse to variably sized outcome rewards delivered after the same short delay may shift to a risk-prone tactic when the rewards are delivered at unpredictable intervals of time (Hamm and Shettleworth, 1987). They appear to discount delayed rewards, favouring a chance at immediacy. Humans also may discount the utility of options with delayed rewards (Samuelson, 1937; citations in Tucker, 2006).

Rogers (1994) combines (i) kin selection (specifically the decay in relatedness from parents to children to grandchildren), (ii) demography (male and female fertility and survivorship schedules through their lifespan) and (iii) population ecology (the rate of population growth or decline) to formulate a model of the ‘natural’ discount rate. Using data from extant natural fertility populations and the assumption that population growth was zero over the long term, he calculates a natural discount rate of 2% per year. Rogers’s model correctly predicts that young adults have a higher discount rate than their elders and, while it focuses on the discount rate for delayed investment in fitness, if preferences are in equilibrium that estimate must equal the discount rate for utility.

Discounting is usually represented either by an exponential or hyperbolic model. Both can be shown to fit experimental data sets, the latter achieving somewhat higher levels of significance (Tucker, 2006). Mathematically, a hyperbolic discount function is represented as:

$$V = A/(1+kD)$$

where V is the discounted value, D is the delay, A is the reward value when D is zero (the return is immediate) and k is the discount rate. Both the exponential and hyperbolic models are, of course, abstractions that entail considerable smoothing. For instance, the discounted value of a crop will jump as it successfully concludes an especially sensitive period of development.

In a risk-sensitive analysis, temporal delay may affect the outcome distribution, the value function, R_{\min} , or all three. We also can divide factors potentially affecting discount rates into those that are exogenous and

those that are endogenous to the individual decision-maker.

There have been few attempts to assess the determinants of human discount rates in naturalistic settings. By experimentally titrating toward indifference between various hypothetical comparisons—Would you prefer x sacks of maize immediately or $x + k$ sacks 6 months from now?—Tucker (2006) was able to determine that the discount rate of individuals who primarily are foragers is significantly greater than those who depend primarily on farming, for populations living in rural Madagascar.

Discounting is linked to risk because time to reward may be unpredictable, with consequences for its value and likelihood. In terms of procedure, this means that a risk-sensitive analysis of behaviours incorporating significant delay must consider separately the effect of delay on the outcome distribution and the value function. But discounting may also occur without any risk. Comparing a small but certain meal now to a large certain meal after several days of hunger is a discounting problem, but not one that has anything to do with risk. That is, discounting may be evident even if the timing and size of each specific outcome is perfectly predictable.

Kacelnik and Bateson (1997) suggest that cognitive constraints related to Weber's Law may help to explain the prevalence of risk-proneness when variability concerns delay to reward. They argue that scalar impacts on the cognitive processing of time intervals introduce positive skew into the organism's perception of the outcome distribution, with the result that more than half of the outcomes fall below the fixed, average reward.

In summary, quantitative models of risk-sensitive adaptations lead us to conclusions that are counter-intuitive. Humour or despair are not our only means of dealing with the unpredictable. There are effective ('ecologically rational', see Landa and Wang, 2002), patterned responses to outcome risk arising from stochastic factors affecting organisms and their environments. The best risk-sensitive behaviour may require that organisms either embrace or avoid options with higher outcome variance. The sure bet is not always the best bet. The conditions that determine this choice can be specified quite precisely, the key analytical elements being the

outcome distribution and the associated value function. In cases of delayed outcomes, both elements must be adjusted for discounting.

29.4. Examples of risk-sensitive adaptation as behaviour

The literature on subsistence risk is large but it is generally qualitative and intuitive, whether focused on prehistory and archaeological analyses (Halstead and O'Shea, 1989; Tainter and Tainter, 1996) or the ethnographic present (de Garine and Harrison, 1988; Cashdan, 1990). Use of formal models is rare. The following examples are exceptions to this generalization. They are described in order to highlight various features of a more rigorous approach to questions of risk-sensitive adaptations, as described in previous sections.

