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FORECLOSURE OF OPTIONS IN SEQUENTIAL RESOURCE DEVELOPMENT DECISIONS

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Foreclosure of Options

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ABSTRACT

This paper analyzes a series of examples of renewable resource development that involve sequential loss of decision options even in the absence of irreversible physical change. It appears that this "pathological" decision behavior arises not because of quantitative errors in judging benefits and costs of investment, but rather because basic qualitative relationships are often overlooked. Systems analysis as it is usually applied may do little more than aggravate the problem; we need new ways of looking at relationships between dynamical natural systems and the sequential investment decisions involved in their development.

1. INTRODUCTION

Resource development decisions are often viewed as isolated, incremental problems involving choice among a series of alternatives at one point in time. Each alternative may be defined by a single investment option, or it may involve closed (feedback) or open loop (fixed) decision rules for future times. But generally the idea is to view the future only in terms of present state and projected (often probabilistic) future events. Recommendations as to best alternatives are usually accompanied by a cautionary comment that future decision analyses (usually by different decision makers) should be made to keep abreast of changing information and goals.

Too often we play down the simple fact that decisions today may foreclose some of our options for tomorrow; large capital investments commit us to policies that try to recover sunk costs, hydroelectric dams permanently destroy landscapes, insecticide spraying leads to explosive preoutbreak conditions, and so forth. We try to represent these problems in the usual decision analysis through introduction of concepts such as option value (1,2,4), discounting rate (13), and "resilience of environmental capital" (6), but these measures are meaningful only if we can make reasonable probabilistic predictions about the future. Far too often the sad experience has been that our "reasonable predictions" (usually trend projections) are worthless: we almost always omit some key functional relationship, trends have nasty habits of suddenly reversing themselves, and human values can change at an alarming rate (witness the "environmental crisis").

The problem would not be so serious if we could simply ignore or erase each mistake, admit our errors, and start afresh. Nor would it be so serious if each irreversible error were no more damaging than any other (that is, if we really had the economist's unlimited world of possibilities). But the world does not appear to be that way: I hope to demonstrate in this paper that the usual decision making procedures can lead to sequences of situations where each mistake is likely to be more serious than the last.

It is clear that we need a better understanding of the <u>process</u> of option foreclosure, of getting locked in, as it occurs in sequences of decision analyses. We need to find measures of option loss that reflect the <u>possibilities</u> rather than just the <u>identifiable probabilities</u> of policy failure. Hopefully, by recognizing and being honest about the foreclosure process as a special kind of decision problem, we can begin to design decision making strategies that move away from the myopia of present planning procedures.

2. SOME CONCRETE EXAMPLES

Before examining some general empirical properties of foreclosing decision sequences, I attempt in this section to clarify the problem with case examples. My intent is to make clear that the problem is not just a matter of nonrenewable resources or irreversible physical changes; that issue has long been of major concern in economics (4,9). Nor am I simply concerned about the obvious fact that human values may be impossible to assess clearly and can change unexpectedly, so decisions now may prevent fulfillment of alternative goals later.

The James Bay Development

Canada recently embarked on the largest single resource development project of its history, a hydroelectric power system in the James Bay area of Northern Quebec. The project was sold originally largely on the basis of expected secondary benefits: it was to provide 100,000 jobs for at least two decades. After construction work had begun, some major problems became apparent(15). First, the employment projection was a bit optimistic; the project will only employ about 12000 men. Second, there will be rather severe environmental damage. Third, the local Indian culture (1200 people) will probably be disrupted due to loss of hunting, fishing, and trapping opportunities. The James Bay Corporation and the Quebec government now admit

publicly that the project perhaps should never have been started, but they argue that too much money and effort has already been invested for it to be simply dropped.
They seriously propose now to develop a uranium enrichment industry in the area, to make use of the power. The power was to be mostly exported in the first place, but Canada has recently been having second thoughts about exporting electrical energy. Further, Canada's nuclear development is largely based on the Candu heavy water system which does not use enriched fuel (and therefore has much lower energy requirements for fuel processing). The enriched fuel will presumably be exported, resulting in more rapid depletion of future Candu fuel supplies and competition for international sales of Candu systems. The latest proposal by the James Bay developers is that Canada should switch its own reactors from the Candu system to enriched fuel systems.

