Alternative Green Payment Policies When Multiple Benefits Matter

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This study investigates the environmental impacts of several forms of policies that offer farmers subsides in return for the adoption of conservation tillage. The policies differ as to whether the tillage practice or one of several environmental benefits is targeted. We develop an Environmental Lorenz Curve which fully represents the performance of the targeting policies, and show that this curve can be directly used to help select the optimal targeting strategy for special classes of social welfare functions. The model is applied to the state of Iowa.

Key Words: conservation policy, Environmental Lorenz Curve, multiple environmental benefits, targeting

Improving the environmental performance of agriculture has emerged as an important goal of U.S. agricultural policy. One potential tool toward this end is the use of green payments, which are payments made to farmers for adopting environmentally friendly practices. A significant step toward green payments in the United States was the passage of the Conservation Security Program (CSP) in the 2002 Farm Bill. Notably, this is the first substantive conservation payments program for land that remains in active production of agricultural commodities.[1] Given the imminent implementation of green payments in U.S. agriculture, there is a clear need to understand the environmental effectiveness of these policies as well as the costs associated with their use.

One likely focus in any agricultural green payments program is the use of conservation tillage which can generate a range of (mostly) positive environmental externalities related to water quality, wildlife habitat, and carbon sequestration. It is well understood that conservation tillage practices under different land characteristics will yield different amounts of environmental benefits. When the social values of these benefits are known, pieces of land can be ranked according to the value of their total environmental benefits and can then be enrolled starting with lands with the highest value. However, these values are unlikely to be known with much precision, and policy makers may find it simpler to target a single benefit. The presence of transactions costs and questions about accurate measurement of some benefits may also favor the targeting of a single benefit, or weighted average of some subset of environmental benefits.

There are also important policy reasons why the government might choose to focus on a single environmental benefit (or small subset). For example, were the United States to commit to an international carbon reduction target, it would be natural to target carbon sequestration in agricultural soils in a green payments program in order to meet those obligations. Likewise, a large-scale carbon market would effectively target carbon sequestration in the same

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[1] Previously, conservation programs for working land have focused on cost sharing through such programs as the Environmental Quality Incentives Program (EQIP). The CSP differs in that it proposes to make payments based on the decision of a farmer to adopt a practice rather than on a fraction of the capital cost or other direct cost of a conservation method. Thus, farmers can expect to be compensated for their full opportunity cost of adoption with the CSP. The Farm Security and Rural Investment Act (2002 Farm Bill) can be accessed online at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=107_cong_bills&docid=f:h2646enr.txt.pdf.

way. As another example, a serious commitment to meeting the Hypoxia Action Plan goals of a reduction of 35% nitrogen loading to the Gulf of Mexico within the next decade would likely necessitate a target of nitrogen reductions. Finally, if local water quality were to be prioritized for environmental improvement,[2] targeting of phosphorous reductions would be natural. Thus, there are many policy scenarios in which the targeting of an individual benefit would be likely.

In policies where a single environmental benefit, or small subset, is targeted, it is important to understand what the consequences will be for the other, nontargeted benefits. For example, if carbon is targeted, how much less nitrogen runoff reduction is achieved than if nitrogen reductions were targeted? Under what circumstances is carbon targeting preferred to nitrogen targeting?

In this paper, we develop and empirically evaluate a form of an Environmental Lorenz Curve (ELC) to formally compare several targeting strategies. Farmers are offered payments in return for adoption of conservation tillage. However, given a limited budget, only those farms with sufficiently high targeted benefits are enrolled. The ELC of an untargeted benefit measures the percentage of this benefit achieved under existing targeting relative to the amount of benefit if this benefit is directly targeted. Higher ELCs thus correspond to higher co-benefits achieved under the chosen targeting strategy.

Again, the CSP provides an example of the relevance of this work. The proposed implementation rules [U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS), 2004] describe the need to target in order to stretch limited conservation resources. Targeting of high-priority watersheds and "good stewards" is being discussed. As the determination of high-priority watersheds may be based on specific environmental benefits of importance, this strategy may be similar to targeting of one or a small subset of environmental benefits.

Babcock et al. (1996, 1997) developed ELCs for the case of a single benefit. Specifically, they used ELCs to measure how much of an environmental benefit can be achieved if the production practice, rather than the benefit, is targeted. In that case, the position of an ELC depends on farm heterogeneity in the chosen benefit: the ELC is always less than one when farms are heterogeneous. The ELCs in the current study extend those of Babcock et al. to multiple benefits, and depend on the rank correlation of the different environmental services provided by the (heterogeneous) farms, rather than directly on farm heterogeneity. The ELC can equal one even if farms are heterogeneous as long as the ranking of farms remains the same across the benefits.

Essentially, the ELCs offer an intuitive way of *describing* the co-benefits of environmental targeting. In this paper, it is also shown that for special classes of social welfare functions, a normalized version of the ELCs can be used for decision making. When the benefits are either perfect substitutes or complements, the ELCs can be directly used to optimally choose the benefit which should be targeted, for each given budget level.

