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# Optimal Design of Government Hierarchy for Ecosystem Service Provision

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## I. Introduction

There is broad consensus and growing concern that humans are transforming the Earth's natural environment. This transformation has the potential to impact humanity as we depend upon the natural environment for the provision of ecosystem services. Thus, efforts to understand anthropogenic shifts in ecosystem service provision have increased in prominence, as have explorations of policies targeting ecosystem service provision. In this paper we consider the optimal design of policy aimed at increasing the provision of these services from privately held land. In particular, we examine the possibility of optimal decision-making hierarchies among government agencies targeting ecosystem service provision. To that end we adapt the theoretical model of hierarchy design developed by Hart and Moore (2005).

The issue of ecosystem service provision has increasingly attracted the international spotlight in recent years due in no small part to its prominence in the Millennium Ecosystem Assessment (MA). The U.N. initiated the MA in order to better understand the impacts on humans of changing ecosystems and to explore the possibilities for mitigating those changes and impacts. Ecosystem change impacts humans through changes in the provision of ecosystem services, defined broadly as the benefits people obtain from ecosystems. The MA explicitly breaks down ecosystem services into four categories: provisioning services, such as food, fuel, fiber, water, and genetic resources; regulating services, such as climate, water, and disease regulation, water purification, and pollination; cultural services, such as spiritual and religious ties, recreation, and aesthetic values; and supporting services, such as soil formation, nutrient cycling, and habitat provision (Gutman 2005; Greenfacts Glossary). According to the MA, degradation and unsustainable exploitation presently threaten over 60% of the Earth's ecosystem services with very real implications for global health and standards of living in the future.

Furthermore, both the exploitation of ecosystem services and the growth rate of that exploitation have been far higher in recent decades than ever before due to population growth and rising standards of living, i.e. consumption (MA 2005).

This increasing pressure on ecosystem services has driven thinking on mitigation strategies. Payment for ecosystem services (PES) has emerged as a broad strategy to encourage the provision of ecosystem services or, in many cases, to discourage activities that reduce service provision. In economic terms, the inability of agents to capture the full rents of ecosystem service provision often results in divergent private and social values of provision. By creating markets for these services, PES arrangements can correct this disincentive and bring provision closer to the socially optimal level. In the context of land, certain uses or management practices by land owners enhance service provision but do not benefit the land owner directly. In other words, there is a positive externality associated with these practices. Payments under PES programs provide incentives for owners to adopt practices and increase service provision.

While a variety of private sector PES schemes have been envisioned and in some cases implemented, most large-scale PES programs to date have been implemented by governments (Gutman 2005). In this paper we concern ourselves with PES programs implemented by government. However, rather than focusing on the design and targeting of specific PES programs, we examine the optimal design of a hierarchy defining the interaction between various government agencies involved in PES schemes. Specifically, we address the following questions. Should we have multiple agencies focusing on separate ecosystem services or one agency coordinating efforts across multiple services? Should policies be implemented nationally, regionally, or locally? Under what conditions and assumptions does one organizational structure stand out as optimal?

We draw on two distinct bodies of literature. First, a number of studies have examined ecosystem services and conservation spending. Costanza et al. (1997) and Daily (1997) emphasize the tremendous contribution of ecosystem services to the global economy, while de Groot, Wilson, and Boumans (2002) highlight the challenges associated with quantifying and monetizing that contribution. Egoh et al. (2007) document the increasing prominence of ecosystem services as a criterion for conservation and call for the continuation of this trend.

Within the ecosystem services literature, a large number of studies deal with the targeting of conservation spending. Because of the nature of ecosystem service provision and the often complex translation from service provision to realization of benefits, sub-optimal targeting strategies likely result in significant social losses. For example, failure to consider threshold effects, spatial linkages, or correlation between alternative benefits could greatly reduce efficiency (Wu 2004).

Ribaudo (1986) points out that conservation efforts traditionally target the onsite resource base rather than incorporating the offsite effects, potentially resulting in significant allocative inefficiency. Wu and Boggess (1999) use a theoretical model of two watersheds to demonstrate the benefit loss from ignoring threshold effects and correlation. Wu, Boggess, and Adams (2000) and Wu and Skelton-Groth (2002) empirically establish the presence of cumulative effects and ecosystem linkages for salmonids in the Pacific Northwest. Babcock et al. (1997) explore the implications of alternative targeting criteria (e.g. benefit-targeting, cost-targeting, benefit-cost targeting, etc.) for social benefits. Wu (2004) addresses the efficiency of conservation spending and provides guidance for efficient policy design.

Each of these papers treats the targeting of conservation spending within a single program. Our study examines the interactions between government agencies and the implications for the allocative efficiency of multiple conservation programs. We are interested in a hierarchy design (i.e. an allocation of authority over resources among different agencies) that maximizes social welfare and draw upon the hierarchy design and organizational structure literature. Specifically, we adopt the theoretical model developed by Hart and Moore (2005) to analyze optimal decision-making hierarchies of government agencies responsible for ecosystem service protection.

