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ENVIRONMENTAL IRREVERSIBILITY AND UNCERTAINTY RELATING TO RESOURCE USE IN AGRICULTURE

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I. Introduction

In this paper, we attempt to provide an introduction to issues of irreversibility and uncertainty as they relate to the environmental effects of agricultural practices. The two issues are considered together because of the synergistic effect that results when they co-exist. Neither irreversibility nor uncertainty are particularly troubling when they exist in isolation; it is the combination of the two that raises complex decision problems. It should be noted from the start that our discussion of uncertainty falls under the category of "risk management" rather than "risk assessment". In other words, we do not address issues relating to the determination of the probabilities of certain events (e.g., the probability that aldicarb applied to potato fields will reach the groundwater). We instead focus on how decisions ought to be made given that uncertainty exists (e.g., given that the effect of aldicarb application on groundwater is unknown).

The paper is organized as follows. In the next section, conceptual issues related to irreversibility are presented, both in general terms and as the idea has been used in the natural resource literature. In the next two sections, the role of uncertainty is discussed. Two aspects of this are addressed. First, the difference between ex-ante and ex-post points of view are presented especially regarding welfare measurement. In particular, the notion of option value is analyzed. Second, where there is uncertainty, there is an opportunity for learning. Aspects of information acquisition and the implications of irreversibility are discussed. Central concepts here are quasi-option value and the value of information. In the final section, irreversibility is analyzed in the context of resource use in agriculture and attendant environmental implications.

II. Concepts of Irreversibility

In this section, several conceptual issues related to irreversibility are discussed, and the impacts of potential irreversibilities on economic decision making, especially investment decisions, are examined.

1. Physical Irreversibility.

In the physical sense, the notion of irreversibility refers to a situation where the choices that are available in the future (x_2) are constrained by the decisions made today (x_1), i.e., x_2 must belong to a set determined by x_1, so that $x_2 \in x_2(x_1)$. For example, if a given stock $\bar{X}$ of a resource is available to be allocated between now and the future with $x_1 + x_2 \leq \bar{X}$, then there is a physical irreversibility because x_2 is constrained to be less than or equal to $\bar{X} - x_1$.

As an example in the context of agriculture, let x_1 be the decision to apply a pesticide that is known to percolate through the soil and eventually contaminate the groundwater, and let x_2 be the decision regarding consumption of unpolluted groundwater in the next period. Since the amount consumed is constrained to be less than or equal to the amount available and the amount available depends on the decision regarding pesticide application (i.e., the choice of x_1), x_1 determines the choices available for x_2. Thus, the choice of x_1 creates a physical irreversibility. If we let $\bar{X}$ be the initial amount of unpolluted groundwater and interpret the application of pesticides as a "consumption" of clean groundwater in the present, then, in the absence of substantial recharge or self-cleansing, x_1 and x_2 must satisfy $x_1 + x_2 \leq \bar{X}$, and the constraint on x_2 takes the form $x_2 \in x_2(x_1) = [0, \bar{X} - x_1]$.

The above concept of irreversibility can be broadened to include the notion of adjustment costs. In this case, both the decision made today and the adjustment cost that one is willing to bear will determine the choice set for the future, i.e., $x_2 \varepsilon x_2(x_1, a)$ where a is the level of adjustment cost. Presumably, if b>a, then $x_2(x_1, a) \subseteq x_2(x_1, b)$, i.e, if more is spent on adjustment, the set of possible choices in the future is enlarged. A decision is fully irreversible if $x_2(x_1, a) = x_2(x_1, b)$ for all a and b, so that given a choice of x_1, no expenditure can restore the initial possibilities.

It is worthwhile noting that a may be an independent choice variable or it may be a function of x_1, and/or x_2. This introduces the idea of making the "degree of reversibility" a choice variable. For example, contamination of groundwater might in some instances be reversible if sufficient funds are spent on clean-up (or isolation of the contaminants). In this case, a would be the level of expenditure on clean-up and the availability of unpolluted groundwater for consumption in the future would depend on both pesticide application in the present (i.e., the choice of x_1) and expenditures on clean-up (i.e., the choice of a). In this case, "reversibility" would be possible but at a cost. For simplicity, the discussion below does not explicitly address the issue of adjustment costs, although it could easily be expanded to do so.

2. Economic Irreversibility

The fact that some decisions imply physical irreversibility may not be important from an economic point of view. From that perspective, the irreversibility associated with the choice of x_1 is only relevant if the resulting constraint on x_2 is binding, since a non-binding constraint implies that the irreversibility has not affected the optimal choice of x_2.

Consider the example of the stock of a resource $\bar{X}$ allocated between the present (x_1) and future (x_2). In this case, $x_2(x_1) = [0, \bar{X} - x_1]$. If the optimal choice of x_2 is strictly less than $\bar{X} - x_1$, for a given choice of x_1, then the irreversibility of that choice is not economically relevant. Note that tastes, income and technology are likely to determine whether the irreversibility constraint will be binding, since these determine future demands for the resource.

An example considered at length in the resource economics literature is the classic problem of preservation versus development. The irreversibility of the development decision will only affect total welfare if it is desirable to have less development in the future than in the present (Krutilla and Fisher, 1975). In Figure 1, the path of development labeled D_t^m is a path where there is no irreversibility and any level of development can be chosen. The path labeled D_t^* is the optimal path when it is recognized that irreversibility exists, i.e., that D_t can only rise or stay constant. A standard result in this literature is that, as long as D_t^* is rising, it corresponds to D_t^m. However, if D_t^m falls, then they depart. In fact, it must be that D_t^* departs from D_t^m before the actual beginning of the downward phase of D_t^m. This is shown in Figure 1a. If, however, D_t^m always rises, i.e., tastes and technology are such that more developed land always is desired, then along D_t^*, $D(0)$ jumps up to $D^m(0)$ and follows it continually, as in Figure 1b. Finally, suppose that D_t^m is always falling. Then along D_t^*,$D(0)$ either stays where it is, or jumps up to the optimal constant level $D(0) + \Delta D$ and then holds this position, as depicted in Figure 1c. Note that these arguments hold whether or not D_t^* is restricted to be non-decreasing. If, for example, land will "revert to the wild" at some constant rate, then this is equivalent to depreciation of capital in a general capital model with irreversibility. This case is presented by Nickell (1978) with very similar results.

