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**Working Paper 99-WP230**  
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## Abstract

Resource purchasing funds have become a major tool for environmental protection and resource conservation. These funds use various strategies to target resources for environmental conservation, the choice of which may lead to striking differences in environmental performance. This paper develops an analytical framework to compare the effects of alternative targeting strategies on consumer surplus, producer surplus, and environmental benefits. We demonstrate that ignoring the output price effect of purchasing funds reduces environmental gain from the purchasing fund and, in some cases, may make a purchasing fund counterproductive. A purchasing strategy that targets resources with the highest environmental benefits may be counterproductive even if the price feedback effect is recognized. This strategy, however, will have the smallest impact on output price and overall resource use among all strategies considered and should be favored by consumers and input providers. A strategy that targets low-cost resources will result in the largest reduction in production and the largest output price increase, and should be favored by resource owners. A strategy that targets resources with the highest benefit-to-cost ratio is efficient and provides the largest environmental benefits for a given budget when the output demand is perfectly elastic. This strategy, however, no longer maximizes total environmental benefit for a given budget when output demand is not perfectly elastic, and should not be the most preferred strategy of any group. We argue that the optimal design of targeting criteria must consider the price feedback effect.

**Keywords:** conservation funds, distributional effects, environmental benefits, targeting strategies.

**JEL classification:** D1, D2.

## ENVIRONMENTAL AND DISTRIBUTIONAL IMPACTS OF CONSERVATION TARGETING STRATEGIES

*“You want to save the environment? Buy it!”*

*Ted Turner’s commencement address,*

*College of Natural Resources,*

*U. C. Berkeley, 1996.*

Resource purchasing funds have become a major tool for environmental protection and resource conservation. Total federal expenditures on resource conservation and environmental programs were estimated to be \$6.7 billion in fiscal year 1996 ([22], p. 264). Examples of purchasing funds abound. A major reform of U.S. agricultural policy in 1996 was the transformation of the Conservation Reserve Program from a supply control program to a conservation fund with a current annual budget of over \$1.8 billion. More than \$15 billion was spent on the program from 1987 to 1996. Recently, the U.S. government purchased the prime forestland in the Headwaters of California, with an acquisition cost of \$480 million. The federal Central Valley Project Improvement Act passed in 1992 established a purchasing fund with an annual budget of \$60 million to divert water from agricultural production to enhance stream flows in the Central Valley of California. National park systems around the world are often established by purchasing “crown jewel” tracts of land. Debt for nature swaps are becoming an increasingly popular method of preserving biodiversity in developing countries. The Nature Conservancy has protected 9.5 million acres of environmentally valuable land and manages 1,500 preserves in the United States.

Existing conservation funds do not use identical strategies for targeting purchases.<sup>1</sup> The Conservation Reserve Program enrolled land based mainly on cost before 1992 [12, 21]. This strategy maximizes the amount of the resource acquired (land or water) regardless of

environmental value. Benefit targeting acquires resources with the highest per-unit environmental value regardless of the per-unit cost. The U.S. Fish and Wildlife Service tends to target wetlands and other water resources based primarily on biological criteria. Benefit-cost targeting obtains resources according to the ratio of environmental benefit to economic cost. There is a growing tendency to employ this criterion in environmental purchasing activities.<sup>2</sup>

Choice of a targeting strategy for a conservation fund may be determined by both political and economic considerations.<sup>3</sup> Several interest groups are potentially affected by conservation funds, including resource owners, consumers, and environmentalists. As purchasing funds become more widely used, the question naturally arises as to which targeting scheme will be preferred by affected groups. Should environmentalists prefer benefit targeting? Should resource owners prefer cost targeting? Should consumers prefer benefit-cost targeting?

In this paper, we attempt to address these questions by comparing the effects of alternative targeting strategies on consumer surplus, producer surplus, and environmental benefits. Our framework assumes a heterogeneous resource base where resource units have a joint distribution of fixed coefficients of output and environmental benefit. This assumption was used by Houthaker [12] and Johansen [13] to provide the theoretical foundation for aggregate neoclassical production functions and was expanded by Hochman and Zilberman [11], Just and Antle [14], and Opaluch and Segerson [16] to environmental policy analysis.<sup>4</sup> Consistent with these studies, we abstract from information problems and assume that the policymaker has full information about resource productivity and environmental benefits.<sup>5</sup> The increased availability of detailed micro-level data combined with GIS techniques make this approach empirically tractable and it has been applied in recent policy debates.<sup>6</sup>

We demonstrate that groups differ in their preference ordering of the conservation strategies. Producers should prefer cost targeting; consumers, labor and input suppliers should prefer benefit targeting; and environmental groups should prefer benefit-cost targeting when output demand is perfectly elastic. We consider price feedback effects associated with inelastic output demand. This feedback reduces the effectiveness of the purchasing fund and may change the preference of environmentalists over benefit or benefit-cost targeting. We show that when output demand is

not perfectly elastic benefit-cost targeting no longer maximizes total environmental benefits for a given budget. We obtain conditions under which ignoring the feedback from increased output price leads to an overall decline in environmental quality and argue that optimal design of purchasing strategies should incorporate output market considerations.

The next section discusses alternative targeting strategies for conservation funds. Section 3 compares the economic, environmental, and distributional effects of these strategies for the case of fixed output price. Section 4 considers the “slippage” of environmental benefits associated with the output price increase. Section 5 derives the targeting criterion that maximizes total environmental benefit when output demand is not perfectly elastic. Section 6 compares the performance of all targeting strategies for the case of inelastic output demand. Section 7 concludes the paper with a discussion of the results.

### Targeting Strategies

Consider a competitive industry producing an output using a resource that also generates environmental benefit. The quality of the resource is differentiated by the output and environmental benefit per unit of resource, both of which are assumed to be fixed (the putty-clay assumption). Let  $y$  be output per unit of resource, and let  $b$  be the environmental benefit per unit of resource if the resource is preserved. Let  $s(y, b)$  be the resource distribution function, where  $y$  varies from 0 to  $\bar{y}$  and  $b$  varies from 0 to  $\bar{b}$ . Production cost per unit of resource is assumed constant and is denoted by  $c$ . In many cases the resource is land and  $y$  is output unit of land, and  $b$  is the environmental benefit provided by one unit of land when it is removed from production. For example,  $b$  may represent biodiversity benefit or reduction in soil erosion.

The difficulty of accurately measuring the social value of environmental benefits creates a formidable obstacle to determining the optimal budget.<sup>7</sup> Governments in many cases set a budget for the purchasing fund and then design a criterion for targeting resources for purchase. In this paper we accommodate this procedure and consider four popular targeting criteria under a given budget. Let  $i$  be an index of the targeting criteria, with  $i = 0$  representing the resource situation before the establishment of the conservation fund. Cost targeting ( $i = 1$ ) purchases the

least expensive resources. Benefit targeting ( $i = 2$ ) purchases the resources with the highest environmental benefit, regardless of cost. Benefit-cost targeting ( $i = 3$ ) purchases resources with the highest ratio of environmental benefit to economic cost. Benefit-maximizing targeting ( $i = 4$ ) maximizes total environmental benefit for a given budget.

Each targeting strategy corresponds to selecting a subset of  $(y, b)$  from the base resource set  $R \equiv \{(y, b); 0 \leq y \leq \bar{y}; 0 \leq b \leq \bar{b}\}$ . Let  $X$  be a subset of  $R$ . The total number of resource units in  $X$  is

$$Q(X) = \iint_X s(y, b) dy db. \quad (1)$$

The total output  $Y(X)$  and the total environmental benefit  $B(X)$  are

$$Y(X) = \iint_X ys(y, b) dy db \quad \text{and} \quad B(X) = \iint_X bs(y, b) dy db. \quad (2)$$

Short-term profit or quasi-rent from using the resource is

$$\Pi(X) = \iint_X (py - c)s(y, b) dy db = pY(X) - cQ(X), \quad (3)$$

where  $p$  is output price. To compare the economic and environmental impacts of alternative targeting strategies, it is important to identify both the resources in production and resources in conservation under each of these strategies.

Let  $U_i$  be the set of resources  $((y, b)$  combinations) in production under strategy  $i$ .<sup>8</sup>

$$U_i \equiv U_i^{ru} + U_i^{ac} \quad (i = 1, 2, 3, 4), \quad (4)$$

where  $U_i^{ru}$  is the set of reused resources — resources utilized both before and after the introduction of the conservation fund, and  $U_i^{ac}$  is the set of activated resources — previously idle resources to be used in production after the establishment of the conservation fund because of the resulting output price increase.

Let  $I_i$  be the set of resources in conservation under strategy  $i$ .

$$I_i \equiv I_i^{rt} + I_i^{rm} + I_i^{lp} \quad (i = 1, 2, 3, 4), \quad (5)$$

where  $I_i^{rt}$  is the set of retired resources — previously utilized resources purchased by the fund,  $I_i^{rm}$  is the set of retained resources — previously idle resources purchased by the fund, which would be used in production if not purchased because of the output price increase, and  $I_i^{lp}$  is the set of low productivity resources — resources in preservation both before and after the introduction of the conservation fund.

By using these notations and the functions defined by equations (1) through (3), the number of resource units in production under strategy  $i$  is  $Q(U_i)$ ,<sup>9</sup> and the number of resource units in conservation under strategy  $i$  is  $Q(I_i)$ . The key performance measures for strategy comparison are: i) aggregate output  $Y_i = Y(U_i)$ ; ii) aggregate short-term profit from production  $\Pi_i = \Pi(U_i)$ ; iii) total producer surplus from both production and the conservation fund  $PS_i = \Pi(U_i^{ru} + U_i^{ac} + I_i^{rt} + I_i^{rm}) = \Pi_i + M$ ; iv) consumer surplus  $CS_i$ ; v) total environmental benefit  $B_i = B(I_i)$ ; and vi) the net gain in environmental benefit  $\Delta B_i \equiv B(I_i^{rt}) - B(U_i^{ac})$ . If  $\Delta B_i < 0$ , the conservation fund is said to be counterproductive. In the next section, we compare the performance of the four targeting strategies, assuming output price is fixed.

### Comparing Targeting Strategies: Fixed Output Price

When output demand is perfectly elastic, output price is not affected by the purchasing fund (i.e.,  $p_1 = p_2 = p_3 = p_0$ ), and no idle resources will be activated by the conservation fund (i.e.,  $U_i^{ac} = 0$ ,  $I_i^{rm} = 0$ , and  $I_i^{lp} = \{(y, b); y < c/p_0\}$  for all  $i$ ). In this case, benefit-cost targeting maximizes total environmental benefit for a given budget (i.e., it becomes identical to benefit-maximizing targeting).

