CORNELL
AGRICULTURAL ECONOMICS
STAFF PAPER

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January 1986

No. 86-1

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RESOURCE DEVELOPMENT AND ENVIRONMENTAL RISK*

by

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This paper is concerned with resource developments which have associated environmental risk. There are numerous resources, both land and marine, whose development or exploitation engenders a risk to the surrounding environment. Offshore production of petroleum, ocean mineral mining, and the industrial development of coastal property are but a few examples. In each case our understanding of the extent of future environmental degradation is not known with certainty at the time that an initial decision on the rate of development must be made.

In the next section, a simple, two-period model of risky resource development is presented. A distinctive feature of this model arises from the fact that the probability of future environmental degradation is dependent on the level of initial development. A "probability effect" which will typically lead to more conservative development decisions is a result of this feature. A numerical example is presented in section three to help illustrate the features of the general model.

Section four presents a number of modifications to the model which focus on the collective aspects of environmental risk and

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* This paper is to appear in a volume of essays honoring James A. Crutchfield. The volume is being edited by Ed Miles and Bob Stokes and will be published by the University of Washington Press, Seattle.

concludes that the level of development will imply a vector of subjective distributions (perhaps one for each individual in society). Some individuals will regard the distribution as acceptable while others will not. Thus, environmental risk becomes a subjectively perceived "public bad." The final section summarizes major conclusions and policy implications.

RESOURCE DEVELOPMENT AND ENVIRONMENTAL RISK: A SIMPLE MODEL

We will consider a simple two-period exhaustible resource model modified to include a conditional distribution for future environmental damage. Let

Q_0 represent the level of production or resource extraction in the first period (t=0), where the total amount available for extraction over the two periods has been normalized to unity, and it is assumed that $1 \geq Q_0 \geq 0$

E_0 represent the present state of environmental quality, assumed given and known with certainty

$E_{1,s}$ represent the environmental quality in state s in future period t=1, where, for simplicity, we assume there are only two possible states for future environmental quality, s=1, where $E_{1,1}$ is "good," and s=2, where $E_{1,2}$ is "bad."

$P_s = f(s|E_0, Q_0)$

represent a known family of conditional probability distributions where a particular distribution will depend on the current level of environmental quality and on the choice of Q_0

$Q_1 = 1 - Q_0$

represent the level of production or resource extraction in the future (t=1), where, with nonsatiation and because "there is no tomorrow" (and thus, no future costs from premature depletion or a severely polluted environment), it is optimal to extract all remaining reserves

$N_0 = N(Q_0, E_0)$

represent the net benefits obtained in the initial period from adoption of Q_0 given E_0

$N_{1,s} = N(Q_1, E_{1,s})$

represent the net benefits in future state s from Q_1 and environmental quality $E_{1,s}$.

The model has been constructed so there is only one decision variable, Q_0. The choice of a particular level for Q_0 will immediately imply Q_1, the level for future extraction, and a particular probability distribution $P_s = f(s|E_0, Q_0)$.

Ignoring discounting and assuming the maximization of expected net benefits to be an appropriate objective, we would wish to

$$\max_{Q_0} E(N) = N(Q_0, E_0) + \sum_{s=1}^{2} N(Q_1, E_{1,s})\, f(s|E_0, Q_0) \ . \tag{1}$$

Noting that $Q_1 = 1 - Q_0$ and that $dQ_1/dQ_0 = -1$, the Kuhn-Tucker first order conditions for Q_0^* to be optimal require:

$$1 \geq Q_0^* \geq 0 \tag{2a}$$

$$\frac{\partial N(Q_0^*, E_0)}{\partial Q_0} \leq \sum_{s=1}^{2} \frac{\partial N(Q_1, E_{1,s})}{\partial Q_1} f(s|E_0, Q_0^*)$$

$$- \sum_{s=1}^{2} N(Q_1, E_{1,s}) \frac{\partial f(s|E_0, Q_0^*)}{\partial Q_0} , \qquad (2b)$$

$$Q_0^* \{ \frac{\partial N(Q_0^*, E_0)}{\partial Q_0} - \sum_{s=1}^{2} \frac{\partial N(Q_1, E_{1,s})}{\partial Q_1} f(s|E_0, Q_0^*)$$

$$+ \sum_{s=1}^{2} (N(Q_1, E_{1,s}) \frac{\partial f(s|E_0, Q_0^*)}{\partial Q_0} \} = 0 \quad . \qquad (2c)$$

