A Paradox for Agro-Environmental Land Policy

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Abstract

A regulator with a fixed budget to spend on securing environmental benefits from farmed land has to choose between how many acres to enroll and the extent of benefits to require of each enrolled acre. Here we consider, given heterogeneous land, what properties of the environmental benefit-to-cost ratio imply for the choice of optimal program as the available budget varies. Conditions are found such that a program of high benefits on few acres is preferred for any budget level. It is also possible that a program delivering low benefits per acre at low cost is preferred on each land type, and yet a high benefit program is optimal policy, a variant of Simpson's paradox.

Keywords: benefit-to-cost ratio, environmental policy, land heterogeneity, Simpson's paradox.

JEL classification: D6; Q2

Introduction

Farmable land can provide a wide variety of public benefits, whereby demand grows with income and urbanization. Traditionally, public intervention has addressed income support within agriculture and also national food security issues. The most significant change in the nature of public land use policy over the past quarter century has concerned environmental benefits. Two general approaches, to be discussed below, have been pursued by governments purchasing environmental services from working land. Which is pursued has depended on the resources at issue as well as the economic, social, and political environments pertaining.

One approach is to influence the character of agricultural production practices, but not so much that the land at issue ceases to be farmed. Commencing arguably as far back as the 1992 Common Agricultural Policy reforms, this has been the dominant approach in European Union countries. Implemented at the nation-state level but co-financed with the European Union, agro-environmental schemes seek to promote nature and yet ensure farm sector vitality. Multi-year contracts are signed, and the land owner receives annual rents in return for fulfilling commitments concerning land stewardship. Approximately 20% of agricultural land in the European Union is covered by such programs. Emphasis is placed on extensive farming, low input and pasture-based systems, organic outputs, and landscape preservation activities.

The other approach is to use public funds to remove land from production for a significant period of time. The Conservation Reserve Program, established in the United States farm bill of 1985, takes this general approach. Much of this land has remained in the program through subsequent contract renewals. The program encourages owners to convert environmentally sensitive land to grass and tree cover, to riparian buffers, and to other nonagricultural natural cover. The contract lasts for at least ten and up to fifteen years, providing the owner with annual rent and sharing the costs of conversion. The questions we ask in this paper are how to compare these programs and how a change in budget might affect program design. The questions are relevant for several reasons.

First, a rise in world grain and oilseed prices over the period 2005-2009 has increased the opportunity cost of entering land into any sort of program that restricts the set of available farming actions. Budgets to purchase environmental benefits from land owners have come under pressure. And newer dilemmas may be on the horizon. If, for example, crop residue removal for cellulosic ethanol does become profitable, then governments may need to consider whether to purchase back some residues to remain *in situ*. In addition, the environmental consequences of spreading scarce budget resources thinly across many acres when compared with concentrated use have become a matter of heated debate (Green *et al.*, 2005; Wätzold and Schwerdtner, 2005; Ewers *et al.*, 2009).

The model used in this work is an extension of the standard constrained benefit maximization specification, as used in Newburn, Berck, and Merenlender (2006), Feng *et al.* (2006), and elsewhere. In it we allow for heterogeneous land types, and also for the available budget to vary. The two programs considered are intensification and extensification. Under intensification, the per acre level of environmental services to be provided is high and the per acre enrollment cost is also high. Under extensification, both benefits and costs are low. Conditions on the benefit-to-cost ratio are identified under which intensification is preferred across all budget levels. Conditions are also found under which extensification is the preferred policy across all budget levels. It is found that extensification can have a higher benefit-to-cost ratio over all land types while intensification is the preferred policy.

This peculiarity, a variant of Simpson's paradox, is due to how the distribution of enrolled acres shifts across programs for a given budget level. Table 1 provides an informal illustration. There are three land parcels, labeled I, II, and III. Under the extensive program the environmental benefit-to-cost ratios are 3, 1.5, and 1.5 while costs sum to 4. Under the intensive program the ratios fall uniformly across parcels, to 2.5, 1.33, and 1.33 but costs sum to 7. The intensive program is dominated for each parcel, and enrolling all land under it is more costly. If the budget available is 4 then all parcels can be enrolled under the extensive program but only parcel I can be enrolled under the intensive program.