The Santee-Cooper Project

Until a few years ago, the U.S. Corps of Engineers had been spending around one million dollars per year on dredging and cleaning operations for Charleston Harbor, the estuary of the Cooper River (72 cfs). Seeing a growing demand for estuarine development (boat basins, domestic and industrial pollution), they expected that diversion of another river (Santee, 15000 cfs) into the system would provide more natural flushing of silt and other pollutants. Unfortunately they neglected to consider a key functional relationship in the hydrodynamics of the estuary (12). When the freshwater flow is low (less than about

5000 cfs), the freshwater mixes rapidly with the salt water, and the whole estuary is flushed each day by tidal movement of the mixed input waters. When the flow is increased, the estuary becomes stratified and the freshwater forms a lens over the salt-water. This lens slows the saltwater movement with each tidal cycle; essentially a stagnant pool of saltwater is created over the estuary bottom. This stagnant pool traps silt and other pollutants. The annual dredging cost has now increased to 6-15 million dollars. Though it would be technically feasible to discontinue the flow diversion, it would be politically difficult and quite expensive to replace the electrical power generation that is also part of the project.

Salmon Enhancement in B.C.

The Canadian government recently decided to increase the productivity of its commercial sockeye salmon populations by investing in artificial spawning areas (a type of "enhancement facility") for some of the adult fish to deposit their eggs. Unfortunately a key functional relationship had not been noticed (14). The salmon are apparently limited in their total abundance not by spawning areas, but by the productivity of the ocean (where the fish grow up after a short period of freshwater life). The enhancement facilities do increase the number of young produced by each spawning fish, as fewer spawners are needed to reach the abundance limit set by ocean conditions - thus a higher percentage of the adult fish can be taken as catch. However, this creates another difficulty; the fish from enhancement facilities are caught by nets that also take other less productive commercial species and species that are of considerable recreational value. To exploit the enhancement fish at higher rates without overexploiting the other species, it will be necessary to build enhancement facilities for the other species also. In the limit, the less productive natural populations could disappear completely, making the fishery economy dependent on a few engineered facilities that are highly vulnerable to natural catastrophes such as floods.

The Spruce Budworm

The spruce budworm is a serious forest pest in Eastern Canada. It attacks mature forest trees, and has had periodic outbreaks (every 40 to 70 years) at least since the 17th century. After World War II, it was decided to use military aircraft to mount an insecticide spraying program over enormous areas of forest land. At first the spraying was directed only at a few areas of mature, valuable forest. However, the land area in mature forest cover has increased steadily, and the spraying program has grown accordingly. The situation is now explosive, with huge areas of mature forest ripe for attack by the insecticide-resistant budworm strain that will inevitably appear. The forest industry and the spraying companies now form a powerful political lobby that may prevent any policy change until it is too late.

Fire Maintained Forests

Many areas of North America and Europe have a vegetation system specially adapted to periodic forest fires (17). The typical vegetation community has three layers: grass, deciduous brush and trees, and large coniferous trees (usually pine). The coniferous trees have adaptations to withstand small forest fires: thick bark and seeds which only germinate after exposure to high temperatures. The system has a natural cycle, involving periodic forest fires that clear away most of the brush and small trees without killing the large conifers. Forest management over the past few decades has been explicitly directed at fire prevention, so the brushy fuel has accumulated to dangerous levels in many areas. The costs of fire prevention are becoming progressively higher, and when fires do occur they are hot enough to destroy the coniferous forest. When the large trees are destroyed over large areas, natural regeneration is very slow and expensive tree planting becomes necessary. There have been expensive test programs involving mechanical removal of the brush, but it appears that large losses to fire will be inevitable in many areas.

The Whaling Industry

Whale fishing has been a perennial pain for conservationists, and the problem has become most acute since World War II. During the late 1940's and 1950's, several nations developed (or allowed development of) large, mechanized whaling fleets and industrial processing facilities. This development was largely based at first on the Antarctic stocks of blue, fin, and sperm whales. The International Whaling Commission, charged by treaty with recommending effective management policies, became bogged down during the postwar development period over a series of questions involving sustainable biological yields and mechanisms for catch regulation. Agreement about biological capabilities of the stocks has now been reached (the Antarctic stocks are all depleted and attention has shifted to northern populations), but an even more serious issue has arisen (8). Japan argues that it should be allowed to deplete all stocks to the minimum level considered safe to prevent extinction, since it must try to rapidly recover the costs of industrial expansion. In other words Japan claims that it has too much at stake in the short run; initiation of sound long range policies should be deferred until all of the world's whale stocks have been depleted.

An Alpine Village

The village of Obergurgl, high in the Tirolean alps of Austria, has received intensive study in the international Man and Biosphere Program. Nestled in a productive valley surrounded by rugged mountains, it is an almost perfect microcosm of economic growth in relation to limited environmental resources (3). Land ownership in the valley is tightly controlled by a few families, so the demographic system is nearly closed to immigration. Fueled by an apparently unlimited demand for winter tourism (skiing) and by population growth in the village, there has been rapid development of tourist facilities since 1950; nearly every young man in the village has been able to build a small hotel or "Gasthaus". Now the building land (safe from avalanches) and the best agricultural land are rapidly disappearing, water pollution problems are becoming severe, and the fragile alpine vegetation communities are breaking down (resulting in severe erosion problems and more avalanches). The population of the village has doubled since 1950, and there is a large cohort of young people who will soon be demanding the opportunity to build hotels. These young people come largely from the poorer farming families who had the land, but neither the time nor the education to join in on the initial boom. Seeing the wealth of their neighbors, these families are now determined to build additional hotels, and they refuse to take seriously any warnings about environmental problems (on which their own business will depend) or the need to maintain some agricultural activities. By using the last safe building land for more hotels, they will even cut off the option of using some land for light industry or other development that might provide an economic buffer against declines in the tourist industry.