Since the future demands for preservation and the output from development will depend on future income levels, income will be an important factor in determining D_t^m. Similarly, if the constraint is binding so that irreversibility is economically important, then a key factor that will determine the effect of that irreversibility on social welfare is substitutability. The analysis of Nickell (1978) is also useful in his treatment of substitution. Both input and output substitutability are important. If two inputs are substitutes in providing a flow of constant-quality services, then the elasticity of substitution between them determines the length of time that the irreversibility constraint is binding and, hence, welfare losses that may occur. Similarly, the existence of substitutes in consumption of service flows of resources and thus the elasticity of demand for the good is important as well in determining the economic importance of irreversibility.

A form of economic "irreversibility" can also exist in the absence of physical irreversibility. Even if current decisions (x_1) do not physically constrain the choice set from which future decisions (x_2) must be chosen, if x_1 influences the level of marginal benefits that result from a choice of x_2, then the result is analytically similar to the case of physical irreversibility. For example, if utility that results from current and future choices takes the form $U(x_1,x_2)$ where $\partial^2U/\partial x_2\partial x_1 \neq 0$, i.e., where the marginal utility of x_2 depends on x_1, then the choice of x_1 is "irreversible" in terms of its effect on overall utility, and it affects the choice of x_2 just as it would if it caused a physical irreversibility. Note that, if decisions are subject to an interremporal budget constraint, then even if current utility depends only on current decisions, overall utility will take the form given above. This can be seen by substituting a three-period intertemporal budget constraint of the form

$$P_1x_1 + P_2x_2 + P_3x_3 = w_o$$

(where P_i is the appropriately discounted price for period i and w_o is initial wealth) into the separable utility function

$$\tilde{U} = U_1(x_1) + U_2(x_2) + U_3(x_3)$$

to eliminate x_3 and yield $\tilde{U} = U(x_1, x_2, w_o)$. Irreversibility exists since the budget constraint implies that, in essence, future consumption levels are constrained by the choice of current consumption.

Thus, having either (i) physical irreversibility or (ii) marginal benefits from future decisions that depend on current decisions (as a result, for example, of an intertemporal budget constraint) can lead to economic "irreversibility". In fact, (ii) includes (i) as a special case, since if $x_2 \varepsilon x_2(x_1)$ is required and the constraint is binding, then clearly the marginal benefits of x_2 depend on x_1. Thus, in what follows we represent the presence of economic irreversibility by writing the benefit function as $U(x_1, x_2, w_o)$.

Models of decision-making in the presence of irreversibility imply an expanded analysis of decisions based on whole time-paths of variables. These can be quite complicated, but the basic approaches are well known and involve dynamic optimization techniques. However, as noted above, when irreversibility and uncertainty co-exist, the issues are far more complex.

III. The Role of Uncertainty

1. Ex Ante vs. Ex Post Decisions and Optimality

Most real world problems involving time also involve uncertainty. For example, there might be uncertainty about future preferences, income levels, prices or resource availability, where the latter includes uncertainty about future environmental quality. The notion of irreversibility discussed above can be extended to include uncertainty by introducing a random state of the world e. In this case, x_1 implies a physical irreversibility if it constrains x_2 to a set $x_2(x_1,a,e)$ where e is the random variable. More generally, economic irreversibility in the presence of uncertainty implies that the benefit function takes the form $U(x_1,x_2,w_o,e)$.

In the presence of uncertainty, it is important to distinguish between ex ante and ex post behavior, where "ex ante" refers to decisions made prior to knowing the future state of the world (i.e., while there is still uncertainty) while "ex post" refers to decisions made after the future state is known (i.e., after the uncertainty has been resolved). Decisions about production or consumption levels might, in some cases, have to be made ex ante, while in other cases it may be possible to delay the decision until the uncertainty has been resolved. For example, the decision to build an irrigation system is ex ante with respect to the random variable "weather", since the decision must be made before one knows whether the next ten years will be wet or dry years, i.e., it is based only on the probabilities associated with different weather conditions and not on the actual outcomes. Alternatively, the decision to use the irrigation system in any given year is ex post with respect to weather since the decision does not have to be made until after the outcome is known, i.e., after one knows if the year is actually wet or dry. Of course, it is possible (and, in fact, likely) that decisions that are optimal from an ex ante point of view are not necessarily optimal ex post. In other words, the decision that would be made when the state of the world is known (the ex post decision) is not necessarily the same as the decision that would be made under uncertainty (the ex ante decision). For example, if the irrigation system is built because there is a high probability that the following years will be dry and then they in fact turn out to be wet, we may regret having spent the money building the system.

However, if the decision must, in fact, be made before the future is known, then as long as it is optimal in an ex ante sense, the fact that it differs from the ex post decision is relevant only for purposes of determining "regret". Ex ante decisions should be judged only on whether they are optimal ex ante and not on whether they are optimal ex post.

To further illustrate the distinction between ex post and ex ante optimality, consider a model of use of an exhaustible resource that is essential for production. Suppose there exists uncertainty about when, if ever, a perfect substitute for the resource will be discovered, which is assumed to be inexhaustible. An optimal ex ante solution to this problem balances the prospects of (a) running out of the resource and (b) holding too much of the resource and having the discovery of the substitute impose capital losses to those holding the resource. If the discovery occurs, the decision to conserve some of the resource will not be optimal from an ex post standpoint. However, it was still the right decision to make at the time, given the positive probability that the discovery would not occur. Similarly, in a model of development versus preservation where future benefits of these are unknown, included in a determination of the optimal amount of current preservation is the opportunity cost of foregoing development only to find out that preservation was not worthwhile.

2. Measures of WTP

The distinction between ex ante and ex post points of view is important in defining willingness-to-pay (WTP) for a given parameter change. Ex ante WTP refers to the compensation that would be required to maintain a reference level of expected utility if the level of compensation were determined while there is still uncertainty about the future. Alternatively, ex post WTP refers to a compensation level that is decided upon once the future is known and is contingent upon the outcome of the uncertainty. It is possible to measure the benefits of a project using either ex ante or ex post WTP (more generally, compensation). More general definitions of WTP are possible (Graham, 1981) but we restrict our discussion to the ex ante and ex post measures.