Benefits under the extensive program are the sum of all benefits, 6 + 1.5 + 1.5 = 9, while benefits under the intensive program are 10 so that the intensive program is preferred. Also, notice that a different conclusion would emerge if the budget were 2 so the optimal program choice is budget dependent. Critical in the example is the assumed land resource heterogeneity. This is an important feature of real landscapes, but it is often overlooked in policy analysis because of the modeling difficulties it introduces. That the optimal program choice can be budget dependent is of practical relevance given the variability of available budget for eco-system services.

The paper is organized as follows. The general modeling framework is provided first, together with some relevant definitions. Budget-constrained welfare when the environmental benefit-to-cost ratio is larger for the higher benefit land type is then analyzed. The case when the ratio is smaller for the higher environmental benefit type is then briefly considered. After further development on the paradox, the paper concludes with a brief discussion.

Framework

Our model has two land types, *h* for land with high environmental benefits to be had from enrolling in a program or contract, and *l* for land with low environmental benefits to be had. Here *h* is held to be larger than *l* in an ordinal index of environmental benefits. Total land at issue is normalized to one unit while the proportion of land that is of type *h* is $\pi \in (0,1)$. There are also two levels of environmental services that a contract can require. These are levels 1 and 2 where level 2 provides larger benefits for both land types and incurs larger costs for both types also. Program 2, abbreviated as P2, represents intensification whereas Program 1, or P1, represents extensification in that less intensive farming will occur over more acres than in P2. The program designer makes available one program for all enrollees. So the choice is P1 for all who enroll or P2 for all who enroll.

With the obvious notation, environmental benefits are $b^{j,k}$ for $(j,k) \in \{(l,1),(l,2),(h,1),(h,2)\} \equiv \Omega$, where $b^{j,1} < b^{j,2}\ \forall j \in \{l,h\}$, $b^{l,k} < b^{h,k}\ \forall k \in \{1,2\}$. Costs are $c^{j,k}$ for $(j,k) \in \Omega$, where $c^{j,1} < c^{j,2}\ \forall j \in\ \{l,h\}$ and all $c^{j,k}$ are positive. So the more demanding program costs more in addition to providing more benefits. One way to compare the programs is that P2 is deep and narrow while P1 is shallow and wide. It is shallow because it offers less benefit per acre. It is wide because costs are such that more acres can be covered with the same budget under P1 when compared with P2. Program budget available amounts to E, and the constraint is binding in that all of E is spent. Net benefits, having removed costs, are $a^{j,k} = b^{j,k} - c^{j,k}$ for $(j,k) \in \Omega$ and all net benefits are assumed to be positive.

Writing the net benefit-to-cost ratios as $r(j,k) = a^{j,k} / c^{j,k}, (j,k) \in \Omega$, we refer to $r(\cdot)$ as the ratio function, with land type and program intensity as the first and second argument, respectively. Ignoring ties, there are twenty-four ways in which the four quantities $r(j,k)$, $(j,k) \in \Omega$, can be ordered along the real line. None can be ruled out *a priori*. It would be excessive to consider all of these, so we will instead assume two intuitive monotonicity restrictions. One is monotonicity in type:

Definition 1: Ratio function $r(\cdot)$ is said to be increasing in environmental benefit land type, or IT, whenever $r(h,1) \geq r(l,1)$ and $r(h,2) \geq r(l,2)$. It is decreasing in land type, or DT, whenever $r(h,1) < r(l,1)$ and $r(h,2) < r(l,2)$.

Definition 1 ensures that the high (resp., low) environmental benefit land will be first enrolled under either program when $r(\cdot)$ is IT (resp., DT). IT has larger environmental benefit per unit cost on the land that delivers higher benefits per acre, regardless of program choice.[1]

Notice that no assumption is made to this point on how $r(j,k)$ changes with program intensity argument *k*, i.e., on whether the benefit-to-cost ratio increases with program intensity. For each land type it is fair to assume, as we have, that if benefits are larger under P2 then so are costs. Were costs smaller under P2, then P2 would obviously be the preferred program for the land type at issue. But this information does not impose signs on $r(l,2)-r(l,1)$ or $r(h,2)$ $-r(h,1)$. The second monotonicity we assume is in program intensity.