29.4.1. Agricultural field scattering (Cuyo Cuyo, Peru)

The peasant agricultural community of Cuyo Cuyo, Department of Puno, southern Peru, rests high in one of many drainages flowing down the eastern escarpment of the Andes. Families here cultivate land on steep, terraced slopes located between 2700 and 4100 m in altitude. Potatoes and other Andean tubers and cereals are major crops, with potatoes making up the bulk of the diet.

In a test of McCloskey's (1976) proposal that field scattering is an effective mechanism of risk reduction, Goland (1993) examined data on more than 600 field plots representing cultivation by 18 families over two annual cropping cycles. Her information allowed her to determine what portion of yield variance among plots was explained by fixed landscape features such as altitude, slope and exposure, and by input factors under the control of the farmers: seeding density, fertilizer, weeding. After statistically removing effects of these variables, the residual variance—a substantial 70% of the total—was presumed to be unpredictable variability due to stochastic environmental features.

Goland then performed an analysis in which she used the empirical experience of each family each year to examine the range of yields they

would have experienced had all of their production been located at any one of the spots they planted. She continued this exercise by looking at all possible combinations of investing their production opportunities in any two plots, any combination of three plots, etc., up to and including the actual number of fields they planted. This gave her a mean and range (standard deviation) of outcomes representing all potential degrees of field scattering, from one consolidated field to the dozen or so scattered plots typical of Cuyo Cuyo practice. In a procedure inspired by the z-score model, she was then able to calculate the odds a family would fall below their minimum need for potatoes, as a function of their degree of field scattering. Figure 29.3 shows the results for one of the 12 families who effectively eliminated the chance of a shortfall through field scattering.

A GIS-based, topographic analysis of the trail network connecting these fields allowed Goland to conduct a time and energy analysis of moving among them with tools and loads. It showed the total cost of scattering to be a 7% decrement to net production, a small value relative to the risk-minimizing gains achieved by scattering. McCloskey's hypothesis was supported.

Goland's work highlights three important methodological issues. First, she isolated the portion of outcome variability that can be attributed to stochastic factors. Not all variation in outcomes is outcome risk. Second, she found a way to quantify the counter-factual elements of her analysis—the consequences of lesser degrees of field scattering than were observed empirically. Counter-factuals usually are left implicit in behavioural study. And finally, she focused on quantifying the costs as well as the

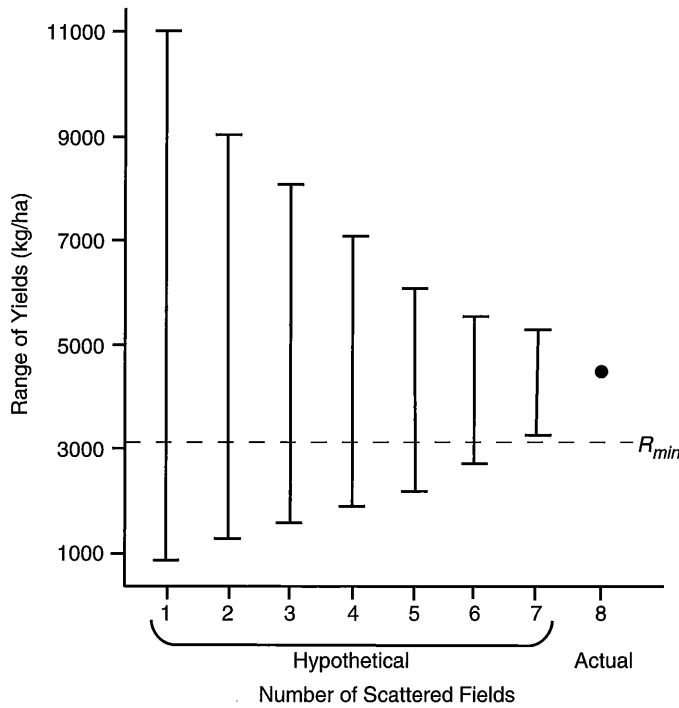


Fig. 29.3 Potential range of yields, compared to the family minimum requirement (R_{min}), as a function of the number of independent (scattered) plots they plant. This household planted eight different fields, obtaining a pooled (average) yield of 4477 kg/ha, comfortably above their requirement of 3100 kg/ha. Had they planted all of their potatoes in just one of the locations of their fields, they would have faced a one-in-eight chance of a catastrophic return of 958 kg/ha.

benefits of the practice, whereas studies of adaptation often rest after showing a benefit.