For $1 > Q_0^* > 0$ condition (2b) must hold as an equality and thus $\{\cdot\} = 0$ in (2c). In this instance the positive level for Q_0 has been determined so as to balance present marginal net benefit with two future costs. The first term on the right-hand side (RHS) of (2b) may be interpreted as expected user cost, that is, the expected value of an additional increment to Q_1 which could be obtained by an incremental reduction in Q_0. The second term on the RHS of (2b) is a probability effect. It measures the change in expected future net benefits resulting from the change in state probabilities. If $-dP_1/dQ_0 = dP_2/dQ_0 > 0$, then an increment in production today will increase the likelihood of a "bad" environment in the future. The negative of this term is an additional cost which is added to expected user cost and compared to the present marginal net benefits of Q_0.

If $Q^* = 0$, then (2b) holds as a strict inequality, implying that not even the first increment in Q_0 is capable of producing marginal net benefits in excess of expected future costs. This corner solution is shown in figure 1(b), while the interior solution ($1 > Q_0^* > 0$) is shown in figure 1(a).

Let P_s denote the development independent prior probabilities over future environmental states $E_{1,1}$ and $E_{1,2}$. In comparing the initial rate of development with and without dependence one obtains:

$$Q_0^* < Q_0 \text{ if } P_1(s|E_0, Q_0^*) < P_1 \quad (3a)$$

$$Q_0^* = Q_0 \text{ if } P_1(s|E_0, Q_0^*) = P_1 \quad (3b)$$

$$Q_0^* > Q_0 \text{ if } P_1(s|E_0, Q_0^*) > P_1 \quad (3c)$$

If the independent prior for maintenance of good environmental quality were higher than the conditional prior for $Q_0^* > 0$, then a more conservative policy of initial development would be optimal. This is reflected in condition (3a). It is possible that an overly pessimistic independent prior might be replaced by a more optimistic conditional prior. In this case, the optimal level of conditional development may exceed that obtained under independence. This is indicated in condition (3c). Identical rates of development would occur if, by chance, the optimal conditional distribution corresponded to the independent priors.

If one believes that the history of economic development has been characterized by unanticipated environmental degradation from large scale projects, then a more pessimistic conditional distribution and positive "probability effect" would lead to a more conservative rate for initial extraction or development.