3. General Properties of Foreclosing Sequences

I could fill many more pages with examples, but the basic issues reappear with monotonous regularity. Nor are they confined to the regional and local scale; witness the current energy crisis and the willingness of American decision makers to consider extreme measures in the Middle East for maintaining high investment in petroleum based industries.

One could argue that the examples simply represent bad decision making and failure to use available methodologies properly. If the decision makers had been more thoughtful in each case and had carefully outlined future options and uncertainties, they certainly *might* have done better. But the sad fact is that people are not omniscient, and they quite likely would have done just what they actually did. In each case the problems arose not because of poor probabilistic assessments of recognized uncertainties, but instead because of fundamental relationships that were not recognized at all.

Let us be more precise about the general sequence of events underlying all of the examples (Table 1). In each case there is an initial, apparently intelligent investment decision. This investment has three critical properties:

(1) it is based on faith that present trends will continue into the future, or that system response will be monotonically related to investment input;

(2) it entails an economic and political commitment to try to recover investment costs, even if there is no irreversible loss of nonrenewable resources;

(3) its shortcomings (due to failure to recognize some basic relationships) can be alleviated at least temporarily by further investment.

The next step is an additional investment (or use of resources) to try to correct the original mistakes. This second investment is again rational in the same terms as the first; the alternative would be to reverse the original decision and accept the investment loss. Most decision makers would find that alternative politically and psychologically unacceptable, for obvious reasons. Thus the sequence is established; some would call this "progress".

If the process of corrective investment could be maintained

Table 1. Summary of the Example Problems.

Case	Critical Initial Decision	Factors Overlooked	Endpoint Consequence of the Sequence
James Bay Project	Hydroelectric development	Power demands, environmental concerns, Indian culture	Rapid depletion of Canadian nuclear fuel reserves, competition for international sales with Candu system
Santee-Cooper Project	Flow diversion	Estuarine hydrodynamic transition from mixed to stratified	Costly dredging program, loss of environmental quality
Salmon Enhancement	Artificial spawning area	Ocean limitation of population size	Costly enhancement program, loss of natural productivity
Spruce Budworm	Insecticide spraying	Forest growth	Enormous spraying cost, explosive outbreak situation
Fire Maintained Forests	Fire control	Growth of brushy fire fuel	Intolerable costs for fire control, destructive fires
Whaling Industry	Management emphasis on catch control	Dynamics of commercial investment	Choice between large economic loss or extinction of whale stocks
Alpine Village	Hotel development	Distribution of wealth	Economic "monoculture" based only on tourism

indefinitely, there would be no problem. But the examples suggest that there are endpoints, with very disturbing properties:

(1) Even if it is highly productive, the endpoint system is dangerously simplified, so that qualitatively similar perturbations[1] have much more disastrous relative effects than at the start of the sequence.

(2) The endpoint system may be impossibly costly to maintain, yet the largest induced economic infrastructure may depend on its maintenance. The sunk costs (potential loss of capital investment) and the immediate costs of failure are highest.

(3) The number of economically acceptable (benefits exceed costs) options for further corrective action approaches zero, even if risk aversion is low.

4. More Precise Definitions of the Problem

Let me now state a specific hypothesis: there exists a special kind of pathological decision behavior that can arise in perhaps all sequential decision problems. This behavior has its roots in a very human characteristic: we do not like to admit and pay for our past mistakes. The main characteristics of the pathological behavior are increasing investment, increasing costs for system maintenance, foreclosure of decision options, and decreased ability of the managed resource system to absorb qualitatively similar natural perturbations. The impression is

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[1] e.g. bad water flow for one year in the area of a salmon hatchery, a single large input of pollutants, a forest fire.

that a single innocuous investment error can lead almost inevitably to destruction of the managed system. Surely such sequences can be avoided in most cases, if we simply recognize their existence and learn to watch out for them at the outset.

Note that each of the example decision sequences of the previous section begins with a decision that was not actually the first development decision for the resource. In each case I have tried to pick up the decision sequence at the critical point where the foreclosure or locking-in process began in earnest.