The model is driven by agents whose ideas about how to best use assets conflict. In the event of conflict, the hierarchy in place determines which agent uses the asset. The authors are able to demonstrate conditions under which certain designs are dominant and others subordinate. This work, which focuses on authority within a hierarchy, is distinct from much of the related literature, which deals with the transmission of information.

Following Hart and Moore (2005), we consider a two-date model of decision-making consisting of a set of natural resources to be managed and the government agencies charged with managing those resources. We treat resources as parcels of land. At time zero agencies are assigned tasks and authority over resources is delegated. Tasks consist of thinking about how to use a subset of the parcels. Authority becomes important when multiple agencies have designs on the same parcel.

Initially, we follow the structure of the Hart and Moore (2005) model quite closely; this includes the exposition of the model in section II and the development of results in section III. We describe both assumptions and results in the context of policy targeting ecosystem service provision on private lands. Subsequently, we consider how well the model as formulated fits this ecosystem services context in section IV. Specifically, we relax assumption 2, develop an alternative specification of the total value function, and discuss its implications.

## II. Model

Due to positive externalities associated with certain practices, the existing management regime on private lands is suboptimal. Suppose that society has decided to intervene and target parcels of private land with PES schemes. There are $m$ parcels of land, $a_1, \ldots, a_m$, available for targeting and $n$ government agencies, $1, \ldots, n$, involved. Each agency implements its own PES program targeting those ecosystem services that fall under its mandate. There is rivality among parcels in that if one agency pays the owner of a parcel to adopt a specific set of management practices that owner cannot adopt the practices advocated by another agency. Furthermore, particular agencies may require conservation of a specific set of parcels to generate benefits for society. When multiple agencies have designs on the same parcel, only one can prevail, reducing or negating the potential of the other agencies to generate value for society. We construct a model of decision-making to inform the delegation of authority between agencies.

For simplicity we treat time as discrete and consider only 2 periods, 0 and 1. At time 1 a decision must be made for each parcel. Specifically, it must be determined whether a particular parcel will be included in any of the PES programs and, if so, in which program. That is, will the owner of a parcel be paid, and which management practices will she be paid to adopt? The decisions must be made at time 1, but authority or hierarchy among the agencies is assigned at time 0. Additionally, agencies are assigned tasks at time 0. A task is defined as achieving a specific environmental goal by conserving or protecting a subset of the $m$ parcels. Each agency is assigned only one task, and each task $t(A_i)$ is associated with (and defined by) a subset of the parcels, $A_i \subset [a_1, \ldots, a_m]$. As a result, there are only $n$ tasks and $n$ subsets of parcels in the model. Agency $i$ is assigned task $t(A_i)$, $i \in [1, \ldots, n]$. For example, the U.S. Fish and Wildlife

Service is responsible for the design of conservation programs to protect fish and wildlife, while the U.S. forest service is responsible for programs to protect forest resources.

Also associated with each task is a probability of success, $0 < p(A_i) < 1$. By success in this context we mean that the agency has an idea about how to achieve its environmental goal by using all of the assigned parcels. Of course, the agency may find itself unable to generate an idea with some probability $1 - p(A_i)$. If the agency both has an idea and is able to implement that idea, it generates value to society $v(A_i)$. As we shall discuss, implementation is contingent on the agency having access to all of the parcels in $A_i$.

With the basic framework of the model in place, we now discuss assumptions.

*ASSUMPTION 1*: Ideas are stochastically independent events. The model does allow multiple agencies to be assigned to the same task, or to consider how to manage the same set of parcels. However, this arrangement does not affect the probability of having an idea. Each agency independently has an idea with probability $p(A_i)$. In other words, there are no synergies across agencies from thinking about the same set of parcels.

*ASSUMPTION 2*: Regardless of the whether it has an idea, an agency assigned to task $t(A_i)$ can only achieve its environmental goal if it has access to all of the parcels in $A_i$. There are no benefits unless the agency protects all of the parcels assigned. This is a restrictive assumption and not particularly realistic in the context of ecosystem services. We explore relaxing this assumption in section III.

*ASSUMPTION 3*: A parcel is eligible for payments from only one agency and adopts the management practices prescribed by that agency. The parcels are rival and scarce, generating conflict. Conflict occurs when multiple agencies have an idea involving the use of the same parcel(s).

*ASSUMPTION 4*: In the case of conflict, access to parcels is determined by a prearranged hierarchy. For each parcel $a_k$ there is a list $L_k$, $k \in [1, \ldots, n]$; this list ranks agencies by authority over the parcel. These lists, specified at time 0, determine the hierarchy of authority over parcels. There is no bargaining at time 1. Furthermore, agency *i* only appears on list $L_k$ if $a_k \in A_i,\ k \in [1,\ldots,m],\ i \in [1,\ldots,n]$.