A Conceptual Model of Targeting and Environmental Lorenz Curves

There are N farms of equal size, normalized to one acre. Currently the farmers are using a certain production practice, say conventional tillage. An alternative practice, e.g., conservation tillage, will affect a range of environmental amenities, indexed by $k = 1, ..., K$. In particular, the environmental improvements of farm n are represented by $X^n = \{X_1^n, ..., X_K^n\}$, where the superscript indexes the farm, and the subscripts index the environmental amenity. Let c^n be the cost of adopting the new practice, i.e., farmer n will enroll if he/she receives payments of at least c^n, and will not enroll otherwise. Letting $x_k^n = X_k^n / c^n$, then the environmental improvement per dollar spent on farm n is $x^n = \{x_1^n, ..., x_K^n\}$.

Given a total budget of C, the government agency chooses which farms to enroll (i.e., which farms will be paid for adopting conservation tillage), in order to maximize the social welfare function $U(X_1, ..., X_K)$, with $U(\cdot)$ increasing and concave in X_k.[3] Here,

$$X_k = \sum_{i \in \Omega^e} X_k^i$$

is the total environmental amenity k achieved when farmers in $\Omega^e \subseteq \Omega = \{1, ..., N\}$ are enrolled and thus adopt conservation tillage. It can be shown that the government should rank the farms by their aggregate

[2] Iowa's governor has recently stated a goal of improving all impaired waters to the degree necessary to remove them from the impaired waters list.

[3] For simplicity, the social welfare is defined as a function of the environmental *improvements*. Strictly, it should depend on the environmental levels, which are the sum of the improvements and the base levels, e.g., $U(Y_1 + X_1, ..., Y_K + X_K)$, where the Ys are the base levels. Introducing these base levels will not affect our results.

marginal environmental contribution per dollar spent, or

$$v^n \equiv \sum_k U_k x_k^n,\ n \in \Omega,$$

and enroll farms from the highest v^n until the budget C is exhausted. Let $\Omega_{(}^e(C)$ denote the optimal set of farmers enrolled given the budget C. Note that if the government has a sufficiently large budget, all farms will be enrolled.

If U_k, the marginal social benefits of the environmental amenities, are easily obtainable, the above rule dictates an optimal targeting strategy for the government: it should target the comprehensive per dollar environmental benefit,

$$v = \sum_k U_k x_k.$$

However, typically U_k is unknown and, as discussed earlier, there are many reasons why a government may choose to target a particular amenity, say X_k. It can be shown that the optimal solution is to enroll farmers from the highest x_k^n until budget C is exhausted. Of course, by inducing farmers to adopt conservation tillage, targeting X_k also brings improvements in other environmental amenities. As shown below, these externalities of targeting X_k can be described by ELCs. Further, under certain normalization conditions, these curves can also aid the choice of the optimal targeting strategies for given classes of the welfare function $U(\cdot)$.

Effects of Targeting Strategies: Environmental Lorenz Curves

Let $\Omega_k^e(C)$ denote the set of farmers enrolled when amenity X_k is targeted, given budget C, and let

$$\hat{X}_{l,k}(C) = \sum_{n \in \Omega_k^e(C)} X_l^n$$

be the total amenity X_l supplied by these enrolled farmers, $k, l = 1, ..., K$. Let $w_{l,k}(C) = \hat{X}_{l,k}(C)/\hat{X}_{l,l}(C)$ be the ratio of the lth amenity achieved under targeting X_k relative to that under targeting X_l, given C. Since the highest level of X_l is achieved when X_l is directly targeted, $w_{l,k}(C) \leq 1$, for all $l = 1, ..., K$. The comprehensive performance of strategy X_k can be represented by a vector $\mathbf{w}_k(C) = \{w_{1,k}(C), ..., w_{K,k}(C)\}$. Roughly speaking, given C, as $\mathbf{w}_k$ increases, targeting X_k is more preferred as its performance in raising other amenities increases relative to targeting those amenities directly.

We denote $\mathbf{w}_k(C)$ the Environmental Lorenz Curve associated with targeting X_k. Its specific profile depends on the rank correlation of the environmental amenities across the farms. Let $x_k = \{x_k^1, ..., x_k^N\}$ be the farm profile of environmental amenity X_k, and r_k the associated rank order. If the r_k, $k = 1, ..., K$ are perfectly correlated, farms that provide more amenity X_l per dollar spent also provide more X_k. Specifically, the order with which the farmers are enrolled is the same, regardless of which amenity is targeted. Then it is possible that $\mathbf{w}_k(C) = \{1, ..., 1\}$. Perfect correlation of the rank order can be a result of stronger conditions, such as the perfect correlation of x_k, $k = 1, ..., K$, or because the farms are homogeneous (i.e., $x_k^i = x_k^j$, $i, j = 1, ..., N$).[4]

When budget C is sufficiently large, all farms are enrolled under any targeting strategy. Then regardless of the correlation among r_k, we know $w_k = \{1, ..., 1\}$. As C decreases, $w_{l,k}$ tends to decrease for $l \neq k$, as increasingly different farms will be enrolled under the two targeting strategies X_k and X_l.