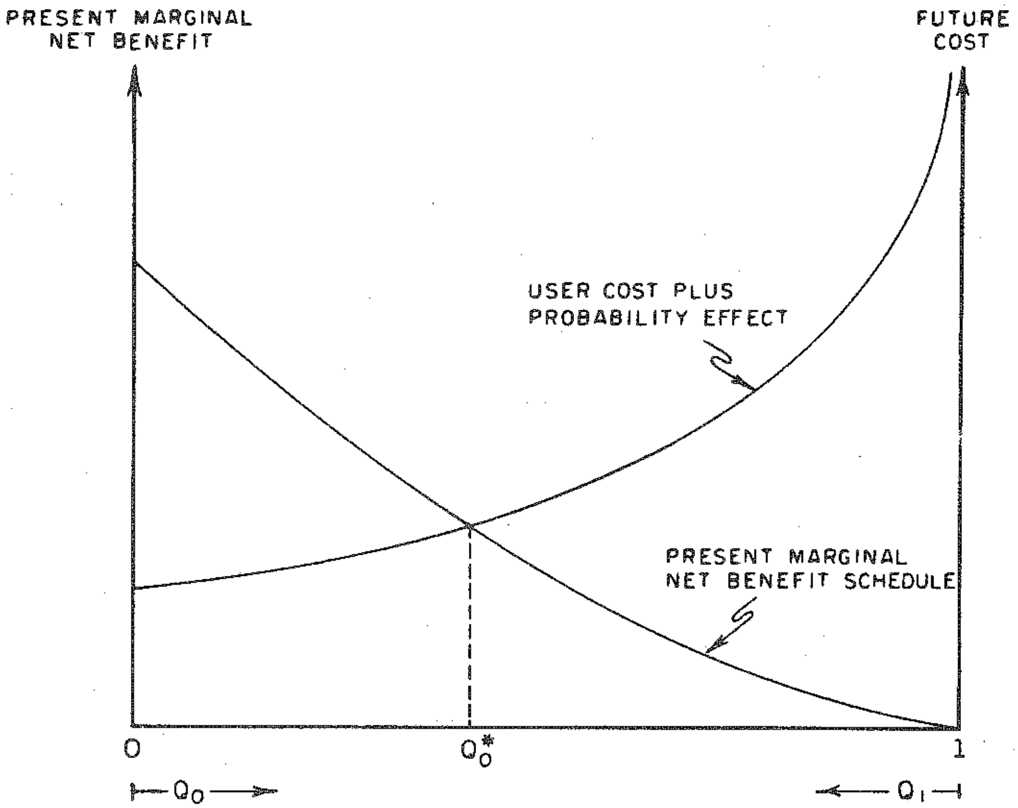

FIGURE 1 (a): INTERIOR SOLUTION ($1>Q_0^*>0$)

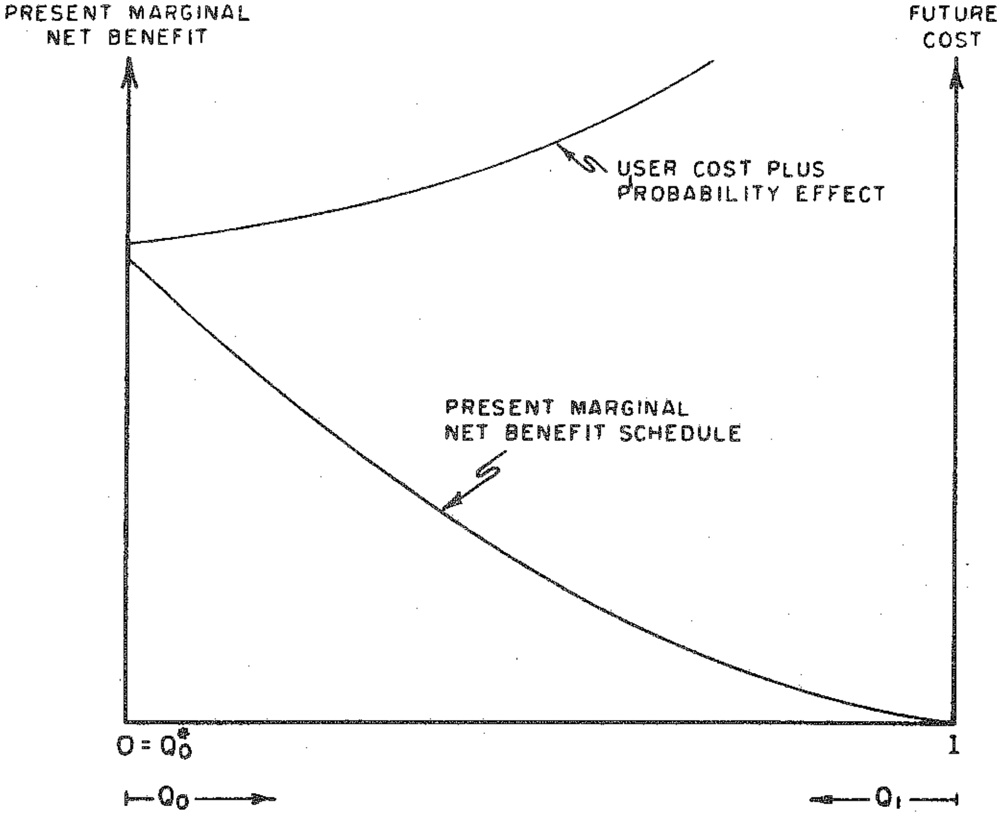

FIGURE 1 (b): CORNER SOLUTION ($Q_0^*=0$)