Consider an expected change in some parameter that affects total utility. If there is uncertainty (regarding, for example, future preferences, income levels, prices or resource availability), then the effect of the change will be uncertain. We let the parameter be denoted by p and the random variable affecting utility be denoted by $\tilde{e}$. Suppose that x_1 must be chosen before the realization of $\tilde{e}$ is known, but that x_2 may be chosen after $\tilde{e}$ is observed. For given x_1, say $\bar{x}_1$, $x_2^*(w_o,p_o,e,\bar{x}_1)$ solves the problem

$$\max_{x_2} U(\bar{x}_1,x_2,w_o,p_o,e), \qquad (1)$$

where p_o is the value of the parameter before the change and e is a particular realization of $\tilde{e}$. Then x_1 is chosen so as to solve

$$\max_{x_1} E\, U(x_1,x_2^*(w_o,p_o,\tilde{e},x_1),w_o,p_o,\tilde{e}). \qquad (2)$$

The solution is this problem is $x_1^*(w_o,p_o)$. Note that, although x_1^* is not a function of the realization of $\tilde{e}$ (and thus is not a random variable itself), it does depend on the parameters of the probability density function of $\tilde{e}$. Let

$$V(w,p) = EU(x_1^*(w,p),\ x_2^*(w,p,\tilde{e},x_1^*(w,p)),w,p,\tilde{e}) \qquad (3)$$

be the indirect utility function given w and p. Then two measures of ex ante compensation can be defined for a change in p from p_o to p_1. These are known as <u>option prices</u>, and as with the compensating variation and equivalent variation measures defined under certainty, they may be designated as compensating option price (COP) and equivalent option price (EOP). They are defined implicitly by

$$V(w_o - COP,\ p_1) = V(w_o, p_o)$$
$$V(w_o, p_1) = V(w_o + EOP,\ p_o),$$

where p_1 is the value of the parameter after the policy change. For simplicity, we restrict our discussion to the compensating option price (hereafter, just option price) with similar arguments possible for the equivalent measure. Thus, option price (OP) is the amount that must be paid or received to ensure that you are at the same level of <u>expected</u> utility after the change as you were before. It is a measure of ex ante compensation since it represents an amount that would be paid or received prior to knowing the state of the world.

One can also define ex post compensation or consumer surplus given a particular state of the world. Define W(w,p,e) by

$$W(w,p,e) = U(x_1^*(w,p), x_2^*(w, x_1^*(w,p), p, e), w, p, e). \tag{4}$$

Then ex post compensation, denoted here by S(e), is defined by

$$W(w_o + S(e), p_1, e) \equiv W(w_o, p_o, e). \tag{5}$$

Note that ex post compensation depends upon the particular realization of the random variable.

In empirical work, many researchers have used the expected value of ex post consumer surplus, E(S(e)), as a measure of the value of the parameter change, rather than using option price. The main reason is that option price is often difficult to measure. This has raised the question of whether use of E(S(e)) over- or under-estimates the option price, i.e., is option value (OV), which is defined as

$$OV = OP - E(S(e)), \tag{6}$$

positive, negative or zero? The answer to this question depends upon the parameter that is subject to change and the nature of uncertainty. For example, Bishop (1982) shows that, if future preferences are uncertain, then the sign of the option value associated with a change in some price is, in general, indeterminate and depends upon the marginal utility of income in different states. Likewise, in the case of uncertainty regarding resource availability, Freeman (1985) shows that the sign of the option value associated with an increase in the probability that the resource will be available is, in general, indeterminate. More definitive conclusions about the sign of option value are possible in special cases.

However, knowing the sign of option value is not likely to be very helpful. There are several reasons for this. First, if there is more than one alternative being considered and more than one parameter is changed, then we would want to know the sign of equivalent option value, since the ranking of projects based on compensating option price may not be consistent with a utility ranking (Hause). However, a ranking of alternatives based on equivalent option values will not, in general, induce a correct ranking on equivalent option prices (Graham-Tomasi and Myers, 1985). Thus, knowning the sign of option value (and not its magnitude) would be useful only if there are two possible outcomes. Secondly, the special cases needed to sign OV unambiguously are quite restrictive since there must be no uncertainty about demands-- only about resource supply--and moreover, the probability distribution on supply uncertainty must be degenerate either with the project or without it.

Finally, knowing the sign of option value still only provides a one-way test. For example, if we know that OV is positive, then if expected surplus is positive, so is option price. However, if expected surplus is negative, no further conclusions can be drawn.

3. Alternative Welfare Criteria

The above section defined two alternative measures of the benefits of a project, an ex ante measure (option price) and an ex post measure (the expected value of consumer surplus). In general, these two measures of benefits or WTP will differ. Which of these is appropriate depends on the welfare criterion being used to judge the project.

Bishop (1985) has identified three alternative extensions of the Hicks-Kaldor potential compensation criterion that might be used to judge projects under uncertainty. The first is the ex post compensation test, which would require that winners be able to compensate losers in all possible future states, i.e., that net benefits be positive under all possible scenarios. Measures of ex post WTP would be needed to apply this test. However, Bishop argues that the test might be considered to be too stringent since few projects are likely to satisfy it.

An alternative, less stringent version of this test is the expected compensation test, which would require that "on average" ex post winners be able to compensate ex post losers. In other words, the expected value of ex post benefits must exceed the expected value of ex post costs. Again, this would rely on the ex post measures of WTP. However, if the decision about the project must be made before the uncertainty is resolved, then Bishop argues that the decision should be based on a notion of ex ante WTP, since there are, in fact, risks associated with the project and ex ante WTP reflects attitudes toward risk while ex post WTP does not.

Thus, a third alternative is the ex ante compensation test, which requires that the ex ante WTP for the project by those who expect to gain from it exceed the ex ante compensation that would have to be paid to those who expect to lose. Of course, those who expect on average to gain may not in fact gain when the uncertainty is resolved and likewise for those who expect to lose. However, as noted above, that is not relevant for purposes of judging whether the ex ante decision was optimal from an ex ante point of view.

Graham (1981) provides a further discussion of the appropriate welfare criterion to use and concludes that the answer depends on the characteristics of risk (e.g., whether it is collective or individual) and the nature of the affected parties (e.g., whether they have identical preferences or not). A key component to this analysis is the potential for risk sharing through alternative compensation schemes, and through insurance or other contingent markets.

In summary, there are several alternative criteria that could be used to determine whether "benefits exceed costs" when the benefits or costs are uncertain. Any single criterion will not generally be preferable to all others in all cases.

