Alternative Green Payment Policies under Heterogeneity When Multiple Benefits Matter

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Abstract

We investigate the environmental impacts of several forms of policies that offer farmers subsides in return for adoption of conservation tillage. The policies differ on whether the tillage practice or one of the environmental benefits is targeted. We develop an environmental Lorenz curve that fully represents the performance of the targeting policies, and we show that these curves can be used directly to help select the optimal targeting strategy for special classes of social welfare functions. We apply the model to the state of Iowa.

Keywords: environmental Lorenz curve, multiple benefits of conservation tillage, targeting subsidy policy.

ALTERNATIVE GREEN PAYMENT POLICIES UNDER HETEROGENEITY WHEN MULTIPLE BENEFITS MATTER

Introduction

Improving the environmental performance of agriculture has emerged as an important goal of U.S. agricultural policy. One potential tool for achieving this is the use of green payments, which are the payments made to farmers for environmentally friendly practices. Notably, conservation payments apply to changes in practices on land that remains in active production of agricultural commodities. Thus, green payments have the potential to be a major policy response to non-point source pollution from agriculture. Policymakers need to understand the environmental effectiveness of these policies as well as the costs associated with their use.

Conservation tillage can generate a range of (mostly) positive environmental externalities related to water quality, wildlife habitat, and carbon sequestration. However, different land characteristics will yield different amounts of these environmental benefits. Thus, which land is most desirable for placement into conservation tillage depends in part on how society values different environmental benefits of the practice. This raises the question of whether specific environmental attributes should be targeted in the design of conservation payment programs and the degree to which there are trade-offs between these environmental benefits. For example, if a policy that targets carbon sequestration is implemented, how much less nitrogen runoff reduction is achieved than if nitrogen reductions were targeted?

In this study, we compare empirically the environmental consequences of alternative conservation policies under which farmers are offered payments in return for their adoption of conservation tillage. The policies differ in which of the multiple environmental benefits is targeted, that is, according to what environmental criterion the farmers are enrolled in the program. We develop a form of environmental Lorenz curve (ELC) to formally compare the alternative policies. The ELC is similar to, but different from, those used in Babcock et al. 1996 and 1997a. The curves developed in this paper relate not only to the heterogeneity of the farms, as in Babcock et al., but also to the rank correlation of the different environmental services provided by the (heterogeneous) farms. We further show that for certain special social welfare functions, the ELCs can be used directly to help choose the optimal targeting strategy.

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, for example, 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 $X^n = (X_1^n,...,X_K^n)$. Let c^n be the cost of adopting the new practice, that is, farmer n will enroll if he 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 $U(X_1,...,X_K)$. Here $X_k = \sum_{i\in\Omega^e} X_k^i$, with Ω^e indexing the set of farmers adopting conservation tillage, and $U(\bullet)$ is increasing and concave in X_k .[1] Let $\Omega = \{1,...,N\}$ be the set of all farms and Ω^σ be the σ -algebra of the subsets of Ω . Then formally, the government's problem is

$$\begin{aligned} &\max_{\Omega^e\in\Omega^\sigma} U(X_1,...,X_K) \\ &\text{s.t.} \quad X_k = \sum_{n\in\Omega^e} X_k^n, \qquad k = 1,...,K \qquad (1) \\ &\qquad\quad \sum_{n\in\Omega^e} c^n \le C \end{aligned}$$

which can be rewritten as

$$\begin{aligned}&\max_{\Omega^e \in \Omega^\sigma} U\Big(\sum_{n\in\Omega^e} c^n x_1^n, \ldots, \sum_{n\in\Omega^e} c^n x_K^n\Big)\\ &\text{s.t.} \quad \sum_{n\in\Omega^e} c^n \le \mathrm{C}\end{aligned} \tag{2}$$