29.4.2. Pastoralism (east Africa)

Mace and Houston (1989) used the method of stochastic dynamic programming models and empirical evidence to predict the mix of small-stock (goats, sheep) and large-stock (camels) that minimizes the chance of household failure in a drought-prone, pastoralist environment. Small stock have high reproductive rates and recover population size quickly, but they are drought-susceptible. They are a high-mean, high-variance resource. Camels reproduce and recover more slowly, but are drought-resistant, making them a low-mean but low-variance resource. Mace shows that optimal investment patterns depend on household wealth. Impoverished households should—and evidence shows they do (Mace, 1990)—invest in small stock and then, as their wealth grows, they trade up, exchanging sheep and goats for camels. This is consistent with the energy-budget rule: engage in more risk-prone management practices when reserves are below the household minimum needs and switch to risk-averse tactics when above.

In a second analysis using the same methodology, Mace (1993) shows that the nomadic pastoralist Gabbra manipulate the breeding of sheep according to the same risk-sensitive principles and long-term goals. Poor households do not restrict male access to ewes, whereas relatively wealthy households impose such restrictions in order to slow breeding rates of females and thus increase their longevity. Both are adopting the tactic that best serves their long-term survival.

29.4.3. Social exchange (prehistoric south west USA)

Precipitation signatures read from tree rings and a wealth of environmental data on soil moisture balance and early maize yields in south west USA are the basis for a risk-sensitive analysis of prehistoric agriculture by the archaeologists Kohler and Van West (1996). They focus on the Mesa Verde region over a period of about 400 years (AD 901–1300) and a society known as the northern Anasazi. Kohler and Van West hypothesize that in periods of fair to relatively

good precipitation (propitious conditions for agriculture), Anasazi households achieved risk-averse outcomes by forming communities and exchanging corn amongst themselves to minimize the likelihood that individual households would suffer debilitating shortfalls. A string of drought years, in contrast, compromised this mechanism and would shift households into a more risk-prone state, which they achieved by dissolving community ties and dispersing. In particularly bad times, each household did best by attempting to make it on its own, the high-variance option.

In fact, the archaeological record of aggregation and dispersion over the four centuries correlates with environmental patterns in the expected manner. Stretches of adequate-to-abundant rainfall are characterized by village formation, whereas periods of extended or closely spaced droughts signal dispersion of households and the disappearance of villages. Community-level social arrangements apparently were adjusted to achieve risk-averse or risk-prone adaptive outcomes, depending on need.

These results echo Hegmon's (1989) simulation of household survival among the early twentieth-century Hopi engaged in corn agriculture. The Hopi practised field scattering and they further reduced yield variation via obligatory inter-household exchange. In a computer simulation of this practice, Hegmon showed that predicted survival over a 20 year period was 46% for completely independent households (no exchange); 73% for unrestricted sharing (pool the total harvest and divide equally); and 92% for a pattern in which households met their own needs and then pooled and divided only the surplus. The most successful tactic for the Hopi recognizes that unrestricted sharing to cover the losses of the least successful may compromise the survival of many who otherwise would have been marginally above their minimum requirements. Hegmon notes that a sharing ethic which acknowledges this limitation will do better over the long term than one which is unconditional.

29.4.4. Fertility

Completed family size also has been analysed from the perspective of risk (Winterhalder and

Leslie, 2002). In pre-modern populations, sub-adult mortality is high and largely unpredictable. A binomial distribution for childhood survival establishes the outcome distribution for number of surviving adult children achieved by a couple. Winterhalder and Leslie argue that the socio-economic conditions in pre-modern populations entailed a non-linear value function for adult children. For instance, a minimum number of adult offspring may have been required to secure inheritance or defence of fixed property assets. Similarly, because children provided old age insurance for their parents, foresight required that young couples allow for mortality and plan for the minimal set needed to provision them. Desertion by the occasional wayward child, varying capacities and uncertain sex ratios would have further complicated achieving the desired size and composition of the set of adult children.