Definition 2: Ratio function $r(\cdot)$ is said to be increasing in program intensity, or IP, whenever both $r(l,2)\geq r(l,1)$ and $r(h,2)\geq r(h,1)$. It is decreasing in program intensity, or DP, whenever $r(l,2)<r(l,1)$ and $r(h,2)<r(h,1)$.

IP has a larger environmental benefit per unit cost in the more intensive program regardless of the land type at issue. The four contexts we will focus on are IT plus IP, IT plus DP, DT plus IP, and DT plus DP. These are illustrated in Figure 1. Notice that the monotonicities place only partial order on $r(j,k),(j,k)\in\Omega$ where each of the four contexts accounts for two possible ways to order the $r(j,k)$. The largest value is at the top of each diamond diagram, the smallest value is at the bottom, and the other two values cannot be ordered based on monotonicity conditions only.

We do not consider the sixteen contexts involving reversals in monotonicities because we think these are less likely to occur. For example, P1 might involve low nitrogen use on crop land while P2 requires both low nitrogen and winter cover on crop land. With $r(h,1)\geq r(l,1)$, then the reversal $r(h,2)<r(l,2)$ would require that the *h* type land advantage over *l* type land under the nitrogen use restriction be completely reversed when both the nitrogen and crop

[1] To confirm this, solve the budget-constrained Lagrangian optimization problem

cover restriction apply.

A third definition we will have some use for is supermodularity:

Definition 3: Ratio function $r(\cdot)$ is said to be supermodular, or SM, if $r(h,2)-r(h,1)\geq r(l,2)-r(l,1)$.

Panel *a* in Figure 2 illustrates when IP applies, in addition to IT, while IP does not adhere in Panel *b*. Panel *b* replaces IP with DP. In Panel *a*, SM does not apply because the vertical gap between ratio values under land type *h* is smaller than under land type *l*. But SM does apply in Panel *b*. The intent of this paper is to establish conditions under which we can be sure that one program is preferred to another regardless of budget availability.

Definition 4: Program *X* is said to *budget dominate* Program *Y*, or $X \succ_{BD} Y$, whenever it (weakly) provides more benefits over all strictly positive budget levels, $E > 0$.

The ordering is transitive in that if $X \succ_{BD} Y$ and $Y \succ_{BD} Z$ then $X \succ_{BD} Z$. Budget dominance is a partial ordering in that $X \not\succ_{BD} Y$ does not imply $Y \succ_{BD} X$. The analysis follows a somewhat different route depending on whether the ratio function is IT or DT, so we will treat each separately.

Increasing in Type

Throughout this section we assume that the ratio function is IT, i.e., that $r(h,1)\geq r(l,1)$ and $r(h,2)\geq r(l,2)$. Condition $r(h,1)\geq r(l,1)$ ensures that when P1 is offered then type *h* land will be enrolled at low budget levels, and only when sufficient budget is available will type *l* land be enrolled. Similarly, condition $r(h,2)\geq r(l,2)$ ensures that type *h* land is enrolled first when

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$\max_{x\in[0,\pi],y\in[0,1-\pi]} b^{l,1}x+b^{h,1}y+\lambda\times(E-c^{l,1}x-c^{h,1}y)$.

P2 is offered.

Three cases arise, these being when budget E (*i*) cannot cover all high-benefit land regardless of program, (*ii*) can cover all high-benefit land under low cost P1 but not under high cost P2, and (*iii*) can cover all high-benefit land under P2 also. More specifically, the cases are

(1) $$\text{Case I}: \quad E \in [0, c^{h,1}\pi); \qquad \text{Case II}: \quad E \in [c^{h,1}\pi, c^{h,2}\pi); \qquad \text{Case III}: \quad E \geq c^{h,2}\pi.$$

Each case is considered in turn where equations are developed in the Appendix.

CASE I: Assuming that P2 will be chosen under indifference, P2 will be chosen if and only if $\Delta^{\text{I}} \geq 0$ where

(2) $$\Delta^{\text{I}} \equiv \overbrace{\left[r(h,2) - r(h,1)\right]}^{\geq 0 \text{ by IP}} E.$$

So the union of conditions IT for both land types and IP for land type *h* ensure that P2 is chosen in Case I. This should be intuitive in that whenever the benefit-to-cost ratio for the high environmental benefit land is larger under P2 than under P1, then the entire budget is spent on P2. Otherwise the entire budget is spent on P1 in this case.

