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RISK, INFORMATION AND THE DEVELOPMENT
OF MARINE RESOURCES

by

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Risk, Information and the Development of Marine Resources†

Jon M. Conrad*

Abstract

The development of offshore oil and gas, the mining of deep sea minerals and the disposal of wastes through ocean dumping have raised important questions about the way we harvest ocean resources and use the marine environment. From an economic perspective all of the above activities involve risk, either to private developers, society at large, or both. This paper presents a simple model of resource development with environmental risk. The model and subsequent modifications are used to characterize the risks inherent in the aforementioned marine activities, and to help define an appropriate role for public policy. The nature of the risks involved, the possibilities for risk spreading, the presence or absence of irreversible consequences, and the expected value of information are shown to be important in determining the rate of development and the way in which net benefits should be evaluated.

I. Marine Resource Development and Environmental Quality

This paper is concerned with resource developments which have associated environmental risk. There are numerous resources, both land and marine, whose exploitation engenders a risk to the quality of the surrounding environment. We will be concerned with three activities: offshore oil and gas, ocean minerals mining, and ocean dumping. The latter activity is not a resource extraction problem, but rather a waste deposition problem. All three activities, however, have the potential to adversely affect the marine environment. In each case our understanding of the extent of future environmental degradation is imperfect. The environmental consequences and costs are not known with certainty at the time that an initial decision on the rate of extraction or deposition must be made.

In the next section a simple model of risky resource development is presented. The third section presents a series of modifications which focus attention on the degree of risk collectivity, the presence of irreversibilites, and the value of information. The specific risks associated with offshore oil and gas, deepsea mining, and ocean dumping are examined in section four. This analysis draws on the simple model

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of section two and the modifications presented in section three. The final section summarizes the major conclusions from the model of risky resource development along with the assessment of the environmental risks for the aforementioned activities. This section concludes with a discussion of the role of liability rules and direct regulation in allocating marine resources and protecting the marine environment.

II. 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 $1 > Q_0 \geq 0$;

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 <u>family</u> 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; and

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

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

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:

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

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

$$Q_0^* \left\{ \frac{\partial N(Q_0^*, E_0)}{\partial Q_0} - \sum_{s=1}^{2} \frac{\partial N(Q_1, E_{1,s})}{\partial Q_1} f(s/E_0, Q_0^*) + \sum_{s=1}^{2} N(Q_1, E_{1,s}) \frac{\partial f(s/E_0, Q_0^*)}{\partial Q_0} \right\} = 0 \quad . \tag{2c}$$

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 $Q_0^* = 0$, 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 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).

If the rate of extraction has no influence on future state probabilities, one obtains the certainty-equivalent rule that present marginal net benefits be equated to expected user cost. This would increase the level of Q_0^* relative to the case where a positive increment in Q_0 increases the likelihood of environmental degradation. Thus, the presence of this type of probability effect would call for a more conservative rate of initial extraction.