Suppose the conservation fund is operated under full information, and resource owners will divert the resource from production if offered the opportunity cost in production. Under cost targeting ( $i = 1$ ), there is a critical output level  $y^*$  such that all resources with output lower than  $y^*$  will be preserved. Thus, the retired resources under this strategy are

$$I_1^{rt} = \{(y, b); c/p_0 \leq y < y^*\}, \quad (6)$$

where  $y^*$  is defined by  $\Pi(I_1^{rt}) = \bar{G}$ , and  $\bar{G}$  is the total budget of the conservation fund. Reused resources under cost targeting are

$$U_1^{ru} = \{(y, b); y \geq y^*\}. \quad (7)$$

Under benefit targeting ( $i = 2$ ), there is a critical level of environmental benefit  $b^*$  such that all utilized resources with  $b > b^*$  will be diverted from production. Thus, retired resources under this strategy are

$$I_2^r = \{(y, b); y \geq c/p_0, b > b^*\}, \quad (8)$$

where  $b^*$  is defined by  $\Pi(I_2^r) = \bar{G}$ . Reused resources under benefit targeting are

$$U_2^{ru} = \{(y, b); y \geq c/p_0, b \leq b^*\}. \quad (9)$$

Under benefit-cost targeting, there is a critical benefit-cost ratio,  $MB^*$ , such that all utilized resources with  $b/(p_0y - c) > MB^*$  will be preserved. Thus, the retired resources under benefit-cost targeting are

$$I_3^r = \{(y, b); y \geq c/p_0, b > MB^*(p_0y - c)\}, \quad (10)$$

where  $MB^*$  is defined by  $\Pi(I_3^r) = \bar{G}$ . The reused resources under this strategy are

$$U_3^{ru} = \{(y, b); y \geq c/p_0, b \leq MB^*(p_0y - c)\}. \quad (11)$$

These three targeting strategies can be illustrated by using Figure 1. The resources in conservation under these targeting strategies are  $I_1 = O + H + I + J + K$ ,  $I_2 = O + J + K + L + M$ , and  $I_3 = O + I + J + L$ . The resources in production under these strategies are  $U_1 = L + M + N$ ,  $U_2 = H + I + N$  and  $U_3 = H + K + M + N$ . The performance of these targeting strategies is compared in proposition 1.

Proposition 1: If the conservation fund has no effect on the output price, then

- (i)  $Q(I_1) \geq Q(I_3) \geq Q(I_2)$ ,      (ii)  $Q(U_1) \leq Q(U_3) \leq Q(U_2)$ ,
- (iii)  $Y_2 \geq Y_3 \geq Y_1$ ,      (iv)  $PS_1 = PS_2 = PS_3 = \Pi_0$ ,
- (v)  $B_3 \geq B_1, B_2$ .

*Proof:* From Figure 1, the difference in the number of resource units in conservation under benefit targeting and benefit-cost targeting is

$$Q(I_2) - Q(I_3) = Q(K + M) - Q(I). \quad (12)$$

Because resources in  $K+M$  are more productive and therefore more expensive than resources in  $I$ , a given budget can purchase more resources in  $I$  than in  $K+M$ . Thus,

$$Q(I_2) - Q(I_3) \leq 0. \quad (13)$$

Under cost targeting, least expensive resources are purchased first. As a result, more resources will be purchased under cost targeting than under benefit or benefit-cost targeting. This result along with (13) implies the relationships in (i). Because  $I_i + U_i = R$  is fixed, (i) implies (ii).

To prove  $Y_2 \geq Y_3 \geq Y_1$ , notice that the resources in production under the three targeting strategies are  $U_1 = L + M + N$ ,  $U_2 = H + I + N$  and  $U_3 = H + K + M + N$ . Thus,

$$Y_2 - Y_3 = Y(H + I + N) - Y(H + K + M + N) = Y(I) - Y(K + M), \quad (14)$$

$$Y_3 - Y_1 = Y(H + K + M + N) - Y(L + M + N) = Y(H + K) - Y(L). \quad (15)$$

To determine the sign of the difference, note that

$$\Pi(I_2^r) = \bar{G} = \Pi(I_3^r) \quad \text{and} \quad \Pi(I_3^r) = \bar{G} = \Pi(I_1^r). \quad (16)$$

By using (2), we obtain

$$p_0 Y(I_2^r) - c Q(I_2^r) = p_0 Y(I_3^r) - c Q(I_3^r), \quad (17)$$

$$p_0 Y(I_3^r) - c Q(I_3^r) = p_0 Y(I_1^r) - c Q(I_1^r). \quad (18)$$

Because  $Q(I_1^r) \geq Q(I_3^r) \geq Q(I_2^r)$ , we have

$$Y(I_2^r) \leq Y(I_3^r) \quad \text{and} \quad Y(I_3^r) \leq Y(I_1^r). \quad (19)$$

Substituting  $I_1^r = H + I + J + K$ ,  $I_2^r = J + K + L + M$ , and  $I_3^r = I + J + L$  into (19) gives

$$Y(K + M) \leq Y(I) \quad \text{and} \quad Y(L) \leq Y(H + K). \quad (20)$$

Finally, by substituting (20) into (14) and (15), we obtain

$$Y_2 \geq Y_3 \geq Y_1. \quad (21)$$

To compare profit and producer net returns under these targeting strategies, note that when the output price is fixed resources that are profitable to use are the same under the three targeting criteria. Specifically,  $U_i^r + I_i^r = U_0 = \{(y, b); y \geq c/p_0\}$  for  $i = 1, 2, 3$ . Thus,

$$PS_i = \Pi(U_i^r + I_i^r) = \Pi(U_0). \quad (22)$$

Because  $\Pi_i = PS_i - M = \Pi(U_0) - M$ , total profit from production under the three targeting strategies are also identical.

To prove  $B_3 \geq B_1$ , note that

$$B_3 - B_1 = B(I_0^l + I_3^r) - B(I_0^l + I_1^r) = B(I_3^r) - B(I_1^r). \quad (23)$$

Substitute  $I_1^r = H + I + J + K$  and  $I_3^r = I + J + L$  into (23),

$$B_3 - B_1 = B(L) - B(H + K). \quad (24)$$

Under both the cost and benefit-cost targeting strategies, resources in  $I+J$  will be targeted for conservation. Thus, the same amount of money is left for purchasing resources in  $L$  under benefit-cost targeting and for purchasing resources in  $H+K$  under cost targeting. Because cost per

unit of benefit is less in  $L$  than in  $H+K$ , a given budget can purchase more environmental benefits from resource in  $L$  than from resources in  $H+K$ , implying that the right-hand side of (24) is greater than zero. Similarly, we can prove that

$$B_3 - B_2 = B(I_3^s) - B(I_2^s) = B(I) - B(K + M) \geq 0. \quad (25)$$

The difference between total benefits under cost and benefit targeting cannot be signed. To see why, note that

$$B_1 - B_2 = B(H + I) - B(L + M). \quad (26)$$

Although resources in  $I+H$  offer less benefit per unit than resources in  $L+M$ , resources in  $I+H$  are less expensive than resources in  $L+M$ . As a result, a given budget can purchase more resource in  $H+I$  than in  $L+M$ . *Q.E.D.*

The differences in output, environmental benefits and the total amount of resource saved under the three targeting strategies depend on the correlation between productivity and environmental benefits. When they are negatively correlated, resources that cost less are also more likely to offer larger environmental benefits. In this case, all three strategies are likely to target the same resources. For example, the differences in the amount of resources purchased and the total output under benefit and cost targeting are

$$Q_1^s - Q_2^s = Q(H + I) - Q(L + M) \quad \text{and} \quad Y_1 - Y_2 = \frac{c}{p_0} [Q(L + M) - Q(H + I)]. \quad (27)$$

These differences would be relatively small when productivity and environmental benefits are negatively correlated because there are fewer resource units in both  $H+I$  and  $L+M$ . Intuitively, a negative correlation between  $b$  and  $y$  implies that, on average, resources that cost less are also more likely to offer larger benefits. As a result, cost targeting and benefit targeting are more likely to target the same resources (resources in  $J+K$ ). On the other hand, when costs and benefits are positively correlated, resources that cost less are also more likely to offer fewer benefits. As a result, most resources purchased under cost ranking will be in  $H+I$ , whereas most resources purchased under benefit ranking will be in  $L+M$ . Because resources in  $H+I$  are less expensive than resources in  $L+M$ , more resources will be purchased under cost targeting than under benefit targeting. As a result, both differences in (27) are relatively large.

Output and the amount of resource saved under benefit-cost targeting are between those obtained under cost targeting and benefit targeting. This suggests that total output and resource saved under all three targeting criteria will be quite close when benefits and costs are negatively correlated, and they will be quite different when benefits and costs are positively correlated. Similarly, it can be shown that the differences in total environmental benefits achieved under the three targeting criteria will be small when productivity and environmental benefits are negatively correlated and large when they are positively correlated.

Proposition 1 suggests that environmentalists should prefer benefit-cost targeting because it results in the largest environmental benefits. Groups that are interested in maintaining higher production levels, such as labor, would prefer benefit targeting over benefit-cost targeting or cost targeting because benefit targeting takes the smallest amount of resource out of production and results in the highest output level. Producers should be indifferent among the three targeting strategies because total producer surplus does not change across the alternatives.

In the next three sections, we analyze the outcomes for the case of downward sloping demand. We first identify conditions under which the targeting strategies may be counterproductive and then compare their economic, environmental, and distributional impacts.

### **Endogenous Output Price and Slippage**

With a downward sloping demand curve, the conservation fund will increase the output price as resources are diverted from production. This increase in output price can cause two types of “slippage”. First, it becomes profitable to use some previously idle resources. These resources would be used in production if not purchased, reducing total environmental benefits. On the other hand, if these resources are purchased, less money is available for purchasing other resources. Second, the increase in output price makes resources more valuable in production. If the resource owners anticipate this price increase, they will ask for higher selling prices. As a result, fewer resources can be purchased with a given budget.

The amount of slippage can be quite significant. For example, 16.76 million acres of cropland were retired under the Conservation Reserve Program (CRP) in 14 major agricultural states in U.S. Midwest by 1992,<sup>10</sup> but total cropland acres were reduced by only 5.3 million acres, implying that 11.46 million acres of non-cropland was converted to cropland in the period. Berck and Bentley [5] estimate that governmental takings of old-growth redwood for inclusion in the Redwood National Park have significantly increased the redwood price. The 1978 taking alone increased the redwood price by 26%. Ironically, these price increases lead to increased profits and the harvesting of more old-growth redwood on other lands. In this section, we show that slippage reduces the effectiveness of the conservation fund and, in some cases, may lead to lower environmental quality.

To analyze the likelihood of the counterproductive outcome, define the benefit intensity of resources in  $X$ ,  $\delta(X)$ , as the ratio of average benefit to average output of resources in  $X$ ,  $E(b|X)/E(y|X)$ . Counterproductive outcomes are likely to occur as the ratio of the benefit intensity of the activated resources to the benefit intensity of the retired resources increases. Denote the elasticity of output demand as  $\mathbf{h} = -D'(p_0) \frac{p_0}{Y_0}$ . In most cases, inelastic demand increases the likelihood of counterproductive outcomes. Finally, denote the average profit per unit of output in set  $X$  as  $E(\mathbf{p}_y | X) \equiv p - c / E(y | X)$  and the change in output price under strategy  $i$  as  $\Delta p_i \equiv p_i - p_0$ .