To solve (2), consider a hypothetical farm m at the margin: the government is indifferent as to whether this farm should be enrolled or not. Forming the Lagrangian $L = U(\bullet) + \lambda(C - \sum_n c^n)$, the optimization condition is $U_1 c^m x_1^m + \bullet\bullet\bullet + U_K c^m x_K^m = \lambda c^m$, where $U_k = \partial U / \partial X_k$. That is, for the marginal farm m, we have

$$\sum_{k=1}^{K} U_k x_k^m = \lambda,$$

and for the other farms, we have

$$\begin{cases}\displaystyle\sum_{k=1}^{K} U_k x_k^n \ge \lambda & n \in \Omega^e\\ \displaystyle\sum_{k=1}^{K} U_k x_k^n < \lambda & n \in \Omega \setminus \Omega^e\end{cases}.$$

Since U_k measures the marginal utility of improving the *k*th environmental amenity, the government should rank the farms by their aggregate 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 big budget, all farms will be enrolled. That is, there exists a budget level $\bar{C}$ such that $\Omega^{e*}(C) = \Omega$ for all $C \ge \bar{C}$.

If the “prices” U_k, or the marginal social benefits of the environmental amenities, are easily obtainable, the previous rule dictates an optimal targeting strategy for the government: it should target the comprehensive per-dollar environmental benefit v. However, targeting multiple amenities may push the transaction costs too high, and the government may choose to target a particular amenity. Suppose the government chooses to target X_k. We can show that the optimal solution is then to enroll farmers from the highest x_k^n until budget C is exhausted.

Let $\Omega_k^e(C)$ denote the set of farmers enrolled when targeting amenity X_k 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, $k, l = 1,...,K$. The efficiency of targeting X_k relative to the optimal targeting is given by

$$\rho_k(C) = \frac{U\left(\sum_{n\in\Omega_k^e(C)} X_1^n,...,\sum_{n\in\Omega_k^e(C)} X_K^n\right)}{U\left(\sum_{n\in\Omega^{e*}(C)} X_1^n,...,\sum_{n\in\Omega^{e*}(C)} X_K^n\right)}. \tag{3}$$

If the government chooses to target only one environmental amenity, it should select the one with the highest $\rho_k(C)$. Again, since the government can enroll all farms with budget $\bar{C}$, we know that $\rho_k(\bar{C}) = 1, \forall k = 1,...,K$.

Typically, the social welfare function $U(\bullet)$ is unknown and the “prices” of the environmental amenities U_k are not easily obtainable. Suppose the government intends to target only one of the environmental amenities directly. Which one should it target? What are the “externalities” of the policy in terms of the other environmental amenities? We will show in what follows that the externalities of the targeting policies 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 $U(\bullet)$.

Effects of Targeting Strategies: Environmental Lorenz Curves

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 strategy X_k relative to that under targeting X_l, given C. The comprehensive performance of strategy X_k can be represented by a vector $w_k(C) = (w_{1,k}(C),...,w_{K,k}(C))$. Since the highest level of X_l is achieved when X_l is targeted, $w_{l,k}(C) \in [0,1]$, $l = 1,...,K$. Roughly speaking, given C, as w_k increases, targeting X_k is preferred, as its performance in raising other amenities increases relative to targeting those amenities directly.

We call $w_k(C)$ a function of C, the ELC 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 let r_k be the associated rank order. If r_k, $k = 1, ..., K$, are perfectly correlated, farms that provide more amenity X_l per dollar spent also provide more X_k. Then $w_k(C) = (1, ..., 1)$: the same farms will be selected under any of the targeting strategies, resulting in an amenity ratio of one for all $k = 1, ..., K$. Also, note that in this case $\rho_k = 1$. 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 that the farms are homogeneous (i.e., $x_k^i = x_k^j$, $i, j = 1, ..., N$). However, correlation among $r_k, k = 1, ..., K$, is different from correlation among $x^n, n = 1, ..., N$, and the latter (with K=1, or only one environmental benefit considered) is what is driving the Lorenz curves in Babcock et al. (1996, 1997a). Even if farms are extremely heterogeneous, there may still be a high rank order correlation among r_k, $k = 1, ..., K$, if lands in the region with high amenities in some aspects also provide high amenities in other aspects.

Note that when $C = \bar{C}$, all farms are enrolled under any targeting strategy. Then, regardless of the correlation among r_k, we know that $w_k(\bar{C}) = (1, ..., 1)$. 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.