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

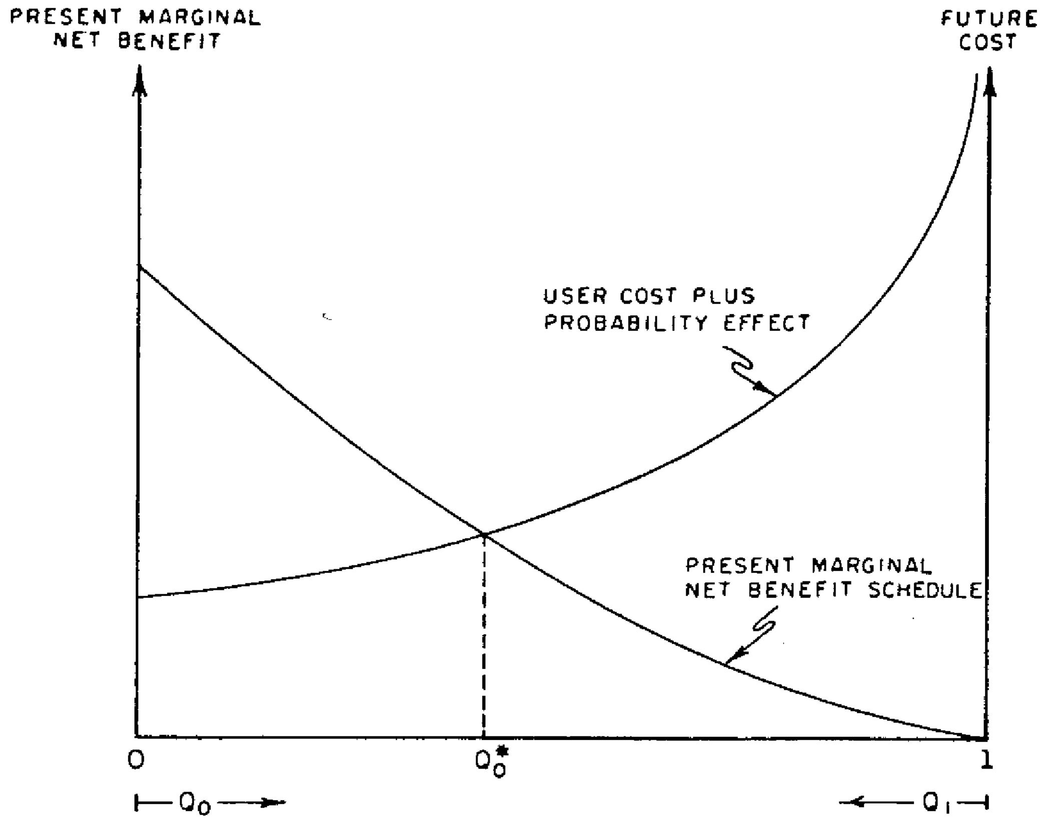

FIGURE 1 (a): INTERIOR SOLUTION ($1 > Q_0^* > 0$)

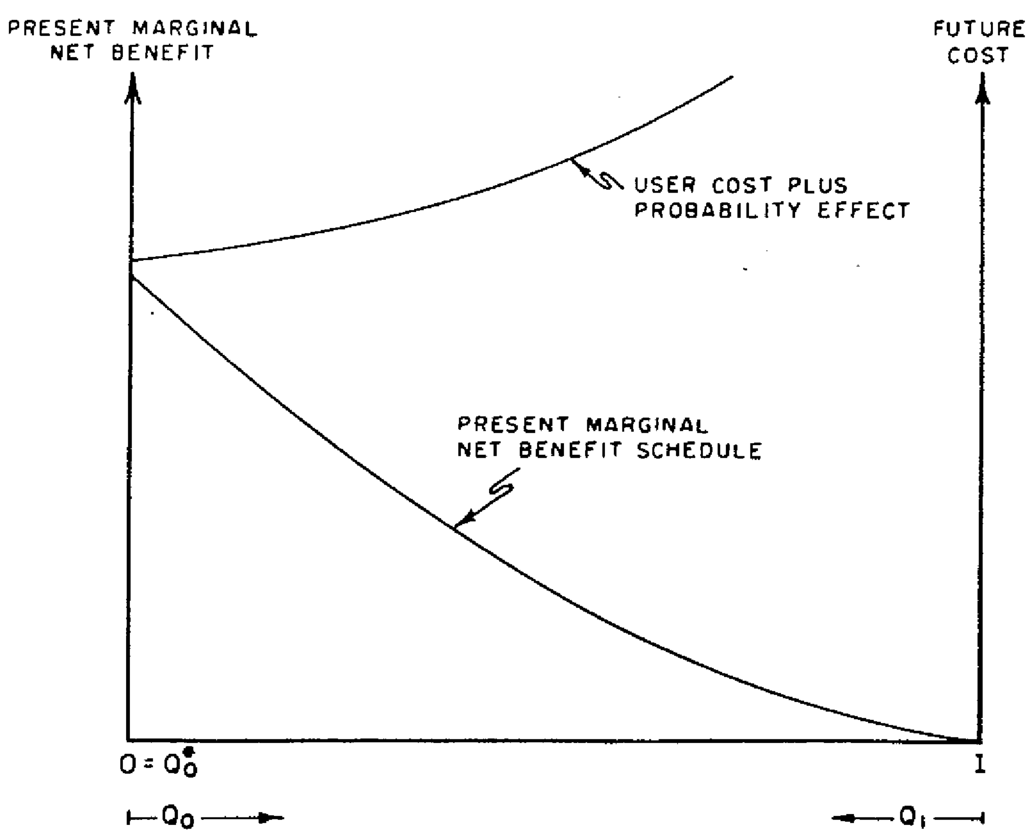

FIGURE 1 (b): CORNER SOLUTION ($Q_0^* = 0$)

