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Perceptions of Risk Perception

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Biological Selection of Risk Preferences

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Biological Selection of Risk Preferences

De gustibus est disputandum!

1. Instrumental Preferences

Economic theory tends to regard people's preferences as given. Indeed methodological individualism is directly based on the idea that individual preferences are the measure of all things. For economists there are no good or bad preferences. Desires and needs are the way they are, and no one is entitled to question them, let alone, presume to pronounce value judgements on them. The view of *homo oeconomicus* as an actor, who makes wise decisions in the light of his own individually held goals and who, at worst, can be tricked into collectively irrational behavior by systematic errors in the social rules of the game, is adhered to with dogmatic obstinacy.

Declaring individual preferences taboo is indispensable for economic policy advice. Failure to observe this taboo would open the door to the whims of advisers and politicians. The taboo enables economic policy advice to concentrate on improving the economic system and the way it is run. However well grounded this methodological postulate may be in normative theory, the fact that so little thought has been devoted in the past to substantiating and explaining preferences is a serious drawback for positive theory.[1]

In this article we disregard the economists' taboo because we want to explain some observable aspects of people's risk preferences and to derive the properties of these preferences from their underlying causes. We find these underlying causes in the fundamental preference for genetic survival, towards which all life on this planet has been directed in the course of biological evolution. Genetically coded preferences that were contrary to this fundamental preference could not become established – an individual with such contrary preferences could not pass on his genes to his descendants. Only "good" or "useful" preferences are observable – however inconceivable this may sound from the point of view of economic preference theory.

Although theories claiming that preferences arise in the process of biological evolution are not exactly popular among economists, the development of socio-biology (cf. e.g. Hamilton 1964; Trivers 1971; Wilson 1975; Smith 1964; Dawkins 1976) has brought about a process of rethinking even in our discipline. The work of Hirshleifer (1977, 1982), in particular, has built important bridges between the disciplines.[2]

Examples of the kind of preference control we are considering that are well known to biologists include such basic human needs as hunger and thirst. Certainly the satisfaction of these needs was intended to ensure the survival of man as a gene carrier and not to generate introspective sensations of happiness. This point becomes even clearer in the case of sexuality. The fact that man is governed by a strong sexual drive is obviously connected with the

fact that this drive is the result of a long process of genetic selection lasting millions of years whose only goal is to ensure the survival of the gene pool. It is evident that the genes responsible for our intelligence would not have survived if they had not allied themselves with the sexual genes. These in turn have left a deep impression on the course of our lives, our desires and our wants.

Hunger, thirst and sexuality are obviously instrumental preferences. They are expedient and useful because, without our being necessarily aware of it, they cause us to adopt modes of behavior which satisfy the underlying, basic preference for the survival of our gene pool.

That these preferences today, in an environment that is changing dramatically, are sometimes not expedient at all, is another story. Drunkenness, obesity and prostitution are the decadent results of preferences which once, at the time of our origin, had useful functions but which today occasionally lead us astray. The positive explanatory force of the genetic biological approach is in no way weakened, however, by the normative meaninglessness of some fundamental human preferences in our modern world.

2. The Evolution of Risk Preferences

Genetic causes can also be drawn upon to explain human risk preferences. Decision making in situations where uncertainty meant that economic choices resulted in probability distributions with a variety of outcomes rather than determinate solutions were the rule in human hunting and gathering societies and even among our animal ancestors. Somehow or other, decisions had to be made despite uncertainty, and the survival of the gene pool depended on the quality of the decision rule, or "preference", selected. Good preferences resulted in plenty of food and enabled the gene pool to survive. Poor ones ended in starvation and extinction.[3]

Economic theory is full of rules about how decisions are made in the face of uncertainty. These rules have been postulated in a more or less ad hoc way by various theoreticans and include Wald's (1945) minimax rule, Niehans' minimax regret rule (1948) and that of Savage (1951), Shackel's (1952, pp. 9-31) focus gain and loss rule, Lange's (1943) mode-span criterion, the Krelle-Schneider criterion of equivalent gains and losses (Krelle 1957,Schneider 1964), the $\mu - \sigma$ criterion, was first used by Fischer (1906, pp. 406 ff.), Machina's (1982) non-expected utility, the expected utility criterion of Bernoulli (1738) and von Neumann and Morgenstern (1947) and many others.