Choices of Targeting Strategies: Normalized Lorenz Curves

As shown in equation (3), choosing the optimal targeting strategy requires information about the social welfare function $U(\bullet)$. We now consider two special classes of welfare functions:

$$U(X_1, ..., X_K) = \sum_{k=1}^{K} \alpha_k X_k \tag{4}$$

and

$$U(X_1, ..., X_K) = \min\{\alpha_k X_k, k = 1, ..., K\}. \tag{5}$$

In the first case, the environmental amenities are perfect substitutes, while they are perfect complements in the second case. Further, we normalize the weights as

$$\alpha_k = \frac{\alpha}{\bar{X}_k}, \tag{6}$$

where $\bar{X}_k = \sum_{n\in\Omega} X_k^n$ is the total environmental amenity k that is provided by all of the farms. Note that $\bar{X}_k$ can be achieved under any targeting strategies: $\hat{X}_{k,l}(\bar{C}) = \bar{X}_k$ for all $l = 1,...,K$. The normalization in (6), together with (4) and (5), implies that when the environment is restored to its "pristine" state, or when all the environmental services of the land have been restored, that is, $X_k = \bar{X}_k$ for all k, each pristine amenity has the same "value" α. Under both (4) and (5), society views these amenities equally at the pristine state.

Let $\phi_{k,l}(C) = \hat{X}_{k,l}(C) / \bar{X}_k$ be the ratio of the *k*th amenity that can be achieved under targeting strategy X_l, relative to the maximum possible amenity level, and let $\phi_l(C) = (\phi_{1,l}(C),...,\phi_{K,l}(C))$ be the vector of amenity ratios achievable under this strategy. Then the utility levels of targeting X_l under (4) and (5) are, respectively,

$$V_l(C) = \alpha \sum_{k=1}^{K} \phi_{k,l}(C); \qquad V_l(C) = \alpha \min\{\phi_{k,l}(C), k = 1,...,K\}. \tag{7}$$

The optimal targeting strategy given budget level C is to select the maximum from $\{V_l(C), l = 1,...,K\}$.

Note that $\phi_{k,l}(C) = w_{k,l}(C)\hat{X}_{k,k}(C) / \bar{X}_k$. Tracing out $\phi_l(C)$ for $C \in [0, \bar{C}]$, we obtain a normalized ELC, which is ELC $w_l(C)$ rescaled by $\hat{X}_{k,k}(C) / \bar{X}_k$. For each targeting strategy, the two payoff functions in (7) correspond to the vertical summation of the curves and the minimum of the normalized ELC curves, respectively. The optimal targeting strategy then can be chosen by comparing the summed or minimum curves of all strategies. Figure 1 illustrates such choices when two environmental benefits are being

