Adaptation and the Option Value of Uncertain Environmental Resources

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Working Paper 90-WP 58
May 1990

ABSTRACT

Just as ecology has benefited from the economic theory of optimization, economics can benefit from the ecological theory of adaptation. We examine the impact of short-term, nongenetic adaptive self-protection on the values individuals attach to uncertain prospective environmental resources. We demonstrate that collective provision of reductions in supply uncertainty does not necessitate a positive option value, given that uncertainty is influenced by the individual's ability to adapt through self-protection. We conclude that the total value of reducing the supply uncertainty of a natural resource is reflected in both the individual's option price payments for collective provision and in his willingness-to-pay for adaptation through self-protection. By ignoring adaptive self-protection, traditional benefit-cost analysis has systematically underestimated the total value of environmental resources that are characterized by uncertain supplies.

INTRODUCTION

The relationship between private self-protection opportunities and the value of public provision of resources in uncertain supply has rarely been explored in environmental economics. The most significant example of this inattention is arguably the economic literature on option value. Weisbrod (1964) expanded the scope of benefit-cost analysis by examining the relevance that uncertainty has for measures of economic well-being. He argued that a complete analysis must account for option value, the difference between the maximum a risk averse individual would be willing to pay to retain the option of future availability of an environmental resource (option price) and expected consumer surplus. Expected consumer surplus is the difference between what a consumer is willing to pay for a good or a state of the world and what he expects he will have to pay. Option value is essentially a risk premium attached to provision of future access to a desired resource. A risk averse individual may be willing to pay an amount (the option value) above his expected consumer surplus for the prospect of seeing, say, a wild species like the grizzly bear or humpback whale, or of visiting a natural ecosystem like the Everglades. By acknowledging the plausible value of claims to future access, Weisbrod (1964) identified a nonuser value that was a previously ignored facet of preferences for environmental resources.[1/] Most of the abundant environmental economics literature on option value has sought to establish whether it is negative, positive, or zero, which would respectively imply that the traditional measures of the economic value of collective efforts at environmental protection are positively, negatively, or not at all biased, e.g., Schmalensee (1972), Bishop et al. (1982), Brookshire et al. (1983), and Plummer and Hartman (1986). It is generally agreed that the sign *of option value is indeterminant for a risk averse consumer. According to this literature, a major exception is that option value will be positive when demand is certain and supply uncertainty is eliminated.*

The option value literature, however, has invariably ignored adaptation, a key behavioral trait long recognized by ecologists. At least since Darwin (1859), ecologists have tried to understand how plant and animal behavior adapts to its environment. Adaptation can be genetic (long-run) or it can be based on learning and experience (short-run), though the ability to learn will have some genetic basis [Barnard (1983)]. For example, predation constitutes one of the most severe everyday pressures that most plants and animals face. Both expend considerable energy resources in acts that increase the likelihood of survival [Hannon (1979; Caraco and Lima (1985)]. That is, plants and animals adapt by engaging in self-protection, a set of acts that reduce the likelihood of an undesirable event or that reduce its severity. Plants employ a wide variety of self-protection devices, including genetic variations, premature abscission, resource sinks, inhibitor proteins, and immune bodies such as granules, fibers, membrane fragments, and viruses [Morgan and Hamilton (1980); Dirzo (1984)]. Similarly, animals self-protect by withdrawing to cover, distracting and diverting, or feigning death, as well as by chemical defenses, startled responses, and warning signals [Edmunds (1974); Harvey and Greenwood (1978); Krebs and Davies (1981)].