to the risks inherent in offshore oil and gas, ocean minerals mining, and ocean dumping. These include the degree of collectivity and ability to spread environmental risk, the possibility of irreversible environmental damage, and learning.

III. 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 activites. 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 [1]). Excessive transactions costs can arise when the risk, while 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 CO_2 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 [8] has shown that when a project poses environmental risk, expected damages plus an aggregate "risk premium" should be deducted from commercial net benefits. Let

$$U^i_{t,s} = U^i(Y_{i,t}, E_{t,s}) \tag{3}$$

represent the utility of the i^{th} 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

$$P^i_s = f^i\ (s/E_{0,1},\ Q_0) \tag{4}$$

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 i^{th} 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

$$U^i([Y_{i,1} - \bar{Y}_{i,1}],\ E_{1,1}) = \sum_{s=1}^{2} U^i(Y_{i,t},\ E_{1,s})f^i(s/E_{0,1},\ Q_0) \quad .(5)$$

If i = 1,..., 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 <u>equivalent variation</u>, that is, the amount of income the group of individuals would be willing to pay to avoid $Q_0 > 0$. The <u>compensating variation</u> 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

$$U^i(Y_{i,1}, E_{1,1}) = \sum_{s=1}^{2} U^i([Y_{i,1} + \tilde{Y}_{i,1}],\ E_{1,s})f^i(s/E_{0,1},\ Q_0) \tag{6}$$

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. [6]).

The subjective distribution in equation (4) 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,..., 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 [2] 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 vacinity 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 [15]. 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 [3] 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 up-dated 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

$$P_{t+1,s} = f(s/E_t, Q_t, \theta) \tag{7}$$

where $P_{t+1,s}$ is the prior 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 estimates 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 irreversibiltiy 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."

Before proceeding to an assessment of the environmetal risks inherent in offshore oil and gas, ocean minerals mining, and ocean dumping, it may be useful to summarize the conclusions of the modifications to the simple model which were discussed in this section.

1. If environmental risks are collective and not subject to reduction by spreading, then the future net benefits defined in the simple model of section two would need to be reduced by an equivalent or compensating risk premium (see equations (5) and (6)).

2. 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."

3. If environmental degradation is irreversible, "quasi-option value" will tend to produce more conservative levels for initial development until one learns more about net benefits (net also of environmental costs) for various levels of development.

4. In the absence of environmental irreversibility, and with variations in development yielding information on the probability of environmental damage, it may pay to have periods of rapid production (development) if the resultant information allows better management in the long run.

These four conclusions, drawn from the economic theory of resource development, might be used in making a qualitative assessment of environmental risk and the role and scope of public policy.

IV. Offshore Oil and Gas, Ocean Minerals Mining, and Ocean Dumping: A Qualitative Assessment

The terms "risk assessment" or "benefit-risk assessment" are frequently encountered in discussions and analyses of actions or projects that pose the risk of environmental degradation. Unfortunately, these terms are not often defined in an operational sense. In the following analysis of offshore oil and gas, ocean minerals mining, and ocean dumping, we will adopt the following definition:

> Net Benefit-Risk Assessment: An analysis of an activity or policy which calculates the present value of expected net benefits explicitly accounting for (1) gross benefits or revenues, (2) project and associated costs, (3) expected environmental or "externality" costs, (4) the cost of bearing environmental risk, and (5) quasi-option value or the expected value of information if the potential degradation is irreversible.