Thus, falling below one's target adult sibling group might have been a disaster; overreaching it might have imposed rather more modest costs. If this is the case, the value function will be non-linear and risk-sensitive family planning would be constrained to overproduce children relative to the optimum, in order to avoid the very high costs of falling short.

Winterhalder and Leslie term this the 'variance compensation hypothesis' (VCH) and they develop mathematical scenarios to show how the direction and magnitude of the effect depends on differing assumptions about the outcome distribution and value function. The VCH is potentially relevant to various population issues: the rate of growth in natural fertility populations, demographic transitions, and processes of agricultural intensification among them. Unfortunately, most demographic work has treated stochastic features of life history as noise and thus without adaptive significance. There are almost no data at present that would allow us to assess this model.

29.4.5. Subsistence diversification (Mikea, central Madagascar)

The Mikea of south central Madagascar are former agriculturalists who fled into forest regions and took up hunting and gathering to avoid the slavery and tribute demands of Andrevola kings and later the taxes imposed on them by French

colonial officials. Presently they mix foraging with low-intensity horticulture, craft production, fishing and marketing in a highly diversified economy. Tucker (2006) argues that discounting can help to explain this mixed portfolio of subsistence activities. Although the average return rate for agriculture makes it highly profitable compared to foraging, cultivation also represents investment in a long-delayed reward with high risk. As a consequence, throughout the early months of the agricultural cycle, the opportunity costs of immediate return foraging compete with investment in a highly discounted agriculture. Three days of field clearing puts no food on the table and Mikea must interrupt cultivation to forage. Likewise the discounted return to weeding is well below that of gathering. As a consequence, foraging and cultivation alternate, the former offering low-level but reliable immediate returns, the latter the potential of a windfall with low reliability. The continued mix of these activities and the desultory level of investment in food production result from an ecologically rational balancing of risk and discounted values.

29.4.6. Late Paleolithic microlithic technology

In an application that is admittedly more speculative, Elston and Brantingham (2002) argue that paleolithic stone tool production may have reflected risk-sensitive choices. They compare the costs and functional advantages of blade stone tools which are lethal but brittle and subject to a high failure rate, to organic, bone and wood tools, which are less lethal but more durable and reliable, to tools made of micro-blade stone set into organics which are lethal and durable but have high production costs. In the argot of Paleolithic technology, wedge-shaped cores are associated with greater uniformity of micro-blade output, making them a risk-averse choice. By contrast, boat-shaped cores imply greater variability and they represent a more risk-prone choice expected only in the dire circumstance of greater need for raw materials than are likely to be available. Neither the experimental nor archaeological data are yet sufficient to test these propositions, although there is a general association of micro-blade

technology with the increasingly variable environment following the Late Glacial Maximum.

This analysis is supported by a second and likewise somewhat provisional study. In a step-wise, multiple regression analysis using data from 20 hunter-gatherer populations, Collard *et al.* (2005) show that the diversity and complexity of their toolkits is highly correlated with environmental variables thought to be reasonable proxies for risk. The same analysis allows them provisionally to reject three other hypothesized predictors of toolkit diversity and complexity: the nature of the resources, residential mobility, and the population size of the foragers. If archaeologists are able to test this proposition as conclusively as they can establish sharing from prehistoric sites (Enloe and David, 1992; Waguespack, 2002)—intra-group transfers of food and other materials also being explicable in part by risk reduction advantages (Winterhalder, 1900)—it will go a long way to establishing the prominence of risk-sensitive behaviour in human prehistory.

29.5. Examples of risk-sensitive adaptations as psychology and decision

Although still limited, ethnographic evidence on adaptive responses to outcome risk is consistent: humans, in a variety of socio-economic systems and for a variety of behaviours, are able to act as if capable of assessing outcome distributions, value functions and needs or aspiration levels, and of implementing effective, risk-sensitive actions. They are sometimes risk-averse and sometimes risk-prone. In this, they continue the evolved capacities found in other species.