*ASSUMPTION 5*: An agency with authority over parcel $a_k$ but without an idea does not use the parcel. In this case the senior agency defers to the highest-ranking agency on list $L_k$ that does have an idea. Multiple agencies with tasks involving the same parcel(s) do not conflict when only one has an idea.

*ASSUMPTION 6*: An agency with authority over parcel $a_k$ and an idea uses the parcel regardless of access to other parcels necessary for the generation of value from its assigned task. Clearly this could lead to inefficiencies, as it could prevent an agency further down the list from generating value.

*ASSUMPTION 7*: At time 0 tasks are assigned and the hierarchy established to maximize expected value at time 1. We are implicitly assuming that the probabilities of success and the values generated in the instance of success are known at time 0 for each task.

*ASSUMPTION 8*: All agencies are capable of carrying out all tasks. This assumption is not unreasonable if we think of agencies recruiting staff with the expertise necessary to complete any task.

With the model assumptions appropriately defined, we now move on to the definition of the date 0 expected value function. We must first develop one further idea. Based on the lists $L_k$ we can formulate a set $S_i$ for each agency which consists of those agencies which can trump agency *i* in terms of authority over any of the parcels in $A_i$, all of which are needed to generate value from task $t(A_i)$. In more concise terms, for each agency *i*,

$$S_i = \left\{ agencies_j \,\middle|\, \begin{array}{l} for\ one\ or\ more\ parcels\ a_k \in A_i,\ i\ and\ \ j\ both \\ appear\ on\ list\ L_k,\ and\ \ j\ appears\ above\ i \end{array} \right\}$$

In order for agency *i* to generate value $v(A_i)$, no agency included in the set $S_i$ must have an idea, for otherwise agency *i* would be lacking at least one parcel $a_k \in A_i$. So the expected value generated by agency *i* is the probability of an idea $p(A_i)$ times the probability that no agency in $S_i$ has an idea times the value $v(A_i)$. It is important to note that this assumes ex ante knowledge of the probabilities and value at time 0. For the total expected value at time 0, we simply sum across *n* agencies.

$$V = \sum_{i=1}^{n} p(A_i) \left\{ \prod_{j \in S_i} \left[ 1 - p(A_j) \right] \right\} v(A_i) \tag{1}$$

**III. Results**

Hart and Moore (2005) use this model to develop a number of results with implications for optimal hierarchy design. Their result development begins with simplified specific cases and moves to more general cases. In this section we follow this development and discuss the results in our ecosystem services context.

*Two Agencies.*

We begin with the simple case of two agencies with tasks $t(A_1)$ and $t(A_2)$. Initially, we consider task selection as exogenous; that is, we ignore the assignment of tasks at time 0. Define set $A = A_1 \cap A_2 \neq \varnothing$. The non-empty intersection provides the potential for conflict. There is at least one parcel that both agencies need to complete their tasks. In the event that only one agency has an idea, there is no conflict, since by assumption 5 an agency with no idea does not use any parcels. However, in the event that both agencies have an idea, the agencies conflict, and we need a hierarchy to establish which agency uses each of the parcels in *A*. In the two agency case, there are only three possible hierarchies. First, agency 1 could be senior to agency 2 all parcels in *A*. Second, agency 2 could be senior on all parcels. Finally, assuming there are 2 or more elements in *A*, each agency could be senior on one or more parcels. We refer to this situation as a crisscross hierarchy.

Note that the model structure rules out both agencies generating value when $A$ is non-empty. If both agencies have an idea, at most one agency will be able to implement its idea. However, it is possible that neither agency generates value when both have an idea if agency 1 is above agency 2 on the list for one parcel and 2 is above 1 on another. This brings us to the first result.

*CLAIM 1*: A crisscross hierarchy is never optimal. In the two agency case, neither agency should be below the other on one list and above on another.

Note that the model structure rules out both agencies generating value when $A$ is non-empty. If both agencies have an idea, at most one agency will be able to implement its idea. However, it is possible that neither agency generates value when both have an idea if agency 1 is above agency 2 on the list for one parcel and 2 is above 1 on another. The crisscross hierarchy has no effect on the expected value generated when no agency or either agency has an idea, but when both agencies have an idea, they both exercise authority over a parcel in conflict. As a result, the total expected value in the two agency case is lower for a crisscross hierarchy than for either of the two other arrangements.

*CLAIM 2*: In the two agency case with exogenous task selection, the agency with the higher value should be senior on all parcels in $A$.

As discussed above, seniority only enters the picture when both agencies have ideas. Total expected value is higher if, in this case, the agency with higher value has authority over all of the parcels it needs. This result applies only in the 2 agency case and implies that the probabilities of having ideas are irrelevant. The irrelevance of the probabilities of having ideas is an artifact of our imposition of exogenous task selection. Considering endogenous task selection gives us one further result.