IV. Information, Uncertainty and Irreversibility

The previous section highlights the fact that, when there is irreversibility and uncertainty, the timing of the resolution of uncertainty (more generally, the receipt of information) relative to the timing of choices is very important. As an example, recall the model above where x_1 was chosen ex ante and x_2 was chosen ex post, i.e., after the value of the random variable $\tilde{e}$ was observed. This is a situation in which perfect information about $\tilde{e}$ is forthcoming before x_2 is chosen. One can compare this to a situation in which both x_1 and x_2 must be chosen under uncertainty about $\tilde{e}$.

Two issues arise in this context. One concerns the optimal choice of x_1 when information will be available versus when it is not, and the other concerns the magnitude of the expected payoffs (i.e., about $V(\cdot)$) in the two cases. The former issue is studied in the literature on quasi-option value; the latter is studied in the literature on the value of information.

Suppose that both x_2 and x_1 must be chosen ex ante. Then we write $\overset{o}{x}_1(w_o,p_o)$ and $\overset{o}{x}_2(w_o,p_o)$ as the solution to

$$\max_{x_1,x_2} \; E\, U(x_1,x_2,w_o,p_o,\tilde{e}),$$

and let

$$\theta(p_o,w_o) = E\, U(\overset{o}{x}_1(\cdot),\overset{o}{x}_2(\cdot),w_o,p_o,\tilde{e}).$$

Here, the "o" signifies that no new information is available before x_2 is chosen. $V(p_o,w_o)$ is defined as above in equation (3), reproduced below:

$$V(p_o,w_o) = E\, U(x_1^*(p_o,w_o),x_2^*(w_o,p_o,\tilde{e}),w_o,p_o,\tilde{e}).$$

Thus, θ is the maximum utility attainable when x_2 must be chosen ex ante, while V is the maximum utility attainable when x_2 can be chosen ex post. Then, the expected value of perfect information is defined to be

$$V(p_o,w_o) - \theta(p_o,w_o) \geq 0.$$

Notice that this is defined in units of utility and is non-negative since having free information never can make you worse off. Money metric measures of the value of information are defined implicitly by

$$\theta(p_o, w_o + EI) = V(p_o, w_o)$$

or by

$$\theta(p_o, w_o) = V(p_o, w_o - CI),$$

where CI is a compensating information value and EI is an equivalent information value.

These definitions can also be applied to situations where less than perfect information will be gained about $\tilde{e}$ before x_2 must be chosen. Often this is represented in Bayesian terms where the decision maker has a prior probability distribution, say $F_1(\tilde{e})$, which is used when x_1 is decided upon. Then (s)he receives a signal or message which is correlated in some way with $\tilde{e}$, and forms via Bayes rule a posterior distribution $F_2(\tilde{e})$ which is "more precise" than $F_1(\tilde{e})$. The posterior is used in the choice of x_2. When x_1 is chosen, the decision maker makes a guess about both what $\tilde{e}$ will be and also what message will be received. One message system is said to be more valuable than another if using it provides a higher expected payoff (Marshak and Miyasawa, 1968).

Of course, information is not costless and one would want to take this into account when deciding how much to purchase. One could make this decision by comparing CI to the cost of the information. Magill and Danthine (1984) present a model where a firm can invest either in capital or in information about a random factor in the production function. They show that, if the firm would not change its investment in capital when it has information (this depends, in their model, on a risk aversion coefficient), then no investment in information is made. Thus, information is not gathered for its own sake. However, when information <u>does</u> change the investment in real capital, if the cost of information acquisition is not "too great", some information is gathered, but it is not generally optimal to reduce all uncertainty by gathering complete information. We conjecture that in a slightly more general model where there is some input which could be chosen ex post to mitigate poor (in an ex post sense) ex ante input decisions, then the substitution possibilities between these inputs will play a role in the decision of how much information to gather. In particular, it would seem that if substitution possibilities are greater, then optimal investment in information will decrease.

One can also inquire into how the prospect of receiving information in the future affects current choices. Jones and Ostroy (1984) provide a very general result along these lines. They study two orderings, one on the variability of the decision maker's prior beliefs about the uncertain future and one on the flexibility of current actions. One set of beliefs is more variable than another if more uncertainty will be resolved before x_2 must be chosen. This could be either because "better" information will be obtained, or because there is more initial uncertainty to resolve. Thus, if one situation involves very little ex ante confidence in beliefs, then beliefs will be more variable than if the decision maker is quite confident of initial information. The ordering on flexibility is just the definition we use above with adjustment costs: one choice of x_1 is more flexible than another if the set of positions attainable in the next period for a given adjustment cost is larger. That is, $\hat{x}_1$ is more flexible than x_1 if $x_2(x_1,a) \subseteq x_2(\hat{x}_1,a)$ for all a. Jones and Ostroy (1984) establish that under fairly general conditions, the ordering "more variability in initial beliefs" induces an ordering on flexibility of initial positions; in particular, an increase in the variability of beliefs leads to an increase in the flexibility of initial positions.

Although this is an interesting result, it is too general in that it gives little guidance as to how much flexibility should be increased. The literature on quasi-option value (QOV) seeks to give more definitive answers in models with considerably more structure than that used by Jones and Ostroy.

Suppose that the problem is one of preservation versus development, with x_1 the amount of land developed in the first period, x_2 the amount of land developed in the second period, and $x_1 + x_2 \leq \bar{x}$ the total area of land. Then any choice x_1 smaller than another is "more flexible" in the ordering of Jones and Ostroy. Irreversibility holds since $x_1 \geq 0$ and $x_2 \geq 0$ is required. Further, the benefit function is written as

$$U = U_1(x_1) + E\, U_2(x_1 + x_2, x_2, \tilde{e}).$$

Note that $U_1(x_1)$ implicitly represents $U_1(x_1, \bar{X} - x_1)$, and U_2 represents $U_2(x_1 + x_2, \bar{X} - x_1 - x_2, x_2, e)$, so that preservation benefits also are included.

Returning to the definitions of $\overset{o}{x}_1$ and $\overset{o}{x}_2$ and x_1^* and x_2^* ($\overset{o}{x}$ is the choice in the no-information scenario, x^* is the choice when perfect information about $\tilde{e}$ is obtained before x_2 must be chosen), the central question concerns the relationship between x_1^* and $\overset{o}{x}_1$. In general, they are different. When will $x_1^* \leq \overset{o}{x}_1$ hold, i.e., when will the prospect of learning about $\tilde{e}$ before x_1 is chosen cause one to choose less development in the initial period?