Choices of Targeting Strategies: Normalized Lorenz Curves

Now we show that the ELCs can be used to choose the optimal targeting strategy for two special classes of welfare functions, where the amenities are either perfect substitutes or perfect complements:

$$U(X_1, ..., X_K) = \sum_{k=1}^{K} \alpha_k X_k \tag{1}$$

and

$$U(X_1, ..., X_K) = \min\{\alpha_k X_k,\ k = 1, ..., K\}. \tag{2}$$

In (1) and (2), the weights α_k are normalized:

$$\alpha_k = \frac{\alpha}{\bar{X}_k}, \tag{3}$$

where

$$\bar{X}_k = \sum_{n \in \Omega} X_k^n$$

is the total environmental amenity k provided by all of the farms. Note that $\bar{X}_k$ can be achieved under any

[4] However, these stronger conditions are sufficient, but not necessary. For example, consider three farmers and two amenities, with $x^1 = \{10, 8\}$, $x^2 = \{2, 4\}$, and $x^3 = \{1, 1\}$. The rank orders are perfectly correlated: $r_1 = \{1, 2, 3\}$ and $r_2 = \{1, 2, 3\}$. That is, the order of enrollment should be farmers 1, 2, and 3, regardless of whether amenity 1 or amenity 2 is targeted. Clearly, the three farms are heterogeneous, and $x_1 = \{10, 2, 1\}$ and $x_2 = \{8, 4, 1\}$ are not perfectly correlated.

targeting strategies for a sufficiently large budget C. The normalization in (3), together with (1) and (2), implies that when the environment is restored to its "pristine" state, or when all the environmental services of the land have been restored (i.e., $X_k = \bar{X}_k$ for all k), each pristine amenity has the same "value" α. Under both (1) and (2), society views these amenities equally at the pristine state.

Consider now a rescaled or normalized version of the ELC: $\varphi_{l,k}(C) = w_{l,k}(C)\hat{X}_{l,l}(C)/\bar{X}_l$. Here, $\varphi_{l,k}(C)$ is obtained from the ELC $w_{l,k}(C)$, rescaled by the total amenity l achieved under budget C relative to the amenity in the pristine state. When C is sufficiently large, $\hat{X}_{k,k}(C) = \bar{X}_k$ and $\varphi_{l,k}(C) = w_{l,k}(C)$. That is, the normalized ELC converges to the ELC as the budget rises.

Substituting in the expression of $w_{l,k}(C)$, we know $\varphi_{l,k}(C) = \hat{X}_{l,k}(C)/\bar{X}_l$. The normalized ELC can thus be interpreted as the fraction of the total possible environmental improvement achieved. Hence, if X_k is targeted, the resulting social welfare under (1) and (2) is, respectively,

(4) $$V_k(C) = \alpha \sum_{l=1}^{K} \varphi_{l,k}(C)$$

and

(5) $$V_k(C) = \alpha \min \{\varphi_{l,k}(C),\ l = 1, ..., K\}.$$

These two payoff functions correspond to the vertical summation and the minimum of the normalized ELC curves, respectively. The normalized ELCs thus offer a simple way of choosing which amenity to target: the one that yields the highest summed normalized ELC (perfect substitutes), or the highest minimum normalized ELC (perfect complements).

Figure 1 illustrates such decisions when there are two environmental benefits. For each budget level, the sum of the normalized ELCs is higher and the minimum of the normalized ELCs is lower, if amenity 1 is targeted. Thus, amenity 1 should be targeted when the two amenities are perfect substitutes, and amenity 2 should be targeted when they are perfect complements.

Application: Conservation Tillage in Iowa

We apply our model to conservation tillage in the state of Iowa, part of the region where agricultural production has been identified as one of the major sources of nitrate loadings into the Mississippi River Basin (Committee on Environment and Natural Resources, 2000) and a large potential source of carbon sequestration (Lal et al., 1998). The simulations are carried out on $N = 12{,}143$ National Resources Inventory (NRI)[5] points (Nusser and Goebel, 1997), each representing a farm. The costs of adoption, c^n, $n = 1, ..., N$, are obtained from Kurkalova, Kling, and Zhao (2003), who present a methodology and empirical estimates of a reduced-form, discrete-choice adoption model for Iowa.