CASE II: With Δ^{II} equal to net benefits under P2 less those under P1, then P2 will be chosen if and only if $\Delta^{\text{II}} \geq 0$ where

(3) $$\Delta^{\text{II}} \equiv \overbrace{\left[r(h,2) - r(h,1)\right]}^{\geq 0 \text{ by IP}} c^{h,1}\pi + \overbrace{\left[r(h,2) - r(h,1)\right]}^{\geq 0 \text{ by IP}} \overbrace{(E - c^{h,1}\pi)}^{\geq 0 \text{ by Case II}} + \overbrace{\left[r(h,1) - r(l,1)\right]}^{\geq 0 \text{ by IT}} \overbrace{(E - c^{h,1}\pi)}^{\geq 0 \text{ by Case II}}.$$

Therefore $\Delta^{\text{II}} \geq 0$. Thus IT over both land types together with $r(h,2) \geq r(h,1)$, or IP for type *h* land only, suffice to identify P2 as the better choice in Case II. Note, in Case I condition $r(h,2) \geq r(h,1)$ is both necessary and sufficient to identify a preference for P2 whereas in Case II the condition is sufficient but not necessary.

CASE III: With Δ^{III} equal to the net benefit difference, P2 less P1, then P2 will be chosen if and only if $\Delta^{\text{III}} \geq 0$ where

(4)
$$\Delta^{\text{III}} \equiv \overbrace{\left[r(h,2)-r(h,1)\right]}^{\geq 0 \text{ by IP}} c^{h,1}\pi + \overbrace{\left[r(h,2)-r(h,1)\right]}^{\geq 0 \text{ by IP}} \overbrace{(c^{h,2}-c^{h,1})\pi}^{\geq 0 \text{ by costs}}$$
$$+\overbrace{\left[r(h,1)-r(l,1)\right]}^{\geq 0 \text{ by IT}} \overbrace{(c^{h,2}-c^{h,1})\pi}^{\geq 0 \text{ by costs}} + \overbrace{\left[r(l,2)-r(l,1)\right]}^{\geq 0 \text{ by IP}} \overbrace{(E-c^{h,2}\pi)}^{\geq 0 \text{ by Case III}}.$$

As with Δ^{I} and Δ^{II}, $\Delta^{\text{III}} \geq 0$ under IT plus IP.

Summarizing over the three cases, we have a land-use intensification result. For any positive budget level, the result provides a condition set under which the purchase of many eco-services over a small acreage base is preferred to the purchase of fewer eco-services over more acres.

Proposition 1: Given IT, then IP is a sufficient condition set for P2 to budget dominate P1, or $P2 \succ_{BD} P1$. It is also necessary.

IP is necessary in that if $r(h,2) < r(h,1)$, then P1 is preferred to P2 in Case I, while if $r(l,2) - r(l,1)$ for large E then $\Delta^{\text{III}} < 0$. Figure 3 graphs how net benefits change with budget E; i.e., the continuous function

(5)
$$\Delta(E) = \begin{cases} \left[r(h,2)-r(h,1)\right]E, & E \in [0, c^{h,1}\pi); \\ \left[r(h,2)-r(h,1)\right]c^{h,1}\pi + \left[r(h,2)-r(l,1)\right](E-c^{h,1}\pi), & E \in [c^{h,1}\pi, c^{h,2}\pi); \\ \left[r(h,2)-r(h,1)\right]c^{h,1}\pi + \left[r(h,2)-r(l,1)\right](c^{h,2}-c^{h,1})\pi & \\ \quad +\left[r(l,2)-r(l,1)\right](E-c^{h,2}\pi), & E \geq c^{h,2}\pi. \end{cases}$$

At points of differentiability, the derivative with respect to budget is given as

(6) $$\frac{d\Delta(E)}{dE} = \begin{cases} r(h,2)-r(h,1) \geq 0, & E \in (0, c^{h,1}\pi); \\ r(h,2)-r(l,1), & E \in (c^{h,1}\pi, c^{h,2}\pi); \\ r(l,2)-r(l,1) \geq 0, & E > c^{h,2}\pi. \end{cases}$$

Under supermodularity then Case I and Case III slopes, respectively $r(h,2)-r(h,1) \geq 0$ and $r(l,2)-r(l,1) \geq 0$, can be ordered where the former would be larger than the latter. The Case II slope is $r(h,2)-r(l,1)$ with $r(h,2)-r(l,1) \geq \max[r(l,2)-r(l,1), r(h,2)-r(h,1)]$ due to IT. Thus, the Case II slope is the largest among the three. As we shall explain, this is the nub of the problem that arises when seeking to identify budget dominance when ratio functions are DP.