Nature too, has, in the course of millions of years, and in innumerable series of experiments, tried out a wide variety of decision rules, and what has proved itself over the ages consciously or unconsciously determines our behavior today. We cannot, of course, know whether what has proved itself up to now is also the best possible decision rule, for evolution has taken place in finite

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time and is still occurring today. Nevertheless, as a research strategy, it seems reasonable to pose the question of which decision rules used in situations of risk, and which risk preferences, are determined by a perfect, ideal-type selection process. The answer to this question seems promising for the development of important hypotheses about the form human risk preferences take.

In our study we concentrate on the conditions that prevailed during most of the time there has been life on our planet. These were the conditions of the primitive, prehistoric hunter/gatherer societies in which our human ancestors and their animal forbears lived. In these conditions the Malthusian laws of population operated without restriction.

There has of course been cultural as well as genetic evolution of preferences, and we concentrate on the latter here simply for the sake of brevity. The application of our conclusions to cultural evolution, in which meme pools - as Dawkins terms them - are selected instead of gene pools is relatively straightforward but will not be attempted here.[4]

A key concept in our discussion of risk preferences is "risk aversion". Our ancestors had to choose between probability distributions of incomes in kind, in the form of food caught or gathered - a flow of nourishment in any case. Let us define risk aversion as the unwillingness to accept the variance of the distribution around a given mean or, to express the same thing in a different way, the readiness to accept an increase in the variance of a probability distribution only if it is "rewarded" with an increase in the mean (or expected) value. Correspondingly, "risk neutrality" is a preference characteristic marked by indifference to an increase in variance for a given mean. Risk aversion is the preference characteristic that explains the existence of the insurance industry. On average, a consumer has to pay charges that exceed the expected value of damages that will be settled by his insurer. The only reason why a customer agrees to a contract that lowers his expected value of disposable income is that he is compensated by a reduction in the variance of his income distribution. But clearly, this reduction in the variance is only an appropriate compensation for a risk averter. All the decision criteria used in situations of risk cited above can model this aversion, and this preference characteristic is normally assumed in the economic literature.

Biological literature, like that of economics is full of studies of the risk preferences of living creatures. In general, the risk aversion hypothesis seems to possess great explanatory force when it comes to assessing the adaptive quality of certain behavioral modes or features of animals and plants from the aspect of uncertainty. Thus the risk aversion assumption has been used to describe the search for food by mammals and birds (Battalio, Kagel, McDonald 1985, Caraco 1981), to explain sexuality (Real

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1980), or even to derive the Bergmann rule according to which the members of a species tend to be larger the further north of the equator they live (Boyce 1979). The literature on these subjects is highly diverse, but there can be no doubt that it has provided the risk aversion hypothesis with a solid empirical foundation.[5]

As the examples show, however, biologists do not see the problem of risk preferences primarily from the aspect of individuals deciding between two alternative actions, each with a different probability distribution of results. In fact they generally make no special distinction between the explanation of behavioral patterns and that of phenotypic characteristics, which are not at all amenable to change by the individual. Moreover, risk aversion (e.g. in the form of concave fitness or utility functions with negative evaluation of variance) is normally only postulated or substantiated heuristically, as economists also traditionally tend to do. Attempts to explain risk aversion itself in terms of the genetic selection process are extremely rare even in biology. The exceptions will be dealt with in Section 5.

The evolution of risk preferences is closely associated with the operation of the law of large numbers. As risk decisions are translated through constant repetition into "practically" safe time paths of the gene population, their selective quality may be measured by the size of the population which emerges after a long time span. To put it more precisely, one strategy shows a greater *selective quality* than another if its long-term pursuit almost certainly generates the larger population. Some biologists would equate "selective quality" with "fitness", but this term is not used uniformly. "Fitness" is generally used to refer only to the relationship between the immediate progeny of a generation and the size of that generation itself. If, as is assumed for the purposes of the present article, this relationship is a stochastic variable, then the selective quality must be governed by a significant correlation, which has yet to be discovered.

