

## Economic Analysis of Biodiversity Conservation: Two Challenging Problems\*

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### Introduction

Why does biodiversity conservation matter? What will happen if we do not take action to conserve it? Can we be sure of protecting an ecosystem and keeping it as we want? These are oft-asked questions in research and practice of biodiversity conservation. From the viewpoint of economics, this study identifies novel and challenging problems behind these questions and suggests directions for future research.

### Two Challenging Problems

Why is biodiversity conservation important for our society? A simple reason is that biodiversity is useful. We know that biodiversity increases the long-run average productivity of bio-resources, works as insurance against diseases and insect pests for agricultural products, and provides models for medicines and industrial chemicals. At the same time, we know that our motivation to preserve biodiversity comes not only from its practical usefulness, but also from its aesthetic value and from ethical considerations such as stewardship. To make the right decisions about conservation/development of an ecosystem, those values need to be taken into account. How, though, can we evaluate those intangible and non-economic values? This is the first problem we investigate.

The second problem concerns uncertainty. Several policy measures for biodiversity conservation have been proposed and implemented. But, do such measures actually ensure conservation? What would happen without such measures? No one has been able to answer these questions convincingly because there is formidable uncertainty between human intervention and its consequences for an ecosystem. Expectation calculation, a conventional method in decision theory, may be unable to tame this type of uncertainty because we may not be able to choose a plausible probability distribution, even in the subjective sense. How can we develop a decision theory approach for this situation? This is the second problem we investigate.

### Diversity Function

The first question mentioned above motivates recent study on *diversity functions*. A diversity function maps a set of species to a nonnegative number that is interpreted as the *existence value* of the ecosystem consisting of the species. The term “existence” signifies that the value is not derived from the practical usefulness of the species, but generated just because they exist.

In his seminal paper, Weitzman (1992) took a course in which the value of diversity was calculated based on the data of the existence value of each species and the *dissimilarity* between two species.

Let  $V(i)$  be the existence value of species  $i$  and  $d(i, j)$  be the dissimilarity of species  $i$  for species  $j$ , which

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\* Summary of the Japanese article by Ken-Ichi Akao: 赤尾健一(2006) 生物多様性の経済分析—多様性関数と不確実性に関する最近の研究—, 環境経済・政策学会年報 11, 136—147.

is a pseudo distance in the sense that  $d(i, j) \neq d(j, i)$  in general. Then the existence value  $V(\{i, j\})$  of the set of species  $\{i, j\}$  is defined by:

$$V(\{i, j\}) = V(\{j\}) + d(i, j) = V(\{i\}) + d(j, i).$$

Weitzman defines the *distinctiveness* of species  $k$  for the set of the species  $S$  by:

$$d(k, S) = \min [d(k, s) | s \in S].$$

We obtain the diversity of the set  $\{i, j, k\}$  as follows:

$$V(\{i, j, k\}) = d(k, \{i, j\}) + V(\{i, j\}).$$

The diversity of a set of four species is derived in a similar way using the diversity of the subset of three species and the distinctiveness of the remaining species. This recursive method enables the diversity to be obtained for any set of species. Weitzman's diversity function has been used in empirical research, including research by Weitzman (1993) and Oka et al. (2001). As the dissimilarity, Weitzman (1993) employs the genetic distance and Oka et al. (2001) use the sum of years with which two species evolved from their common ancestor.

Nehring and Puppe (2002) take another approach. They assume that each species has its own valuable attributes. Their diversity function is constructed by summing up the values of the attributes contained in the set of species under consideration. Let species  $i, j, k$  be flowers. Suppose that species  $i$  has the attributes "fragrant" and "gorgeous,"  $j$  has "fragrant" and "exotic," and  $k$  has "gorgeous" and "exotic." Denote the values of the attributes "fragrant," "gorgeous" and "exotic" by  $\lambda_f, \lambda_g$  and  $\lambda_e$ , respectively. Following Nehring and Puppe, the diversity of the set of three flowers is calculated by:

$$V(\{i, j, k\}) = \lambda_f + \lambda_g + \lambda_e.$$

In general, the diversity of a set of the species  $S$  is defined by

$$V(S) = \lambda(\{A_1, \dots, A_m\}) = \sum_{j=1}^m \lambda(\{A_j\}),$$

where  $\{A_1, \dots, A_m\}$  is the attributes contained in  $S$ .

Nehring and Puppe show that:

- (a) their diversity function is a kind of Neumann-Morgenstern utility function, so that expected utility approach is applicable;
- (b) their "attributes" approach replicates Weitzman's diversity function as a special case; and
- (c) Weitzman's diversity function is too restrictive to express our evaluation of biodiversity.