If IT plus DP cannot support $P2 \succ_{BD} P1$, then can they support $P1 \succ_{BD} P2$? Under DP, $r(h,2)-r(h,1) < 0$ and $r(l,2)-r(l,1) < 0$. This means that the marginal effect of budget on the difference in program net benefits, P2 less P1, is to make the difference more negative over the domains of Case I and Case III. The only concern is what happens over the domain of Case II, where $r(h,2)-r(l,1)$ cannot be signed based on IT plus DP.

To pursue the matter, consider the function supremum value,

(7) $$\Phi \equiv \sup_{E\in(0,\infty)} \Delta(E).$$

If $r(h,2) > r(l,1)$ then continuity and (5) ensure that the supremum will occur at either $\lim_{E\to 0} \sup_{E\in(0,\infty)} \Delta(E) = 0$ or at $E = c^{h,2}\pi$. The former instance is trivial for it means the absence of either program. Turning to $\Delta(E)$ evaluated at $E = c^{h,2}\pi$, we seek to ascertain whether

(8) $$\left[r(h,2)-r(h,1)\right]c^{h,1}\pi + \left[r(h,2)-r(l,1)\right](c^{h,2}-c^{h,1})\pi \geq 0.$$

Alternatively, relation (8) may be written as

(9) $$r(h,2) \geq r(h,1)w + r(l,1)(1-w), \qquad w \equiv \frac{c^{h,1}}{c^{h,2}} \in [0,1].$$

If no admissible parameter values can be found such that relation (8) is true then conditions IT plus DP would ensure $P1 \succ_{BD} P2$. If such parameter values do exist then we cannot infer that $P1 \succ_{BD} P2$.

Condition $r(h,2) < r(l,1)$ will do to ensure that $\sup_{E\in(0,\infty)} \Delta(E) < 0$, but that is in addition to IT plus DP. Panel *a* in Figure 4 shows when all conditions are satisfied while Panel *b* shows when condition $r(h,2) < r(l,1)$ is not satisfied but IT plus DP are. When $r(h,2) \geq r(l,1)$ then there exist ratio and cost values satisfying IT plus DP such that $\Delta(E) \geq 0$ in the neighborhood of $E = c^{h,2}\pi$, as depicted in Figure 5. For example, let $c^{h,1} = 2$, $c^{h,2} = 4$ and $\pi = 0.5$ so that $\Phi = 2r(h,2) - r(h,1) - r(l,1)$. Evaluations $r(h,2) = 2$ and $r(h,1) = 3$ satisfy DP on *h* and then $\Phi = 1 - r(l,1)$. Under these evaluations, $1 \geq r(l,1) > r(l,2) > 0$ ensure that $\Phi \geq 0$ while DP on *l* is satisfied. Finally, IT are satisfied on *h* and *l* as $r(h,1) = 3 > 1 \geq r(l,1)$ and $r(h,2) = 2 > 1 \geq r(l,2)$. Finally, $r(h,2) = 2 \geq r(l,1) = 1$.

In summary, we have a land-use extensification result.

Proposition 2: Given IT, then (*i*) DP is a necessary condition for $P1 \succ_{BD} P2$ but it is not sufficient; (*ii*) DP plus $r(h,2) < r(l,1)$ are necessary and sufficient conditions when the value of $w \equiv c^{h,1} / c^{h,2} \in [0,1]$ is not known; (*iii*) DP plus $r(h,2) < r(h,1)w + r(l,1)(1-w)$ are necessary and sufficient conditions when $w \in [0,1]$ is known.

For any positive budget level, the result provides a condition set under which spreading eco-services over a large acreage base is more beneficial than concentrating the eco-services on a smaller base. We note for future reference that (*iii*) fails under $r(h,2) < r(l,1)$, when IT plus DP give the total ordering $r(l,2) < r(l,1) < r(h,2) < r(h,1)$.