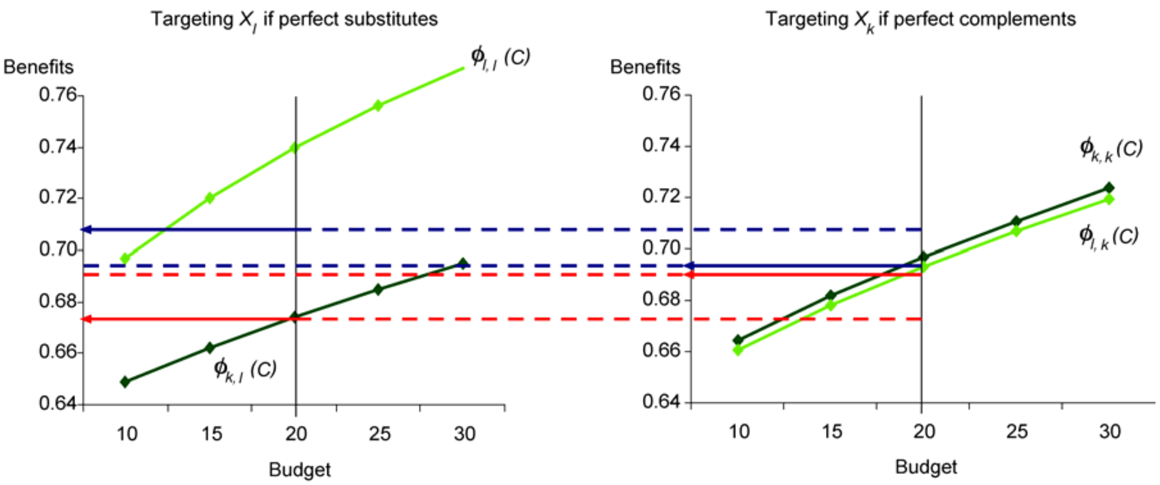

FIGURE 1. The choice of optimal targeting strategy

considered, X_l and X_k, for a given budget $C^*= 20$. In this figure, $1/2\{\phi_{l,l}(C^*)+\phi_{k,l}(C^*)\}$ > $1/2\{\phi_{k,k}(C^*)+\phi_{l,k}(C^*)\}$; thus, targeting benefit X_l is preferred under the assumption of perfect substitutability. However, $\min\{\phi_{k,k}(C^*),\phi_{l,k}(C^*)\} > \min\{\phi_{l,l}(C^*),\phi_{k,l}(C^*)\}$, meaning that targeting benefit X_k is the optimal choice under perfect complementarity.

Application: Conservation Tillage in Iowa

We apply our model to conservation tillage in the state of Iowa, with each of the $N = 12{,}143$ National Resource Inventory (NRI) (Nusser and Goebel 1997) points representing a farm. The costs of adoption, c^n, $n = 1,\dots, N$, are obtained from Kurkalova, Kling, and Zhao 2003, which presents a methodology and empirical estimates of a reduced form, discrete-choice adoption model for Iowa. Here, we briefly summarize this model and explain how we use it.

The conservation tillage adoption model in Kurkalova, Kling, and Zhao 2003 is derived under the assumption that a farmer will adopt conservation tillage if the expected annual net return from conservation tillage exceeds that from conventional tillage plus a premium associated with uncertainty. The premium in turn depends on the variability of the net returns to conservation tillage and conventional tillage, and other explanatory variables. Given per-acre subsidy c^n, the model returns the adoption probability, $p_n\left(c^n\right) \equiv p\left(c^n, \overline{s}_n\right)$, where $p(\bullet)$ is logistic, and vector $\overline{s}_n$ is a collection of producer and site-specific variables, including the production site's physical and climatic characteristics, the crop grown, farmer characteristics, as well as the expected net return to conventional tillage. This adoption model is estimated on a random sub-sample of NRI points located in Iowa. In the empirical implementation, we slightly modify the model described earlier to account for the continuous probability of adoption.

The basic data come from the 1992 NRI (USDA-SCS 1994). The NRI data are statistically reliable for national, state, and multi-county analysis of non-federal land (Nusser and Goebel 1997) and thus are reasonably representative of Iowa agricultural land. In our calculations, we treat each NRI point as representing a producer with a farm size equal to the number of acres represented by the point (the NRI expansion factor). The NRI provides information on the natural resource characteristics of the land and the crop grown (1992 and 1991 seasons). For additional information on the data source and model, see Kurkalova, Kling, and Zhao 2003.

The field-specific environmental benefits from conservation tillage, $X_n^K, k = 1,...,K, n = 1,...,N,$ are estimated at each of the data points using the Environmental Policy Integrated Climate (EPIC) model version 1015 (Izaurralde et al. 2002).[2] We consider $K = 4$ environmental benefits, including carbon sequestration, nitrogen runoff reduction, reduction in water erosion, and reduction in wind erosion. EPIC is a commonly used simulation model adaptable for large regional analyses (e.g., Plantinga and Wu 2003; Babcock et al. 1997b). The simulations are carried out at a field-scale level for areas homogeneous in weather, soil, landscape, crop rotation, and management system parameters. EPIC operates on a continuous basis using a daily time step and is capable of simulating multi-year periods. The model accounts for the effects of tillage on surface residue, soil bulk density, and mixing of residue and nutrients in the soil plow layer. Version 1015 of EPIC includes an updated (relative to earlier versions) carbon simulation routine that is based on the approach used in the Century model developed by Parton et al. (1994).