The theory of adaptation is transferable to human behavior with respect to environmental resources in uncertain supply. Although both short-run [e.g., Viscusi (1979)] and long-run [e.g., Alchian (1950)] adaptations are well represented in most areas of economics, the option value literature has consistently assumed that the individual treats the probability of resource *supply as exogenous; i.e., his short-run ability to adapt by privately influencing an uncertain outcome is presumed to be predetermined or nonexistent. Exogeneity is by no means an obvious assumption and it is not difficult to find perfectly reasonable, everyday human counter-examples. When a potable water supply is uncertain, individuals often choose to adapt by providing self-protection in the form of bottled water, water filters, or both. Other examples of short-run adaptation through self-protection include purchases of air purifiers and conditioners to increase the likelihood of acceptable air quality, and the construction of air vents and isolation panels to reduce the likelihood of radon contamination [Smith and Johnson (1988)]. These and similar examples conform to what Mohring and Boyd (1971) term impure public goods which have benefits that are partially rivalrous or excludable.*

This paper makes an important and neglected point. Humans adapt. This influences their valuations of uncertain environmental resources. Given short-run adaptation (self-protection), we demonstrate that collective efforts to eliminate supply uncertainty need not have a positive option value. An individual who can adapt via self-protection will have a wider variety of choices before and after the resolution of uncertainty. Self-protection therefore reduces his option price for collective provision and thus makes it possible that he will attach a trivial or a negative option value to collective provision. Therefore, any concept of ex ante valuation must include both voluntary self-protection and collective option price payments if the actual economic benefits of a nonmarketed environmental resource are not to be underestimated. Conrad (1986) has made a similar point. However, he does not directly address the impact of self-protection upon option value, nor does he allow the individual to influence collective provision through an option price payment. Gallagher and Smith (1985) and Smith (1985) refer to changes in probabilities in combination with individual adjustment opportunities, but they do not treat self-induced changes in the probabilities of alternative states as an adjustment opportunity.

SELF-PROTECTION AND OPTION VALUE

Most individuals perceive that they can exercise substantial control over their lives, including the ability to do something about many of the uncertainties which they face [Perlmuter and Monty (1979); Stallen and Tomas (1984)]. One form of control is the use of market insurance to redistribute income and wealth toward undesirable outcomes. Given actuarially fair insurance and decreasing marginal utility of income, insurance would be acquired in an amount such that the individual is indifferent as to which state of nature ultimately occurs. No matter what the realized state of nature, the ex post compensation which the insurance supplies maintains the ex ante utility level. Questions of ex ante versus ex post valuation therefore become irrelevant.

With incomplete markets, consumers are not fully insured, and ex ante willingness to pay thus becomes relevant. Since complete markets rarely if ever exist for environmental resources, ex ante measures are especially appropriate for these goods. It is these measures that explain the individual's choices. If the individual is provided the opportunity to make option price payments for environmental resources, the efficiency with which he can allocate his wealth among states of nature is enhanced [Cook and Graham (1977)]. An ex ante value measure then refers to the minimum expenditures the consumer must make in order to maintain his expected utility when the *probability of a future state of nature changes. However, nowhere does the option value literature explicitly recognize that individuals can adapt by adopting what Ehrlich and Becker (1972) term acts of self-protection, thereby influencing the probability that a state will occur.*

For simplicity, consider an individual under a given liability regime who is uncertain about which of two mutually exclusive and jointly exhaustive states of nature will occur. This individual, whose preferences and income are independent of these states, makes an atemporal choice in a von Neumann-Morgenstern framework where his expected utility is an increasing, strictly concave, and differentiable function of his certain income, Y, and an environmental resource, Q. Thus, in the absence of self-protection or an option payment, expected utility, EU, is

$$EU = \pi_0 U(Y,Q_1) + (1-\pi_0)U(Y,Q_2), \tag{1}$$

where E is an expectations operator, $\pi_0 (0 \leq \pi_0 \leq 1)$ *is the individual's initial degree of belief that level* Q_1 *of the environmental resource will occur,* $1-\pi_0$ *is his degree of belief in the occurrence of* Q_2*, and* $U(Y,Q_1) > U(Y,Q_2)$*. Given concavity of the utility function, option price, OP, is then that ex ante sure payment which holds expected utility constant when the probability of* Q_1 *being realized has changed; that is, following Freeman (1985):*