The last finding is exemplified by the case of flowers above. When we lose species  $i$  from the three flowers, we do not lose the diversity of attributes and thus the loss of diversity is zero. However, Weitzman's diversity function suggests a diversity loss. Although the example is quite artificial because in the real world each flower species has its own individuality, the point is that Weitzman's diversity function may face a logical contradiction. Nehring and Puppe clarify that Weitzman's diversity function is well behaved only if the attributes are located on a line (one dimensional attribute case).

While the attributes approach by Nehring and Puppe is more comprehensive than Weitzman's approach, it allows too many attributes to be included in the diversity function, so it seems difficult to find a plausible functional form. Due to this difficulty, the attributes approach has not been applied to empirical research.

### Ambiguity

The second problem, the issue of how to develop a decision theory approach, has been studied from several perspectives. Among them, much interest has been attracted by a generalization of the expected utility hypothesis. Gilboa and Schmeidler (1989) assume that an agent cannot specify a probability of an uncertain event, but can have a set of possible probability distributions (multi-priors) and can assign a probability to each prior in the set. In other words, this is a situation in which an agent considers a lottery of a lottery. This type of uncertainty is called *ambiguity*, or *Knightian uncertainty*, after Frank Knight, the great economist of the early twentieth century who distinguished risk and true uncertainty; the former is defined as randomness with knowable probabilities and the latter as randomness with unknowable probabilities.

In addition to the axioms for expected utility hypothesis, they posited the axiom called *uncertainty aversion*: an agent weakly prefers the average distribution of priors to the set of priors. Then, the agent makes a decision such that it maximizes the expected utility under the *worst* prior in the sense that the expected utility is minimized. The utility is called the maxmin expected utility (*MEU*).

The formal illustration is as follows. Consider a two period model covering today and tomorrow. Suppose an ecosystem consists of  $n$  species. There are  $2^n$  possible states for the situation of the ecosystem tomorrow. Let diversity function  $V(s)$  express the present value of the biodiversity in monetary terms when state  $s \in S \equiv \{s_1, s_2, \dots, s_{2^n}\}$  is realized. A prior  $\phi$  on conservation is represented by a probability distribution of the states  $p^\phi(s; c)$ , where  $c$  denotes conservation effort invested today. Denote by  $\Phi$  the set of the priors. An agent then solves:

$$MEU(\Phi, p^\phi, V) = \max_{c \geq 0} E \left\{ \min_{\phi \in \Phi} \sum_{s \in S} p^\phi(s; c) V(s) - c \right\}.$$

This is the maxmin expected utility. The maxmin expected utility is not as optimistic as the expected utility (*EU*):

$$EU(p^\phi, V) = \max_{c \geq 0} E \left\{ \sum_{s \in S} p^\phi(s; c) V(s) - c \right\} \geq MEU(\Phi, p^\phi, V).$$

On the other hand, the maxmin expected utility is not as pessimistic as the maxmin utility (*MU*):

$$MU(\Phi, p^\phi, V) = \max_{c \geq 0} \{V(\underline{s}(c)) - c\} \leq MEU(\Phi, p^\phi, V),$$

where  $\underline{s}(c) = \arg \min_{s \in S} \{V(s) \mid p^\phi(s; c) > 0, \phi \in \Phi\}$ . Therefore, decision making based on the *MEU* cares about a possible bad event more than the *EU*, but less than the *MU*. Note that the *MU* suggests an extremely deliberate decision such as “do not go out because you may have a traffic accident.”

The main difficulty of the maxmin expected utility is that there is no plausible assumption about the set of priors  $\Phi$ . Prevailing assumptions such as rectangularity (Chen and Epstein, 2002) are employed to keep a model analytically tractable, but the economic justification is difficult.

### Perspective for future research

Recent developments in the theory of diversity function and the treatment of uncertainty provide greater insight into the theoretical grounds of biodiversity conservation. However, further research is necessary before being able to apply these insights in practice, particularly to decision making for conservation/development. The standard decision tool is cost/benefit analysis (CBA). These new approaches suggest that conventional CBA should be modified by incorporating the existence value of diversity as a benefit of conservation and by replacing the expectation operation with one of maxmin expected utility. However, the problems set out above make it quite difficult to fully satisfy both tasks.

A promising strategy is to seek a feasible modification of a conventional CBA that underestimates the expected value of benefit of biodiversity conservation in comparison with the ideal CBA which incorporates the existence value of biodiversity and ambiguity. A conservation project that passes the CBA is a project most likely to be worthwhile implementing.

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