We consider two policy designs in response to slippage. One is unrestricted targeting, where targeting is not restricted to resources in production. In this case, some of the previously idle resources that become profitable to use are purchased. The other is restricted targeting, where a purchasing fund is designed to purchase only resources in production. The CRP, for example, targets only cropland currently in production. In this case, some low quality resources that were idle before will be utilized because of the price increase. Thus, six policy scenarios are evaluated below.

*i. Unrestricted Cost Targeting:* This case is depicted in Figure 2a, where  $I_{1a}^m$  is retained resources,  $I_{1a}^r$  and  $I_{1a}^p$  are retired and low productivity resources, and  $U_{1a}^m$  is the reused resources. Because all previously idle resources are either purchased or still unprofitable to use, there are no

activated resources (i.e.,  $U_{1a}^{ac} = 0$ ). The total environmental gain under the strategy is  $\Delta B_{1a} = B(U_{1a}^{rt})$ , which is positive except when output demand is perfectly inelastic. With a perfectly inelastic demand, the environmental gain will disappear, and the conservation fund is fully transferred to owners of low-quality resources.

*ii. Restricted Cost Targeting:* This case is depicted in Figure 2b. In this case, some previously idle resources are activated because of the output price increase from  $p_0$  to  $p_{1b}$ . Production resources in  $I_{1b}^{rt}$  are purchased, and previously idle resources in  $U_{1b}^{ac}$  are activated and used. The net environmental gain is  $\Delta B_{1b} = B(I_{1b}^{rt}) - B(U_{1b}^{ac})$ .

*iii. Unrestricted Benefit Targeting:* This case is depicted in Figure 3a. The introduction of the purchasing fund raises output price to  $p_{2a}$ . Previously idle resources in  $U_{2a}^{ac}$  are activated, while previously idle resources in  $I_{2a}^{rt}$  are purchased. Previously used resources in  $I_{2a}^{rt}$  are purchased. The net environmental gain under this targeting strategy is  $\Delta B_{2a} = B(I_{2a}^{rt}) - B(U_{2a}^{ac})$ .

*iv. Restricted Benefit Targeting:* This case is depicted in Figure 3b. When benefit targeting only purchases previously utilized resources ( $I_{2b}^{rt}$ ), some of the low productivity resources ( $U_{2b}^{ac}$ ) will be activated because of the output price increase. The net environmental gain under this targeting strategy is  $\Delta B_{2b} = B(I_{2b}^{rt}) - B(U_{2b}^{ac})$ .

*v. Unrestricted Benefit-Cost Targeting:* This case is depicted in Figure 4a. The previously utilized resources in  $I_{3a}^{rt}$  are retired, previously idle resources in  $I_{3a}^{rt}$  are retained, and previously idle resources in  $U_{3a}^{ac}$  are activated. The net environmental gain is  $\Delta B_{3a} = B(I_{3a}^{rt}) - B(U_{3a}^{ac})$ .

*vi. Restricted Benefit-Cost Targeting:* This case is depicted in Figure 4b, where resources in  $I_{3b}^{rt}$  are retired, and resources in  $U_{3b}^{ac}$  are activated. The net environmental gain is

$$\Delta B_{3b} = B(I_{3b}^{rt}) - B(U_{3b}^{ac}).$$

As output demand becomes more inelastic, slippage tends to increase. In some cases, the introduction of purchasing fund may be *counterproductive* from an environmental perspective.

Proposition 2: All restricted targeting criteria and unrestricted benefit targeting may reduce environmental quality. The conditions for the counterproductive outcome are

$$\Delta B_{1b} \leq 0 \quad \text{iff} \quad \frac{\mathbf{d}(I_{1b}^{rt})}{\mathbf{d}(U_{1b}^{ac})} \leq \frac{Y(U_{1b}^{ac})}{Y(I_{1b}^{rt})} = 1 - \mathbf{h} \frac{\Delta p_{1b} Y_0 E(\mathbf{p}_y | I_{1b}^{rt})}{p_0 M}, \quad (28)$$

$$\Delta B_{2a} \leq 0 \quad \text{iff} \quad \frac{d(I_{2a}^r)}{d(U_{2a}^{ac})} \leq \frac{Y(U_{2a}^{ac})}{Y(I_{2a}^r)} = 1 - h \frac{\Delta p_{2a} Y_0 E(\mathbf{p}_y | I_{2a}^r)}{p_0 [M - Y(I_{2a}^r) E(\mathbf{p}_y | I_{2a}^r)]}, \quad (29)$$

$$\Delta B_{2b} \leq 0 \quad \text{iff} \quad \frac{d(I_{2b}^r)}{d(U_{2b}^{ac})} \leq \frac{Y(U_{2b}^{ac})}{Y(I_{2b}^r)} = 1 - h \frac{\Delta p_{2b} Y_0 E(\mathbf{p}_y | I_{2b}^r)}{p_0 M}, \quad (30)$$

$$\Delta B_{3b} \leq 0 \quad \text{iff} \quad \frac{d(I_{3b}^r)}{d(U_{3b}^{ac})} \leq \frac{Y(U_{3b}^{ac})}{Y(I_{3b}^r)} = 1 - h \frac{\Delta p_{3b} Y_0 E(\mathbf{p}_y | I_{3b}^r)}{p_0 M}. \quad (31)$$

*Proof:* First, we prove (28). By definition,

$$Y_0 = Y(I_{1b}^r + U_{1b}^r) = D(p_0), \quad (32)$$

$$Y_{1b} = Y(U_{1b}^{ac} + U_{1b}^r) = D(p_{1b}). \quad (33)$$

The difference between (32) and (33) is

$$Y(I_{1b}^r) - Y(U_{1b}^{ac}) = D(p_0) - D(p_{1b}) \cong D'(p_0)(p_0 - p_{1b}) = \eta \frac{\Delta p_{1b} Y_0}{p_0}. \quad (34)$$

Also the budget constraint implies

$$M = pY(I_{1b}^r) - cQ(I_{1b}^r) = Y(I_{1b}^r)E(\mathbf{p}_y / I_{1b}^r), \quad (35)$$

$$Y(I_{1b}^r) = M / E(\mathbf{p}_y / I_{1b}^r). \quad (36)$$

Divide (34) by (36) and then rearrange terms,

$$\frac{Y(U_{1b}^{ac})}{Y(I_{1b}^r)} = 1 - h \frac{\Delta p_{1b} Y_0 E(\mathbf{p}_y | I_{1b}^r)}{p_0 M}. \quad (37)$$

By definition,

$$\Delta B_{1b} = B(I_{1b}^r) - B(U_{1b}^{ac}) = \delta(I_{1b}^r)Y(I_{1b}^r) - \delta(U_{1b}^{ac})Y(U_{1b}^{ac}). \quad (38)$$

Thus,  $\Delta B_{1b} \leq 0$  if and only if

$$\frac{\delta(I_{1b}^r)}{\delta(U_{1b}^{ac})} \leq \frac{Y(U_{1b}^{ac})}{Y(I_{1b}^r)}. \quad (39)$$

Substituting (37) into (39) gives (28). The proofs of conditions (29)-(31) are similar and omitted. *Q.E.D.*

Proposition 2 demonstrates that counterproductive outcome may occur under all restricted targeting criteria, and under unrestricted benefit targeting. Restricted cost targeting will result in a counterproductive environmental outcome under condition (28). The LHS of (28) is the ratio of the benefit intensity of the retired resources ( $I_{1b}^r$  in Figure 2b) to the activated resources ( $U_{1b}^{ac}$ ). The RHS of (28) is the ratio of the output of the activated resources to the output of the retired resources. The purchasing fund will reduce environmental quality if the aggregate benefits of activated resources are greater than the aggregate benefits of the retired resources. The retired resources produce more output than the activated resources (output price increases with the purchasing fund). Condition (28) shows that if the purchasing fund has a counterproductive effect, the benefit to output ratio of activated resources must be larger than the benefit to output ratio of retired resources ( i.e.,  $\delta(U_{1b}^{ac}) > \delta(I_{1b}^r)$  ).

To satisfy condition (28), environmental benefits must be negatively correlated with productivity. This happens, for example, when most resources are concentrated along line  $bc$  in figure 2b. But the negative correlation between  $y$  and  $b$  is only a necessary condition since it guarantees the LHS of (28) is less than one. For counterproductive outcome to occur, the output demand has to be sufficiently inelastic so that the RHS of (28) is larger than the LHS of (28).

Unrestricted benefit targeting will result in counterproductive outcome under condition (29). This condition suggests that the smaller the ratio of the benefit intensity of retired resources ( $I_{2a}^r$  in Figure 3a) to the activated resources ( $U_{2a}^{ac}$ ), the more likely the counterproductive outcome to occurs. The counterproductive effect will not happen when benefits and productivity are negatively correlated and  $LHS > 1$ . The RHS of (29) is the ratio of the output of the activated resources to the output of the retired resources. The counterproductive effect is more likely as the RHS is closer to one, which occurs when the output demand is inelastic ( $\mathbf{h}$  is small).

With unrestricted benefit targeting, much of the money will be spent to purchase high productivity resources in  $I_{2a}^r$  in Figure 3a. Significant price increases (for small  $\mathbf{h}$ ) will activate low productivity resources in  $U_{2a}^{ac}$ . More resources may be activated than retired (even though activated resources produce less output). If productivity has a much larger variation than envi-

ronmental benefits, and environmental benefits are positively correlated with productivity (for example, when most resources are concentrated along line  $ab$  in Figure 3a), then the purchasing fund may be counterproductive.

Restricted benefit targeting will result in a counterproductive environmental outcome under condition (30). This condition is likely to hold when (a) output demand is quite inelastic, (b) environmental benefits and productivity are negatively correlated, and/or (c) the variation in productivity is much larger than the environmental benefits. Under (a),  $h$  is very small and the right-hand side of (30) is close to one. Unlike the case of unrestricted benefit targeting, negative correlation between  $y$  and  $b$  will increase the likelihood of counterproductive effect of restrictive benefit targeting. Under the negative correlation (for example, when resources are concentrated along  $cb$  in Figure 3b), the resource intensity of activated resources is greater than that of the retired sources, and the LHS of (30) is more likely to be less than one. When variation of productivity is large, much of the budget will be spent on purchasing some highly productive resources under benefit targeting. Thus, as output price increases, more resources may be activated than retired. Condition (c) is especially important if the correlation is positive because it makes the LHS of (30) smaller (for example, when resources are concentrated along  $ab$ ). In this case, when environmental benefits do not vary greatly, the environmental loss from activating low productivity resources may be greater than the gains from preserving previously utilized ones.

Restricted benefit-cost targeting will result in a counterproductive environmental outcome under condition (31). The LHS of (31) is the ratio of the benefit intensity of the retired resources to the benefit intensity of the activated resources. It is likely to be less than one if the correlation between  $b$  and  $y$  is negative (for example, when most resources are concentrated along  $cd$  in figure 4b). As in previous cases, the negative correlation is not sufficient to cause the counterproductive effect. It also requires relatively inelastic demand.