At each of the data points, two 30-year simulations are run, one assuming conventional tillage and the other assuming conservation tillage. The NRI database provides baseline land use and other input data for the simulations. The quantities of the four environmental benefits are computed as the differences between appropriate EPIC outputs under conservation tillage and that under conventional tillage, averaged over the 30 years.

Results

We estimated the four categories of environmental benefits obtainable under five targeting strategies at 40 budget levels roughly corresponding to the amount of federal funding potentially available to Iowa through the Conservation Security Program.[3] In addition to policies that target each one of the four environmental benefits previously listed, we also consider a practice-based policy that maximizes the number of acres of land in conservation tillage, enrolling low-cost farms first regardless of their environmental benefits. Figure 2 presents the ELCs associated with this practice-based policy. From Figure 2, we see that the practice-based policy provides high proportions of the benefits obtainable from the policies that target the respective benefits. Note that the ELCs are increasing and concave in the budget level.

To aid comparison of alternative targeting schemes, Figures 3 through 6 present respectively the ELCs of the benefits when targeting carbon, nitrogen runoff, water erosion, and wind erosion. Again, the ELCs are increasing and concave in the budget. Note from Figures 3 and 4 that even at low budget levels, more than 40 percent of the potentially obtainable benefits from direct targeting can be achieved with the policies that target carbon sequestration or nitrogen runoff. Further, Figures 2 through 6 illustrate that more than 40 percent of the potentially obtainable carbon from direct carbon targeting can be achieved with the policies that target conservation tillage or the other benefits in question. These results indicate high correlation among the benefits considered, as well as high correlation between the benefits and the acreage in conservation tillage. Further, since high proportions of environmental benefits are obtained under the practice-based policy, the farms are relatively homogeneous in their land characteristics. Finally, from the

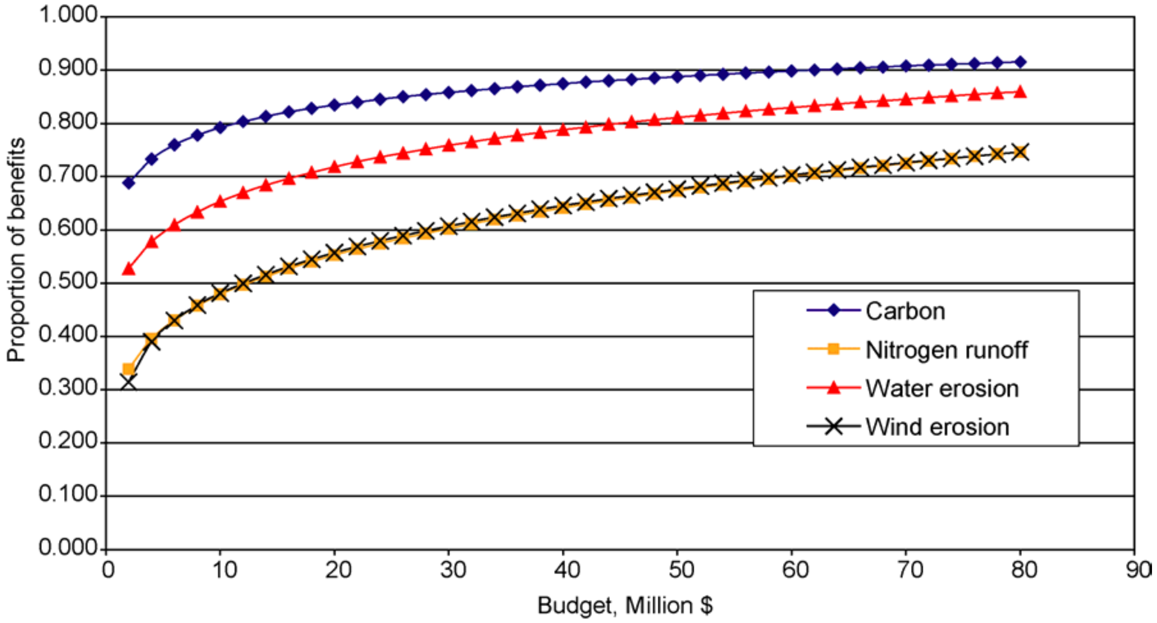

FIGURE 2. The environmental Lorenz curves associated with the practice-based policy