However, the careful qualification of this assertion ('able to act as if...') brings us to the admission that we know very little about how this is accomplished at the level of psychology and cognition, individual choices, social context and learning; little about how it works as decision-making, conscious or not.

By the standards of probability and statistics, humans in experimental settings prove to be quite fallible in their judgments (Tversky and Kahneman, 1974). Were it otherwise, university classes in these subjects would be more intuitive

and less necessary. Our choices regularly deviate from those ascertained through the formalities of probability and utility theory, and much has been made in psychology of our shortcomings and susceptibilities when making decisions in uncertain or unpredictable circumstances. But this evaluation of human rationality makes sense only if the adaptive demands on evolving human beings have had the same structure as is represented in probability theory. Two examples of the cognition of risk-sensitive decisions make this point.

Rhode *et al.* (1999) argue that we have inherited from our foraging past a specific cognitive mechanism for solving risk-sensitive, adaptive problems. They explicitly address the claim, based on standard expected-utility theory, that humans exhibit an irrational ambiguity avoidance, that is, they tend to avoid options with unknown distributions due to missing or imprecise information, even if those options have the same or greater expected value than a fixed reward.

Rhode *et al.* (1999) assume that people quite reasonably equate an ambiguous outcome distribution with an unpredictable one, and, having evolved as a risk-sensitive hunter-gatherer, assess not only their personal value function but the outcome distribution and R_{\min} . Re-cast as a risk-sensitive choice, we sometimes quite reasonably reject the higher-mean/high-variability option. Using experimental protocols, these authors show that people prefer ambiguity to transparent but greater unpredictability; they also elect ambiguity over certainty in situations in which the reward structure predicts a risk-prone choice. Both results point to a single conclusion: ambiguity avoidance is not an indiscriminate matter of avoiding uncertainty. Rather it is tactical, and rational. They also show how their interpretation provides a more consistent and parsimonious explanation of the Ellsberg two-colour problem and other results from experimental psychology.

Rhode *et al.* (1999) infer from their work a domain-specific cognitive module designed by evolution in the context of our foraging past. It gives us the capacity to assess outcome distributions, value functions and R_{\min} or aspiration levels. While such a capacity could be related to hunter-gatherer subsistence, similar adaptive

problems arise in technological and fertility choices. If a cognitive module exists for comparing the three variables of a risk-sensitive adaptation, it probably has more general sources and applications.

A second case is framing effects, an example of a cognitive heuristic approach which emphasizes the way in which human cognition can go wrong via irrational preference reversals. Tversky and Kahneman (1974) presented subjects with treatment options for a population of 600 hypothetical patients facing a fatal illness. A deterministic-outcome treatment plan resulted in sure survival for 33% of the patients and death for the remainder; a probabilistic-outcome plan resulted in a 33% chance all individuals would survive. When the question was phrased as the number of patients who would be saved, the majority of test subjects made the deterministic choice. When phrased as the number who would perish, subjects elected the probabilistic option. Strictly speaking, this shift due to a rephrasing is irrational as the expected utilities of the treatments are the same.

An evolutionary approach to this experiment would direct attention to the size and nature of the groups found in human prehistory: 15–30 individuals in the immediate band, many of them kin. Wang (1996) repeated the treatment-selection experiments but included group sizes of six and 60, finding that the framing effect disappeared. Further, subjects tended towards the probabilistic treatment option, a result consistent with a risk-sensitive approach if we make the reasonable assumption that the value function is convex for small groups typical of hunter-gatherers. Saving four (0.33×12) members of your small band only to have them starve is a poor choice if you have a 33% chance of saving a viable economic unit. Wang argues that we are designed to reason effectively when the experimental set-up is attuned to the context in which such capacities evolved. As the decision shrinks to the family domain and concerns relatives, subjects become more probabilistic and risk-prone; more rational.