It should be noted that the definition of selective quality does not imply that the preference with the lower selective quality will disappear from the population in the long run. It could, of course, be argued that the larger population is more powerful and will drive out and/or destroy the smaller one through war or by depriving it of its food supplies. However a really precise selection of preferences is not present simply because one produces a larger population than the other, without it being clear how much larger this population is.

A more precise selection criterion is that of *selective dominance*. Let us take a selectively dominant preference as one which induces such a large growth of population that, by comparison, the relative sizes of populations resulting from other preferences will be converge to zero with a probability that approximates cer-

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tainty. A preference that is selectively dominant vis-à-vis others will therefore assert itself without physically or economically supplanting the weaker population. The inferior preferences may also lead to growing populations, but the relevant growth rates will still be lower, in a sense still to be precisely established, than those of the best preference, and the difference between the two growth rates will be translated in the course of time into a widening relative distance between the resulting populations.

3. A Selection Model

The growth of a population is determined by the number of children reaching the age of reproduction. If we take Q_t as the growth factor of generation t, we can define this factor as the quotient of the number of children K_t and the size of the parent generation G_t:

$$Q_t = K_t/G_t.$$

Q_t is what determinate genetic models refer to as "fitness". If the size of the first generation considered, G_1, is taken as given, the size of the generation T is clearly

$$G_T = G_1 \cdot Q_1 \cdot Q_2 \ldots \cdot Q_{T-1}.$$

The number of children in each generation depends on the food supply available to the populations and on the natural fertility, which defines an upper limit for Q_1. Under pure Malthusian conditions, natural fertility is not a binding restriction. Instead, the number of children has a simple proportional relationship to the food supply available to the children. If this food supply is doubled, the number of children who grow up to form the next generation of parents will also double. Without limiting the general applicability, we can select the units in which food production is measured such that the quantity of food available to the children is numerically equal to the number of children K_t. The whole food production of a generational period, i.e. the economic income, is given by

$$Y_t = \lambda G_t + K_t = G_t(\lambda + Q_t)$$

in which λ is a constant multiplication factor ($\lambda > 1$) which measures the parents' greater consumption relative to that of the children.

In each generation, the growth factor Q_t is a random variable characterized by a very specific, objective probability distribution. If the size of the parent generation G_t is historically given, this distribution clearly determines the probability distributions both of the number of children K_t and of the income Y_t.

The distribution of Q_t is determined both by the random influences of nature and by the economic choices of the gene hosts. Each generation has a finite supply of alternative courses of action open to it, each of which generates a specific of probability distribution Q_t. It is assumed that depending on exogenous environmental influences, the quantity of available distributions of Q_t may be subject to certain changes from generation to generation. In particular, the best distribution, whatever it may be, may change over time.[6]

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Among the alternative courses of action available, there are some that involve low levels of risk and some that involve high levels. There are some that promise a high yield, and some from which a more modest yield may be expected. In concrete terms, these alternative courses of action may be, for instance, hunting methods, foraging patterns, migration decisions, seasonal hoarding, and so on. Let us assume that the concrete actions are selected in accordance with genetically established decision rules and preferences which are subject to a biological trial-and-error process. Because of accidents of genetic mutation, there may have been many different primeval populations which adopted different decision rules for themselves and their descendants. The question is, which of these primeval populations, and hence which decision rules, have prevailed in the evolutionary process.

4. The Selectively Dominant Decision Rule

In an attempt to answer the question of which decision rule has been selected, it is useful to recall the significance of the expected-value rule for gambling situations. Suppose a player can choose between two strategies with stochastic net gains X and X', the expected value of the first being greater than that of the second [$E(X) > E(X')$]. What strategy will he choose if he has the opportunity of repeating the game very frequently without altering his stake and if he wants to win the highest sum possible in the long term? The answer is obvious: naturally the strategy with the higher potential win in each individual game, i.e. X. Whatever the probability distributions of X and X' may be, this decision leads almost certainly to a greater win in the long run, assuming, of course, that the games in the period concerned show a sufficient degree of stochastic independence.