A NUMERICAL EXAMPLE

To illustrate the arguments of the general model, consider the following numerical example. Let

Q_0 represent the rate of initial development to be determined so as to maximize the present value of expected net benefits, $0 \leq Q_0 \leq 1$

E_0 represent the current state of environmental quality which is assumed to be "good," specifically $E_0 = 1$

$E_{1,s}$ represent the unknown state of environmental quality in the future (t=1), where $E_{1,1} = 1$ if environmental quality remains good and $E_{1,2} = 0$ if the quality of the environment degrades to "bad"

$f(E_{1,1}|Q_0) = e^{-aQ_0}$
represent the conditional probability that environmental quality will remain good, given Q_0 and assuming $a > 0$

$f(E_{1,2}|Q_0) = 1 - e^{-aQ_0}$
represent the conditional probability that environmental quality will degrade to $E_{1,2} = 0$

$N_0 = E_0Q_0(1 - Q_0)$
represent current period net benefits from initial development at rate Q_0

$N_{1,s} = E_{1,s}Q_1(1-Q_1)$
represent the net benefits obtained in future state s

$\rho = 1/(1+\delta)$
represent the discount factor applied to future expected net benefits.

Given the possibilities for future environmental quality, their conditional probabilities, and with $Q_1 = 1 - Q_0$, the expression for expected net benefits becomes:

$$N(Q_0) = Q_0(1 - Q_0) + \frac{Q_0(1 - Q_0)e^{-aQ_0}}{(1+\delta)} \quad . \tag{4}$$

Since $N(Q_0)$ is concave

$$N'(Q_0) = - \frac{aQ_0(1 - Q_0)e^{-aQ_0}}{(1 + \delta)} + (1 - 2Q_0)[1 + \frac{e^{-aQ_0}}{(1+\delta)}] = 0 \tag{5}$$

is both a necessary and sufficient condition for determining Q_0^*. Equation (5) was solved using the Newton method for the parameter values $a = 5.0$ and $\delta = 0.1$. The optimal rate of development was $Q_0^* = 0.4447$ with a conditional probability $P(E_{1,1}/Q_0^*) = 0.1082$. If a resource development agency had viewed good or bad environmental quality as equally likely and independent of Q_0, they would have adopted $Q_0 = 0.5$.

The simple two-period model with conditional state probabilities would seem to describe the underlying relationship for many development/environment controversies. There are important subtleties, however, which the simple model cannot consider, and which are relevant to the risks inherent in resource development or residuals management. These include the degree of collectivity and ability to spread environmental risk, the possibility of irreversible environmental damage, and learning.

MODIFICATIONS TO THE SIMPLE MODEL

Uncertainty and risk are pervasive qualities of life. We face risk at home, at work, in our cars, in the products we consume, and in our recreational activities. Most of these risks, however, are individual risks in that the consequences resulting from a particular decision and future "state of nature" affect only the individual, household, or firm making the decision. It is also the case that the future state that occurs for one individual is often independent of the state realized by others. The psychic cost to individuals facing independent risks can be reduced by private insurance firms who, through spreading the risk of underwriting among many stockholders and by investing premiums in a diversified portfolio, produce a more or less optimal allocation of risk. In other words, when risks are individual and independent in nature, private underwriters will often be able to redistribute and reduce the cost of risk-bearing in the most efficient way.

Individual risks that are not insurable by private underwriters are often subject to "moral hazard" or excessive transactions costs. Moral hazard occurs when an individual, once insured, has the ability and economic incentive to influence the future state of nature, usually at the expense of the underwriter (see Kenneth Arrow 1971). Excessive transactions costs can arise when the risk, although individual and not subject to moral hazard, is "rare" or the relevant states of nature (contingencies) are difficult to define, necessitating complex and (excessively) costly contracts.