This issue is discussed at length by Hanemann (1983). In general, the result $x_1^* \leq \overset{o}{x}_1$ does not hold. However, it will hold if

$$U_2(x_1 + x_2, x_2, \tilde{e}) = \psi(x_1 + x_2, \tilde{e}) - \gamma(\tilde{e}) g(x_2),$$

where ψ is concave in $x_1 + x_2$ and g is convex. In fact, this seem quite reasonable if $g(x_2)$ is the cost of development. The amount by which x_1 is lower when information is obtainable is determined by the marginal user cost of initial development. This cost represents the expected present value of the loss of future net benefits that results from a marginal increase in initial development. It can be thought of as the amount of a tax per unit of development that could be placed on a myopic decision maker who ignores the potential for learning in order to induce him or her to make the same initial development decisions as the decision maker who incorporated learning into his/her decision rule.

In most of the QOV literature, the development decision takes on an "all-or-none" character, i.e., $x_1 = 0$ or $x_1 = 1$. This would be the case if the benefit functions U_1 and U_2 were linear in x_1 and $x_1 + x_2$, or if technological considerations constrained the decision in this fashion. When the decision is all-or-none, the marginal user cost takes on a simple and appealing form: it is the value of information conditional on there being no development in the first period. Naturally, if the area is developed completely initially, then information has no value because of the irreversibility constraint and the completely inflexible initial position. The value of information when $x_1 = 0$ gives the change in the maximized objective function from being able to have a choice on x_2; as such, it gives the advantage of initial preservation over initial development due to information and, therefore, also gives the change in the decision rule on x_1.

Now suppose instead that the decision is not of an all-or-nothing variety, i.e., partial development during the first period is possible. In this case, there is a clear difference between an expected value of information and a change in the decision rule, and the marginal user cost of development is not equal to this value of information. Hanemann (1983) claims that QOV is not well defined in this context. We argue instead that one merely has two well-defined concepts which are applicable to different questions. The value of information is relevant to decisions on "information purchases." The marginal user cost relates to optimal choices of control variables.

Bernanke (1983) and Graham-Tomasi (1983) have presented similar analyses of user costs in the general (i.e., not all-or-nothing) case. Bernanke studies the choice of a single project from a menu of possible investment projects and discusses the gain in the second period from flexibility relative to mypoic choices based on first-period benefits alone. Graham-Tomasi (1983) analyzes a development versus preservation model. In his model, the decision maker who ignores learning behaves myopically. Assuming differentiability, he shows that the marginal user cost of initial development decisions is given by (in the case of perfect information)

$$\tau = \rho \int_{\bar{E}} \frac{\partial V^2}{\partial x_1} (x_1, \tilde{e}) \; d\, F(\tilde{e})$$

where ρ is a discount factor, $V^2(x_1, e)$ is the maximum second period payoff given the choice of x_1 and the realization of $\tilde{e}$, $F(\tilde{e})$ is the prior probability distribution on $\tilde{e}$, and $\bar{E}$ is the set of realizations of $\tilde{e}$ such that the decision maker would reverse development ($x_2 < 0$) if (s)he could, i.e., $\bar{E}$ is the set of realizations of $\tilde{e}$ such that the irreversibility constraint is economically meaningful as we discussed above. It is important to note that in Graham-Tomasi (1983) for realizations of $\tilde{e}$ in the compliment of $\bar{E}$ the marginal user cost is zero. This may not hold in more general formulations. Thus, in this work, as well as in Bernanke (1983), there is an asymmetry between "good news" and "bad news," and this asymmetry creates the quasi-option value.

While this result holds in a fairly specialized model, the concept of a marginal user cost for initial inflexible decisions due to irreversibility and the potential receipt of information is quite powerful and can be developed in more general models. In particular, in the development-preservation literature, x_2 and x_1 are perfect substitutes in the second period. If they are not perfect substitutes, the degree of substitutability between them will play a role in determining optimal choices of x_1. Of course, so will the shape of the benefit function for the good produced by x_1 and x_2, and this will depend in turn on the availability of substitutes in consumption.

V. Irreversibility in Resource Use in Agriculture

In the context of resource use in agricultural production, there are several potentially irreversible impacts which can be identified. To the extent that certain policies can and should be devised to mitigate these impacts, for the reasons discussed above, such policies should incorporate an awareness of irreversibility, of uncertainty, and of the possible receipt of information in the future.

Figures 2, 3 and 4 depict diagrams of the elements of the policy program of resource use and environmental effects in agriculture. The first diagram, Figure 2, depicts the structure of the overall problem. The next two elaborate in more detail two components of the first diagram, i.e., those encased in a dotted line. We believe that these capture the breadth of our problem area, and the scope of a possible research agenda.

Several of the impacts identified are irreversible or subject to modification only with high adjustment costs. These include:

(1) contamination of groundwater, which is often virtually irreversible since the natural cleansing rate is very slow and accelerated clean-up costs are very high;

(2) human health effects from contaminated groundwater or surface water, since often the consumption of contaminated substances produces chronic or long-term effects;

(3) aquatic/ecological effects of contaminated surface water, since exposure of fish to high levels of certain chemical substances or aquatic conditions can inhibit normal reproductive processes. However, this may represent adjustment costs, since restocking can occur. Any fundamental ecological disruption may be considered irreversible;

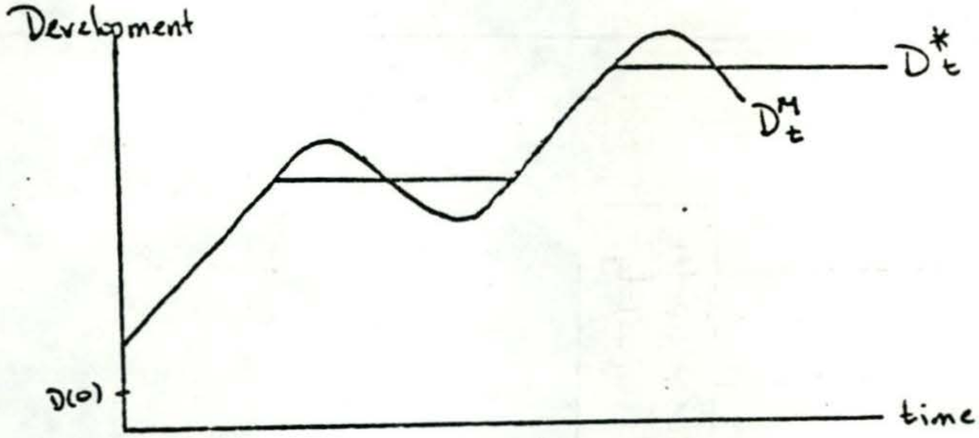
(4) productivity effects of soil loss, since build-up of soil is very slow. While other inputs may substitute for soil to some extent, this obviously is not true for all soil depths; and