The "game" of evolution is structured somewhat differently, as it is not a game in which the stake is constant. The generational link as described earlier defines a game in which the stake is endogenously determined, a situation familiar from portfolio theory. The greater the random success of a generation, i.e. the greater the food production, the greater the number of children and the greater the generation in the next period in which, once again, a choice has to be made between alternative strategies with stochastic results. In brief, unlike the gambler, nature links the generational risks not according to an additive, but according to a multiplicative function.

Because of this multiplicative link, a logarithmic expected-value rule and not the simple expected-value rule is useful here. This can be seen immediately by logarithmizing the second equation.

$$\ln G_T = \ln G_1 + \ln Q_1 + \ln Q_2 + \ldots \ln Q_{T-1}$$

The logarithmic form turns the multiplicative link back into an additive one and implies that the player's expected value rule can be applied in a perfectly analogous way to the logarithms of the stochastic growth factors $Q_1, Q_2 \ldots Q_{T-1}$

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Let us assume for the sake of simplicity that the probability distributions of the growth factors between the generations are not correlated. It then becomes clear that the rule that always selects the highest expected value of the logarithm of Q, $E(\ln Q)$ exhibits the highest possible selective quality in the sense of the above definition. The selection of actions which maximize $E(\ln Q)$ is virtually certain to yield the highest value of the logarithm of the population in the long run and thus, logically, the highest possible value of the population itself. The size of the initial population is just as unimportant as is the gambler's initial stake in terms of the final winnings to be gained from the alternative decision rules. The largest population in the long run is the one that always maximizes the logarithm of Q, and this applies even if that population was initially the smallest.[7]

The result can and must be made considerably more precise in the sense of the selective dominance defined earlier if it is to be demonstrated that the logarithmic expected utility rule is actually selected in any meaningful way. Such enhanced precision is indeed possible. As formally proved in a separate article (Sinn 1993), with the aid of the Chebyshev inequality, the selection of the strategy which maximizes $E(\ln Q)$ is not only virtually certain to yield a higher population than any other strategy, it also leads to a population size compared with which the size of population resulting from any other strategy diminishes towards zero. More precisely, the quotient of the two populations tends towards values which with a probability approximating certainty remain below a threshold which in the course of time diminishes towards zero. If, in the early stages of human evolution, there were very many populations each following different strategies, then the representatives of strategies other than that of maximizing $E(\ln Q)$ must now account for only a negligible fraction of the total population, and practically all human beings have within them genetic preference patterns which are in keeping with the maximizing of the expected logarithm of the growth factor Q. This decision rule or preference structure is indeed selectively dominant over all others.

5. Related Approaches in Biology

The stochastic logarithm principle is of such fundamental importance to the evolution of the species that it would be strange if it were not used in evolutionary biology. Though, as already explained, deterministic approaches continue to dominate this field, and the risk-theory approaches also work mainly with decision rules that are either postulated ad hoc or based on experimental results, the papers by Cohen (1966, 1967), Tuljapurkar and Orzack (1980) and Tuljapurkar (1982) represent notable exceptions.[8] Logarithmic selection criteria have a more or less key function in these works.

Cohen's articles are particularly interesting because they are

also concerned with maximizing the expected logarithm of a growth factor, and because they reveal analytical weaknesses whose discovery is important to an understanding of the problem. Cohen deals with the "decision problem" of trees that reproduce via seeds and are able to delay the germination process. He demonstrates that delaying germination can be interpreted as a beneficial risk diversification for part of the seed population as it reduces the risk of encountering unfavourable weather conditions. Cohen calculates the optimum germination strategy using the following hypotheses:
- that maximizing the expected logarithm of the growth factor yields the highest possible expected value for the seed population in the long run; and
- that maximizing this expected value is the goal or result of the biological evolution process.[9]

Although the decision rule employed by Cohen is correct, the reasoning he uses to substantiate it is incorrect in two respects. Firstly, it is not true that maximizing the expected logarithm of Q yields the highest possible expected value for the seed population in the long run. Because of the stochastic independence of the growth factors which Cohen himself also assumes, the expected value of the population at time T is

$$E(G_T) = G_1 \cdot E(Q_1) \cdot E(Q_2) \cdot \ldots \cdot E(Q_{T-1}),$$

and is obviously maximized precisely when the period-specific simple expected values of the growth factors are maximized.