A Simple Classification

The examples suggest that we can distinguish at least three types of option foreclosure, in terms of the mechanisms that prevent retreat from faulty investment points:

(1) classical situations involving "irreversible" physical change

(2) situations involving changes in expectations for future returns, i.e. political or economic acceptability

(3) situations involving loss of capital reserves to error correction (forced investments necessary to satisfy basic constraints imposed by society)

Of these, the irreversible physical changes are perhaps the <u>least</u> bothersome, since they are easily recognized and exposed for judgement in the decision making process.

Changes in political and economic acceptability can be defined more precisely in the context of Paretian analysis. Consider a situation in which there are two kinds of benefits or beneficiaries, and a fuzzy or ill defined set of decision options that are expected to produce different combinations of these benefits (Figure 1). Suppose that the system is currently operating (or producing, or expected to produce) with a dominated policy (i.e. better options are possible). An indifference curve of equally acceptable benefit combinations can be drawn through the current policy, and options below this curve are presumably foreclosed. If there is an incremental investment to a new policy position (e.g. when position 2 in Figure 1 is perceived), additional options are lost. The key point is that the real Pareto frontier is likely to be poorly defined (though in a limited physical world it must exist), and the higher benefit options near it are likely to be associated with some of the difficulties outlined above (system simplification, etc.).

Loss of capital reserves to error correction is well illustrated in the salmon example. The Canadian government has decided to invest $300 million in salmon enhancement over the next few years. Yet each spawning channel, which costs less than $1 million, may force additional investments of up to $10 million in hatchery facilities. At that rate, it would not take long to remove all flexibility from the investment program.

A Policy Resilience Perspective

The option foreclosure process is analagous to Holling's ecological "resilience" idea (7). He argues that ecological state spaces are characterized by stability regions. When the boundaries between these regions are crossed, entirely different ecological behavior can be expected (for example,

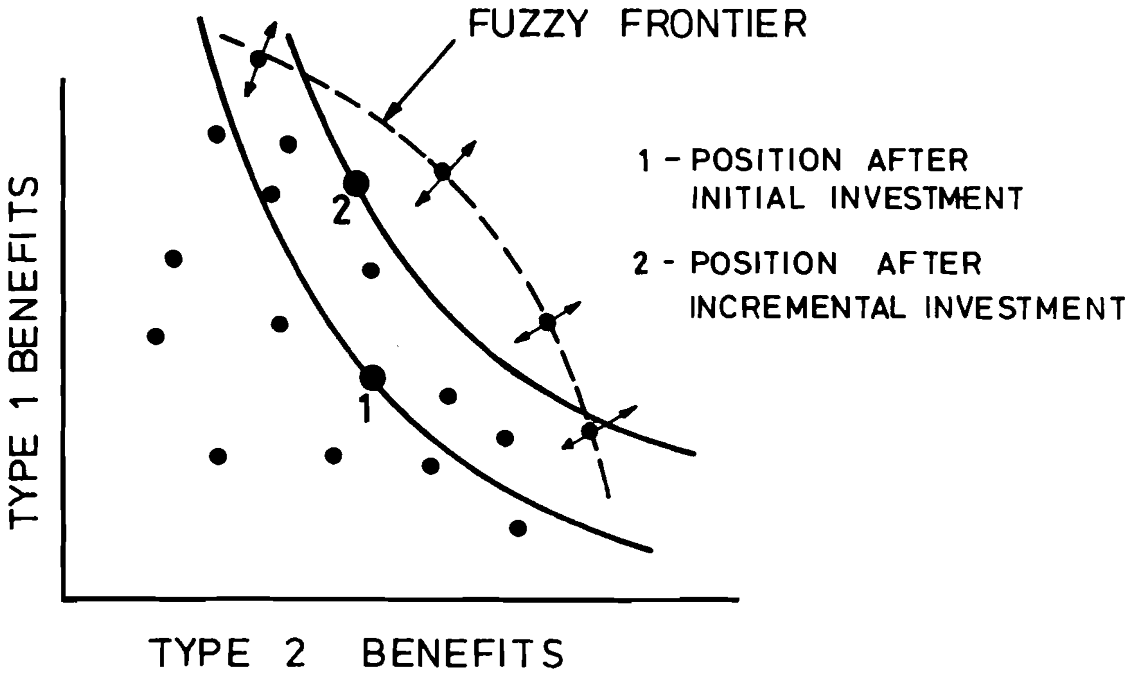
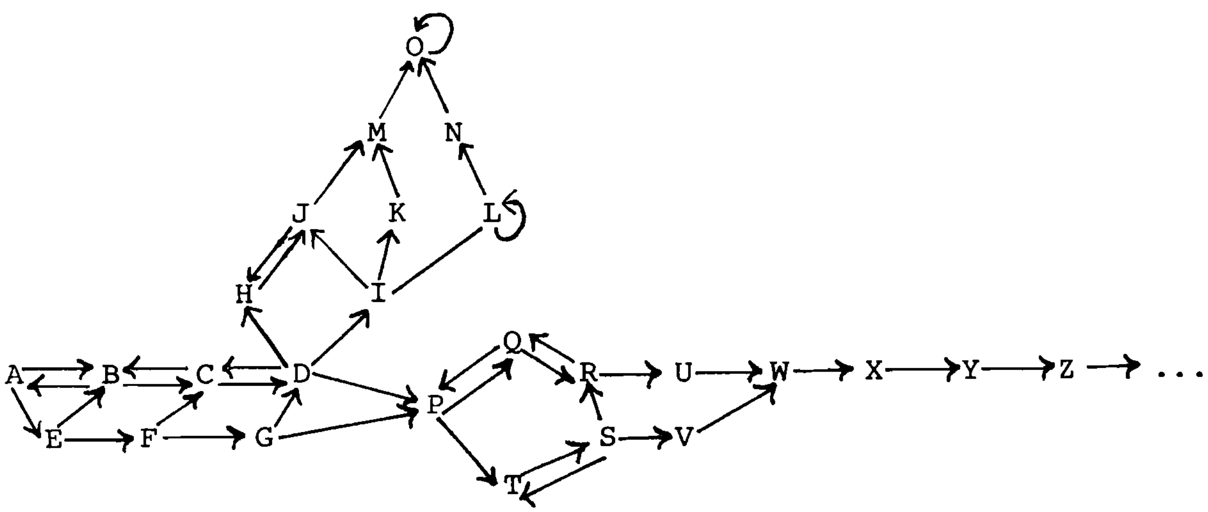