Decreasing in Type

Suppose instead that the ratio function is DT, whereby $r(h,1) < r(l,1)$ and $r(h,2) < r(l,2)$. Condition $r(h,1) < r(l,1)$ ensures that when P1 is offered then type *l* land will be enrolled at low budget levels, and type *h* land will be enrolled only when sufficient budget is available. Similarly, condition $r(h,2) < r(l,2)$ ensures that type *l* land is first enrolled when P2 is offered.

Analogous to eqn. (5), the difference in program net benefits, P2 less P1, is given by the continuous, piecewise linear function $\Delta(E)$ where

$$(10) \quad \Delta(E) = \begin{cases} \left[r(l,2) - r(l,1)\right]E, & E \in [0, c^{l,1}\pi); \\ \left[r(l,2) - r(l,1)\right]c^{l,1}\pi & \\ \qquad + \left[\{r(l,2) - r(l,1)\} + \{r(l,1) - r(h,1)\}\right](E - c^{l,1}\pi), & E \in [c^{l,1}\pi, c^{l,2}\pi); \\ \left[r(l,2) - r(l,1)\right]c^{l,1}\pi + \left[r(l,2) - r(h,1)\right](c^{l,2} - c^{l,1})\pi & \\ \qquad + \left[r(h,2) - r(h,1)\right](E - c^{l,2}\pi), & E \geq c^{l,2}\pi. \end{cases}$$

Upon evaluating at $E = c^{l,2}\pi$, the condition $\Delta(E) \geq 0$ resolves to

$$(11) \qquad r(l,2) \geq r(l,1)x + r(h,1)(1-x), \qquad x \equiv \frac{c^{l,1}}{c^{l,2}} \in [0,1].$$

The DT analogous of Propositions 1-2 is

Proposition 3: Given DT, then (*i*) IP is a sufficient condition set for $P2 \succ_{BD} P1$. It is also necessary; (*ii*) DP is a necessary condition for $P1 \succ_{BD} P2$ but it is not sufficient; (*iii*) DP plus $r(l,2) < r(h,1)$ are necessary and sufficient conditions when the value of $x \equiv c^{l,1} / c^{l,2} \in [0,1]$ is not known; (*iv*) DP plus $r(l,2) < r(l,1)x + r(h,1)(1-x)$ are necessary and sufficient conditions when $x \in [0,1]$ is known.

From this we note that condition (11) fails under $r(l,2) < r(h,1)$, when DT plus DP give the total ordering $r(h,2) < r(l,2) < r(h,1) < r(l,1)$.

Paradox

Under DP, both $r(l,2) < r(l,1)$ and $r(h,2) < r(h,1)$ apply. In other words, P1 is preferred to P2 on both low-benefit land and high-benefit land so that one might think that P1 must be the program to implement regardless of budget available. And yet budgetary circumstances arise in which (9) applies for IT and (11) applies for DT so that P2 is preferred. The oddity can be understood by recognizing that P1 is the less costly program so that it allows for larger acreage enrollment. So one should not compare the programs acre by acre, but rather acreage portfolio by acreage portfolio. Under P1 more acres are enrolled and so the mass distribution weighting over *h* and *l* acres differs across programs.

In statistics, the phenomenon is often referred to as Simpson's paradox or the amalgamation paradox (Sunder, 1983; Good and Mittal, 1987; Pavlides and Perlman, 2009). This is because what is true conditional on event A and true conditional on event B may not be true conditional on event A union B. To state the issue more clearly, suppose that IT applies. Let P1 enroll $a^{1,h}$ acres of type *h* and $a^{1,l}$ acres of type *l* while P2 enrolls $a^{2,h}$ acres of type *h* and $a^{2,l}$ acres of type *l*. Then DP statements $r(l,2) < r(l,1)$ and $r(h,2) < r(h,1)$ are entirely consistent with

(12) $$\frac{a^{l,2}r(l,2) + a^{h,2}r(h,2)}{a^{l,2} + a^{h,2}} > \frac{a^{l,1}r(l,1) + a^{h,1}r(h,1)}{a^{l,1} + a^{h,1}}.$$

The conditions one needs for (12) to occur are that (*a*) $r(l,1) \le r(h,2)$, and then (*b*) acreage weights shift so as to place a larger weight on the lower benefit-to-cost ratio value under P1, namely, $r(h,1)$, than under P2, namely, $r(h,2)$. Lower costs for P1, when together with the budget constraint, create the shift in acreage shares to ensure a shift toward *l* type acres under P1 when compared with P2. IT allows for the possibility that overall benefits fall under P1 when compared with P2.