Secondly, because of the extreme asymmetry of the population distribution resulting from the multiplicative linking of the growth factors, maximizing the expected value of G_T has no selective quality at all. Examples can be constructed in which the expected value of the population size tends towards infinity over time, but the species as such is almost certainly doomed to extinction.

This flaw in argumentation has since been recognized in the biology literature, with help from Cohen himself (Lewontin and Cohen 1969, Tuljapurkar and Orzack 1980), but it has not yet been really corrected.[10] The distribution parameters of the population emerging in the long term have been specified and highly complex multi-variable growth models constructed, in which logarithmic laws play a role.[11] But the selective dominance which, despite all the flaws in its reasoning, Cohen's stochastic logarithm rule exhibits, has to the best of our knowledge not yet been proved (but cf. Sinn 1993).[12]

Quite apart from this fact, biologists have anyway not paid any particular attention to the problem of the selection of decision rules in the narrower sense. They have generally been concerned with genetically conditioned characteristics of the phenotype and with how these characteristics influence stochastic reproduction patterns. The selection of stimulus-response patterns is also stud-

ied. But the question of which systematic decision rules are applied by decision-makers endowed with reason has never to our knowledge been posed by biologists.

An important paper devoted to this question and, significantly, written by an economist is that of McAfee (1984). McAfee postulates that human evolution has selected decision rules that maximize the life expectancy of the phenotype, as this would implicitly maximize the number of children. He then goes on to assume that the biological actors in his model are exposed to repeated stochastic decision-making situations in which they gather food that can either be eaten immediately or stored for later consumption. On the basis of these assumptions he succeeds in showing that the optimal decision rule is characterized by an expected utility approach with (declining, absolute) risk aversion.[13]

McAfee's approach is related to that of the present work with regard to the question posed, but not with regard to the model structure. He makes no provision for intergenerational links and does not consider selective dominance in a formal way. The maximization of the expected number of children is only postulated and is not, in fact, as has been shown, compatible with the logarithm law. All the same, this approach could provide a useful contribution to the further development of our model in which the generation period is split up into sub-periods with separate decision problems.

6. Economic Interpretation of the Result

To understand what the stochastic logarithm rule means from an economics point of view, we have to turn again to the definitional equations $Q = K/G$ and $Y = \lambda G + K$. Firstly it is important that – as the parent population G in the decision-making situation is constant – maximizing $E(\ln Q)$ is the same as maximizing $E(\ln K)$. Then the fact that the food consumption of the parent generation, G, is part of the total production, Y, must be taken into account. It follows from both these points that the selectively dominant decision strategy can be described by an expected utility formula in which the utility function is a logarithmic one with the amount by which the total consumption exceeds that of the parents as its argument. The following graph shows the resultant utility function. The result has a number of non-trivial implications for decisions in situations of uncertainty.

First, it should be noted that evolution has produced the expected utility criterion. In view of the dozens of other decision rules which have been discussed in the literature in recent years – in particular in the non-expected utility literature – this is a remarkable outcome. Evolution-generated preferences satisfy all the Neumann-Morgenstern rationality axioms needed to derive the expected utility rule, including the independence axiom much disparaged in recent literature.[14]