Proposition 3: The environmental effects of unrestricted cost targeting and benefit-cost targeting are always nonnegative, i.e.,

$$\Delta B_{1a} = \frac{\delta(I_{1a}^{rt})M}{E(\pi_y | I_{1a}^{rt})} \geq 0, \quad (40)$$

$$\Delta B_{3a} = Y(I_{3a}^{rt}) dU_{3a}^{rt} \left[ \frac{dI_{3a}^{rt}}{dU_{3a}^{ac}} + \frac{h\Delta p_{3a} Y_0}{p_0 Y(I_{3a}^{rt})} - 1 \right] \geq 0. \quad (41)$$

*Proof:* Condition (40) follows from  $\Delta B_{1a} = \delta(I_{1a}^{rt})Y(I_{1a}^{rt})$  and  $M = E(\pi_y | I_{1a}^{rt})Y(I_{1a}^{rt})$ . For unrestricted benefit-cost targeting,  $Y(I_{3a}^{rt}) - Y(U_{3a}^{ac}) = D(p_0) - D(p_{3a}) \cong \eta \frac{\Delta p_{3a} Y_0}{p_0}$ . Divide both sides of this equation by  $Y(I_{3a}^{rt})$  and rearrange terms,

$$\frac{Y(U_{3a}^{ac})}{Y(I_{3a}^{rt})} = 1 - \eta \frac{\Delta p_{3a} Y_0}{p_0 Y(I_{3a}^{rt})}. \quad (42)$$

By definition,

$$\Delta B_{3a} = B(I_{3a}^{rt}) - B(U_{3a}^{ac}) = Y(I_{3a}^{rt}) dU_{3a}^{ac} \left[ \frac{dI_{3a}^{rt}}{dU_{3a}^{ac}} - \frac{Y(U_{3a}^{ac})}{Y(I_{3a}^{rt})} \right]. \quad (43)$$

Substituting (42) into (43) gives (41). Because  $\delta(I_{3a}^{rt}) \geq \delta(U_{3a}^{ac})$ , (42) and (43) together imply  $\Delta B_{3a} \geq 0$ . *Q.E.D.*

Expression (40) suggests that the total environmental benefit achieved under unrestricted cost targeting depends on the budget, the benefit intensity of the retired resources, and the demand elasticity. The per-unit cost of the retired resources increases as demand gets more inelastic, reducing the amount of resources that can be purchased with a given budget. Figure 4a provides the intuition for expression (41). Clearly, all points in  $I_{3a}^{rt}$  are above  $oc$ , whereas all points in  $U_{3a}^{ac}$  are below this line. Thus, the benefit intensity of the activated resources in  $U_{3a}^{ac}$  is lower than the benefit intensity of the retired resources in  $I_{3a}^{rt}$ .

In summary, the results of this section suggest that slippage reduces the effectiveness of conservation funds and, sometimes, may lead to counterproductive environmental outcomes. In the next section, we show that because of slippage, cost-benefit targeting is no longer maximizing total environmental benefit for a given budget.

### Benefit-maximizing Targeting Strategies

When output demand is perfectly elastic, cost-benefit targeting maximizes total environmental benefit for a given budget. This result does not hold for inelastic output demand, however.

Proposition 4: If output demand is not perfectly elastic, then total environmental benefits will be maximized for a given budget if resources are ranked and purchased from high to low according to

$$\frac{b}{(1+r)p_4y-c},$$

where  $\rho > 0$  if  $\eta < \infty$  and  $\rho = 0$  if  $\eta = \infty$ . This benefit-maximizing targeting criterion puts a larger weight on output than benefit-cost targeting:

$$p_4 \leq p_3 \leq (1+\rho)p_4.$$

Proof: See the Appendix. Proposition 4 shows that only when output demand is perfectly elastic (i.e.,  $\eta = \infty$  and  $\rho = 0$ ), does benefit-cost targeting maximize total environmental benefit. When demand is not perfectly elastic, the price feedback must be considered in designing targeting criteria to maximize total environmental benefits. Specifically, output price must be adjusted by  $(1+r)$  when the benefit-cost ratio is calculated. This adjustment will effectively put a larger weight on output and a relatively smaller weight on environmental benefits than benefit-cost targeting when deciding which resources to purchase. This adjustment aims to reduce the price feedback effect associated with inelastic demand, and is done by reducing purchase of output below the level under benefit-cost targeting. Specifically, total output will be reduced by a smaller amount if more high-benefit and high-output resources are purchased. For example, suppose there are two types of resources. Each unit of type-1 resource produces two units of output and three units of environmental benefits, and each unit type-2 resources produces one unit of output and one unit of environmental benefits. Suppose output price is one dollar and the production cost per unit of resource is 50 cents. Then profit per unit of resource would be \$1.5 for type-1 resources and \$0.5 for type-two resources. The benefit-cost ratio is 2 for both types of resource. If the output price is fixed, it does not matter which type of resource you purchase because you will receive the same amount of environmental benefit. However, if the output demand is highly inelastic, one would prefer to purchase the high-output high-benefit resource because the total output would be reduced by a small amount and, as a result, the slippage would be smaller. For example, a budget of \$15 would allow you to purchase 10 units of type-1 resources, which would reduce output by 20 units, or 30 units of type-2 resources, which would

reduce the total output by 30 units. This example illustrates that slippage would make the high-benefit high-output units relatively more attractive.

The effect of inelastic demand on targeting is illustrated in Figure 5. Under benefit maximization, resources are ranked and purchased according to  $b/[(1 + \rho)p_4 - c]$ , and resources in areas A and E are purchased. Under benefit-cost targeting, resources are ranked and purchased according to  $b/(p_3y - c)$ , and resources in areas H, E, and D are purchased. By purchasing resources in area H instead of resources in area A, benefit-cost targeting causes a greater price increase. As a result, it has to purchase resources in area D, which would otherwise enter into production. It also has to pay a higher price for resources in area E. In addition, it causes more slippage than benefit-maximizing targeting by area C. This suggests that benefit-cost targeting spend too much money on low-output and low-benefit resources and too little money on high-output and high benefit resources.

The purchasing fund agency is in essence acting like a monoposonist. It realizes that it can affect the price of resources it purchases and, therefore, will modify its purchasing strategy to reduce the opportunity cost of benefit release. By purchasing more high-benefit and high-output resources than benefit-cost targeting, the agency can reduce the output price increase, which will reduce the purchasing cost and slippage.

As output demand becomes increasingly inelastic, more and more high-benefit and high-output resources will be purchased in order to reduce the slippage. Graphically, the line  $b/[(1 + \rho)p_4 - c] = \lambda_4$  becomes flatter and benefit-maximizing targeting becomes more like benefit targeting. However, it will not become equivalent to benefit targeting as the demand elasticity  $\eta_c$  approaches zero because  $\rho$  approaches a positive number which is less than infinite (see the definition of  $\rho$  in the Appendix). On the other hand, as output demand becomes increasingly elastic, more and more low-benefit and low-output resources will be targeted for conservation under benefit-maximizing targeting. Slippage will disappear and benefit-maximizing targeting becomes identical to benefit-cost targeting as the demand elasticity approaches infinity and  $\rho$  approaches zero.

The relative efficiency of benefit-cost targeting and benefit-maximizing targeting is illustrated in figure 6. Previous studies ([4, pp. 36-55; 11]) suggest that benefit-cost targeting maximizes total environmental benefit for a given level of market surplus (i.e., the sum of consumer, producer and government surpluses). However, a fund manager is often subject to a budget constraint instead of a market-surplus constraint. By switching from benefit-cost targeting to benefit-maximizing targeting, the fund manager would be able to achieve a higher level of environmental benefit, but with the loss of market surplus as a cost. Graphically, the manager moves from  $a$  to  $b$  in Figure 6a or from  $a'$  to  $b'$  in Figure 6b, trading market surplus for environmental benefits. The value of the additional environmental benefits is smaller than the loss of market surplus, resulting in a net social loss (point  $b$  is located inside the frontier curve). The fund manager cannot move along the frontier curve because of the budget constraint. To achieve the level of environmental benefit  $B_{B/M}$  by using benefit-cost targeting, the fund manager would need a larger budget ( $\bar{G}'$ ). By using benefit-maximizing targeting, the manager can “stretch” the purchasing power of the budget by reducing the increase in the output price through purchasing some high-benefit and high-output resources.

### Comparing Targeting Strategies: Inelastic Output Demand

This section compares the economic, environmental, and distributional effects of the four targeting strategies for the case of downward sloping output demand. The analysis focuses on only unrestricted targeting criteria because they are less likely to cause counterproductive environmental outcomes.

Proposition 5: If the distribution function is continuous in  $y$  and  $b$  and targeting is unrestricted, then

- |       |   |      |   |
|-------|---|------|---|
| (i)   | $Y_2 \geq Y_4 \geq Y_3 \geq Y_1,$             | (ii) | $p_1 \geq p_3 \geq p_4 \geq p_2,$             |
| (iii) | $CS_2 \geq CS_4 \geq CS_3 \geq CS_1,$         | (iv) | $PS_1 \geq PS_3 \geq PS_4 \geq PS_2,$         |
| (v)   | $Q(U_2) \geq Q(U_4) \geq Q(U_3) \geq Q(U_1),$ | (vi) | $Q(I_1) \geq Q(I_3) \geq Q(I_4) \geq Q(I_2),$ |
| (vii) | $B_4 \geq B_3 \geq B_1, B_4 \geq B_2$         |      |   |

*Proof:* We prove first that . According to proposition 1, this result holds when the output demand is perfectly elastic. So, we only need to prove that the result also holds when the output demand is not perfectly elastic. We prove the result by negation. Consider a continuum of demand curves that vary with one parameter ( $\varphi$ ). An increase in  $\varphi$  increases the price elasticity at all points along the demand curve. Because the distribution function is continuous, output levels under the targeting criteria are also continuous functions of  $\varphi$ . Suppose  $Y_2 < Y_3$  when demand is highly inelastic (small  $\varphi$ ). Then there must be a more elastic demand curve (with higher  $\varphi$ ) such that and. implies

$$E(y|U_2)Q(U_2) = E(y|U_3)Q(U_3), \quad (44)$$

where  $E(y|U_i)$  is the average output per unit of resource in  $U_i$ . Because

$I_2^r + I_2^m + U_2 = I_3^r + I_3^m + U_3$  (see Figures 3a and 4a). Thus,

$$E(y|I_2^r + I_2^m)Q(I_2^r + I_2^m) + E(y|U_2)Q(U_2) = E(y|I_3^r + I_3^m)Q(I_3^r + I_3^m) + E(y|U_3)Q(U_3). \quad (45)$$

Equation (44) and equation (45) together imply

$$E(y|I_2^r + I_2^m)Q(I_2^r + I_2^m) = E(y|I_3^r + I_3^m)Q(I_3^r + I_3^m). \quad (46)$$

The budget constraint implies that

$$\left[ p_2 E(y|I_2^r + I_2^m) - c \right] Q(I_2^r + I_2^m) = \left[ p_3 E(y|I_3^r + I_3^m) - c \right] Q(I_3^r + I_3^m). \quad (47)$$

Because , equations (46) and (47) together imply

$$Q(I_2^r + I_2^m) = Q(I_3^r + I_3^m), \quad (48)$$

which cannot hold because the same amount of money is spent on resources in  $I_2^r + I_2^m$  and  $I_3^r + I_3^m$ , and resources in  $I_3^r + I_3^m$ , on average, cost less than resources in  $I_2^r + I_2^m$ . This suggests that  $Y_2 \geq Y_3$  and must always hold. Similarly, we can prove that  $Y_2 \geq Y_4$  and  $Y_3 \geq Y_1$ . These results together with  $Y_4 \geq Y_3$  from proposition 4 establish the relationships in (i) and (ii).