*CLAIM 3*: With endogenous task assignment, it is never optimal for the agency with the lower probability of having an idea to be junior.

It seems counter-intuitive that this should be the case, but it is easy to prove by contradiction. Assume the contrary, that in an optimal hierarchy agency 2 has a lower probability of having an idea, i.e., $p(A_2) < p(A_1)$, and that 2 is junior to 1. By claim 2, $v(A_2) < v(A_1)$, for otherwise agency 2 would be senior. Therefore task 1 is strictly superior to task 2 as it has a higher probability of coming to fruition and a higher value if it does come to fruition. By assumption 7, tasks are chosen at time 0 to maximize total expected value at time 1, and by assumption 8 both agencies are capable of performing both tasks. Therefore, both agencies should be working on task 1 simultaneously, thus contradicting our original assumption that the hierarchy is optimal. This result means that seniority should be inversely related to the probability of having an idea in an optimal hierarchy, a notion which proves to be generally applicable and central to other results.

*Three Agencies*.

We move now to the case of three agencies. However, at this point we restrict ourselves to only two parcels, $a_1$ and $a_2$. Now there are two distinct classes of tasks; agencies may be specialists considering a single parcel, or they may be coordinators considering both parcels. We assume that the probability of having an idea for specialists is $p_s$ (regardless of which parcel is involved) and that the probability of an idea for a coordinator is $p_c$. The associated values are $v_s$ and $v_c$.

Again, we begin with exogenous task selection: agencies 1 and 2 are specialists, agency 3 a coordinator. There are two distinct hierarchy designs as delineated below. We rule out a third design in which the coordinator is senior on one parcel and junior on another as it is never optimal. This is easily shown using the logic applied to crisscross hierarchies in the two agency case. The results here hinge on the implicit assumptions that the probabilities of a specialist having an idea, $p_s$, and the value (if implemented) generated by a specialist, $v_s$, are identical across parcels.

TABLE 1

| HIERARCHY *css* (coordinator senior) | | HIERARCHY *ssc* (coordinator junior) | |
|---|---|---|---|
| Parcel $a_1$ | Parcel $a_2$ | Parcel $a_1$ | Parcel $a_2$ |
| 3 | 3 | 1 | 2 |
| 1 | 2 | 3 | 3 |

We can calculate the total expected value at date zero for each hierarchy.

$$V(css) = p_c v_c + (1 - p_c) 2 p_s v_s \tag{2}$$

$$V(ssc) = 2 p_s v_s + (1 - p_s)^2 p_c v_c \tag{3}$$

These expressions are the sums of all the possible values times their respective probabilities. In the 2 task case, this gives us two terms in each expected value. Combining (2) and (3) yields

$$\begin{aligned} V(css) > V(ssc) \ &\Rightarrow (2 - p_s) v_c > 2 v_s \\ V(css) < V(ssc) \ &\Rightarrow (2 - p_s) v_c < 2 v_s \end{aligned} \tag{4}$$

We are left with three possibilities: i) If $v_c > 2v_s$, then the coordinator should be senior regardless of $p_s$, since her idea is more valuable than both of the specialists' ideas combined. ii) If $v_s > v_c$, then the specialists should be senior regardless of probabilities, since either one of their ideas alone surpasses the value of the coordinator's idea. iii) If $2v_s > v_c > v_s$, then probabilities play a role in the optimal hierarchy design. In particular, there is a critical value of $p_s$ below which the coordinator should be senior and above which the specialist should be senior. Intuitively, we only have conflict if the coordinator and at least one specialist have ideas. In the case of conflict it is better for the coordinator to be senior when only one specialist has an idea and better for the specialists to be senior when they both have ideas. If $p_s$, which we have assumed to be equal for both specialists, is large then it is relatively likely that both specialists will have ideas.

Notice the distinction between this situation and the one encountered with only two agencies. With exogenous tasks and two agencies, claim 2 told us that only the relation between the values affected the optimal hierarchy design. With three agencies and exogenous tasks, the probabilities also impact the optimal design. There is no analog to claim 2 with three or more agencies.

Moving on to endogenized task selection with three agencies, consider two hierarchies *sss* and *ccc*, which are detailed below. Now, these hierarchies are possible in addition to the two detailed in Table 1. Associated with *sss* and *ccc* are two expected values, which are also provided below. We maintain the assumption that all specialists have the same probabilities and values and extend this assumption to coordinators as well.