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The Selectively Dominant Expected Utility Function
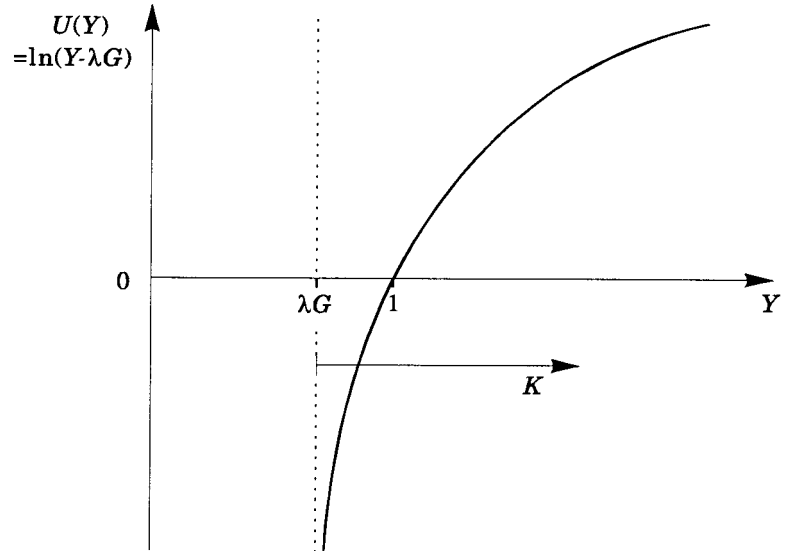
Second, risk aversion is a selectively dominant preference characteristic. This is shown by the fact that the utility function $U(Y)$ is concave. Uniform variances around a given mean are disadvantageous in evolutionary terms. This can be readily understood if we compare two populations, one of which (thanks to a proven production strategy) produces four children per family in each generation, and the other six and two in alternate generations. The mean number of children per family is the same in both populations, but the first will certainly grow faster. To compensate for the drop in the number of children from four to two in one generation, an increase in the next of four to eight is necessary, and not just of four to six. The expected value has to increase in line with the variance if an evolutionary disadvantage is to be avoided. This is precisely what is meant by risk aversion.

Third, the utility function is logarithmic, if only in relation to consumption by the children. The logarithmic utility function has a long tradition in risk theory. Daniel Bernoulli (1738) found it plausible when writing his famous essay on the expected utility rule, and the function crops up frequently in psychophysical literature. For instance the Weber/Fechner experiments measuring sensations in response to a variety of stimuli were strongly indicative of logarithmic sensation functions, as they proved that thresholds of sensation can be defined only in relation to the underlying stimulus (Weber 1834, Fechner 1860a and b). Neurological measurements also show that the electric pulse frequency in nerve paths is a logarithmic function of the strength of the stimulus (Fröhlich 1921, Adrian 1928). And finally, the famous cross-

modality-matching experiments which Stevens (1959) conducted at Harvard can be interpreted as confirming logarithmic basic preferences (cf. Sinn 1980, pp. 130 et seq.), and the biological experiments performed on pigeons by Caraco et al. (1980) also point to a logarithmic utility function.[15] It is surely no coincidence that the logarithmic function, on the one hand, plays such a prominent role in various disciplines concerned with the investigation of human preferences, and, on the other hand, is found in our study to be the result of a dominant evolution strategy.

7. Conclusions

Our essay is intended to give food for thought by combining interdisciplinary approaches and to encourage further research, at least in our own discipline, economics. The model from which the logarithm rule is derived is the simplest one we can imagine for dealing with the present topic. Certainly there are many useful extensions and modifications to this model that would merit further investigation, despite the doubtless progressive rise in formal effort involved.

One such modification would be to introduce a more differentiated time structure with periods shorter than one generation. The logarithm rule for generational risks would then have to be used to derive utility functions for sub-generational risks, and the question is whether these utility functions will again be logarithmic or whether they will exhibit other characteristics.

Another possible modification is to take into account competition for resources between different populations. The evolution pattern we have studied up to now postulates that – starting from the original population in which the decision rule is initially established by genetic mutation – a very large number of subsequent generations can evolve without the resources available to the individual being noticeably diminished by this expansion. This assumption appeared to us to be admissible in view of the limited numbers of primitive human populations reported by biologists and historians. Human evolution might indeed have taken place in the absence of competition for resources. Nevertheless, the Malthusian balance has certainly been attained within historical times, and it has only recently, with the industrial revolution, been (temporarily) suspended again. Whether, and to what extent, such scarcity and rivalry effects played a role in the evolution of risk preference remains to be examined.