(5) off-site effects of erosion may include some effects which can be reversed at some cost (e.g., siltation of reservoirs and navigation routes) and others which are irreversible or reversible only at high cost (e.g., loss of wildlife habitat in streams or backwater areas of rivers).

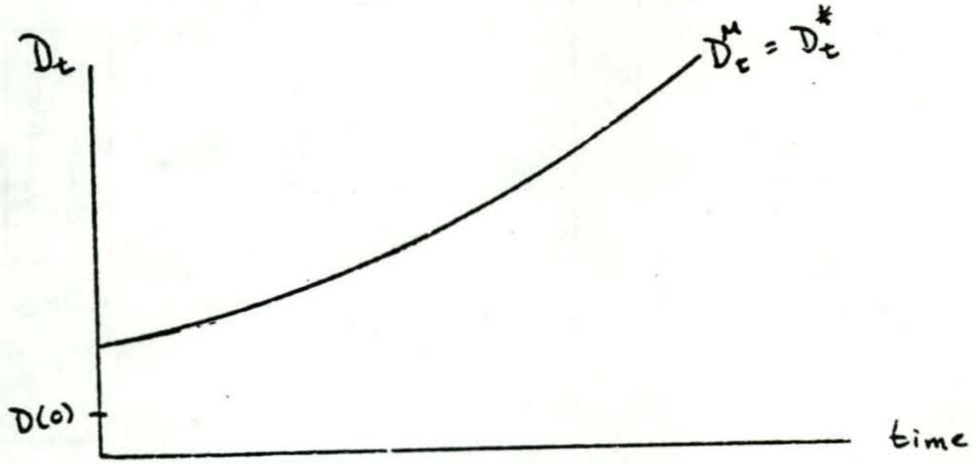
As depicted in the diagrams in Figures 2-4, these are interconnected. For example, soil erosion may cause irreversible on-site and (possibly) off-site effects. However, some methods of reducing erosion, such as conservation tillage, may entail greater use of chemical inputs which cause irreversible losses of groundwater quality. Other methods, such as switching to pasture on steep slopes may lead to problems of animal waste management and irreversible environmental effects from this source. As well, change in agricultural land uses to adoption of some conservation measures and other forces may involve irreversible uses of land for other purposes.

As discussed above, the economic and policy implications of irreversibility depend on substitution possibilities both in consumption and production of goods and services. For example, a constant-quality water service may be provided by a combination of a nature input of a given quality and capital in the form of treatment. Some kinds of contaminants may involve greater substitutability between water and capital in production than other kinds. Further, different final services have different substitution and welfare implications. For example, groundwater used for irrigation water may be contaminated with little economic effect while untreatable contamination of wells for drinking water may involve very expensive substitutes and large economic effects.

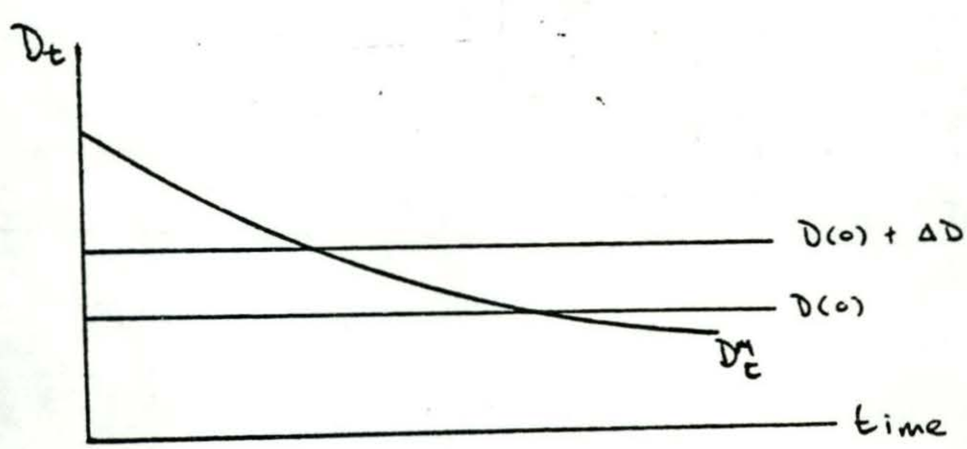
FIGURE 1


Development
D_t^*
D_t^M
D(o)
time

(a)


D_t
$D_t^M = D_t^*$
D(o)
time

(b)


D_t
$D(o) + \Delta D$
D(o)
D_t^M
time

(c)