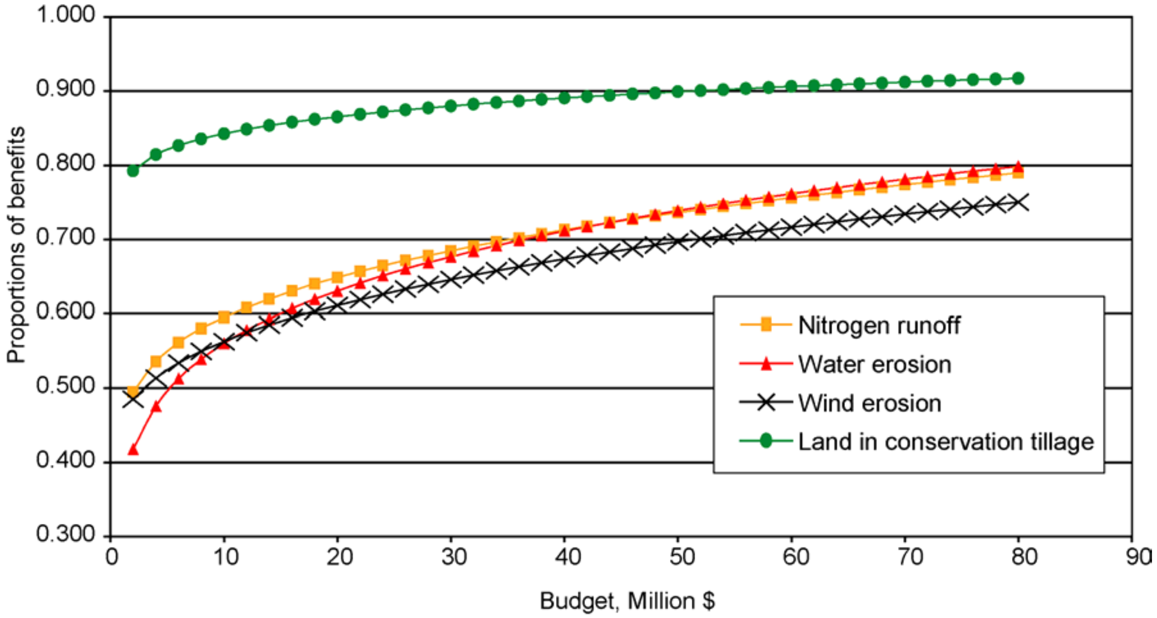

FIGURE 3. Environmental Lorenz curves associated with carbon targeting

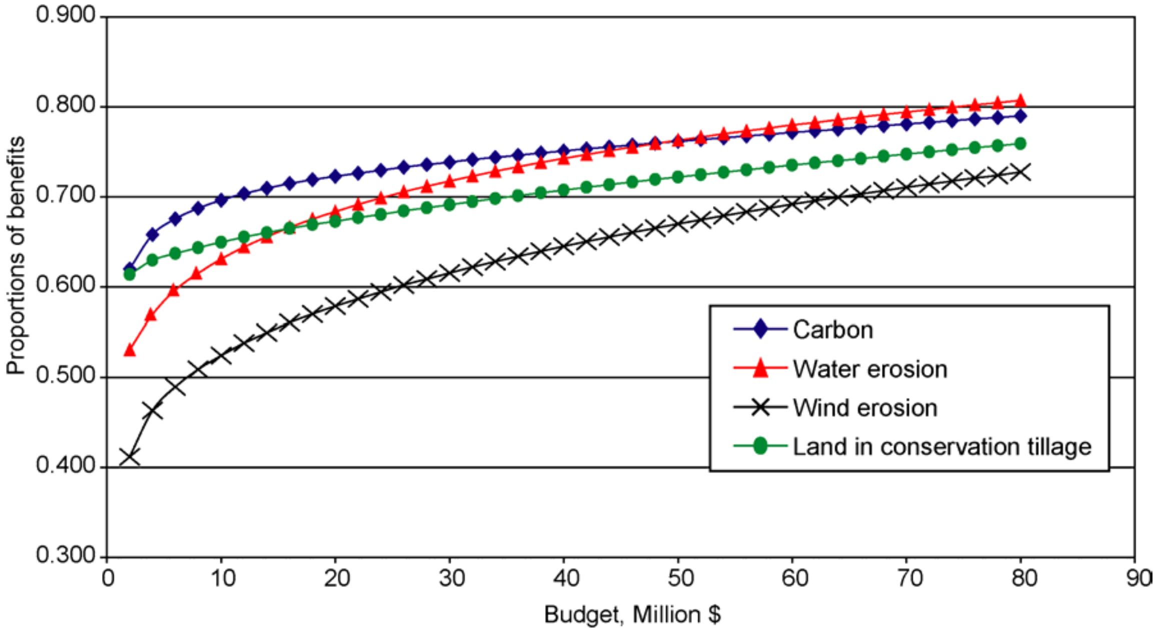

FIGURE 4. Environmental Lorenz curves associated with nitrogen runoff targeting

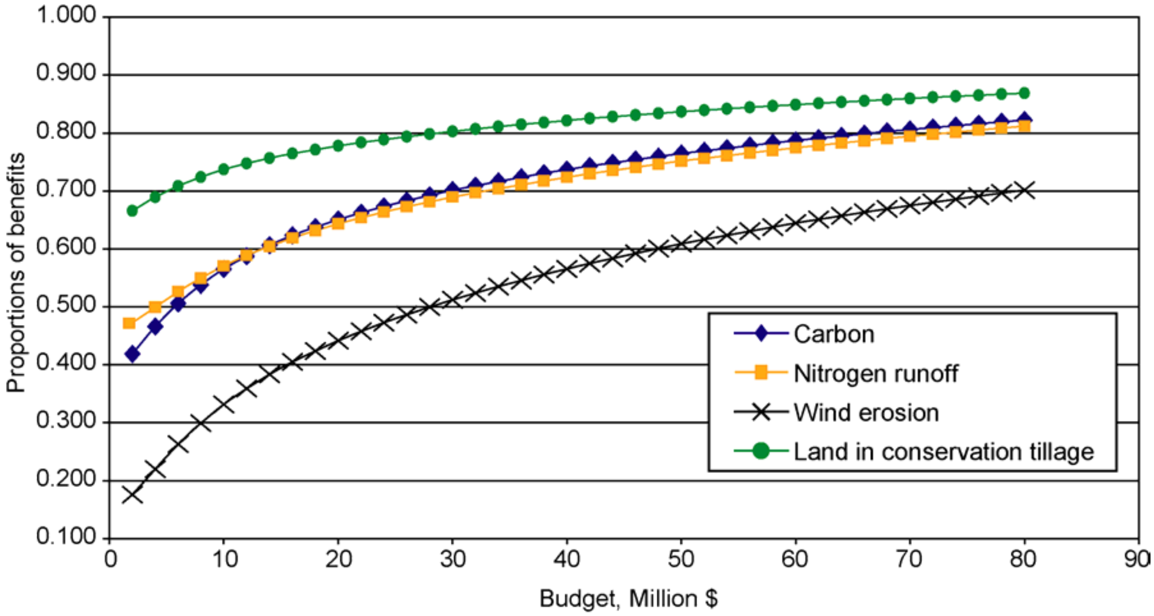

FIGURE 5. Environmental Lorenz curves associated with water erosion targeting

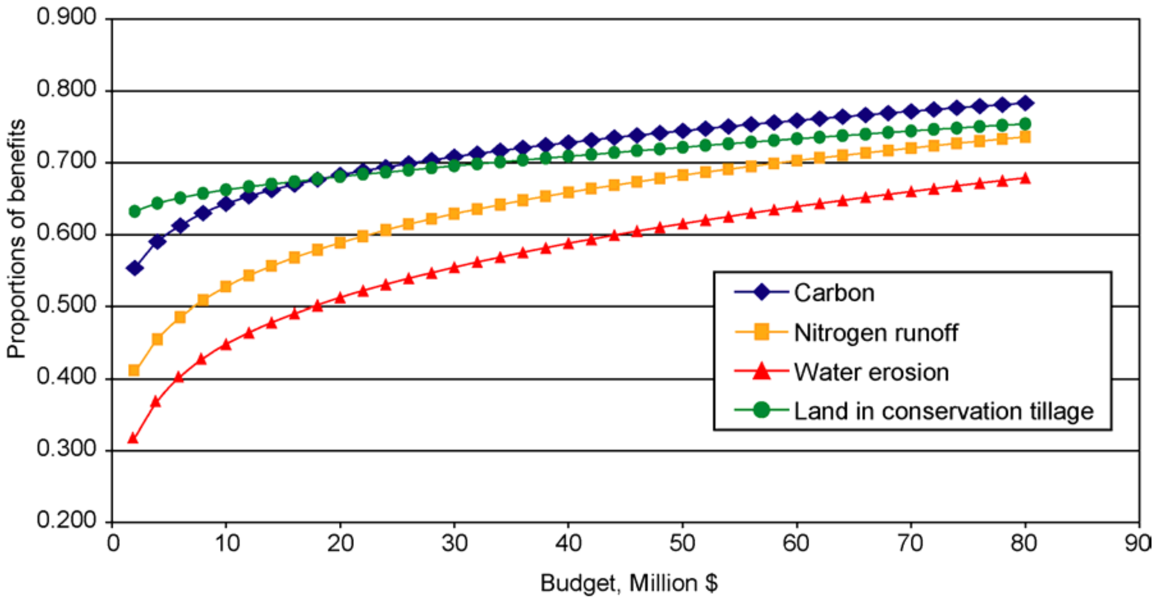

FIGURE 6. Environmental Lorenz curves associated with wind erosion targeting

figures, we see that carbon sequestration is correlated mostly with conservation tillage acreage: targeting either one provides high proportions of the other attribute.

Now we investigate which of the single-benefit targeting policies is most desirable under the special social welfare functions previously given. Under the equal weights criterion (or when the environmental benefits are perfect substitutes), the policymaker chooses a policy that provides the highest percentage of the normalized total achievable benefits. Under the max-min criterion (or when the benefits are perfect complements), the policymaker chooses the policy that provides the greatest level of the minimum percentage. Table 1 gives summaries of the estimated choices of the policies. We find that the choices of the best policies under the two criteria depend on the level of conservation budget.