Conclusion

Using the standard model for environmental benefits and a direct, if reduced-form, approach to comparing environmental programs, we have explored two variants of the same question: When should a limited budget to purchase environmental services be concentrated on a few acres rather than spread over many? and Does the level of budget matter?

The answer to the first question depends on how the benefit-to-cost ratio varies with land type, and also with the intensity of services required by the programs at issue. As our paradoxical example shows, intuition may not be sufficient to establish which program is better. The answer to the second question is that, even in our simple model with strong structure on benefit-to-cost ratios, the ranking of programs can depend on the budget available. Sometimes the best choice at one budget level will not be the best at another level. This observation is of practical relevance because "pilot programs" are sometimes evaluated before widespread implementation, and because program funds can vary with fiscal circumstances.

In the United States, land attributes can be obtained from a variety of sources, including the National Resources Inventory. Evidence on environmental benefits to be expected from different programs can be obtained by applying physical models to these data. Surveys exist to estimate the costs of implementing certain practices in certain areas while cost information can also be obtained from programs that have been implemented. It should be possible to check for patterns in environmental benefit-to-cost ratios, be they monotonicity in calculated environmental benefits, in land quality, or in program intensity. Caution is always warranted when integrating data from eclectic sources. Nonetheless, we believe that such endeavors are necessary to establish stylized facts for policy modelers, and to facilitate the more hands-on aspects of program design.

We do recognize shortcomings in our framework, where each parcel of land is viewed in isolation. It has long been recognized among ecologists that geographic scale is important to sustain an ecosystem. Patchwork enrollment in programs ignores positive spatial externalities. Agglomeration bonuses are one example of policy endeavors to incentivize coordinated enrollment over privately owned land (Smith and Shogren, 2002; Parkhurst *et al.*, 2002). We would also like to address how program benefits are bundled when spending a given budget. Under what conditions would it be better to offer the eco-services embodied in intensive Program 2 separately on different land tracts, rather than as a bundle on the same land tract?

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Appendix

Case I: If P1 is chosen and the budget is insufficient to cover all high net benefit land then the net program benefit amounts to $a^{h,1}\phi$ where $\phi < \pi$ is the fraction of land covered. Since the budget is spent in full, it follows that $E = c^{h,1}\phi$ so that $\phi = E / c^{h,1}$ and net benefits may be re-written as $r(h,1)E$. Similarly, if P2 is chosen and the budget is insufficient to cover all high net benefit acres, then net program benefit amounts to $r(h,2)E$. This leads to eqn. (2).

Case II: If low-cost P1 is chosen with sufficient budget such that some of the low net benefit land enters P1, then net program benefit amounts to $a^{h,1}\pi + \rho a^{l,1}$ where $E = c^{h,1}\pi + \rho c^{l,1}$ so that $\rho = (E - c^{h,1}\pi) / c^{l,1}$ and net benefits may be re-written as $a^{h,1}\pi + (E - c^{h,1}\pi) r(l,1) =$ $[r(h,1) - r(l,1)]c^{h,1}\pi + r(l,1)E$. If high-cost P2 is chosen, then net benefits are $r(h,2)E$, as previously established in Case I. With Δ^{II} equal to net benefits under P2 less those under P1, P2 will be chosen if and only if $\Delta^{\text{II}} \geq 0$ where

$$\begin{aligned}\Delta^{\text{II}} &\equiv \left[r(h,2) - r(l,1)\right]E - \left[r(h,1) - r(l,1)\right]c^{h,1}\pi \\ &= \left[r(h,2) - r(h,1)\right]c^{h,1}\pi + \left[r(h,2) - r(h,1)\right](E - c^{h,1}\pi) + \left[r(h,1) - r(l,1)\right](E - c^{h,1}\pi).\end{aligned} \tag{A1}$$

This establishes eqn. (3) where IT has been applied.