FIGURE 2

General Interactions

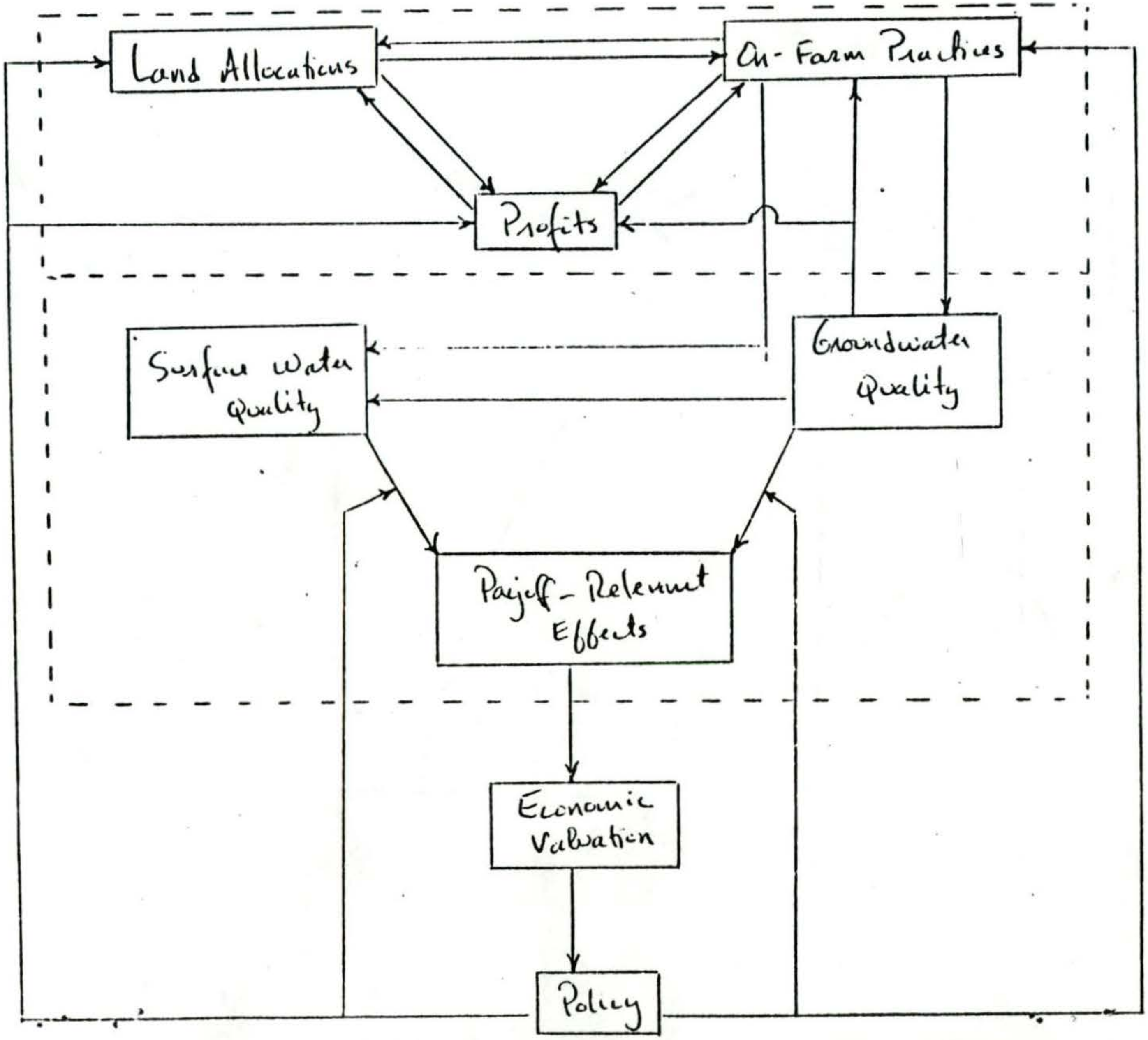


FIGURE 3

Land, Practices, Profits

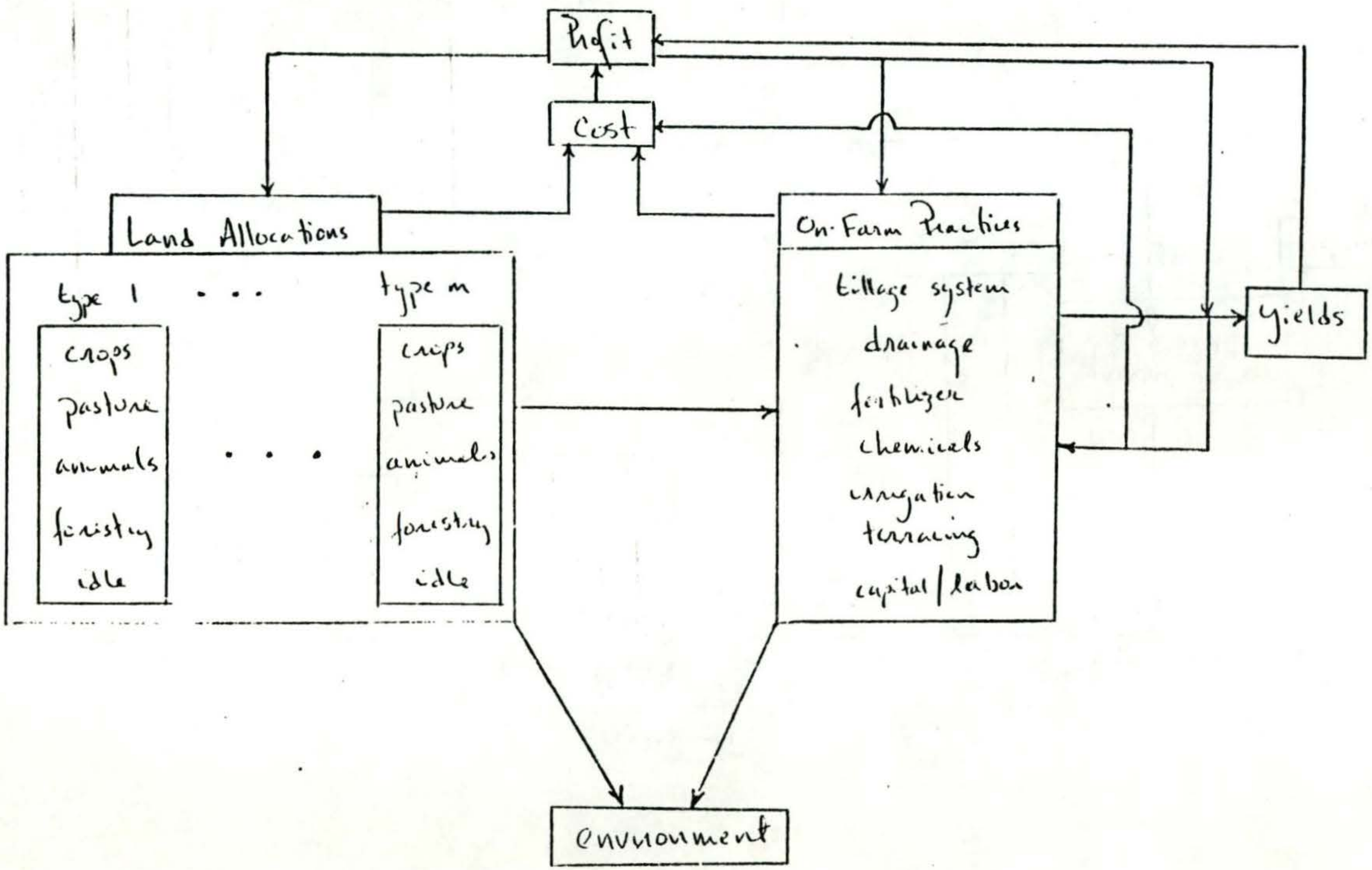
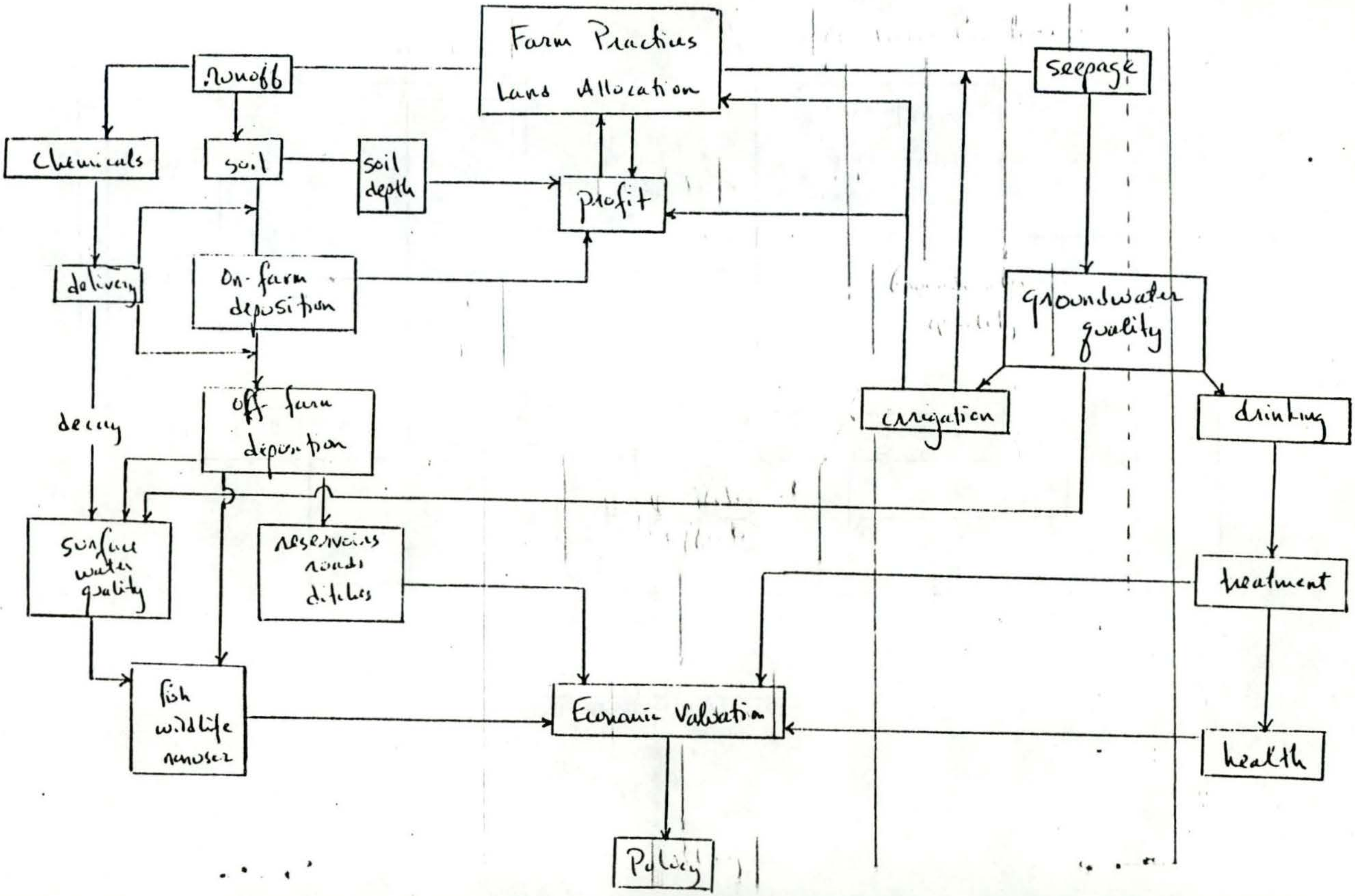


FIGURE 4

Environment



References

Bernanke, B.S. (1983). "Irreversibility, Uncertainty, and Cyclical Investment," Quarterly Journal of Economics, 98:85-106.

Bishop, Richard C. (1982). "Option Value: An Exposition and Extension." Land Economics 58(1):1-15.

Bishop, Richard C. (1985). "Resource Valuation Under Uncertainty: Theoretical Principles for Empirical Research." Unpublished manuscript.

Freeman, A. M. (1985). "Supply Uncertainty, Option Price, and Option Value." Land Economics 61(2):176-181.

Graham, Daniel. (1981). "Cost-Benefit Analysis Under Uncertainty," American Economic Review, 71:715-25.

Graham-Tomasi, Theodore. (1983). "Uncertainty, Information and Irreversible Investments." Draft manuscript. Department of Agricultural and Applied Economics, University of Minnesota, St. Paul.

Graham-Tomasi, Theodore and Robert Myers. (1985). "Uncertain Supply of Environmental Quality and the Measurement of Welfare Change," unpublished.

Hause, J.C. (1975). "The Theory of Welfare Cost Measurement," Journal of Political Economy 83:1145-82.

Hanemann, W.M. (1983). "Information and the Concept of Option Value." Working Paper No. 228, Giannini Foundation of Agricultural Economics, University of California.

Jones, R. and J. Ostroy. (1984). "Flexibility and Uncertainty," Review of Economic Studies, 51:13-32.

Krutilla, J. V. and A. C. Fisher. (1975). The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources. (Baltimore, Md: Johns Hopkins University Press): pp. 48-57.

Magill, M.J. and J. Danthine. (1984). "Investment in Information Acquisition." MRG Working Paper No. M8430, University of California at Los Angeles.

Marschak, J., and K. Miyasawa. (1968). "Economic Comparability of Information Systems," International Economic Review, 9:137-174.

Nickell, S.J. (1978). The Investment Decisions of Firms, Oxford: Oxford University Press.