TABLE 1. Best targeting strategies under alternative social welfare functions

Budget (Million $)	Benefits are Perfect Substitutes	Benefits are Perfect Complements
2-36	Minimize nitrogen runoff	Minimize nitrogen runoff
38-70	Minimize nitrogen runoff	Maximize carbon sequestration
72-80	Maximize carbon sequestration	Maximize carbon sequestration

Conclusions

In this paper, we investigate the environmental impacts of several forms of policies that offer farmers subsides in return for adoption of conservation tillage. The policies differ on whether the tillage practice or one of the environmental benefits is targeted. We develop an ELC that fully represents the performance of the targeting policies and show that these curves can be used directly to help select the optimal targeting strategy for special classes of social welfare functions.

We apply the model to the state of Iowa and find that the practice-based policy that targets conservation tillage acreage provides high proportions of the four benefits relative to the policies that target the benefits directly, especially at high budget levels. When the environmental benefits are perfect substitutes or complements, the optimal targeting strategy depends on the budget level. For intermediate budget levels (e.g., between $38 and $70 million), nitrogen runoff and carbon sequestration respectively are the optimal targeting strategies.

It must be noted, however, that our empirical results 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., the discussion in Antle and Mooney 2002), a desirable extension of our study would involve a more spatially explicit model for benefits related to water quality.

Endnotes

1. For simplicity, we define the social welfare 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 Y's are the base levels. Introducing these base levels will not affect our results.

2. Earlier versions of EPIC were called the Erosion Productivity Impact Calculator (Williams 1990).

3. The Conservation Security Program of the 2002 farm bill provides $2 billion for five years (U.S. Congress, 2002). 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.

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