FIGURE 1. Indifference curves through existing or expected benefit situations can define sets of foreclosed options.

a boundary might be defined by the extinction threshold for some species). He argues further that some policies may alter the size or stability properties of the desirable state space regions. Instead of an ecological state space, we can think of an abstract decision space. The idea is that there should exist decision combinations that can be applied sequentially for long periods of time without serious consequences. There exist other decisions (outside of boundaries analogous to stability boundaries) that lead to a positive feedback response (investment making more investment necessary, making more...) and a narrowing tunnel of feasible or viable decision combinations.

One way of looking at the analogy is to consider a set of possible investment decisions: $\{A,B,C,D,\ldots\ldots,n\}$. Presumably some of these decisions are sensible only if others have been made. Let us denote by arrows ($\longrightarrow$) those incremental investment decisions that are politically and economically feasible (though not necessarily Pareto admissible) after any initial decision has been made. We can then draw a network of decision transitions:



It appears that networks of this kind can have some very interesting properties:

(1) There can be "stable" regions (A→B→C→D→E→F transitions versus P→Q→R→S→T transitions).

(2) There can be sequences leading to a positive feedback endpoint (O) as in the budworm and forest examples.

(3) There can be open ended, irreversible sequences (W→X→Y→Z) that depend on the economist's world of unlimited potential substitutes (technological innovation).

Presumably one aim of systems analysis should be to help find sequences that lead out of the traps.

There is no necessary association between state space behavior (stability boundaries, extinction limits, etc.) of the resource system, as opposed to the locking-in process. We would call the natural budworm system resilient - it fluctuates enormously but persists over time. There is no reason to believe that the existing, managed budworm system is any less resilient in that sense; it is bound to undergo a very large fluctuation when the insecticides fail, but it will quite probably still exist. In evolving to become a periodic pest, the budworm itself played a game analogous to the locking-in process: it became more and more specialized and efficient at attacking balsam fir trees. Also, it is probably not true that the present managed equilibrium between budworm and trees is less stable in the sense that it has a narrower region of state space stability - it is just that the same <u>qualitative</u>

perturbation (insecticide resistence) will cause a much larger state change now.

We can bring the decision space and state space resilience concepts together with a very simple-minded model, based on the whaling example. Let us consider the main decision variable for whaling management to be the level of fleet investment, I (number of operating vessels, say). Suppose that this investment has an annual unit repayment cost or depreciation rate r. The annual fixed costs are then rI. Suppose that the total operating costs for fishing are related to whale population N according to the simple relationship o.c. = $\frac{q}{N}$ I where q is a constant. Suppose that the boats can take an annual catch equal to cNI (this is reasonable only provided cNI << N), and that each whale can be sold at a price p. Then the boats will not go out unless catch is greater than operating costs: $cNI \geq \frac{q}{N} I$, or equivalently $N \geq \sqrt{\frac{q}{cp}}$. (1)
This inequality sets one boundary in the state-decision space. Next, let us pretend that the whale stock can produce an annual sustainable catch (excess of births over natural deaths) $C_s = aN(1 - bN)$ where a and b are positive constants. This equation says that the sustainable catch is small for small populations sizes, larger for intermediate populations, and small for large populations. Now let us ask: at what investment levels is it economically feasible (not necessarily profitable) to maintain a given stock size? The answer is given by the simple inequality $pC_s \geq rI + \frac{q}{N} I$ (provided $N \geq \sqrt{\frac{q}{cp}}$)

which can be rewritten as:

$$\frac{aN^2(1 - bN)p}{Nr + q} \geq I \ . \qquad (2)$$

That is, it is economically feasible to maintain a decision-state combination $\{I,N\}$ only if it satisfies this inequality.