In both examples cited, human reasoning in the face of unpredictable outcomes proves to be quite fallible when assessed by the normative canons of formal probability theory and economic rationality. By contrast, risk-sensitive

decisions prove to be more robust when the test of what is rational is framed by the 'ecological rationality' (Landa and Wang, 2001) we would expect from the settings and adaptive problems actually faced by our ancestors. These decision studies, far from undermining the assumptions of behavioural ecology, appear to support them.

29.6. Pressing analytical issues

Much about risk-sensitive behaviour is only nascently and imperfectly understood. For instance, we know little about the actual structure of environmental variation and how it affects outcome distributions. This severely limits our ability to make conjectures about ecological rationality. For instance, experimental psychologists have made much of the failure of human cognition to readily appreciate the statistics of independent samples. However, if the environments of human adaptation are significantly autocorrelated (M. W. Grote and B. Winterhalder, unpublished data), such conclusions will need to be reassessed. Obvious and attractive proxy metrics of patterning in an environmental feature, like rainfall, may not correspond to a metric of more immediate interest, like yield (Lee *et al.*, in press). Human behaviour and, by implication, human cognitive mechanisms have been designed to solve the problems of living in actual socio-ecological environments, not the abstractions of a statistics textbook (Barrett and Fiddick, 2000).

Likewise, we have far too few studies of value functions (Henrich and McElreath, 2002; Kuznar, 2002). As a consequence it is not possible to be empirically precise about their shape, or to say with confidence how they respond to such basic variables as age, sex, socio-economic status and security, health, number of descendants, population growth or decline, social history, or other relevant factors.

Continuing with the components of a basic risk-sensitive analysis, there has been little work on R_{\min} or the related concept of aspiration level. For instance, in a stratified society there may be multiple aspiration levels across the full range of socio-economic statuses or class (Friedman and Savage, 1948; Kuznar, 2002). The study of how

discounting affects these parameters is just beginning, as is analysis of the assumptions that underlie risk-sensitive models.

29.7. Conclusion

The analysis of risk-sensitive behaviour and decisions faces two hurdles: (i) there is a tendency in some social sciences to see environmental stochasticity as noise, thus not as an element of environment for which there can be effective, patterned responses; and (ii) those who seek to analyse risk often rely on intuitive, qualitative assessments of what are and are not appropriate behavioural responses. In fact, there are adaptive responses to outcome risk that can be studied effectively using formal concepts and models.

I see three conclusions in this brief summary:

1. The behavioural ecology of risk-sensitive adaptations and the evolutionary psychology of risk-sensitive cognition and decision-making are necessary complements. Kacelnik and Bateson (1997) recommend 'theoretical plurality' for this topic, with a reminder that it will be most successful if the various theories pay attention to one another. Evolutionists acknowledge a distinction between ultimate analysis focused on the explanation of evolutionary or adaptive advantage, and proximate analysis focused on explanation of mechanisms (Mayr, 1976). This is roughly the distinction between the behavioural ecological study of adaptation—How did it come about?—and the evolutionary psychology study of cognition and decision—How does it function? The former is showing risk-sensitive behaviour in a variety of settings; the latter is beginning to reveal the linkage between these settings and the 'ecological rationality' of cognition and decision. Neither is complete without the other.
2. Evolutionary psychology has sometimes entailed the premise that the human mind is made up of specific modules, each designed to solve a particular problem in a particular context. These modules can be inferred by reverse-engineering observations of contemporary behaviour in terms of their Pleistocene, evolutionary context, also known as the EEA

or environment of evolutionary adaptedness (critical review in Buller, 2005).

If risk-sensitivity is such a module, it would appear that it is better described as a quite general capacity, not limited to a particular task or context. The bases for this claim are: first, the logically sufficient conditions for hypothesizing a risk-sensitive element to any adaptation—unpredictable outcomes and non-linear adaptive consequences—are themselves likely to be ubiquitous; and second, we now have suggestive empirical evidence from behavioural ecology that humans exhibit risk sensitivity across a wide variety of behaviours and contexts: subsistence production and distribution in hunter-gatherer, pastoralist and agricultural societies, choice and design of technological implements, and reproductive behaviour. Also in favour of this argument is the fact that the cognitive capacity to act in a risk-sensitive manner long antedates hominids and the evolution of the neural features unique to our species.