The first three items are standard to any benefit-cost analysis of a resource development project. The fourth item, measuring the cost of bearing some specific environmental risk would require the application of contingent valuation techniques. Estimation of an equivalent or compensating risk premium would require an iterative interview process to determine the amount that an individual would pay to avoid the risk of the environment being degraded to some level below current quality, or the amount that must be received to voluntarily face such a risk. An average risk premium might then be multiplied by the number of affected individuals to determine the aggregate risk premium representing the cost of bearing that environmental risk.

With irreversibilites, quasi-option value will be associated with project scale and initial rates of development. To adequately consider these values may require a multi-period model that allows the analyst to consider what might be learned and the levels of "regret" associated with different levels of irreversible development or environmental damage.

The net-benefit assessment of this section is qualitative and subjective in that the author will speculate on the relative magnitudes of the five items in our definition. The "bottom line," item (1) net of items (2) through (5), if positive, will indicate that some initial level of activity would seem warranted or, if the marine activity is currently ongoing, that a positive level, subject to possible modifications, is appropriate. If, based on current expectations, the risk adjusted net benefits are negative, the marine activity would not be commenced, or if ongoing, terminated. To facilitate the analysis for later summarization, we adopt the following notation. Let:

B represent the level of gross benefits or revenues associated with some initial or current ongoing level for the marine activity,

C represent project and associated costs so that $N = B - C$ represents commercial (private) net benefits as discussed in sections two and three of this paper,

E represent expected environmental costs such as the net financial losses imposed on other marine businesses or the net "utility" losses suffered by residents or tourists,

R represent the cost of environmental risk measured as an equivalent or compensating aggregate risk premium, and

O represent the quasi-option value foregone by initiating development (at some level) now or maintaining current levels for ongoing marine activities.

It should be noted that there are commercial risks in offshore oil and gas and ocean minerals mining. This is especially true for the latter activity where volatile metals' prices and uncertainty over regulations by the United Nations International Sea-Bed Authority have raised questions about economic profitability on purely private (commercial) grounds.

The benefits from disposal of sludge and other wastes through ocean dumping accrue primarily to coastal municipalities in the form of cost-savings over other forms of disposal (primarily landfill and incineration). The extent of these savings is a function of the cost and capacity of other disposal alternatives and the environmental regulations under which they operate. It has been noted elsewhere (National Advisory Committee on Oceans and Atmosphere [11]) that ocean dumping is only one of several options for disposal of wastes and an optimal "residual management policy" needs to consider all disposal alternatives simultaneously to determine the best mix of disposal techniques and receiving media. Thus, the qualitative net benefit-risk assessment presented here is only a partial analysis in that it does not consider the increased risk to groundwater or air quality if sludge or other wastes were disposed of by landfill, land application, or incineration.

Offshore Oil and Gas

The revenues derived from moderate to large finds of oil and natural gas are very large. The cost of exploration and development, while large, has been decreasing as a result of improved seismic survey techniques and ocean engineering (Eckert [7]). The expected environmental costs are collective and potentially significant for individuals harvesting fish and shellfish resources or deriving income from coastal tourism. These risks result from toxic drilling muds, from chronic low level spills and less frequent, but more dramatic, large spills of crude or distillate products (Council on Environmental Quality [5]). Biologists believe that the most damaging event would be a nearshore spill of a light distillate (Offshore Oil Task Group [12]). Nearshore areas tend to be the most productive biologically, while lighter distillates tend to be more toxic to marine life. If a nearshore site is subject to a chronic discharge or series of spills, "semi-permanent" contamination could result (Offshore Oil Task Group [12]).

When production, transport, and distribution activites pose the threat of contaminating commercial fisheries or unique coastal amenities, the collective risk premium reflecting the cost of risk borne by the coastal community may be significant. Quasi-option value reflecting the expected loss, should environmental degradation prove irreversible, is probably small.

From a national perspective, continued exploration for and production from OCS fields would appear to yield positive net benefits even after adjustment for expected environmental costs, costs of risk bearing, and quasi-option value (from potential irreversibilities). It may be the case that a particular coastal community or region with a significant stake in commercial fishing or tourism will experience negative local net benefits.