Figure 2 shows how these whale equations look in decision-state space. The space is partitioned into regions, based on inequalities (1) and (2) and on the assumption that there exists an extinction threshold for the population. Stochastic stock changes or uncontrolled investment would tend to move the system out of the "stable" region where it is economically feasible to maintain the biological system. Likewise, parameter changes could expand or contract the region; examining inequality (2), the suggestion is that price increases should expand the region, while depreciation rate increases (r) should contract it. Within the region, a variety of investment options are available; outside the region to the right, only fixed or increasing investment is feasible. Near the left side of the graph, only fixed investment (followed by collapse) is feasible, and extinction is likely. It is as though there is a narrowing tunnel of feasible next actions as the lefthand boundary of the feasible management region is approached from the right (see Figure 2). The width of the feasible region decreases as investment is increased; thus the system becomes dangerously "unstable" to state and parameter perturbations

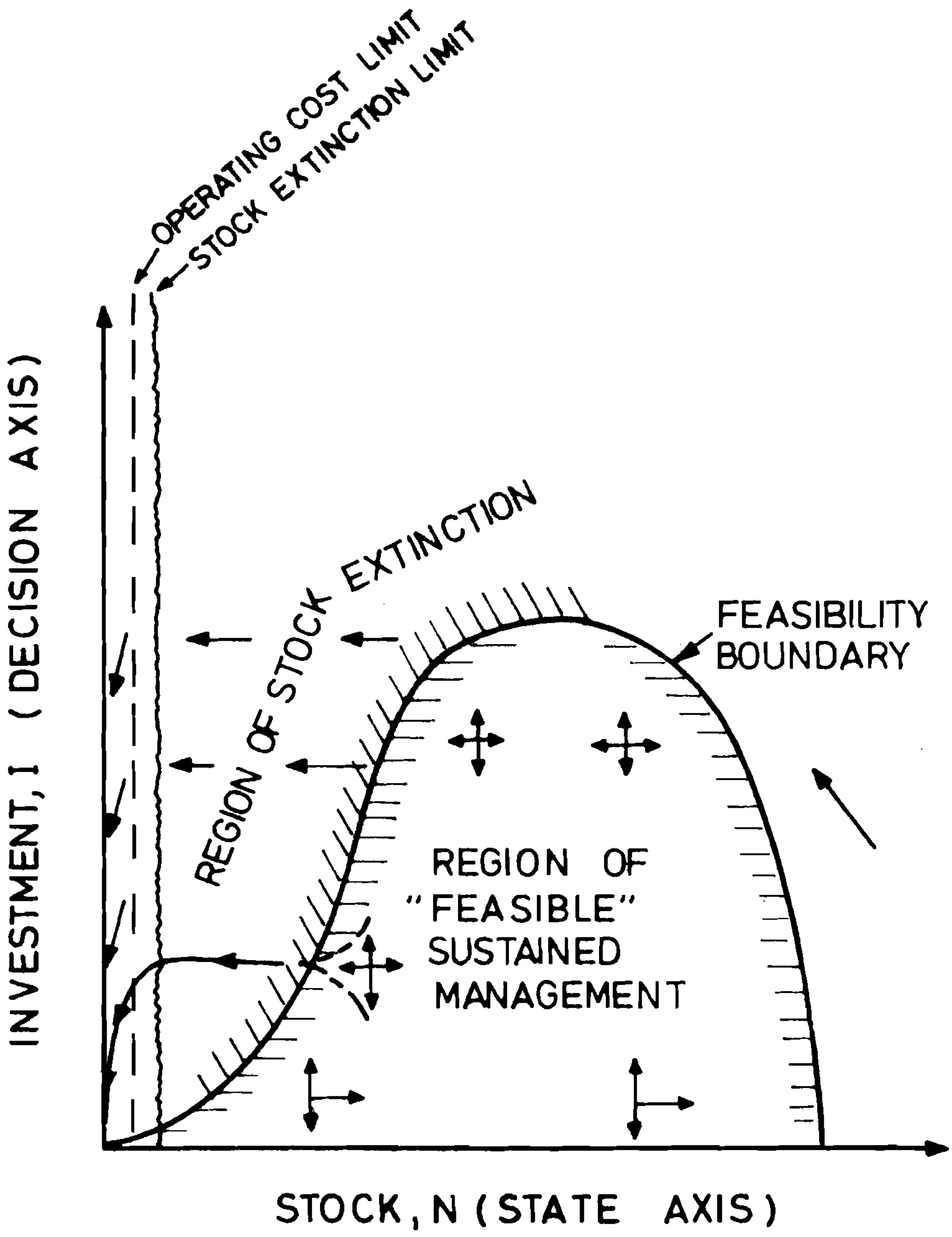


FIGURE 2. Partitioning of the decision - state space for whale management. Explanation in text. "Feasible" ≡ economic benefits > costs.

as investment is pushed to its limit for economically feasible sustained yield management.