We consider $K = 4$ environmental benefits from conservation tillage, including carbon sequestration, nitrogen runoff reduction, reduction in water erosion, and reduction in wind erosion. The farm-specific environmental benefits, X_k^n, $k = 1, ..., K$; $n = 1, ..., N$, are estimated at each of the data points using the Environmental Policy Integrated Climate (EPIC) model, version 1015 (Izaurralde et al., 2002).[6] EPIC has been extensively tested and validated for predicting erosion and nutrient loss reduction benefits from adoption of conservation tillage under a wide range of conditions, including data collected in Iowa (Edwards et al., 1994; King, Richardson, and Williams, 1996; Chung et al., 1999, 2001, 2002). The average carbon sequestration benefits of adopting conservation tillage in the sample, 50.6 g C m^{-2} yr^{-1}, compare favorably with those reported by Lal et al. (1998) and fall in the range 57 ± 14 g C m^{-2} yr^{-1} estimated by West and Post (2002). The latter study summarized 67 long-term agricultural experiments consisting of 276 paired treatments.

Details of the simulations are available in Kurkalova, Kling, and Zhao (2004), who estimate the environmental benefits obtainable under five targeting strategies at a range of budget levels roughly corresponding to the amount of federal funding potentially available to Iowa through the Conservation Security Program.[7] In addition to policies that target each of the four environmental benefits listed above, also considered is a practice-based policy which maximizes the number of acres of land in conservation tillage, enrolling low-cost farms first regardless of their environmental benefits. Kurkalova, Kling, and Zhao (2004) provide results that can directly be interpreted as the un-normalized ELCs $w_{l,k}(C)$ for the sample. Here, we extend their

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[5] The NRI survey of sample points is conducted every five years by the USDA/Natural Resources Conservation Service (see, e.g., USDA/NRCS, 1994).

[6] Earlier versions of EPIC were called Erosion Productivity Impact Calculator (Williams, 1990).

[7] The Conservation Security Program of the 2002 Farm Bill provides \$2 billion for five years. Even if Iowa crop producers get as much as one-fifth of the yearly total, the program funding is limited to \$80 million per year.