3. Finally, and drawing somewhat more speculatively on the previous two observations, synthesis of insights from behavioural ecology and evolutionary psychology may help us to predict which of our capacities are domain general and which are domain specific, and in what circumstances. Among the basic adaptive tools likely to be domain general are the ability to make marginal assessments, to appraise opportunity costs, and to discount delayed outcomes, along with the capacity to assess and respond to risk.

References

- Barrett, H. C. and Fiddick, L. (2000) Evolution and risky decisions. *Trends in Cognitive Sciences*, 4: 251–252.
- Bernoulli, D. (1954; first published 1738) Exposition of a new theory on the measurement of risk. *Econometrica*, 22: 23–36.
- Buller, D. J. (2005) Evolutionary psychology: the emperor's new paradigm. *Trends in Cognitive Sciences*, 9: 277–283.
- Caraco, T., Martindale, S. and Whittam, T. S. (1980) An empirical demonstration of risk-sensitive foraging preferences. *Animal Behaviour*, 28: 820–830.
- Cashdan, E. (ed.) (1990) *Risk and Uncertainty in Tribal and Peasant Economies*. Westview Press, Boulder, CO.
- Collard, M., Kemery, M. and Banks, S. (2005) Causes of toolkit variation among hunter-gatherers: a test of four competing hypotheses. *Canadian Journal of Archaeology*, 29: 1–19.