Haefele (5) has proposed a very simple and general model to describe societal relationships between population and the development of energy resources. This model provides a second kind of example of boundaries in the state-decision space. His equations lead to the phase relationship between energy and populations as shown in Figure 3.

He argues that we are now along the separatrix "A" and that we should move away from this separatrix to the right, into the stable growth region a. I would argue just the opposite: we should make every effort to remain *on* the separatrix, so as to keep open the option of moving to a low-population, high-energy system. It is easy to imagine politically feasible investments for moving away from the "b" transient, whereas the "a" transients lock us into a growth situation with few palatable options for retreat.

5. Towards Better Methodologies

The empirical examples above indicate that the process of option loss is triggered by ignorance about the existence of system relationships. If this is so, how can it be possible to avoid the trap, without going to the ridiculous extreme of not investing at all? Strictly speaking, this question has no answer; it is always possible to make mistakes. Let us

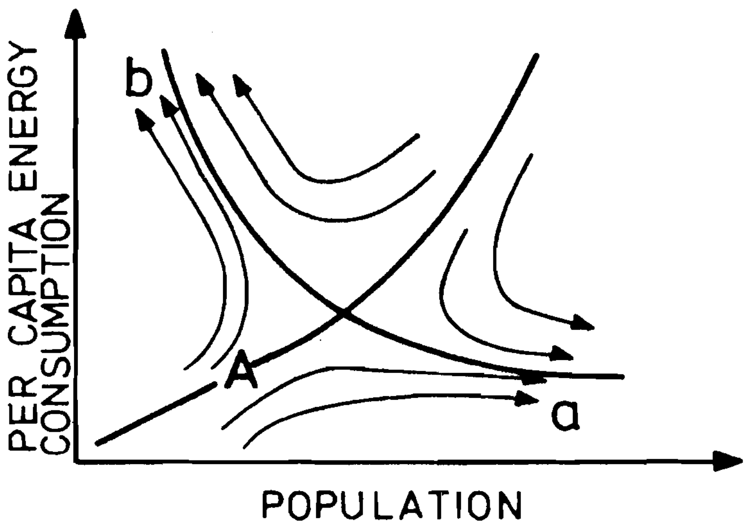


FIGURE 3. Häfele's societal model for energy development.

first ask for simple steps and guidelines that can be followed to make the difficult situations at least less likely.

The first, utterly critical step is to shift our basic way of thinking about systems decision problems. Now we tend to think about single decisions or operating policies, and we work desperately to predict natural system consequences of these. Environmental modelling and cross-impact analyses (10) are good examples: we impose various policies on a simulated system, then ask for the system consequences. <u>We should instead be asking about the decision consequences of policy failure</u> - that is, we should ask questions such as: "If policy x fails or proves inadequate, what kind of decisions are likely to be taken next?" If we can begin to identify dangerous sequences by asking such questions, it should become much easier to make qualitative choices at each decision point, without resorting to deceptive quantitative indicators such as cost-benefit ratios.

<u>Some Preliminary Housecleaning</u>

Before identifying some approaches to avoid the locking-in process, let us first examine some of the widely used decision tools that apparently help to cause the problem in the first place. This should help narrow the search for better methodologies.

Perhaps the most dangerous decision tool now available is deterministic cost-benefit analysis. In theory the method takes risks into account through discounting rates and through inclusion of opportunity costs. However, there is a temptation in applying cost-benefit analysis to assume that "secondary" benefits and costs are likely to be small relative to "primary" ones (16); thus there is a tendency to ignore the kind of "corrective investment" process that could lead to a pathological decision sequence. Cost-benefit analysis is particularly good at leading us into the "economies of scale" trap (witness the James Bay); larger unit investments are one of the surest ways to get boxed into a position from which it is politically infeasible to retreat.

A slightly more attractive set of techniques is available under the general heading "decision making under uncertainty" (11). Decision trees and subjective probability assessments give some hope of helping to better structure our thinking about sequential decision problems. One difficulty is that decision trees become unmanageably large in a hurry, and the "normative form" of analysis may lead us to overlook the dangerous branches. Also decision tree analyses tend to concentrate our attention on future investment possibilities, when we should often be considering retrogressive branches involving the acceptance of investment losses due to past mistakes.