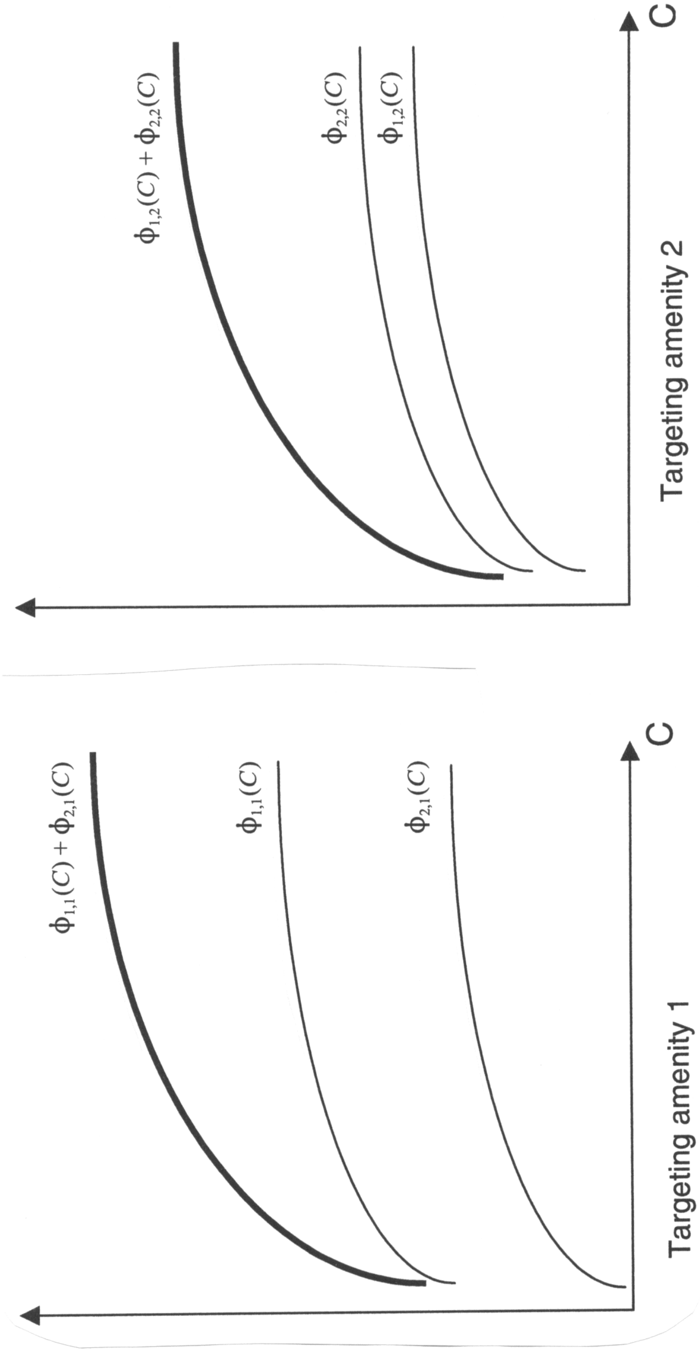

Figure 1. The choice of the optimal targeting strategy using normalized ELCs

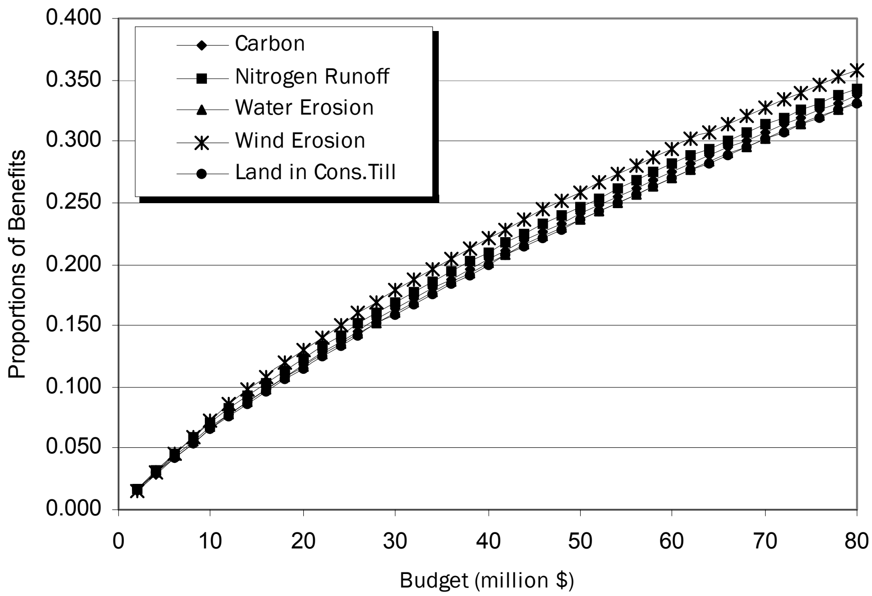

Figure 2. Normalized ELCs associated with the practice-based policy: $\varphi_{l,k}(C)$, *k* = land in conservation tillage, *l* varies

study to derive normalized ELCs to determine the optimal target under the two social welfare functions developed earlier.

Results

In figure 2, the normalized ELCs associated with a practice-based policy (where total land in conservation tillage is maximized regardless of specific environmental benefits) are presented. At a budget of about $10 million, a practice-based policy achieves approximately 10% of the total potential improvement possible for the four environmental benefits as well as for land in conservation tillage. The ELCs are increasing and concave in the budget level, but the highest ELC does not necessarily represent the environmental benefit being targeted. In figure 2, the ELCs for wind erosion and nitrogen runoff lie above the curve for land in conservation tillage.

To put these numbers in context, the overall rate of adoption of conservation tillage rises from about 63% to about 75% as the budget increases.[8] These numbers differ from the corresponding ELC in figure 2, because the normalized ELC measures the percentage of environmental benefit achieved relative to the total remaining benefit possible, and thus uses a different denominator for comparison than the total adoption rate.

To compare the environmental effectiveness of the alternative targeting schemes, figures 3–6 present the ELCs of the benefits when carbon, nitrogen runoff, water erosion, and wind erosion are targeted, respectively. Again, the ELCs are increasing and concave in the budget.

In all cases, only a small fraction of the total possible environmental benefits can be achieved at small budget levels, regardless of which benefit is being targeted. However, at large budget levels ($70–$80 million dollars per annum), up to 40% of the total potential benefits are achieved—this percentage reaches over 50% for the cases of wind erosion and nitrogen runoff when those two benefits are targeted, respectively.

There are some important differences in the fraction of environmental benefits that can be achieved based on different targeting strategies. For example, the percentage of total water erosion reduction achieved when wind erosion is targeted ranges from under 3% to 28%. However, when water erosion itself is targeted, over 40% of the benefits can be achieved. Thus, the choice of benefit to target may have important consequences for overall environmental quality.

There are also notable differences in the rate of increase in the Lorenz curves as the budget rises.

[8] The per acre subsidies needed to achieve a 75% adoption rate range from zero to $34.25/acre, with an average of $5.74/acre.