Ocean Minerals Mining

The commercial or private net revenues obtainable from ocean minerals mining would appear more uncertain than the expected environmental damages, risk premium, and foregone quasi-option value. The current world-wide recession has depressed almost all metals' markets and, in particular, the markets for manganese, copper, nickel, and cobalt which comprise the commercially refinable metals found in deep-sea nodules. The international consortia who have developed the technology to harvest deep-sea nodules are also hesitant to start mining under the United Nations Sea-Bed Mining Authority which has the power to license mining companies, set production quotas, and compel the transfer of technology to the United Nation's own mining company called the Enterprise (United Nations [13]). The gross benefits or revenues from ocean minerals mining could be small or large, while the costs of ocean mining will probably be large.

The environmental impacts from mining include the destruction of benthic life in the path of the nodule collector, possible benthic mortality in adjacent areas from the "benthic plume" created by the collector, and the "surface plume" emanating from the mining vessel as it separates sediments and benthos from the nodules, discharging the former overboard.

Mortality of benthic life in the path of the collector sled seems all but certain (U.S. Department of Commerce [14]). The dispersion and effect of the benthic plume is speculative, as is the effect of the surface plume on near-surface, pelagic species. In spite of the almost certain mortality at the mining site and the uncertain effects on the adjacent benthic areas and at the surface, the expected environmental costs, aggregate risk premium, and quasi-option value foregone would all appear small to insignificant. Such an assessment is based on the facts that the area to be mined is insignificant relative to the whole Northeastern Pacific, the benthic species are not commercially valuable nor would mining threaten them with extinction, and the "surface plume" is not expected to affect whales, dolphins, or species (such as tuna) of commercial importance. Thus, while the net benefit-risk assessment is ambiguous, its sign (positive or negative) would appear to depend on commercial and political considerations and not on environmental, risk, and quasi-option values.

Ocean Dumping

Ocean dumping is the most difficult activity to assess even in a superficial and qualitative exercise such as this. As noted earlier, the benefit from ocean dumping lies in the cost savings achieved when compared to the marginal costs of the next best disposal alternative. There would also appear to be a trade-off in environmental risks from groundwater contamination and air pollution to despoiling of the marine environment. What can we surmise?

We will confine our discussion to four types of wastes: sewage sludge, industrial wastes including chemicals and heavy metals, acid wastes and dredge spoils (Mueller and Anderson [10]). The benefits of ocean dumping are moderately large given the scarcity and limited capacity of existing landfill sites (Gross [9]). The cost of ocean dumping is netted out in calculating these savings. The expected environmental costs will depend on location, wind and current trajectories throughout the year, and the value of marine resources and amenities at or near the dump sites. For many of the current nearshore dumping sites in the eastern United States, the expected environmental costs would appear to be small to moderate based on foregone harvests of finfish and shellfish. The aggregate risk premium of commercial fishermen and tourist interests, while positive, is probably small. The foregone quasi-option value resulting from cumulations of BOD demanding sludge and toxic chemicals would appear small to moderate. While commercial fishermen are familiar with dump locations and will avoid such sites, it is also the case that many sites are, for all practical purposes, permanently contaminated and incapable of supporting species of commercial value. On net, when one deducts expected environmental costs, the aggregate risk premium, and foregone quasi-option value, the assessment of nearshore dumping is probably negative.

The qualitative magnitudes expected for gross benefits (B), project and associated costs (C), environmental costs (E), the aggregate risk premium (R), and quasi-option values foregone (O) are summarized in Table 1. Qualifications for each net benefit-risk assessment are given in the last column of that table. An alternative interpretation of Table 1 is that it represents the author's current working hypotheses about these three marine activities. In future research he hopes to obtain quantitative estimates of the items contained in the definition of a net benefit-risk assessment. Such estimates will hopefully provide a more informed basis from which to evaluate these activities and to suggest appropriate public policies. In the next section we will summarize the major conclusions of this paper and briefly explore their policy implications.

V. Conclusions and Policy Implications

Most resource developments and waste disposal activities pose a risk to the quality of the environment in the vacinity 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 the entire planet. It may be difficult or impossible to spread the environmental risk borne by groups of individuals; and their aggregate risk premium, representing a psychic but non-the-less real cost, should be deducted from net commercial (private) benefits.