There has been much interest recently in Paretian analysis and metagame theory because they help us to think about problems of multiple objectives and conflicting interests. But these methods require a very precise statement of available options and possible outcomes. This requirement may be a great psychological aid (it is nice to feel that a problem is under control, with very explicit boundaries), but the dangers are as great as in cost-benefit analysis.

I have been a strong advocate of large simulation models with lots of control knobs and points for entering decision options (3). The process of building such models involves a way of thinking that helps to identify the potentially critical functional relationships, but I find a dangerous tendency to be lulled into believing that all of the major factors have been taken into account. We were over a year along into a happy exercise in salmon enhancement modelling before our programmer (Mike Staley) turned up the ocean survival relationship that may trigger a bad sequence of future decisions (see examples section). We should have been concerned with the decision possibilities in the first place, rather than with our detailed modelling of the salmon production system.

General Options for Approaching the Problem

We must go beyond the trivial awareness that decisions follow one another and can lead into trouble. It seems to me that there are at least three strategic options for further work:

(1) We can try to devise better methods for identifying (discovering, anticipating) dangerous relationships and decision sequences. That is, we can try to get rid of the unknowns that cause the trouble in the first place.

(2) We can try to analyze known critical decision points

in hopes that such points have special attributes that make them recognizable even if we cannot see the entire foreclosing sequence that they entail. There are some obvious possibilities for development of indicators: size of initial capital investment, etc.

(3) If we simply admit that it is impossible to avoid foreclosing sequences, we can try to find general strategies for incremental investment that permit graceful retreat when mistakes are recognized. Holling's budworm work (6) on spreading of variability in space rather than time is a step in this direction. Another way to discuss this option is in terms of adaptive control: How can we make the process of detecting and correcting errors more effective, without retreating to such small and widely spaced incremental investments that development becomes prohibitively costly? In relation to this option, there is a need to devise criteria and indicators other than short run economic efficiency for judging investments.

A Format for Practical Analysis

In the long run, the best strategies may be to devise new investment approaches and criteria for development (third option above). However, it is likely that myopic efficiency criteria will continue to dominate development planning for some time. Thus the immediate need is for approaches that help uncover the nasty surprises and decision consequences before investment commitments are made. Considering the variety of surprises that can occur, such approaches must necessarily be of an interdisciplinary, systems character; they must involve a more critical and imaginative dialogue than has been developed through teamwork in the past.

A variety of methodologies now exists for identifying critical assumptions and impacts, such as expert review techniques (e.g. the Delphi method), cross-impact analyses, and interdisciplinary workshops (15). These methodologies can be given a stronger focus for asking more careful questions if they are oriented to the specific task of producing large scale dynamic models. Such models rarely have any real predictive power, but they do force a more careful statement of assumptions than is usual in verbal discourse, and they have a sometimes embarrassing way of revealing unnoticed assumptions by producing ridiculous predictions.

Let us assume that we have gone through a modelling exercise aimed at revealing the system consequences of some decision options. We can then construct a table analogous to a cross-impact matrix, but with the model assumptions listed against the decision options:

		Assumptions (1)	(2)	(3)	....
	(1)				
Investment Options	(2)				
	(3)				

Then for each row-column position in the table, we can ask the question: "What corrective investment(s) would follow under this (row) decision option if this (column) assumption is violated?". Such an "option-assumption" table is a purely psychological tool, intended to help organize the process of asking questions about decision consequences. Also, it is a first-order tool; it does not help to ask about the consequences if several assumptions are simultaneously incorrect. We have applied a simplified version of the procedure in dealing with the salmon enhancement problem in cooperation with scientists of the Canadian government. The results were remarkable: not only were some startling decision consequences revealed, but the questioning also helped to stimulate the scientists to do imaginative thinking about new options to consider for the initial investment program.

Each element of the option-assumption table can be viewed as a window, opening into a future decision tree or another option-assumption table; the problem of analysis can quickly become impossibly large. There may be no way to avoid some "pruning" (11) of the problem, by arbitrarily closing some windows that seem particularly improbable. At this point in the analysis it may be worthwhile to begin introducing some formal methods from decision theory; judgemental probabilities for different assumption errors can be elicited and combined with expected costs and benefits to arrive at filter weightings for each window. The windows with low weightings can then be filtered out or discarded in further analyses. This procedure, and other formalisms that might be applied later in weighing the remaining alternatives, are only meaningful if the original modelling or assumption identification exercise has been successful. There will always remain some residual uncertainty (unrecognized windows); the important thing is to minimize this uncertainty before the formal decision analysis is undertaken.

6. CONCLUSION

This paper has attempted to draw together a different perspective on sequential decision problems in resource development. It has been long on questions and criticisms, but short on constructive suggestions. The main conclusion is simple: while we may avoid some pathological decision sequences by more careful systems analysis, the real need is for more imaginative approaches to the design of investment programs better able to cope with nasty surprises.

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