- Daly, M. and Wilson, M. (2002) Editorial introduction: two special issues on risk. *Evolution and Human Behavior*, 23: 1–2.
- de Garine, I. and Harrison, G. A. (eds) (1988) *Coping with Uncertainty in Food Supply*. Clarendon Press, Oxford.
- Elston, R. G. and Brantingham, P. J. (2002) Microlithic technology in Northern Asia: a risk-minimizing strategy of the Late Paleolithic and Early Holocene. In R. G. Elston and S. L. Kuhn (eds) *Thinking Small: Global Perspectives on Microlithization*, pp. 103–116. American Anthropological Association, Washington, DC.
- Enloe, J. G. and David, F. (1992) Food sharing in the Paleolithic: carcass refitting at Pincevent. In J. L. Hofman and J. G. Enloe (eds) *Piecing Together the Past: Applications of Refitting Studies in Archaeology*, pp. 296–315. Tempvs Reparatum, Oxford.
- Friedman, M. and Savage, L. J. (1948) The utility analysis of choices involving risk. *Journal of Political Economy*, LVI: 279–304.
- Goland, C. (1993) Field scattering as agricultural risk management: a case study from Cuyo Cuyo, Department of Puno, Peru. *Mountain Research and Development*, 13: 317–338.
- Grote, M. W. and Winterhalder, B. (2006) Robust search path characteristics of a spatially explicit forager (manuscript).
- Halstead, P. and O'Shea, J. (eds) (1989) *Bad Year Economics: Cultural Responses to Risk and Uncertainty*. Cambridge University Press, Cambridge.
- Hamm, S. L. and Shettleworth, S. J. (1987) Risk aversion in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 13: 376–383.
- Hegmon, M. (1989) Risk reduction and variation in agricultural economies: a computer simulation of Hopi agriculture. *Research in Economic Anthropology*, 11: 89–121.
- Henrich, J. and McElreath, R. (2002) Are peasants risk-averse decision makers? *Current Anthropology*, 43: 172–181.
- Henrich, J. and McElreath, R. (2003) The evolution of cultural evolution. *Evolutionary Anthropology*, 12: 123–35.
- Kacelnik, A. and Bateson, M. (1997) Risk-sensitivity: crossroads for theories of decision-making. *Trends in Cognitive Sciences*, 1: 304–309.
- Kohler, T. A. and Van West, C. R. (1996) The calculus of self-interest in the development of cooperation: sociopolitical development and risk among the Northern Anasazi. In J. A. Tainter and B. B. Tainter (eds) *Evolving Complexity and Environmental Risk in the Prehistoric Southwest*, pp. 169–196. Addison-Wesley, Reading, MA.
- Kuznar, L. A. (2002) Evolutionary applications of risk sensitivity models to socially stratified species: comparison of sigmoid, concave, and linear functions. *Evolution and Human Behavior*, 23: 265–280.
- Kuznar, L. A., Henrich, J. and McElreath, R. (2002) On risk-prone peasants: cultural transmission or sigmoid utility maximization? and Reply. *Current Anthropology*, 43: 787–789.
- Landa, J. T. and Wang, X. T. (2001) Bounded rationality of economic man: decision making under ecological, social, and institutional constraints. *Journal of Bioeconomics*, 3: 217–235.
- Lee, C. T., Tuljapurkar, S. and Vitousek, P. M. (in press) Risky business: temporal and spatial variation in preindustrial dryland agriculture. *Human Ecology*.
- Mace, R. (1990) Pastoralist herd compositions in unpredictable environments: a comparison of model predictions and data from camel-keeping groups. *Agricultural Systems*, 33: 1–11.
- Mace, R. (1993) Nomadic pastoralists adopt subsistence strategies that maximise long-term household survival. *Behavioral Ecology and Sociobiology*, 33: 329–334.
- Mace, R. and Houston, A. (1989) Pastoralist strategies for survival in unpredictable environments: a model of herd composition that maximises household viability. *Agricultural Systems*, 31: 185–204.
- Mayr, E. (1961) Cause and effect in biology. *Science*, 134: 1501–1506.
- McCloskey, D. N. (1976) English open fields as behavior towards risk. In P. Uselding (ed.) *Research in Economic History vol. 1*, pp. 124–170, JAI Press, Greenwich, CT.
- Rhode, C., Cosmides, L., Hell, W. and Tooby, J. (1999) When and why do people avoid unknown probabilities in decisions under uncertainty? Testing some predictions from optimal foraging theory. *Cognition*, 72: 269–304.
- Rogers, A. R. (1994) Evolution of time preference by natural selection. *American Economic Review*, 84: 460–81.
- Samuelson, P. A. (1937) A note on measurement of utility. *Review of Economic Studies*, 4: 155–161.
- Stephens, D. W. and Charnov, E. L. (1982) Optimal foraging: some simple stochastic models. *Behavioral Ecology and Sociobiology*, 10: 251–263.
- Tainter, J. A. and Tainter, B. B. (eds) (1996) *Evolving Complexity and Environmental Risk in the Prehistoric Southwest*. Addison-Wesley, Reading, MA.
- Tucker, B. (2006) A future discounting explanation for the persistence of a mixed foraging-horticulture strategy among the Mikea of Madagascar. In D. J. Kennett and B. Winterhalder (eds) *Behavioral Ecology and the Transition to Agriculture*, pp. 22–40, University of California Press, Berkeley, CA.
- Tversky, A. and Kahneman, D. (1974) Judgment under uncertainty: heuristics and biases. *Science*, 185: 1124–1131.
- Waguespack, N. M. (2002) Caribou sharing and storage: refitting the Palangana site. *Journal of Anthropological Archaeology*, 21: 396–417.
- Wang, X. T. (1996) Domain-specific rationality in human choices: violations of utility axioms and social contexts. *Cognition*, 60: 31–63.
- Winterhalder, B. (1990) Open field, common pot: harvest variability and risk avoidance in agricultural and foraging societies. In E. A. Cashdan (ed.) *Risk and Uncertainty in Tribal and Peasant Economies*, pp. 67–87. Westview Press, Boulder, CO.
- Winterhalder, B. and Leslie, P. (2002) Risk-sensitive fertility: the variance compensation hypothesis. *Evolution and Human Behavior*, 23: 59–82.
- Winterhalder, B. and Smith, E. A. (2000) Analyzing adaptive strategies: human behavioral ecology at twenty-five. *Evolutionary Anthropology*, 9: 51–72.
- Winterhalder, B., Lu, F. and Tucker, B. (1999) Risk-sensitive adaptive tactics: models and evidence from subsistence studies in biology and anthropology. *Journal of Archaeological Research*, 7: 301–348.