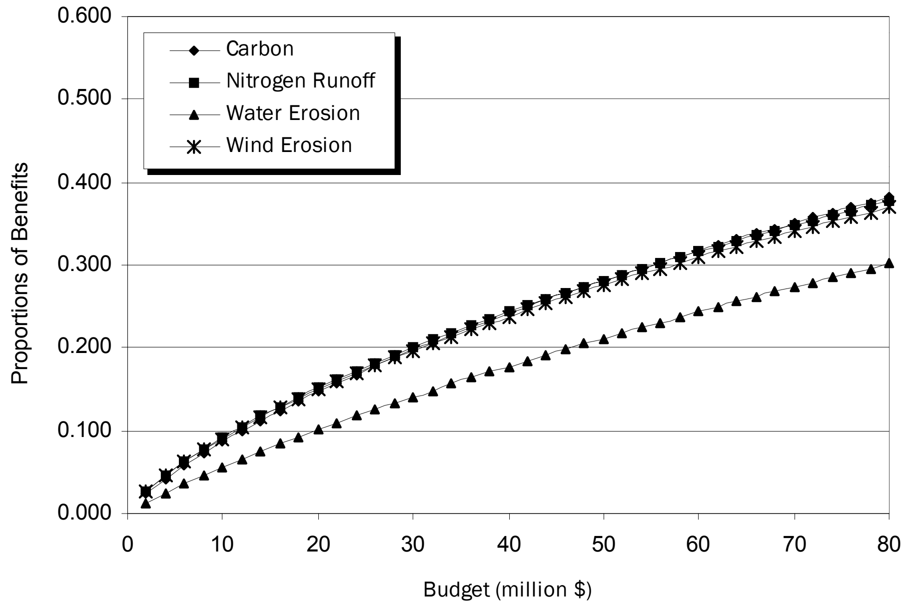

Figure 3. Normalized ELCs associated with carbon targeting: $N_{l,k}(C)$, k = carbon, l varies

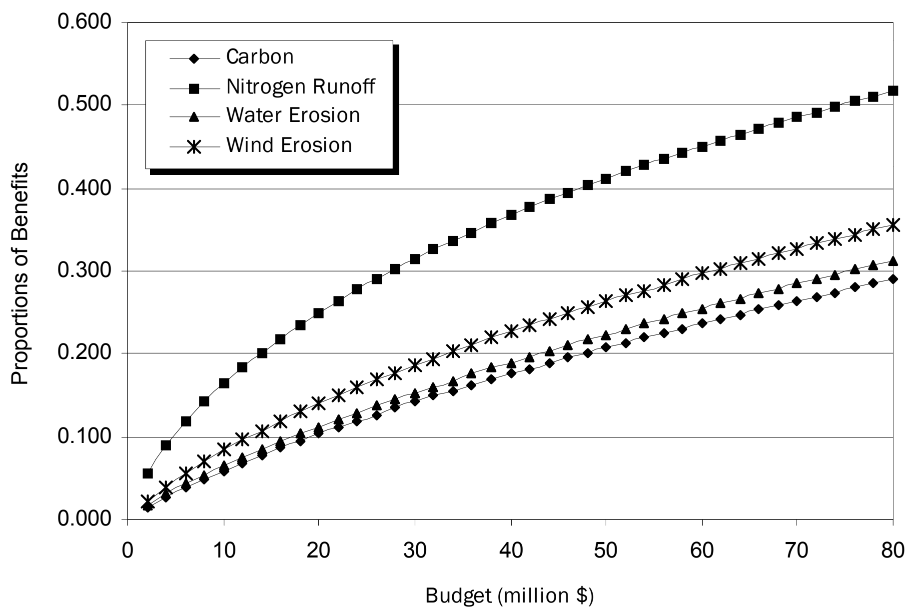

Figure 4. Normalized ELCs associated with nitrogen runoff targeting: $N_{l,k}(C)$, k = nitrogen runoff reduction, l varies

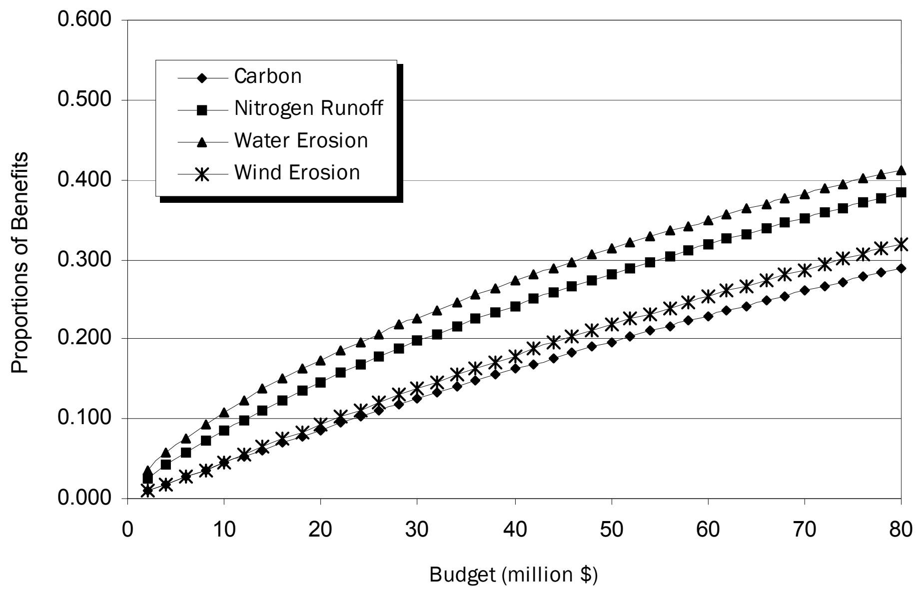

Figure 5. Normalized ELCs associated with water erosion targeting: $N_{l,k}(C)$, *k* = water erosion reduction, *l* varies