The environmental risks envisioned in the model of section two are not individual in nature and may not be insurable by private underwriters. They tend to be collective in nature, with many people realizing the same future state. The blow-out of an offshore platform may result in the state "oil spill" for a large number of coastal residents. The climatic effects from increasing levels of carbon dioxide could be global in nature. The "public good" characteristics of environmental quality may in turn imply that environmental risks are collective. How should such risks be evaluated and what are their implications for planning and project implementation?

In contrast to project costs and benefits which accrue to individuals and may be "spread" thinly among a large group of investors or beneficiaries, Fisher (1973) has shown that when a project poses environmental risk, expected damages plus an aggregate "risk premium" should be deducted from commercial net benefits. Let

$$U^i_{t,s} = U^i\,(Y_{i,t},\ E_{t,s}) \tag{6}$$

represent the utility of the ith individual in state s in period t, where $Y_{i,t}$ is the individual's known (nonstochastic) income and $E_{t,s}$ is again environmental quality in state s. If resource development is undertaken at initial rate Q_0, let

$$P^i_s = f^i(s|E_{0,1},\ Q_0) \tag{7}$$

represent the personal (subjective) probability distribution for environmental quality in the future (t=1) assuming it is presently good ($E_{0,1}$). If $Q_0 > 0$, we will assume $P^i_2 > 0$; that is, the ith individual views resource development as posing a risk of environmental degradation. Then assuming $U^i(\cdot)$ concave, so that the i^{th} individual is risk-averse, and $Q_0 > 0$, there will exist a risk premium $\bar{Y}_{i,1} > 0$ such that

$$U^i([Y_{i,1} - \bar{Y}_{i,1}], E_{1,1}) = \sum_{s=1}^{2} U^i(Y_{i,t}, E_{1,s}) f^i(s|E_{0,1}, Q_0) , \quad (8)$$

If $i = 1,\ldots,I$, the aggregate of the individual risk premiums would be $\sum_{i=1}^{I} \bar{Y}_{i,1}$ which would be added to expected damages and subtracted from net commercial (or private) benefits. In this instance the aggregate risk premium is an equivalent variation, that is, the amount of income the group of individuals would be willing to pay to avoid $Q_0 > 0$. The compensating variation would calculate the minimum amount necessary to compensate the group of individuals for the risk implied by $Q_0 > 0$. For the i^{th} risk-averse individual there will exist some $\tilde{Y}_{i,1} > 0$ such that

$$U^i(Y_{i,1}, E_{1,1}) = \sum_{s=1}^{2} U^1([Y_{i,1} + \tilde{Y}_{i,1}], E_{i,s}) f^i(s|E_{0,1}, Q_0) \quad (9)$$

The aggregate premium in this case is $\sum_{i=1}^{I} \tilde{Y}_{i,1}$, which will be larger than the equivalent premium $\sum_{i=1}^{I} \bar{Y}_{i,1}$ when environmental quality exhibits a positive income effect; that is, where the i^{th} individual demands higher levels of environmental quality at higher levels of personal income (see Currie et al. 1971).

The subjective distribution in equation (7) pinpoints another important aspect of environmental risk. Not only is it usually collective, but the individuals affected may hold different prior probabilities as to the environmental quality which might result from a given Q_0. Even if individuals have the same preferences between income and environmental quality ($U^i(\cdot) = U(\cdot)$ for all $i = 1,2,\ldots,I$), they may differ on the appropriate level for Q_0 if they have different conditional priors. Such a situation is likely to occur when prior experience with development technology, project design, or environmental response is limited. With limited data on which to base future expectations, it is unlikely that all individuals would share the same conditional probability distribution.