TABLE 2

| HIERARCHY *sss* (three specialists) | | HIERARCHY *ccc* (three coordinators) | |
|---|---|---|---|
| Parcel $a_1$ | Parcel $a_2$ | Parcel $a_1$ | Parcel $a_2$ |
| 1 | 2 | 1 | 1 |
| 3 | | 2 | 2 |
| | | 3 | 3 |

$$V(sss) = [1-(1-p_s)^2]v_s + p_s v_s \qquad (5)$$

$$V(ccc) = [1-(1-p_c)^3]v_c \qquad (6)$$

In the expression *V(sss)*, the first term represents value generated for parcel 1, which is realized if either agency 1 or agency 3 have ideas. The second term represents the value generated for parcel 2 when agency 2 has an idea. For *V(ccc)* we have only one term, since the same value $v_c$

is generated unless no one has an idea. Comparing our four expected value expressions, we can derive the following results.

*RESULT 1*: $p_c < p_s \Rightarrow V(ssc) < \max[V(css), V(sss)]$

*RESULT 2*: $p_s < p_c \Rightarrow V(css) < \max[V(ssc), V(ccc)]$

Notice that both of these results suggest that claim 3 continues to hold in the three agency case; namely, it is never optimal for an agency with a lower probability of having an idea to be junior. Interestingly, the relative values are unimportant in these results. If the probabilities meet certain conditions, then we can say that certain hierarchies are suboptimal regardless of the values. Of course, the relative values determine which of the two alternatives is preferable.

Also notice that we have not ruled out hierarchies in which coordinators are junior to specialists. It is counter-intuitive to have a strategic planner below a specialist in a hierarchy. We have two options in order to rule out this possibility. First, we may assume that $v_c > 2v_s$ in which case strategies favoring the coordinator dominate as shown in (4). However, this assumption is overly restrictive. We achieve the same result if instead we impose the monotonicity condition that $p_c < p_s$. Thinking of the coordinator as a strategic planner, it may not be unreasonable to assume that her probability of having an idea using multiple parcels would be lower than that of specialists devoted to individual parcels.

*General Results.*

We now consider the model in its most general form: $n$ agencies and $m$ parcels with endogenous task selection. There is one central result which drives all others. It is a generalization of claim 3, which we saw in the 2 agency case and which seemed to hold in the three agency case.

*LEMMA*: In an optimal hierarchy, if $p(A_j) < p(A_i)$, then for any parcel $a_k \in A_i \cap A_j$, $j$ appears above $i$ on list $L_k$.

Though this result suggests that only probabilities are important in the optimal delegation of authority, values still play a role. Recall assumption 7, which stated that tasks are assigned at time 0 to maximize the time 1 total expected value. Given optimal task assignment, agencies with lower probabilities should be senior. Tasks with low probabilities must have associated high values to justify their assignment in the first place. For a proof see the appendix of the Hart and Moore paper (2005).

*PROPOSITION 1*: Crisscross hierarchies are never optimal. If $i$ appears above $j$ on the list $L_k$ associated with parcel $a_k$, then there is no parcel $a_{k'}$ where $i$ appears below $j$ on the list $L_{k'}$.

This result seems intuitively easy to accept, as crisscross arrangements have the capacity to block both agencies involved from generating value. In fact, when $p(A_i) \neq p(A_j)$ the above lemma precludes crisscross hierarchies. So the cases of interest occur where $p(A_i) = p(A_j)$. This can occur where the tasks are identical or where the sets $A_i$ and $A_j$ have a non-empty intersection. In either case, the result implies that one agency should have authority over all of the parcels that both tasks have in common.

One particularly interesting situation occurs when $A_i \subset A_j, i \neq j$, or when $j$'s task is broader in scope than $i$'s. In order to derive general results in this situation, we must further develop the notion of monotonicity introduced above. First, define a productive task as one associated with a positive value; in an optimal situation, all tasks assigned at time 0 would be productive. Strictly defined, monotonicity requires that for any two productive tasks $t(A)$ and $t(B)$, $A \neq B$, if $A \subset B$ then $p(A) < p(B)$.

*PROPOSITION 2*: Assume that we have monotonicity, and consider an optimal hierarchy. If $A_i \subset A_j, A_i \neq A_j$, then $\forall a_k \in A_i$, $j$ is above $i$ on list $L_k$. This follows directly from the lemma and the definition of monotonicity.

If we are prepared to assume that tasks are nested and the associated values are conditionally superadditive, we can develop further results. Nestedness requires that for task *t(A)* and *t(B)* either $A \subset B$, $B \subset A$, or $A \cap B = \varnothing$. Conditional superadditivity requires that the value associated with a task *t(A)* is greater than the sum of the values generated by any partition of the parcels in *A*. Formally, let $A = A^1 \cup A^2 \cup \ldots \cup A^p$. Then *v(A)* is conditionally superadditive if $v(A) \geq v(A^1) + v(A^2) + \ldots + v(A^p)$. This is the general context analog of the condition $v_c \geq 2v_s$ in the 3 agency case. Nestedness and superadditivity are strong conditions, and we discuss their applicability to ecosystem services context in the next section.