To prove results in (iii), note that by definition,

$$CS_i = \int_0^{Y_i} D^{-1}(\mathbf{d})d\mathbf{d} - D^{-1}(Y_i)Y_i. \quad (49)$$

Differentiate with respect to ,

$$\frac{\mathcal{J}CS_i}{\mathcal{J}Y_i} = -Y_i \frac{\mathcal{J}D^{-1}(Y_i)}{\mathcal{J}Y_i} > 0. \quad (50)$$

Because  $Y_2 \geq Y_4 \geq Y_3 \geq Y_1$ , we get

$$CS_2 \geq CS_4 \geq CS_3 \geq CS_1. \quad (51)$$

Producer surplus equals the sum of production profit and payments from the conservation fund:

$$PS_i = \Pi_i + M = \Pi(U_i^{ru} + I_i^{rt} + I_i^m) = \int_0^{\bar{b}} \int_{c/p_i}^{\bar{y}} (p_i y - c) s(y, b) dy db. \quad (52)$$

Differentiating with respect to gives

$$\frac{\partial PS_i}{\partial p_i} = \int_0^{\bar{b}} \int_{c/p_i}^{\bar{y}} y s(y, b) dy db = Y(R - I_i') > 0. \quad (53)$$

Because  $p_1 \geq p_3 \geq p_4 \geq p_2$ , (53) implies  $PS_1 \geq PS_3 \geq PS_4 \geq PS_2$ . Higher output prices increase profit of utilized resources (intensive-margin effect) and profitable resource base (extensive-margin effect). Resource owners will benefit from a higher price whether they use the resources in production or sell them to the conservation fund.

Now, we prove . implies that

$$E(y | U_3) Q(U_3) \geq E(y | U_1) Q(U_1), \quad (54)$$

Graphically,  $U_1 = C + I$  and  $U_3 = D + I$  in figure 7a. Since  $E(y | U_3) < E(y | U_1)$ , expression (54) implies  $Q(U_3) \geq Q(U_1)$ .

To prove  $Q(U_2) \geq Q(U_3)$ , we need to prove  $Q(E) \geq Q(C + H)$  in figure 7b because  $U_2 = E + I$  and  $U_3 = C + H + I$ . Note that  $Y_3 \leq Y_2$  implies that  $Y(C + H) \leq Y(E)$ . Suppose  $Q(E) < Q(C + H)$ , then

$$p_3 Y(E) - c Q(E) > p_3 Y(C + H) - c Q(C + H) > p_3 Y(C) - c Q(C) > p_2 Y(C) - c Q(C). \quad (55)$$

This suggests that less money is spent on resources in C under benefit targeting than on resources in E under benefit-cost targeting, which cannot be because benefit-cost targeting must purchase resources in F and pay a higher price for resources in D, while benefit targeting spends all money on resources in D and C. Thus, the relationship  $Q(U_2) \geq Q(U_3)$  must always hold. Similarly, we can prove that  $Q(U_2) \geq Q(U_4)$ .

To prove  $Q(U_4) \geq Q(U_3)$ , we need to prove  $Q(H) \geq Q(C + A)$  in figure 5 because  $U_4 = H + F$  and  $U_3 = A + C + F$ . Note that  $Y_3 \leq Y_4$  implies that  $Y(C + A) \leq Y(H)$ . Suppose  $Q(H) < Q(C + A)$ , then

$$p_3Y(H) - cQ(H) > p_3Y(C + A) - cQ(C + A) > p_3Y(A) - cQ(A) > p_4Y(A) - cQ(A). \quad (56)$$

This suggests that less money is spent on resources in A under benefit maximization than on resources in H under benefit-cost targeting, which cannot be true because benefit-cost targeting must purchase resources in D and pay a higher price for resources in E. Thus, the relationship  $Q(U_4) \geq Q(U_3)$  must hold. This result together with  $Q(U_2) \geq Q(U_4)$  and  $Q(U_1) \leq Q(U_3) \leq Q(U_2)$  implies (v). Because  $Q(U_i) + Q(I_i) = Q(R)$  is a constant, expression (v) implies (vi).

Now, we prove (vii). By definition,  $B_4 \geq B_i$  for  $i = 1, 2, 3$ . To prove  $B_3 \geq B_1$ , we use figure 7a. The difference in total environmental benefits for cost targeting and benefit-cost targeting is

$$B_1 - B_3 = B(D) - B(C). \quad (57)$$

The fund purchases resources in area  $(D+E+F)$  under cost targeting and resources in area  $(C+E)$  under benefit-cost targeting. Because the price is higher under cost targeting, more money is spent on resources in area C than in area D. Also, because the benefit-cost ratio of resources in C is higher than the benefit-cost ratio of resources in D, more benefits would be purchased in C than in D. Thus,  $B_1 - B_3 < 0$ . *Q.E.D.*

Proposition 5 suggests that benefit targeting results in the largest amount of resource used in production and the smallest amount of resource in conservation. As a result, the output is highest and the output price is lowest under benefit targeting. Consumers who do not care the environment should prefer benefit targeting to the other strategies because consumer surplus is highest under this targeting strategy. Other groups that may support benefit targeting are labor and input suppliers because this strategy has the smallest impact on production. Benefit targeting should be the least preferred strategy of the resource owners because it results in the lowest producer surplus.

With cost targeting, more resources are diverted from production than the other strategies, resulting in the largest reduction in output and the largest price increase. Cost targeting also results in the largest increase in producer surplus because resource owners receive the highest prices and have the lowest production cost (the number of resources utilized under this strategy is smallest). Essentially, cost targeting is most preferred by resource owners because it is most

effective in reducing supply and enables them to take advantage of market power. Indeed, the Conservation Reserve Program that aims to provide environmental benefit and farm income supports used cost targeting before 1992.

When the output price is fixed, benefit-cost targeting maximizes total environmental benefit for a given budget. It is also efficient because it maximizes total environmental benefit for a given level of market surplus. However, when the output demand is not perfectly elastic, benefit-cost targeting no longer maximizes total environmental benefit for a given budget. To maximize total environmental benefits, the price feedback must be considered in designing targeting criteria. Specifically, output must be given a larger weight than in the case of benefit-cost targeting when deciding which resources to purchase. Without this adjustment, benefit-cost targeting may even provide few environmental benefits than benefit targeting. Indeed, when the output demand is not perfectly elastic, benefit-cost targeting should not be the most preferred strategy of any group.

### **Conclusions**

New efforts aimed at increasing environment quality have led to establishment of funds to purchase environmental goods and to conserve natural resources. These funds use various purchasing strategies, the choice of which may lead to striking differences in environmental performance. This paper develops an analytical framework that recognizes spatial heterogeneity of resources in providing output and environmental benefits. We show that the performance of a purchasing strategy depends on the variability of and correlation between productivity and environmental benefits of resources.

We demonstrate that ignoring the output price effect of purchasing funds may have severe consequences. A purchasing fund should foresee the possible activation of previously idle resources as a result of output price increase, and purchase some of these idle resources. Limiting purchasing only to resources currently in production, as the CRP has been implemented, may reduce environmental gain from the purchasing fund and, in some cases, may make a purchasing fund counterproductive.

A purchasing strategy that targets resources with the highest environmental benefits may be counterproductive even if the possibility of slippage is recognized. This strategy, however, will

have the smallest impact on output price and overall resource use among all strategies considered and should be favored by consumers and input providers. A strategy that targets low-cost resources will result in the largest reduction in production and the largest output price increase, and should be favored by resource owners. A strategy that targets resources with the highest benefit-to-cost ratio is efficient and provides more environmental benefits than cost or benefit targeting when the output price is fixed. However, when the output demand is inelastic, benefit-cost targeting is neither efficient nor maximizing total environmental benefit for a given budget. This criterion tends to target too many units of low-benefit and low-cost resources.

# Figures

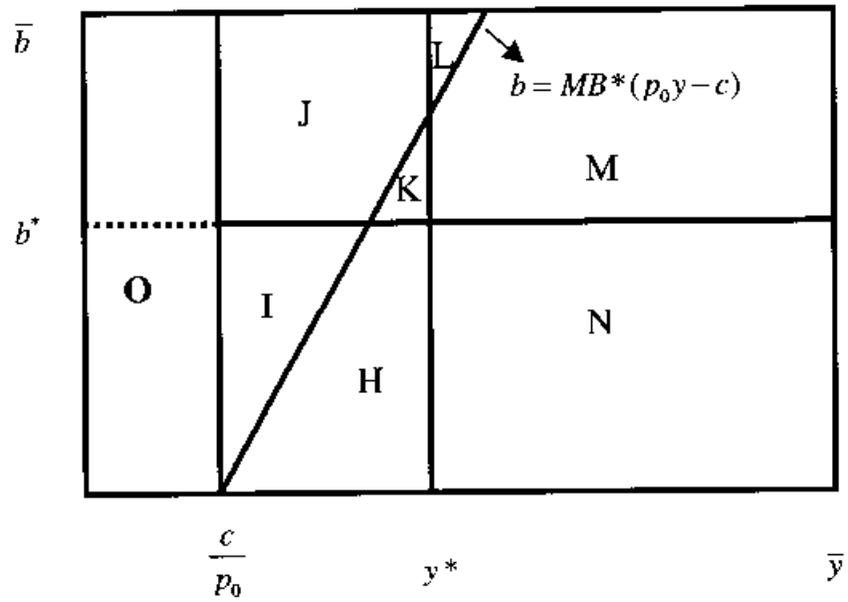


Figure 1. A comparison of alternative targeting strategies for fixed output price