$$\pi U(Y-OP,Q_1) + (1-\pi)U(Y-OP,Q_2) = \pi_0 U(Y,Q_1) + (1-\pi_0)U(Y,Q_2), \tag{2}$$

where $\pi > \pi_0$*. In accordance with the traditional collective option value literature, the payment of OP "secures" access to the benefits of the predetermined probability,* π*, of the desirable state,* Q_1 *[Smith (1985), p. 304)]. Typically, the desirable state is represented as a pure public good* which is independent of any individual's actions, and which the relevant collective agency finances by sure payments from everyone.

More realistically, one might view the individual as one of a collection of potential beneficiaries, any one of whom by increasing the size of a voluntary option price payment to a collective agency can enhance the probability of Q_1. Similarly, the individual might improve his probability of privately commanding Q_1 by adopting assorted self-protection strategies. The collective and private alternatives are unlikely to be perfect ex ante substitutes for him, if only because of differences in his ability to influence the probability of the desirable state. For example, contributions to the construction of a public water treatment plant might make it more likely that everyone will get "safe" drinking water. Alternatively, an individual could accomplish the same end for himself alone by purchasing a water filter for his home.

The current theoretical and empirical option value literature has not explicitly recognized the valuation implications of private substitution possibilities. Government action is held to be the only possible way to finance increased probability of provision [see Greenley et al. (1981), Brookshire et al. (1983), Walsh et al. (1984), and Smith and Desvousges (1987), for example]. No framework for incorporating self-protection is evident in these analyses.

When opportunities are available to adapt by making probability-influencing collective option price payments or to engage in self-protection, the left-hand-side of (2) can be rewritten as

$$EU = \pi(s,OP)U(Y-s-OP,Q_1) + [1-\pi(s,OP)]U(Y-s-OP,Q_2), \qquad (3)$$

where s is self-protection expenditures, and $\pi(\bullet)$ is differentiable and increasing in s and OP. The individual then selects $s \geq 0$ and $OP \geq 0$ to maximize (3). Both private self-protection and collective option price are ex ante payments that maintain expected utility. Defining $W = Y-OP-s$, the following first-order Kuhn-Tucker conditions result:

$$\frac{\partial EU}{\partial s} = \frac{\partial \pi}{\partial s}\,[U(W,Q_1)-U(W,Q_2)] - \pi(\bullet)\frac{\partial U(W,Q_1)}{\partial W} - (1-\pi(\bullet))\frac{\partial U(W,Q_2)}{\partial W} \leq 0,$$
$$s \geq 0, \qquad s[\frac{\partial EU}{\partial s}] = 0 \tag{4}$$

$$\frac{\partial EU}{\partial OP} = \frac{\partial \pi}{\partial OP}\,[U(W,Q_1)-U(W,Q_2)] - \pi(\bullet)\frac{\partial U(W,Q_1)}{\partial W} - (1-\pi(\bullet))\frac{\partial U(W,Q_2)}{\partial W} \leq 0,$$
$$OP \geq 0, \qquad OP[\frac{\partial EU}{\partial OP}] = 0 \tag{5}$$

The terms $(\partial\pi/\partial s)[\bullet]$ and $(\partial\pi/\partial OP)[\bullet]$ in (4) and (5) represent the expected marginal benefits of adaptation to be had increasing the probability of Q_1. The $\partial U/\partial W$ terms are the marginal costs of adaptive self-protection in terms of reduced income. If the expected marginal benefits of the probability change equal the marginal costs of s or OP, it follows that s and OP will be selected so that

$$\frac{\partial \pi}{\partial s} = \frac{\partial \pi}{\partial OP}. \tag{6}$$

In this case, an interior solution to the individual's utility maximization problem is implied: the individual makes a payment for the collectively supplied good and purchases some private self-protection as well, (s, OP) = (+, +). The relative amounts of collective option payments and private self-protection expenditures that he chooses will depend upon their relative marginal productivities in securing increases in π.