*PROPOSITION 3*: Assume monotonicity and nestedness. Then the optimal hierarchy is a pyramid, and each agency has the same ranking on every parcel it considers. In other words, if agency *j* is senior to agency *i* on one parcel, *j* should be senior to *i* on all parcels.

*PROPOSITION 4*: Assume nestedness and conditional superadditivity. Then the optimal hierarchy attains first-best.

### *Optimal Level of Centralization*

In the conservation context, the notion of centralization versus decentralization becomes important. Should decisions be made and programs implemented at the national, regional, or local level? Should we have one agency in charge or several working in tandem? We can think of the level of decentralization as increasing in the likelihood that a local specialist will make a decision. To illustrate the implications of the model in this setting, we return to an example with only 2 parcels, $a_1$ and $a_2$, and 4 agencies. Following the 2 agency example, we assume that specialists are identical with probability of having an idea $p_s$ and value $v_s$. Likewise, coordinators are identical with probability of having an idea $p_c$ and value $v_c$. We also assume monotonicity, i.e. $p_c < p_s$. Our general results allow us to rule out crisscross hierarchies and tell us that coordinators should be senior to specialists. Furthermore, the optimal hierarchy will be symmetric, or the same number of specialists will work on each parcel. This leaves us with only three possible optimal hierarchies.

TABLE 3

| HIERARCHY *C* (centralized) | | HIERARCHY *D* (decentralized) | | HIERARCHY *I* (independent) | |
|---|---|---|---|---|---|
| Parcel $a_1$ | Parcel $a_2$ | Parcel $a_1$ | Parcel $a_2$ | Parcel $a_1$ | Parcel $a_2$ |
| 1 | 1 | 1 | 1 | 1 | 2 |
| 2 | 2 | 2 | 2 | 3 | 4 |
| 3 | 3 | 3 | 4 | | |
| 4 | 4 | | | | |

Hierarchy *C* represents a centralized approach. All 4 agencies think about both parcels, thus all 4 are coordinators. Hierarchy *D* represents a decentralized approach. Agencies 1 and 2 are coordinators, thinking about both parcels; while agencies 3 and 4 each specialize in thinking about a particular parcel. Hierarchy *D* is less centralized than *C* because there is a higher probability of a local specialist making a decision. Since *C* consists of only coordinators, there is a zero probability of a specialist implementing an idea. Under *D*, however, specialists decide how to use both parcels with some non-zero probability when neither coordinating agency has an idea. Under hierarchy *T*, all agencies are specialists. Agencies 1 and 3 think about how to use parcel $a_1$, while agencies 2 and 4 independently consider how to use parcel $a_2$. Associated with the hierarchies are time 0 expected values.

$$V(C) = [1-(1-p_c)^4]v_c \tag{7}$$

$$V(D) = [1-(1-p_c)^2]v_c + (1-p_c)^2\, 2p_s v_s \tag{8}$$

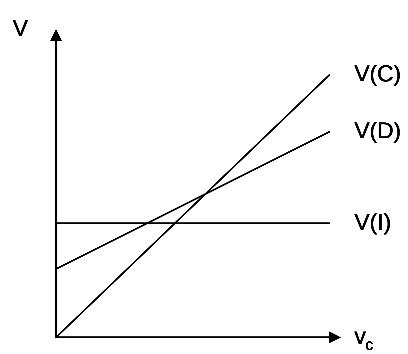
$$V(I) = 2[1-(1-p_s)^2]v_s \tag{9}$$

If we think of these expected values as functions of $v_c$ and hold $v_s$ constant, we can plot the expected values. *V(C)* is positively sloped and passes through the origin. *V(D)* has a positive intercept and slope; however, it is less steep than *V(C)*. *V(T)* is a horizontal line, since it does not depend on $v_c$. It can be easily shown that *V(D)* intersects the vertical axis below *V(T)* using the fact the probabilities are bounded between 0 and 1. Furthermore, we can derive a critical value of $p_c$ where all three lines intersect at a single point.

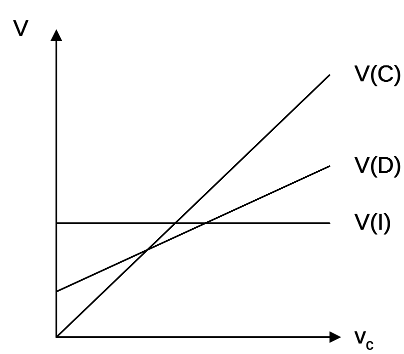
$$p_c^* = 1 - \sqrt{1 - p_s} \tag{10}$$

Our critical value varies as we allow $p_s$ to vary, and it is bounded below by zero and above by $p_s$. As we allow $p_c$ to take on values different from $p_c^*$, we get the two scenarios depicted in figure 1. Since our goal is to maximize expected value, the hierarchy design associated with the uppermost line is preferred. As we vary $v_c$, holding probabilities constant, notice that the preferred design changes. In figure 1a, *V(I)* is best for small values of $v_c$, but as $v_c$ increases *V(D)* and subsequently *V(C)* are best Also note that when $p_c > p_c^*$, hierarchy *V(D)* is never optimal (figure 1b).