Interdisciplinary approaches of the kind presented here have their drawbacks. Before the researcher can reap the fruits of his labor, he must face the daunting task of familiarizing himself with a new terminology and an apparently infinite body of literature. And even after doing all the work, he frequently still finds himself falling between two stools. The danger that this could apply in our present case, too, is one of which we are well aware. Nevertheless, we consider the path we have taken to hold the promise

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of success. Stigler and Becker (1977. p. 89), two winners of the Nobel Prize for Economics, once complained that, of all the branches of economic science, it is precisely the field of risk theory that is full of ad hoc assumptions. If one wishes to combat such tendencies and look for additional explanation patterns, taking a look over the thick wall surrounding one's own field of specialization can do no harm. In the present case, we have shown that risk behavior, which in the past could be plausibly explained only on the basis of axiomatic assumptions, can also be generated from a perfectly simple evolution model.

Notes:

1 Note however Simon's theory of bounded rationality (1955), Lancaster's consumer theory (1966), Stigler and Becker's theory of addiction and habitual behavior (1977) and various theories on the influence of advertising (e.g. Borden 1942, Kaldor 1950, Telser 1962, Taylor and Weiserbs 1972). A very early exception may be seen in Veblen (1899) who investigates the influence of status and neighbourhood effects on consumer habits. Frank (1987) argues that emotional characteristics such as guilt and vindictiveness can be rationally explained.

2 Cf. also his articles in the "Papers & Proceedings" volume of the American Economic Review (1978) and in the collected volume edited by Dupré (1987).

3 The terms "preference" and "decision rule" are used synonymously in this article. In the literature of economics, the term "decision rule" is more general than "preference", as decision rules allow for individual differences. This article treats the selection of a decision rule in a risk situation as including a well-defined preference structure.

4 On the relationship between biological and social evolution cf. e.g. Boyd and Richerson (1980) or Witt (1985, 1987) and the references given there.

5 An excellent overview is given by Stephens and Krebs (1986, ch. 6).

6 It is assumed that in each period there is at least one distribution which definitely avoids the extinction of the species: $Q > Q_{min} > 0$. A selection model with fatal probabilities is to be found in Farrell (1970).

7 A similar result was demonstrated by Latané (1959) for a stochastic intertemporal portfolio problem, in which an investor always reinvests all earnings. Latané's proof cannot, however, be interpreted in the sense of the characteristic of selective dominance discussed in the next paragraph. To our knowledge it has not yet been proved in the literature that the logarithmic expected utility maximizer is always selected. Cf. also Section 5.

8 Cf. also Haldane and Jayakar (1963) and Karlin and Lieberman (1974).

9 Cf. especially Cohen (1967, p. 10): "For any organism, long-term natural selection selects those traits which maximize the long-term expectation of its population size."

10 Cohen's approach nevertheless enjoys a certain popularity, because it yields plausible implications with regard to the genetic evolution pro-

cess. To select $E(\ln Q)$ as a fitness criterion is the same as selecting the geometric mean of the Q distribution, exp $E(\ln Q)$. Real (1980) argues that the geometric mean is a good fitness criterion, because the value of this mean, in contrast to the arithmetic mean $E(Q)$, is driven to zero by the potential loss of just one generation. This argument is correct, but does not only support the logarithmic utility function. In addition to the geometric mean, there are many other mathematical means (e.g. the so-called certainty equivalents in the class of utility functions with a relative risk aversion of more than one; cf. Sinn 1980) that assume the value zero if attributes with the value zero have a strictly positive probability.

11 Cf. especially Tuljapurkar (1982).

12 Tuljapurkar and Orzack (1980) assert that the survival quality of a decision rule depends on the mean and the variance of the logarithm Q, because both determine, given frequent repetition, the mean and the variance of the logarithm of the long-term population distribution G_T. Although the latter part of this statement is true, the first part is false. As is shown in Sinn (1993), it is not a matter of the variance. Selective dominance requires the maximizing of $E(\ln Q)$ *without* regard to the variance of $\ln Q$.

13 The qualification must be made here, however, that all attributes of the probability distribution must be positive. If the distributions scatter into the negative range, so that death cannot be ruled out, a preference for risk may under certain circumstances be necessary in order to maximize the expected life span. Cf. also Rubin and Paul (1979) and Sinn (1982).

14 Cf. the exhaustive account in Machina (1987).

15 Specifically, Caraco et al. estimate a utility function $U(s) = \ln(1 + s)$, in which s is the number of feed grains per time unit.

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