Case III: In this case, when low-cost P1 is chosen, then the calculations in eqn. (3) apply. When high-cost P2 is chosen, then the net program benefit amounts to $a^{h,2}\pi + a^{l,2}\gamma$, $\gamma \geq 0$, where $E = c^{h,2}\pi + c^{l,2}\gamma$ so that net benefits may be written as $a^{h,2}\pi + (E - c^{h,2}\pi) r(l,2) =$ $r(l,2)E + [r(h,2) - r(l,2)]c^{h,2}\pi$. Taking the difference and rearranging, P2 will be chosen if and only if $\Delta^{\text{III}} \geq 0$ where Δ^{III} is as given in eqn. (4).

Table 1. Environmental benefit to cost ratios for three land parcels.

Program	Extensive			Intensive		
Parcel	I	II	III	I	II	III
Benefit	6	1.5	1.5	10	2	2
Cost	2	1	1	4	1.5	1.5
Ratio	3	1.5	1.5	2.5	1.33	1.33

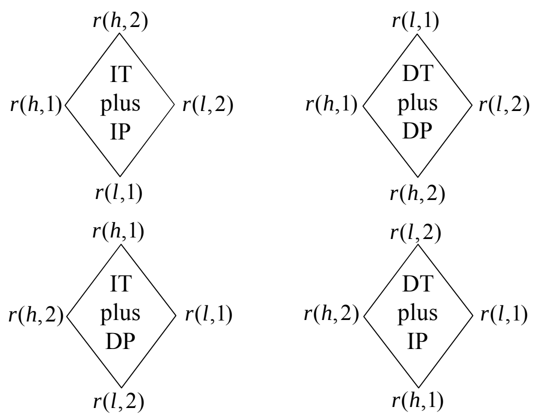


Figure 1. Lattices partially ordering ratios under monotonicity conditions

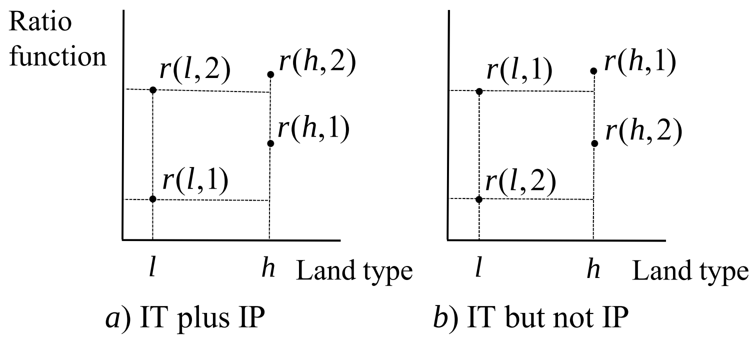


Figure 2. Ratio function and program intensity

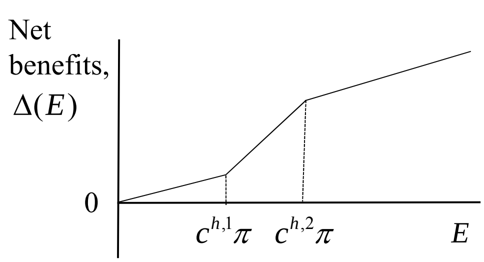
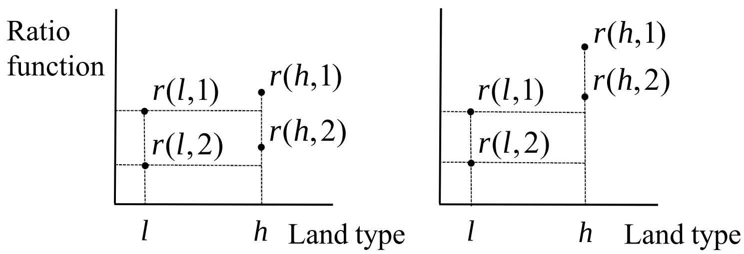


Figure 3. Budget dominance: P2 benefits less P1 benefits under IT



a) IT plus DP plus $r(h,2) < r(l,1)$

b) IT plus DP plus $r(h,2) \geq r(l,1)$

Figure 4. Ratio function conditions for extensification

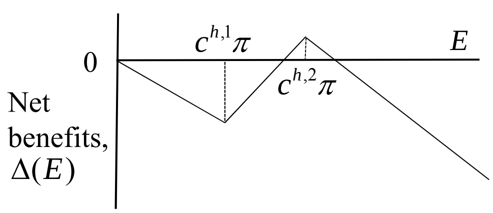


Figure 5. Budget dominance failure under IT plus DP