As noted by Barnard (1983), the manner in which a species adapts depends on effectiveness. If a particular protection activity is especially effective at reducing a natural selection pressure, then one should expect organisms to engage in this activity prior to using other defensive activities. Similarly, if self-protection is more effective than collective provision of the resource, then the individual will choose to self-protect. Thus if $\partial\pi/\partial s > \partial\pi/\partial OP$ for all feasible (s, OP) pairs, then a boundary solution would be obtained in which the optimal pair has the form (s, OP) = (+, 0). This implies that private self-protection expenditures are positive but that the option price payment for collective provision is zero. If the individual can always produce a given probability increase at less cost by adapting through self-protection than by making an option price payment, he will do so. Basically, by introducing adaptive self-protection in an option value discussion, one allows the individual to substitute between own and collective provision of a desirable state of nature. Because it expands the consumer's choice set and thereby improves his ability to allocate risk among states, an opportunity to self-protect reduces his demand for collective provision of the desirable state but increases his overall demand for that state. Since discrepancies in utilities are reduced among states, collective option prices, as is evident from expression (5), must fall. The value of altering the uncertainty is reflected in the individual's voluntary collective option payments and in his willingness to pay for self-protection. Consequently, any concept of option value which refers only to collective provision may result in underestimates of the actual ex ante value that individuals attach to the prospective provision of the environmental resource.

If the availability of self-protection can reduce option price, then it can also impact option value. Recall the definition of option value, OV:

$$OV = OP - E(CS). \qquad (7)$$

As in Cook and Graham (1977), E(CS), expected consumer surplus, is the consumer's ex ante benefit from having an entitlement to the desirable state, where we define compensating consumer surplus as $U(W - CS, Q_1) = U(W, Q_2)$ *such that* $E(CS) = (1-\pi)CS$. *Graham (1981, p. 72) demonstrates that the use of E(CS) to measure ex ante value is correct if and only if complete contingent claims markets exist. Marshall (1976) shows that such markets imply that risk must be exogenous. It follows that E(CS) does not vary with self-protection efforts.*

If adaptive self-protection is an efficient choice for the consumer, then, in accord with the argument surrounding (6), option price, as customarily defined, can be small or zero. A glance at (7) immediately reveals that a small or a zero option price causes a smaller or even a zero or a negative option value. It follows that large or even positive option values can exist only when the individual is an inefficient self-protector, or if he is uninformed about opportunities for self-protection. For example, large scale disasters such as the Chernobyl nuclear accident do not create much opportunity for efficient adaptation through self-protection. Iodine tablets can be ingested to reduce the probability of illness, but in general private actions prove too expensive and complicated to be economically feasible. A collective agency may prove a more efficient provider given scale economies. In addition, if the individual is uninformed about self-protection, he is more likely to demand collective provision. This demand would be reflected in a higher option price. In behavioral ecology terms, self-protection acts as the primary defense (e.g., crypsis) while collective action is a secondary defense (e.g., early warning) that is used as a back-up strategy [Barnard (1983)].

If efficient self-protection is available, a collective agency may find it more cost-effective to provide information about the properties of or ways to acquire the desired good than to provide the desired good itself. In the case of radon gas, information programs have yielded promising results [see Smith and Johnson (1988)]. Indeed, public alarms that cause individuals to self-protect have long been observed in ecological systems. Warning signals in mammal herds and alarm calls among flock-forming birds are common examples. Rhoades (1983) and Baldwin and Schultz (1983) found evidence of airborne pheromonal releases from damaged plants that alerted undamaged plants and caused the latter to protect themselves from herbivore attacks. [See Charnov and Krebs (1975) for an alternative view of the manipulative, self-interested role of alarm calls.]