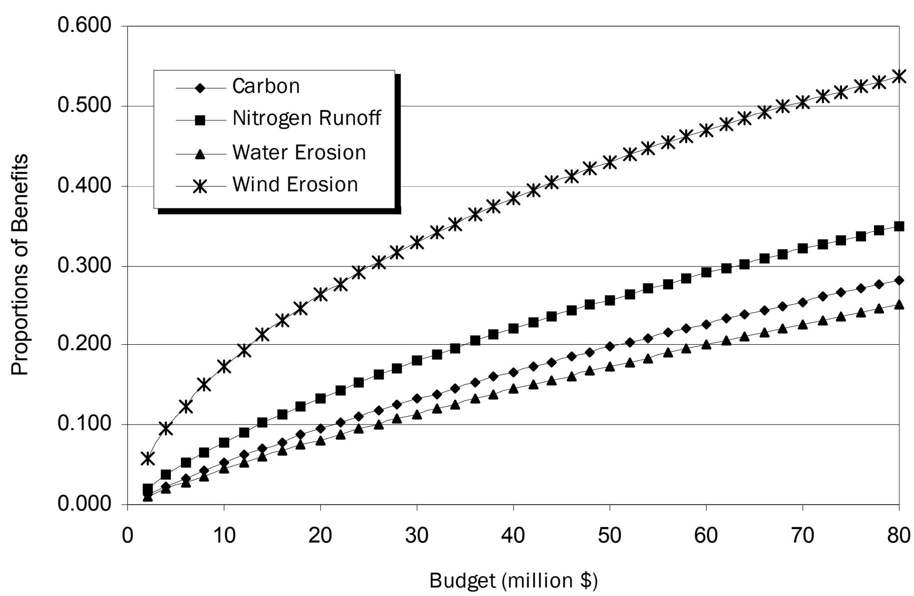

Figure 6. Normalized ELCs associated with wind erosion targeting: $N_{l,k}(C)$, *k* = wind erosion reduction, *l* varies

The ELCs associated with targeting wind erosion benefits (figure 6) provide a striking example. At low budget levels, only 1%–3% of carbon, nitrogen runoff, and water erosion benefits are gained, with benefits just a bit higher for wind erosion. However, as the budget rises, the fraction of wind erosion benefits gained rises quickly, the nitrogen runoff gain rises relatively quickly as well, but both water erosion and carbon benefits lag.

We now address the question of which of the single-benefit targeting policies is most desirable under the special cases of the two social welfare functions discussed earlier in the section describing the conceptual model. Under the equal-weights criterion (or when the environmental benefits are perfect substitutes), the policy maker would like to choose a policy that provides the highest percentage of the normalized total achievable benefits. Figure 7 shows the average of the four ELCs from figures 3–6 and identifies each curve by the benefit targeted. As clearly observed from figure 7, the targeting of nitrogen runoff yields the highest sum of benefits at all budget levels. The targeting of water erosion achieves the lowest level. Thus, a policy maker with an equal-weight form of a social welfare function would choose to target nitrogen runoff, regardless of the budget level.

Under the max-min criterion (or when the benefits are perfect complements), the policy maker would like to choose the target that provides the greatest level of the benefit which is being represented by the lowest Lorenz curve. Figure 8 presents the lowest ELC from each of the four targeted benefits (i.e., the lowest ELC from figures 3–6). In this case, the optimal benefit to target depends upon the budget level. For budgets between \$2 and \$32 million, the results suggest nitrogen runoff should be chosen. However, at budgetary levels above \$32 million, carbon sequestration should be the targeted benefit.

Conclusions

In this paper, we have investigated the environmental impacts of several forms of policies offering farmers conservation payments in return for adopting conservation tillage. The policies differ in whether the tillage practice or one of the environmental benefits is targeted. Normalized Environmental Lorenz Curves are employed to represent the performance of the targeting policies, and it is shown that these curves can be directly used to help select the optimal targeting strategy for special classes of social welfare functions.

It is increasingly important to understand the relationship between the multiple benefits associated with conservation programs and the implications of targeting for the full suite of environmental benefits, as the 2002 Farm Bill signaled a clear change in conservation policy away from a primary focus on land retirement programs and into working lands programs with the adoption of the Conservation Security Program. Tight federal budgets and increasing interest in measuring environmental improvements suggest the likelihood of targeting as an important tool in the future. This paper contributes to an understanding of these tradeoffs by examining the targeting of land for conservation tillage adoption to achieve gains in four key environmental benefit measures: carbon sequestration, nitrogen runoff, wind, and water erosion.

Applied to the state of Iowa, the model shows that when the environmental benefits are perfect substitutes or complements, the optimal targeting strategy depends on the budget level. For budget levels above \$32 million, nitrogen runoff and carbon sequestration are, respectively, the optimal targeting strategies.