**Figure 1**



(a) $p_c < p_c^*$



(b) $p_c > p_c^*$

This concludes our development of the model and results of Hart and Moore (2005). Though we discussed the model in the context of multiple agencies working to enhance ecosystem service provision, we maintained the assumptions of the model, some of which proved quite restrictive in our case. In the next section, we reformulate the model in less restrictive form and analyze the impact on the results.

**IV. Extensions**

The key feature of the model is the expected value function given in equation 1. This concise expression accurately reflects time 1 expected value only if the eight assumptions presented in section II hold. Relaxing assumptions will necessitate the formulation of a new expected value function. We are particularly interested in relaxing assumption 2, which states that an agency $i$ must have access to all of the parcels in $A_i$ to generate value. It seems implausible that an agency which conserves the bulk of the parcels under consideration generates zero value (i.e., has no effect on the level of ecosystem service provision). To that end, we adapt equation 1.

When assumption 2 holds, there is only one event in which each agency will generate value. The agency in question must have an idea, and, simultaneously, all senior agencies must fail to have an idea. When we relax this assumption an agency no longer requires all of its assigned parcels, and there are many possible value-generating events. We also must specify precisely how the loss of a single parcel (or multiple parcels) affects the value generated. Thus, the expected value function becomes more complicated.

We begin with an expression for the expected value from a single agency $i$. First we need some additional notation. Let $m_i$ be the number of parcels in $A_i$. Let $p_{-i}$ be the probability of conflict on any single parcel in $A_i$. By conflict, we mean that a senior agency uses the parcel in question, and agency $i$ does not. At this point we assume that $p_{-i}$ is constant across all parcels in

$A_i$. We can now calculate the probability of conflict on any given number of parcels in $A_i$, as given below.

$$\begin{aligned}
(1-p_{-i})^{m_i} &= \textit{probability of conflict on zero parcels} \\
(1-p_{-i})^{m_i-1}p_{-i} &= \textit{probability of conflict on exactly one parcel} \\
(1-p_{-i})^{m_i-2}p_{-i}^2 &= \textit{probability of conflict on exactly two parcels} \\
&\vdots \\
(1-p_{-i})p_{-i}^{m_i-1} &= \textit{probability of conflict on all parcels but one} \\
p_{-i}^{m_i} &= \textit{probability of conflict on all parcels}
\end{aligned}$$

The expected value for agency $i$ is given by equation 11, where $\gamma$ represents the share of the value $v(A_i)$ realized if agency $i$ implements its idea on all the parcels in $A_i$ but one. This parameter can take values between zero and one. The share of the value realized when all but n parcels are conserved is then $\gamma^n$. For simplicity, we replace $p(A_i)$ and $v(A_i)$, the probability of agency $i$ having an idea and the associated value, with $p_i$ and $v_i$. These quantities apply for every event faced by agency $i$ and therefore precede the brackets.

Each term in the brackets represents a class of events defined by a particular number of parcels in conflict, beginning with zero and ending with $m_i$ *-1*. Each term consists of a weighting factor reflecting the number of possible realizations of the event as well as the probability of the event and the share of the full value generated. For the weights, we use the combination operator, which gives us the number of different ways of selecting a given number of conflict parcels from the $m_i$ parcels in $A_i$. The first bracketed term has weight $C_0^{m_i} = 1$ and share $\gamma^0 = 1$. Also note that we do not include the event where all $m_i$ parcels are in conflict. An agency generates zero value if it does not have access to any parcels.

$$V_i = p_i v_i \left[(1-p_{-i})^{m_i} + C_1^{m_i} p_{-i}(1-p_{-i})^{m_i-1}\gamma + \ldots + C_{m_i-1}^{m_i} p_{-i}^{m_i-1}(1-p_{-i})\gamma^{m_i-1}\right] \quad (11)$$

$$V_i = p_i v_i \left[(1-p_{-i}) + p_{-i}\gamma\right]^{m_i} - p_i v_i C_{m_i}^{m_i} p_{-i}^{m_i}\gamma^{m_i} \quad (12)$$

We can simplify equation 11, as it is a binomial expansion of equation 12. We include the final term in equation 12 to account for the term left out of the brackets in equation 11.

As mentioned above, for a single agency, $p_{-i}$ is constant across parcels. Specifically, we define this probability as a function of the probabilities of having an idea associated with every agency senior to $i$ on one or more parcels, here $p_j$. Let $J_i$ be the number of agencies senior to $i$. Then, $p_{-i} = f(p_1,\ p_2,\ \ldots\ ,\ p_j,\ \ldots\ ,\ p_{J_i}),\ \ j \in [1,\ J_i]$. Moreover, the probability of conflict should be increasing in the probability of a senior agency having an idea, thus $\partial p_{-i} / \partial p_j \geq 0$.