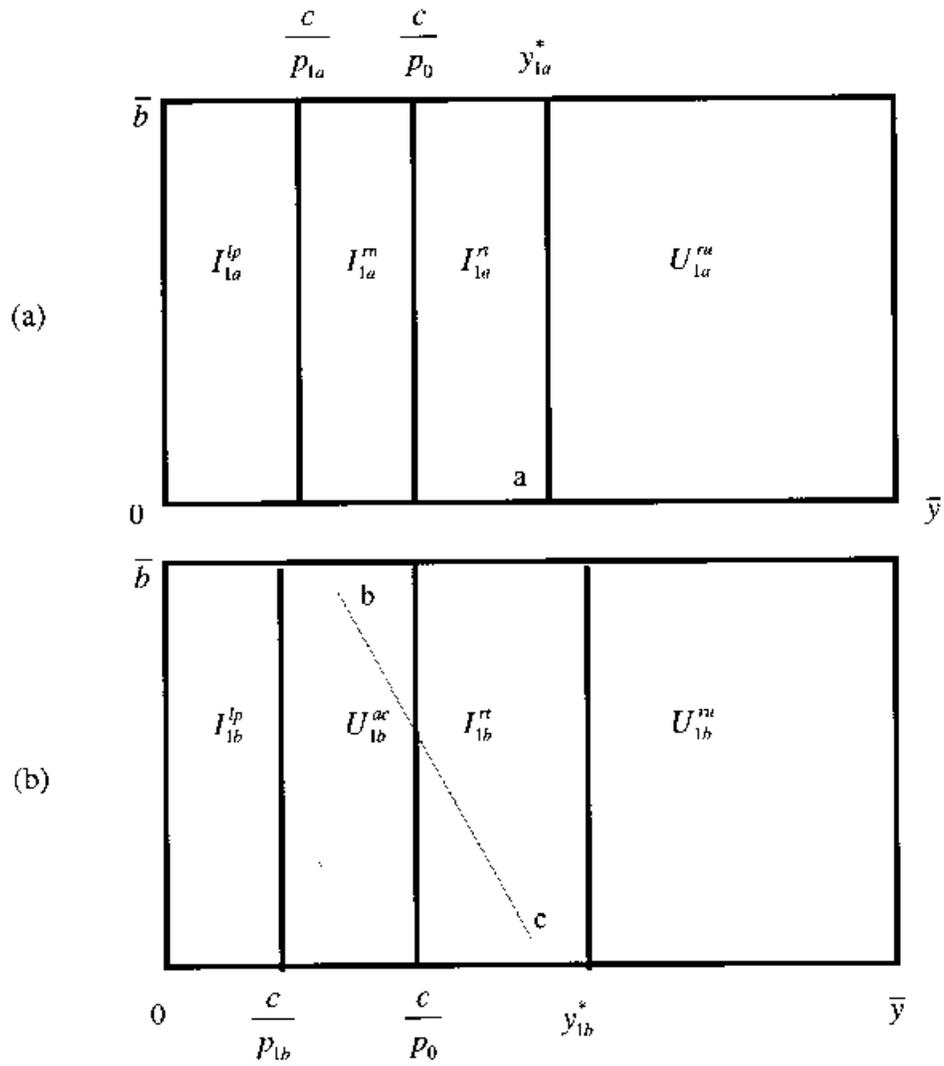


Figure 2. Unrestricted vs. restricted cost targeting

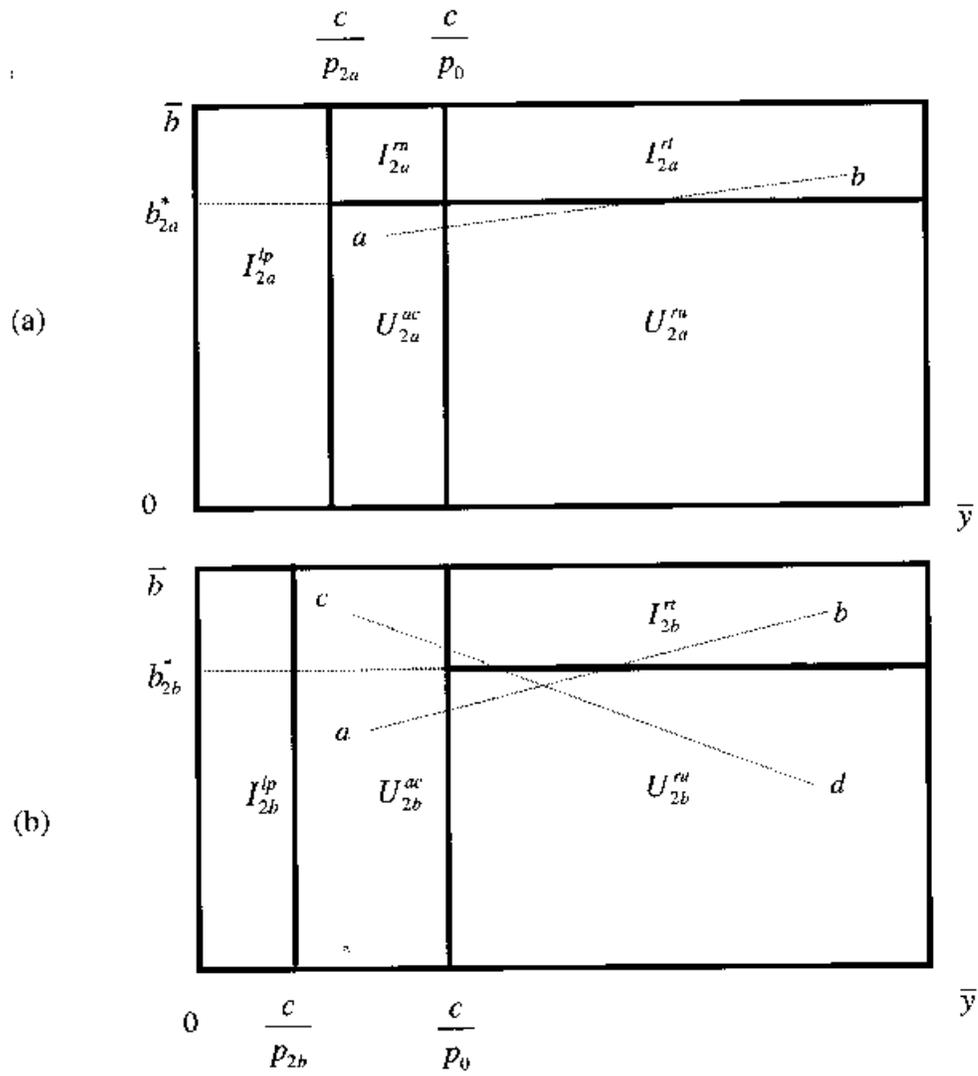


Figure 3. Unrestricted vs. restricted benefit targeting

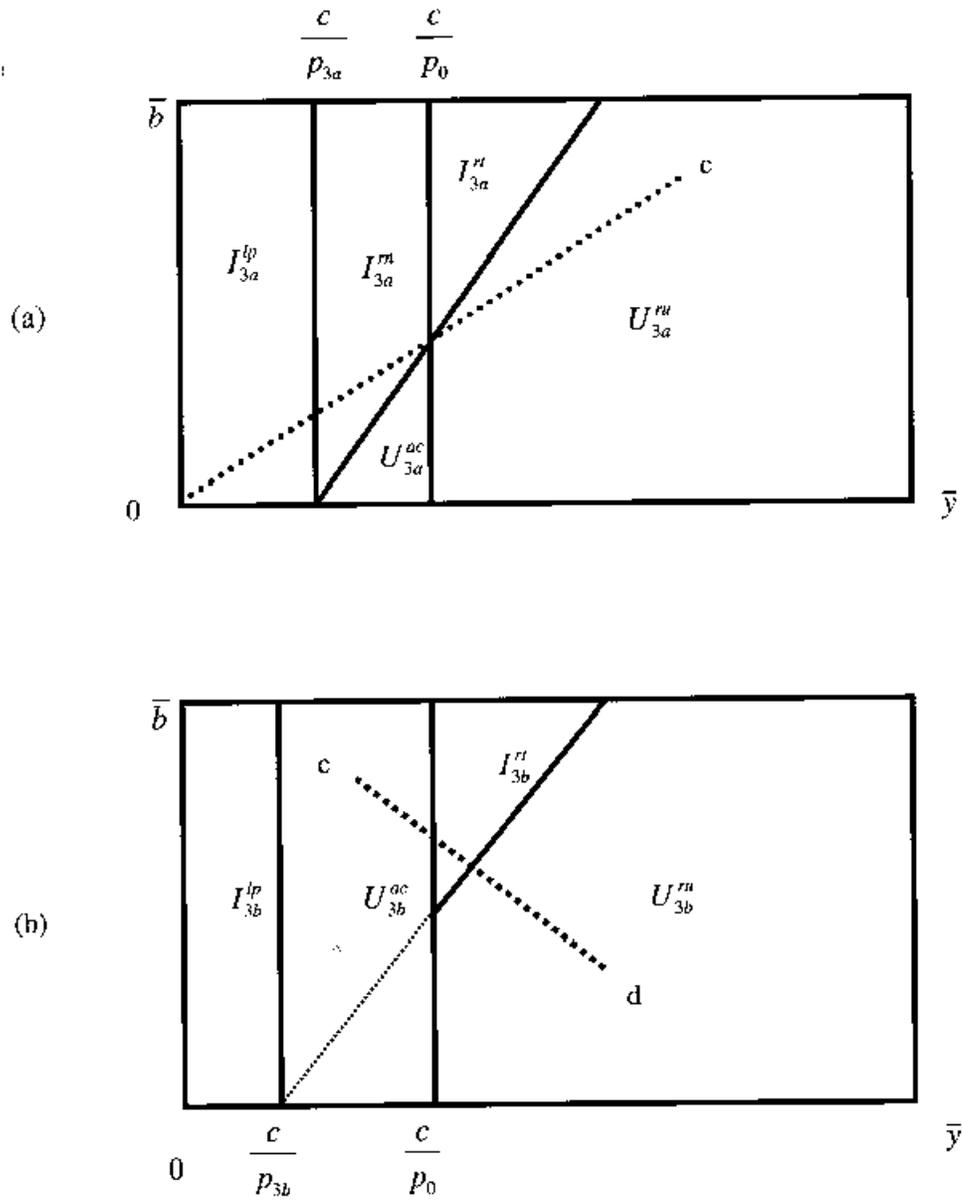


Figure 4. Unrestricted vs. restricted cost-benefit targeting

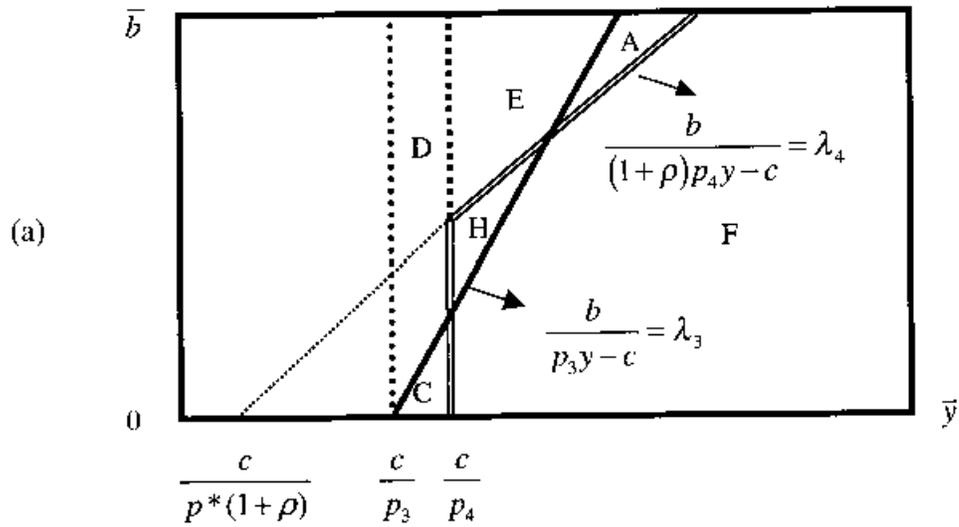


Figure 5. Benefit-cost targeting vs. benefit-maximizing targeting