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.

A qualitative and admittedly subjective evaluation of benefits, project costs, expected environmental costs, aggregate risk premiums, and quasi-option values resulted in risk-adjusted net benefits which were positive, ambiguous, and negative for offshore oil and gas, ocean minerals mining, and nearshore ocean dumping, respectively. Offshore oil and gas, while yielding positive risk-adjusted net benefits nationally, may inflict negative net benefits on those communities with local economies that are significantly dependent on commercial fishing and coastal tourism. Ocean minerals mining has ambiguous risk-adjusted net benefits, but this is the result of commercial and political uncertainty as opposed to significant environmental risks. Finally, ocean dumping, the most difficult to assess, would seem likely to result in negative risk-adjusted net benefits for nearshore

Table 1: Offshore Oil and Gas, Ocean Minerals Mining, and Ocean Dumping: A Qualitative Assessment.

MARINE ACTIVITY	GROSS BENEFITS B	PROJECT AND ASSOCIATED COSTS C	EXPECTED ENVIRONMENTAL COSTS E	AGGREGATE RISK PREMIUM R	QUASI-OPTION VALUE FOREGONE O	NET BENEFIT RISK ASSESSMENT	COMMENTS
Offshore Oil and Gas	Very Large	Large	Moderate	Small	Small	Positive	Risk-Adjusted Net Benefits Appear Positive for the Nation as a Whole. Coastal Communities With a Significant Economic Interest in Commercial Fishing and Tourism Could Experience Negative Net Benefits When Expected Environmental Costs and Risk Premiums are Assessed.
Ocean Minerals Mining	Small to Large	Large	Small	Very Small	Very Small	Ambiguous	Risk-Adjusted Net Benefits are Ambiguous Because of Commercial (Private) and Political Uncertainity, Not Because of Expected Environmental Cost or Risk-Bearing.
Ocean Dumping	Moderate	(The Entry Under Gross Benefits Reflects Cost-Savings That Net Out the Cost of Dumping; Transport Costs, Etc).	Small to Moderate	Small	Small	Negative	Ocean Dumping is the Most Difficult of the Three Activities to Assess. Additional Research on the Environmental Costs of Existing Sites, Alternative Disposal Techniques, and More Distant Dump Sites is Needed.

dump sites receiving sludge or toxic wastes. If this assessment is correct, the recent decision to delay a ban on nearshore dumping is inappropriate. Additional research should be directed at the biological consequences and economic benefits and costs of nearshore dumping including the costs of alternative disposal techniques, the increased risks to groundwater and air quality, and the expected environmental and transport costs from disposal sites that are further offshore.

The public policies for dealing with environmental risk have relied heavily on direct regulations that specify equipment and procedures for offshore oil and gas production and the amount, timing, and types of wastes that may be disposed at certain sites. Economists have tended to recommend financial incentives for dealing with pollution and have proposed effluent charges (or taxes) as a means of dealing with the more obvious forms of pollution. In the case of uncertain externality, where the damage, if any, from a particular activity is stochastic, the analogue to an effluent charge is a strict liability rule which defines financial liability for damages in all conceivable environmental states (see Conrad [4]). The behavior of firms engaged in resource extraction, transport, and distribution would presumably incorporate the expectation of future damage claims into their production and pollution control (prevention) decisions. The threat of liability would in turn lead to the socially optimal (conditional) distribution for environmental risk.

The difficulty of extending this reasoning to exotic and uncertain pollutants or potentially damaging activities is the additional uncertainty of knowing what family of prior distributions the private production firm is currently operating under, and whether the firm is responsive to all damages or only legally "provable" damages. The long term and cumulative impact of mining and dumping activites coupled with the often diffuse groups affected by marine environmental quality make exclusive reliance on liability rules an unadvisable policy. It is further the case that private firms have little incentive to incorporate quasi-option values when determining rates of production or preventative measures. These values, difficult to measure as they are, may imply that direct regulation, as opposed to economic incentives, have an important role to play in protecting the marine environment.

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