Aggregating equation 12 across all $n$ agencies gives us our total expected value. We drop the weight from the last term in equation 13 since it is equal to unity. Notice that if $\gamma = 0$, this expression reverts to one quite similar to equation 1. No value is generated in the case of conflict.

$$V = \sum_{i=1}^{n} p_i v_i \left[(1 - p_{-i}) + p_{-i}\gamma\right]^{m_i} - \sum_{i=1}^{n} p_i v_i p_{-i}^{m_i} \gamma^{m_i} \tag{13}$$

We have relaxed assumption 2 and developed an alternative total value function that is more appropriate for the ecosystem services context. Unfortunately, by introducing many more possible value-generating events, we have muddied the water and cannot derive many of the precise results proved under all assumptions. For example, since conflict on a single parcel no longer blocks the generation of value by both parties, crisscross hierarchies may be optimal. Future efforts will focus on deriving results based on our new value function.

Furthermore, though we relaxed one assumption, we have also added two new assumptions. Both impose some degree of homogeneity on the parcels being considered. First, for each agency $i$, the probability of conflict is assumed to be equal across all parcels in $A_i$.

Though necessary for tractability, this assumption is not particularly realistic, given that the probabilities are known and authority structure specified in time 0.

Second, we assume that each unavailable parcel has the same impact on the value, namely the multiplicative factor $\gamma$. On a large enough scale, this may be a reasonable assumption. On a smaller scale, it may be problematic. More importantly, this assumption does not account for many of the relevant features of ecosystem services identified in the literature (e.g. threshold effects or joint production). Under threshold effects we should see large differences in the share of value generated as we move around some critical mass of parcels. With joint production, it is possible that one agency could realize full value even in the face of conflict if the senior agency put the conflict parcel(s) to a compatible use.

. There is a gap in the literature pertaining to the optimal design of an institutional structure to govern interactions between multiple agencies engaged in promoting the provision of ecosystem services. Certainly the hypothesis that alternative hierarchies between agencies may have significantly different welfare effects warrants investigation. The considerable losses due to sub-optimal targeting strategies in individual programs have been well documented. The stakes are high, as development and growth place further pressure on often strained natural systems.

**References**


Babcock, B., P. Lakshminarayan, J. Wu, and D. Zilberman. 1997. “Targeting Tools for the Purchase of Environmental Amenities.” *Land Economics* 73: 325-339.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. O'Neill, J. Paruelo, R. Raskin, P. Sutton, and M. van den Belt. 1997. “The Value of the World's Ecosystem Services and Natural Capital.” *Nature* 387: 253–260.

Daily, G., 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington: Island Press.

de Groot, R., M. Wilson, and R. Boumans. 2002. “A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services.” *Ecological Economics* 41: 393–408.

Egoh, B., M. Rouget, B. Reyers, A. Knight, R. Cowling, A. Jaarsveld, A. Welz. 2007. “Integrating Ecosystem Services into Conservation Assessments: A Review.” *Ecological Economics* 63: 714-721.

Greenfacts Glossary. *Scientific Facts on Ecosystem Change*. Source: Millennium Ecosystem Assessment, 2005. http://www.greenfacts.org/en/ecosystems/

Gutman, Pablo. October, 2005. *PES: Basic Concepts and Outstanding Issues – A WWF Perspective*. Presentation at the Workshop: The Prospects of PES in Europe and the NIS. Sofia, Bulgaria. http://assets.panda.org/downloads/pes_basic_concepts.pdf

Hart, O. and J. Moore. 1999. “On the Design of Hierarchies: Coordination versus Specialization.” *Journal of Political Economy* 113: 675-702.

Millennium Ecosystem Assessment. 2005. Millennium Ecosystem Assessment Press Release. London, http://www.millenniumassessment.org/en/Article.aspx?id=58

Ribaudo, M. 1986. “Consideration of Offsite Impacts in Targeting Soil Conservation Programs.” *Land Economics* 62: 402-411.

Wu, J. 2004. “Using Sciences to Improve the Economic Efficiency of Conservation Policies.” *Agricultural and Resource Economics Review* 33: 18-23.

Wu, J., R. Adams, and W. Boggess. 2000. “Cumulative Effects and Optimal Targeting of Conservation Efforts: Steelhead Trout Habitat Enhancement in Orgeon.” *American Journal of Agricultural Economics* 82: 400-413.

Wu, J. and W. Boggess. 1999. “The Optimal Allocation of Conservation Funds.” *Journal of Environmental Economics and Management* 38: 302-321.

Wu, J., and K. Skelton-Groth. 2002. Targeting Conservation Efforts in the Presence of Threshold Effects and Ecosystem Linkages.” *Ecological Economics* 42: 313-331.