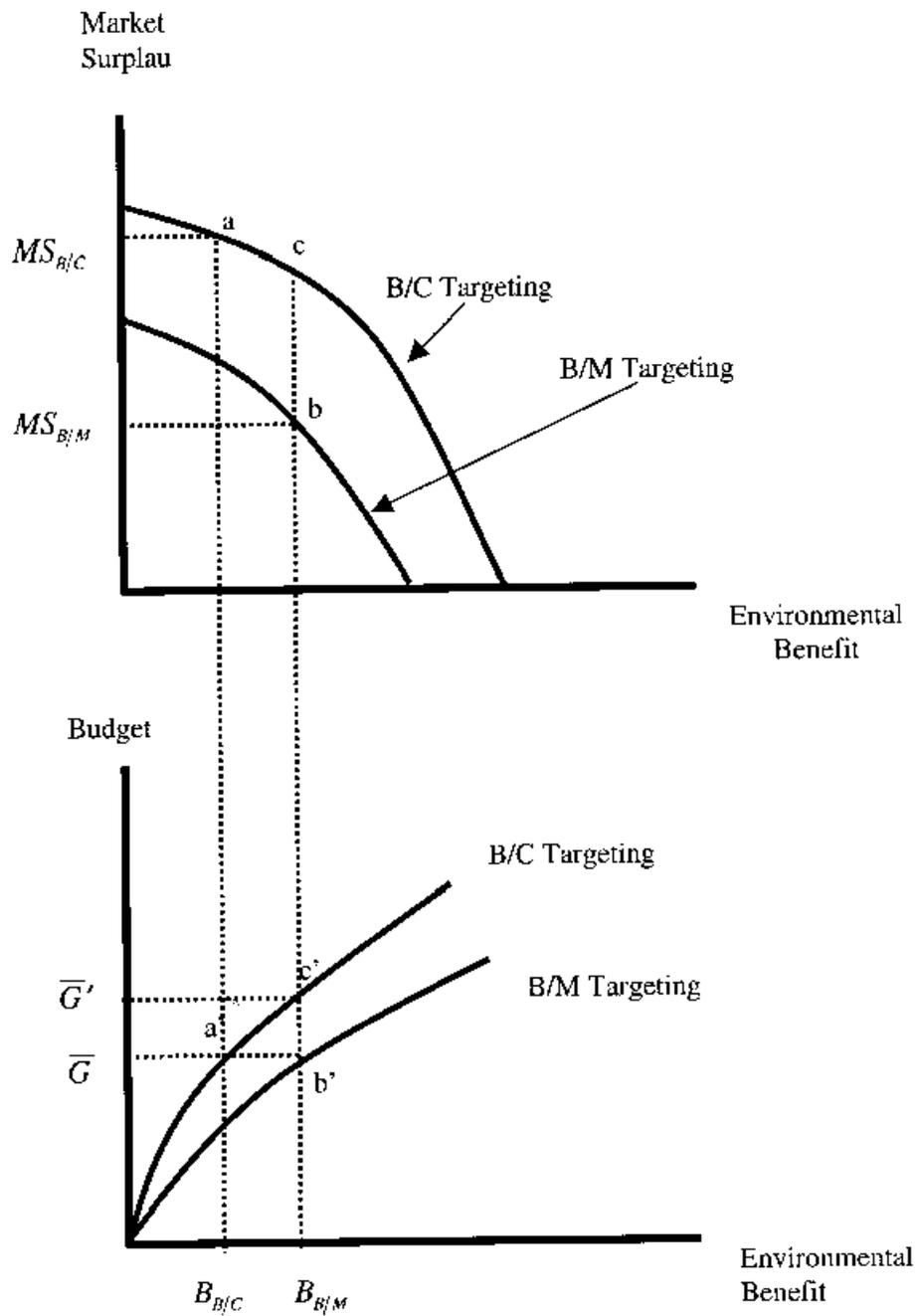


Figure 6. The relative efficiency of benefit-cost targeting vs. benefit-mzsimizing targeting

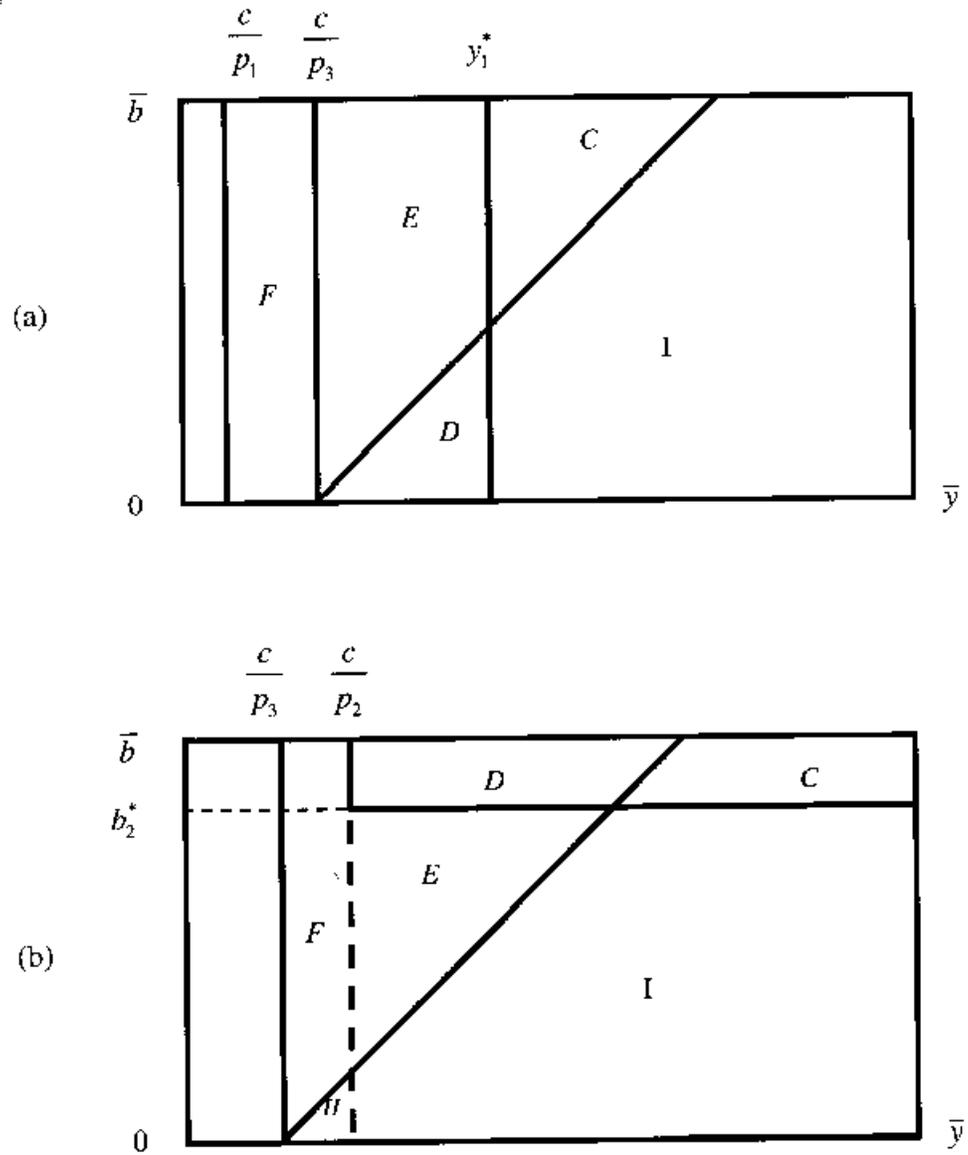


Figure 7. A comparison of alternative targeting criteria for inelastic output demand

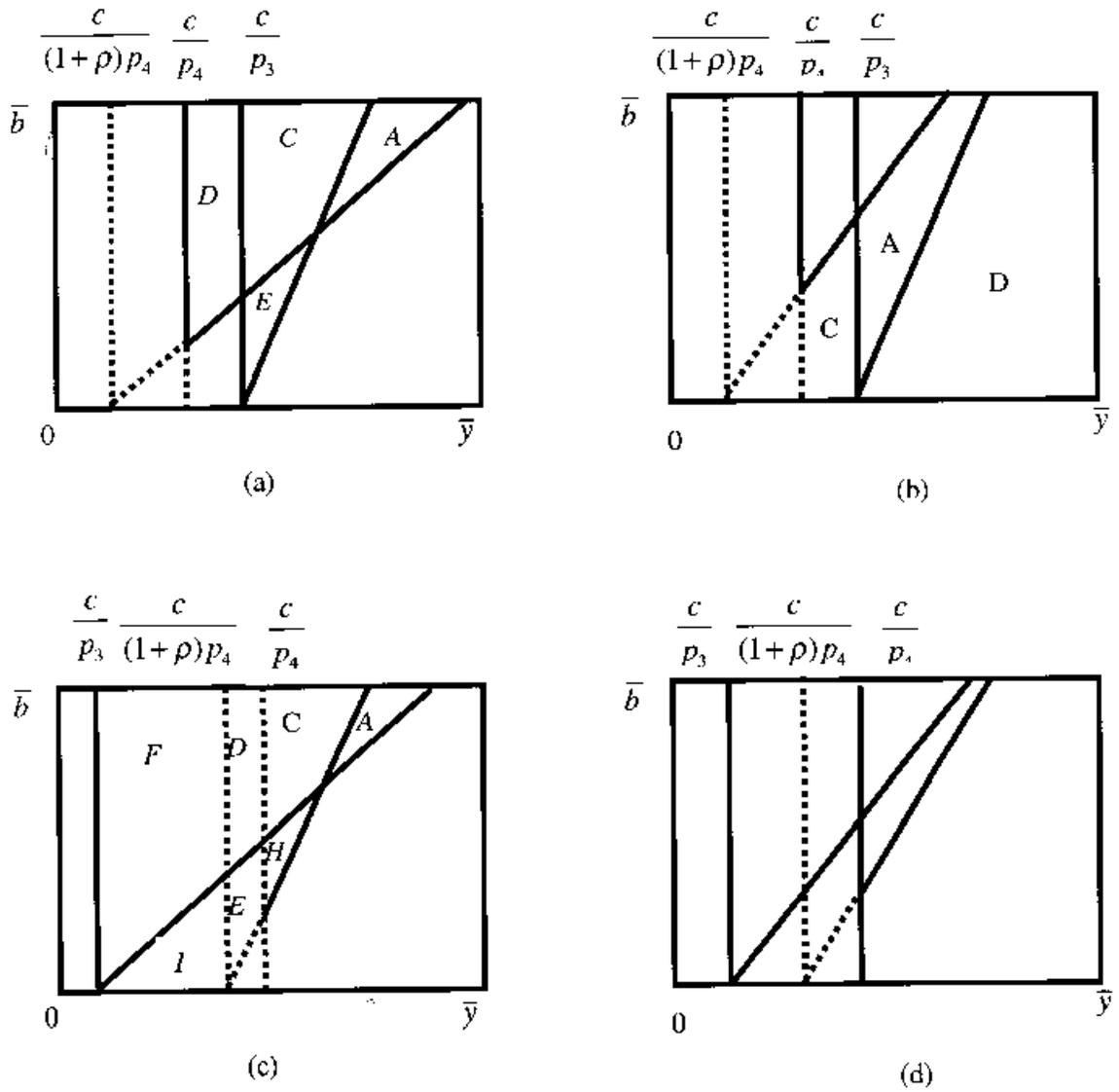


Figure 8. A comparison of alternative targeting criteria for inelastic output demand