The preceding results reenforce the findings of Freeman (1985) about ambiguities in the sign of supply-side option value when a residual uncertainty remains about the provision of the desirable state even after some collective act has been undertaken. However, Bishop (1982), Brookshire et al. (1983), and Freeman (1985), among others, have shown that, under conditions where adaptation is nonexistent, the sure provision of a collectively supplied desirable state of nature results in a strictly positive option value for a risk averse individual. Even this single case of determinacy fails to hold when adaptation through self-protection is available. For example, in the perfectly plausible case where $E(CS) \geq s > OP$, then (7) becomes

$$OV = OP - E(CS) < 0. \tag{8}$$

In the extreme case where the individual would prefer not to have any collective provision whatsoever, (7) is

$$OV = -E(CS) < 0. \quad (9)$$

More generally, the individual's ability to adapt to uncertainty through self-protection implies that collectively supplied protection may be redundant, thereby providing no additional welfare benefits.

SUMMARY AND CONCLUSIONS

Although the ability to adapt and act independently on one's own behalf is a prominent feature of many, perhaps most, environmental and health and safety issues, its relevance to the determination of option value has not heretofore been explored. Our result indicates that just as ecology has profited from the insights of the economic theory of optimization, the option value literature can learn from the ecological ideas about adaptive self-protection. The recognition of adaptability simply expands the number of circumstances in which the sign of option value, as traditionally defined, can be shown to be ambiguous. If various reasonable interdependencies (e.g., technical complementarities, price interactions) were introduced along with adaptation into the analysis, the list of cases with ambiguous signs would undoubtedly expand. Even the case of the sure provision of the desirable state, which the literature has predicted to possess a positive option value for collective provision, is easily shown to be unsignable when adaptive self-protection is available. A complete measure of ex ante value, therefore, must include both self-protection and collective option price expenditures. Otherwise, traditional benefit-cost analysis will systematically underestimate the total value of environmental resources characterized by uncertain supply.

Footnotes

1/ Environmental economists have also developed other current nonuser values for environmental resources. Existence value is the value an individual attaches to the mere existence of an environmental resource even though he will never use or visit the resource. Bequest value is the desire of current generations to ensure future generations have access to the resources [see Walsh et al. (1984)]. Of course, the environment has many other values such as scientific or religious, but economists have not yet found a systematic way to incorporate them into the benefit-cost framework.

References

Alchian, A., 1950. Uncertainty, evolution and economic theory. J. of Political Economy, 58: 211-222.

Baldwin, I. and Schultz, J., 1983. Rapid changes in tree leaf chemistry induced by damages: Evidence for communication between plants. Science, 221: 277-279.

Barnard, C.J., 1983. Animal Behavior. Ecology and Evolution, New York: John Wiley and Sons.

Bishop, R., 1982. Option value: An exposition and extension. Land Economics , 58: 1-15.

Brookshire, D.S., Eubanks, L.S. and Randall A., 1983. Estimating option prices and existence values of wildlife resources. Land Economics, 59: 1-15.

Caraco, T. and Lima, S.L., 1985. Survivorship, energy budgets, and foraging risk, in M. Commons, S.J. Shettleworth, and J. Nevin (eds.) Quantitative Analysis of Behavior. Cambridge, MA: Ballinger Publishing Co., 132-159.

Charnov, E. and Krebs, J., 1975. The evolution of alarm calls: Altruism or manipulation. American Naturalist, 109: 107-112.

Conrad, J., 1986. On the evaluation of government programs to reduce environmental risk. American J. of Agricultural Economics, 68: 1272-1275.

Cook, P.J. and Graham, D.A., 1977. The demand for insurance and protection: The case of irreplaceable commodities. The Quarterly J. of Economics, 91: 143-156.

Darwin, C. 1859. On the Origin of Species. London: Murray.

Dirzo, R., 1984. Herbivory: A phytocentric overview, in R. Dirzo and J. Sarukham (eds.) Perspectives on Plant Population Ecology, Sunderland, MA: Sinauer Assoc. Publishing, 141-165.