Suppose that in addition to being collective, the environmental risk from $Q_0 > 0$ was also irreversible in the sense that once $E_{t,2}$ occurred (a state of bad environmental quality), it was impossible to return to $E_{\tau,1}$ (a state of good environmental quality) for $\tau > t$. Arrow and Fisher (1974) addressed this problem within the context of a model where the net benefits from development were uncertain and where development could not be reversed. The uncertainty in net benefits could result when environmental damage is deducted from commercial net benefits. Irreversibility could result if some environment in the vicinity of the development could not be returned to its pre-development state should net benefits prove negative. Future expected net benefits were conditional on the net benefits realized in the present period.

In determining an optimal development strategy, Arrow and

Fisher identified a concept they referred to as "quasi-option" value, to distinguish it from "option" value identified earlier by Weisbrod (1964). The effect of quasi-option value was similar to risk aversion in that a particular area would be less likely to be developed or less of an area would be developed at a particular point in time. While similar in effect, quasi-option value was distinct in that there was no presumption of risk aversion. The delay or reduction in the rate of development was the result of an optimal planner not wishing a large-scale commitment to a development that was risky and irreversible. Larger-scale development could always occur at a later date if realized net benefits were positive. Irreversibility, however, precluded return to the initial state of "undevelopment."

Conrad (1980) has shown that both option value and quasi-option value are related to a more fundamental concept: the expected value of information. Within his model learning was passive. The prior distribution over future states was updated based on the observed state of environmental quality in the present period, and probabilities were not conditional on the level of previous period development. The simple model in section two of this paper would permit active learning strategies if it were extended to a multi-period framework with more than two periods. In such a framework the selection of an initial development rate may allow a planner to gain additional information on the sensitivity of future state probabilities. For this to be the case, the family of conditional distributions cannot be known with certainty. It must depend on other, unknown, parameters as well as the current environmental state and rate of development. For example, suppose

$$P_{t+1,s} = f(s|E_t, Q_t, \theta) \tag{10}$$

where $P_{t+1,s}$ is the probability that environmental state s will occur in period t+1 given the environmental state in period t, production or development in period t, and the parameter θ. If θ is not known with certainty, one might base the selection of Q_t on an estimate of θ, denoted $\hat{\theta}_t$, to indicate that this estimate of θ is a function of our experience with the development process through period t. If Q_t will influence the precision of our estimate of the unknown parameter θ, it may actually pay to adopt initial rates for Q_t which are suboptimal in the short run if those short-run losses can be recouped because of better decisions (from better information) in the long run. In general, different levels for Q_t may be expected to provide different information about the conditional distribution, and the selection of a particular Q_t may reflect, in part, this difference. If irreversibility is not present, the value of information may lead to higher levels or more variable levels in Q_t to determine "what one might get away with environmentally."

CONCLUSIONS AND POLICY IMPLICATIONS

Most resource developments and waste disposal activities pose a risk to the quality of the environment in the vicinity of the extraction or disposal site. It is plausible that the level of initial or current development (disposal) will influence the relative likelihood of future environmental states. When this is the case, a "probability effect" will often result in an additional future cost which must be added to expected user cost and balanced with present net marginal benefits.

Environmental risks tend to be collective, either to residents of a region or to the entire planet. It may be difficult or impossible to spread the environmental risk borne by groups of individuals. Their aggregate risk premium, representing a psychic but nonetheless real cost, should be deducted from net commercial (private) benefits.

Individuals may disagree over the appropriate level for a resource development activity because they have different preferences with regard to environmental quality, different subjective priors as to the probability of environmental degradation, or different levels of disposable income. Environmental risk, in the form of a particular conditional distribution (or set of subjective distributions), becomes a "public bad."

When development or disposal activities raise the possibility of irreversible damage, positive levels for these activities, based on commercial net benefits, are likely to ignore quasi-option value, that is, the loss incurred in perpetuity from a "bad" decision which cannot be reversed. With potential irreversibilities, lower initial rates of development allow one to learn about the degree of environmental sensitivity, and if rates of development or dumping are less damaging (or less frequently damaging), they may be increased at a later date.

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