## Endnotes

1. The terms purchasing funds and conservation funds are used synonymously in this study.
2. Two U.S. Department of Agriculture programs, the Conservation Reserve Program and the Environmental Quality Incentive Program, have an explicitly stated objective of maximizing the quantity of environmental benefit per dollar expended.
3. The competing public choice view of government maintains that government develops policies in response to special interest groups' demands [19]. The special interest groups attempt to seek rents through influencing government policies, and the government's objective is to maximize political support from interest groups receiving rents.
4. There is significant evidence to support the assumption of fixed coefficient technology at the micro level. Studies show that the von Liebig production function (which assumes fixed coefficient technology) is very effective in explaining yields of agricultural crops [6, 15, 17].
5. There have been significant efforts at addressing issues of asymmetric information and uncertainty in bidding for resources [8, 10, 23].
6. Babcock, et al. [2, 3] applied this framework for redesigning the Conservation Reserve Program. Sunding et al. [20] used it to assess the economic and environmental impact of alternative designs of the Central Valley Improvement Act in California.
7. Even if the optimal budget can be determined, the use of conservation funds to purchase resources out of production may not be the best way to achieve the optimal resource allocation when conservation funds are raised through taxation. There are deadweight losses associated with taxation due to both administrative costs of tax collection and economic costs of market distortions [1, 9].
8. Any plus sign in set operations represents union, i.e.,  $\cup$ .
9. Based on the definition of  $\int$  and properties of integration, for any  $f, g$ ,  $\int (f + g) = \int f + \int g$ . Thus, if  $f \geq 0$ , then  $\int f \geq 0$ . The same properties hold for functions  $f$ .
10. The 14 states include those in the Corn Belt (Iowa, Illinois, Indiana, Ohio, Missouri), Lake States (Michigan, Wisconsin, Minnesota), Northern Plains (North Dakota, South Dakota, Nebraska, Kansas), and Southern Plains (Oklahoma and Texas). The estimate is based on the 1982, 1987 and 1992 National Resources Inventory conducted by the U.S. Department of Agriculture.

## Appendix

*Proof:* Let  $r(y, b)$  be the share of resources with  $(y, b)$  that is used in production after the establishment of the conservation fund.  $r(y, b) = 0$  if  $py - c < 0$ . Thus, the resource in conservation is  $R - \{(y, b) \mid 0 \leq b \leq \bar{b}, c/p \leq y \leq \bar{y}\}$ , and the total environmental benefit is

$$B = \int_0^{\bar{b}} \int_0^{\bar{y}} bs(y, b) dy db - \int_0^{\bar{b}} \int_{c/p}^{\bar{y}} br(y, b)s(y, b) dy db. \quad (\text{A1})$$

The total output and total units of resource in production are

$$Y_c = \int_0^{\bar{b}} \int_{c/p}^{\bar{y}} yr(y, b)s(y, b) dy db \quad \text{and} \quad Q = \int_0^{\bar{b}} \int_{c/p}^{\bar{y}} r(y, b)s(y, b) dy db. \quad (\text{A2})$$

Under the full information assumption, the total program cost is

$$G \equiv \int_0^{\bar{b}} \int_{c/p}^{\bar{y}} (py - c)[1 - r(y, b)]s(y, b) dy db, \quad (\text{A3})$$

where  $p = D^{-1}(Y_c)$  is the inverse demand function.

Suppose the objective of the fund manager is to maximize total environmental benefit.

Then the relevant optimization problem for the fund manager is

$$\text{Max}_{r(y, b)} B, \quad (\text{A4})$$

$$\text{s.t. } G \leq \bar{G}, \quad 0 \leq r(y, b) \leq 1, \quad D(p) = Y_c, \quad (\text{A5})$$

where  $B$ ,  $G$ , and  $Y_c$  are defined by (A1) through (A3). The equilibrium condition  $D(p) = Y_c$  implicitly defines the output price as a function of the purchasing strategy. We denote the function by  $p = h(r(y, b))$ . For any given  $(y, b)$ , differentiating both sides of  $D(p) = Y_c$  with respect to  $r(y, b)$ , we obtain

$$D'(p) \frac{\mathcal{I}p}{\mathcal{I}r(y, b)} = y + \frac{c^2}{p^3} \int_0^{\bar{b}} r\left(\frac{c}{p}, b\right) s\left(\frac{c}{p}, b\right) db \frac{\mathcal{I}p}{\mathcal{I}r(y, b)}.$$

Solving for  $\partial p / \partial r(y, b)$  gives,

$$\frac{\partial p}{\partial r(y, b)} = -\frac{p^3 y}{p^2 \eta_c Y_c + c^2 E r_{c/p}}, \quad (\text{A6})$$

where  $Y_c = D(p_4)$ ,  $\eta_c$  is the demand elasticity evaluated at  $Y_c$ , and  $E r_{c/p}$  is the percent of resources with output level (c/p) that are not purchased by the fund. By substituting  $p = h(r(y, b))$  into  $B$  and  $G$ , the Lagrangian for the maximization problem defined by (A4) and (A5) can be simply written as

$$L = B + \mathbf{g}(\bar{G} - G) + \int_0^{\bar{b}} \int_0^{\bar{y}} [\mathbf{a}(y, b)r(y, b) + \mathbf{b}(y, b)(1 - r(y, b))] dy db, \quad (\text{A7})$$

where  $\gamma$  is the Lagrange multiplier for the budget constrain, and  $\alpha$  and  $\beta$  are the Lagrange multipliers for the constraints of  $0 \leq r(y, b) \leq 1$ . By differentiating (A7) with respect to  $r(y, b)$  for any given  $(y, b)$ , we obtain the first-order condition for the maximization problem:

$$\begin{aligned} \frac{\mathcal{J}L}{\mathcal{J}r(y, b)} &= \frac{\mathcal{J}B}{\mathcal{J}r(y, b)} + \frac{\mathcal{J}B}{\mathcal{J}p} \frac{\mathcal{J}p}{\mathcal{J}r(y, b)} - \mathbf{g} \left[ \frac{\mathcal{J}G}{\mathcal{J}r(y, b)} + \frac{\mathcal{J}G}{\mathcal{J}p} \frac{\mathcal{J}p}{\mathcal{J}r(y, b)} \right] + \mathbf{a}(y, b) - \mathbf{b}(y, b) \quad (\text{A8}) \\ &= \frac{\mathcal{J}B}{\mathcal{J}r(y, b)} - \mathbf{g} \frac{\mathcal{J}G}{\mathcal{J}r(y, b)} + \left[ \frac{\mathcal{J}B}{\mathcal{J}p} - \mathbf{g} \frac{\mathcal{J}G}{\mathcal{J}p} \right] \frac{\mathcal{J}p}{\mathcal{J}r(y, b)} + \mathbf{a}(y, b) - \mathbf{b}(y, b) = 0 \end{aligned}$$

Substitute (A1), (A3) and (A6) into (A8),

$$-b + \mathbf{g}(p_4 y - c) + \left[ -\frac{c}{p_4^2} E b_{c/p} - \mathbf{g} \Delta Y \right] \frac{(-p_4^3 y)}{p_4^2 h_c Y_c + c^2 E r_{c/p}} + \mathbf{a}(y, b) - \mathbf{b}(y, b) = 0, \text{ or} \quad (\text{A9})$$

$$-b + \gamma[(1 + \rho)p_4 y - c] + \alpha(y, b) - \beta(y, b) = 0, \quad (\text{A10})$$

where  $\mathbf{r} = (p_4^2 \mathbf{g} \Delta Y + c E b_{c/p}) / [\mathbf{g} p_4^2 h_c Y_c + c^2 E r_{c/p}]$ ,  $p_4$  is the equilibrium output price under the benefit maximization,  $\Delta Y$  is output that would be produced by the preserved resources,  $\gamma$  is the marginal environmental benefit of conservation fund, and  $E b_{c/p}$  is the average benefit per unit of resources with output level (c/p) that are not purchased by the fund. The Lagrangian multiplier  $\alpha$  and  $\beta$  satisfy the Kuhn-Tucker conditions:

$$r(y, b) \cdot \alpha(y, b) = 0 \quad \text{and} \quad [1 - r(y, b)] \cdot \beta(y, b) = 0. \quad (\text{A11})$$

Thus, if the resource with  $(y, b)$  is purchased (i.e.  $r(y, b) = 0$ ), . From (A10) we get

$$-b + \mathbf{g}[(1 + \mathbf{r}) p_4 y - c] \leq 0 \quad \text{or} \quad (\text{A12})$$

$$\frac{b}{(1+r)p_4y-c} \geq g. \quad (\text{A13})$$

Now, prove that  $p_4 \leq p_3 \leq (1+\rho)p_4$ . First, we prove that  $p_4$  cannot be greater than  $p_3$ . Suppose  $p_4 > p_3$ , then  $(1+\rho)p_4 > p_3$ . In this case, we have either figure 8a or figure 8b. However, both figures are false. Figure 8b is false because it implies that benefit-maximizing targeting produces less total benefit than benefit-cost targeting. Under benefit-cost targeting, resources in D are used in production, while under benefit maximization, resources in D+A+C are used in production. To show that  $p_4 > p_3$  cannot hold in figure 8a, note that under the cost-benefit targeting, resources in area (E+C) are purchased, while under the benefit maximization, resources in area (A+C+D) are purchased. Because resources in C cost more under the benefit maximization, less money must be spent on resources in A than in E. Also, because the average benefit-cost ratio is higher in E than in A, i.e.,

$$E\left(\frac{b}{p_3y-c} \middle| E\right) > E\left(\frac{b}{p_3y-c} \middle| A\right) \geq E\left(\frac{b}{p_4y-c} \middle| A\right). \quad (\text{A14})$$

The resources in A must provide few benefits than resources in E, which contradicts the result that benefit-maximizing targeting maximizes total environmental benefit. Thus,  $p_4$  cannot be greater than  $p_3$ .

To prove that  $p_4(1+\rho) \geq p_3$ , we need to show that figure 8c and figure 8d cannot hold. Clearly, figure 8d cannot hold because it implies that total output is lower under the benefit maximization than under the benefit targeting, which contradicts the result that  $p_4 \leq p_3$ . To show that figure 8c is also false, note that under the benefit maximization, resources in area (H+C) are purchased, while under benefit-cost targeting, resources in area (A+C+D+F) are purchased. Because  $p_4 \leq p_3$ , less money must be spent in area A than in area H, i.e.,

$$p_3Y(A) - cQ(A) \leq p^*Y(H) - cQ(H) \leq p_3Y(H) - cQ(H). \quad (\text{A15})$$

Also, because the total output is higher under benefit maximization than under benefit-cost targeting,  $Y(A) \geq Y(H+E+I) > Y(H)$ . This, together with (A15) implies that  $Q(A) > Q(H)$ , which cannot hold because resources in A are more expensive and less money is spent on resources in A. Thus, figure 8c is also false and it must be true that  $p_4(1+\rho) \geq p_3$ .

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