It must be noted that the empirical results obtained for Iowa may not be easily generalized to other states or regions. Multiple factors, such as soil structure and climate, may change not only the levels but also the correlations between the multiple benefits of conservation tillage, and thus alter the patterns of empirical findings.

Finally, the empirical results of this study are based on EPIC, which provides the estimates of environmental benefits at the edge of the field, and does not account for spatial movement of sediment and nutrients in drainage areas. While this feature of EPIC does not pose a limitation in the case of carbon sequestration for the reduction of greenhouse gases (see, e.g., discussion in Antle and Mooney, 2002), a desirable extension of this study would be to use an in-stream water quality model that explicitly accounts for the movement of soils and nutrients from fields through river beds and water bodies. This would allow consideration of the non-additive nature of water quality benefits from conservation tillage and could improve the accuracy of the benefit assessment.

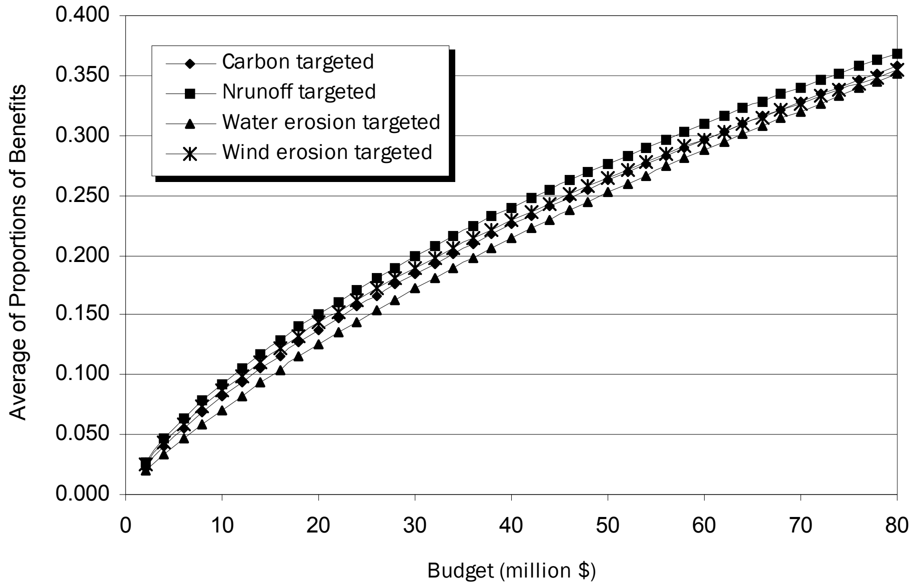

Figure 7. Choice of best targeting strategy when benefits are perfect substitutes:
$$V_k(C) = \frac{1}{4}\sum_{l=1}^{4} \phi_{l,k}(C) \text{ for various } k$$

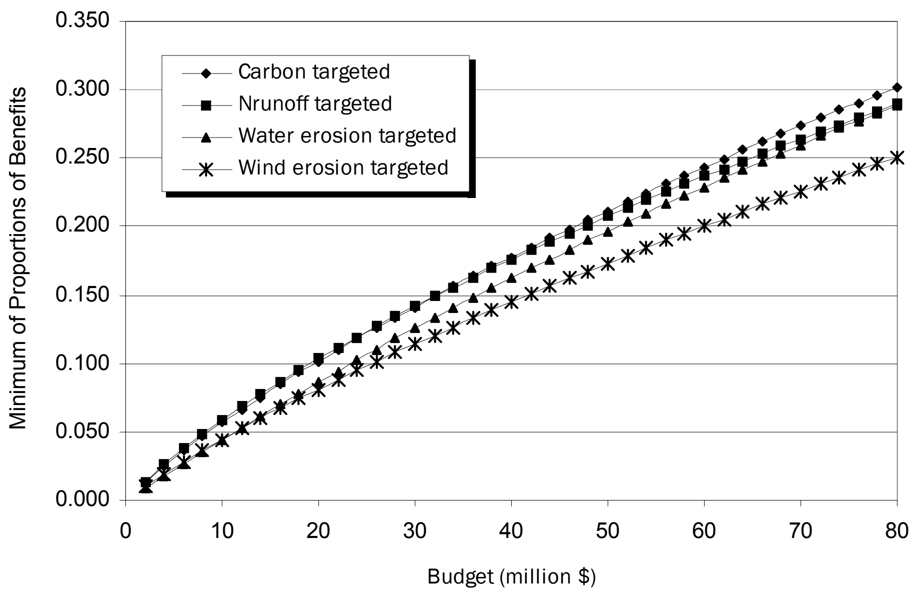

Figure 8. Choice of best targeting strategy when benefits are perfect complements:
$$V_k(C) = \min_{l=1,\ldots,4} \phi_{l,k}(C) \text{ for various } k$$

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