Edwards, M., 1974. Defense in Animals, Harlow: Longman.

Ehrlich, I. and Becker, G.S., 1972. Market insurance, self-insurance, and self-protection. J. of Political Economy, 80: 623-648.

Freeman, A.M. III, 1985. Supply uncertainty, option price, and option value. Land Economics, 61: 176-181.

Gallagher, D.R. and Smith, V.K., 1985. Measuring values for environmental resources under uncertainty. J. of Environmental Economics and Management, 12: 132-143.

Graham, D.A., 1981. Cost-benefit analysis under uncertainty. The American Economic Review, 71: 715-725.

Greenley, D.A., Walsh, R.G. and Young, R.A., 1981. Option value: Empirical evidence from a case study of recreation and water quality. The Quarterly J. of Economics, 96: 657-673.

Hannon, B., 1979. Total energy costs in ecosystems. J. of Theoretical Biology, 80: 271-293.

Harvey, P. and Greenwood, P., 1978. Anti-predator defense strategies, in J. Krebs and N. Davis (eds.) Behavioral Ecology: An Evolutionary Approach, Oxford: Blackwell, 129-154.

Krebs, J.R. and Davies, N.B., 1981. An Introduction to Behavioral Ecology. Oxford: Blackwell Scientific Publications.

Marshall, J., 1976. Moral hazard, The American Economic Review 66: 880-890.

Mohring, H. and Boyd, J.H., 1971. Analyzing externalities: "Direct interaction" vs. "asset utilization" frameworks, Economica, 38: 342-361.

Morgan, N. and Hamilton, W., 1980. Low nutritive quality vs. defense against herbivores. J. of Theoretical Biology, 86: 247-254.

Perlmuter, L. and Monty R., 1979. Choice and Perceived Control, Hillsdale, N.J.: Lawrence Erlbaum Associates.

Plummer, M.L. and Hartman, R.C., 1986. Option value: A general approach, Economic Inquiry, 24: 455-471.

Rhoades, D., 1983. Responses of alder and willow to attack by tent caterpillars and webworms: Evidence for pheromonal sensitivity of willows, in P. Hedin (eds.) Plant Resistance to Insects, Washington, DC: American Chemical Assoc., 56-68.

Schmalensee, R., 1972. Option value and consumer surplus: Valuing price changes under uncertainty, The American Economic Review, 62: 813-824.

Smith, V.K., 1985. Supply uncertainty, option price, and indirect benefit estimation, Land Economics, 61: 303-307.

Smith, V.K. and Johnson F.R., 1988. How do risk perceptions respond to information: The case of radon, The Review of Economics and Statistics, 70: 1-8.

Smith V.K. and Desvousges, W., 1987. An empirical analysis of the economic value of risk changes, J. of Political Economy, 95: 89-114.

Spence, A.M. and Zeckhauser, R., 1972. The effects of the timing of consumption decisions and the resolution of lotteries on the choice of lotteries, Econometrica, 40: 401-403.

Stallen, P. and Tomas, A., 1984. Psychological aspects of risk: The assessment of threat and control, in P. Ricci, L. Sagen, and C. Whipple, eds., Technological Risk Assessment, The Hague, Netherlands: Martinus Nijhoff Publishers, 276-293.

Viscusi, W.K., 1979. Insurance and individual incentives in adaptive contexts. Econometrica, 47: 1195-1207.

Walsh, R.G., Loomis, J.B. and Gillman, R.A., 1984. Valuing option, existence, and bequest demands for wilderness, Land Economics, 60: 14-29.

Weinstein, M.C., Shepard, D.S., and Plisken, J.W., 1980. The economic value of changing mortality probabilities: A decision-theoretic approach. The Quarterly J. of Economics 94: 373-396.

Weisbrod, B.A., 1964. Collective-consumption services of individual-consumption goods, The Quarterly J. of Economics, 78: 471-477.