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Environmental Conservation in Agriculture: Land Retirement versus Changing Practices on Working Land

Hongli Feng, Lyubov A. Kurkalova, Catherine L. Kling, and
Philip W. Gassman

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**Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu**

Hongli Feng is an assistant scientist, Lyubov Kurkalova is an associate scientist, Catherine Kling is a professor of economics and division head, and Philip Gassman is an assistant scientist, all in the Resource and Environmental Policy Division, Center for Agricultural and Rural Development, Iowa State University.

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For questions or comments about the contents of this paper, please contact Hongli Feng, 560D Heady Hall, Iowa State University, Ames, IA 50011-1070; Ph: 515-294-6307; Fax: 515-294-6336; E-mail: hfeng@iastate.edu.

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**Environmental Conservation in Agriculture:
Land Retirement versus Changing Practices on Working Land**

Abstract

The study develops a conceptual framework for analyzing the allocation of conservation funds via selectively offering incentive payments to farmers for enrolling in one of two mutually exclusive agricultural conservation programs: retiring land from production or changing farming practices on land that remains in production. We investigate how the existence of a pre-fixed budget allocation between the programs affects the amounts of environmental benefits obtainable under alternative policy implementation schemes. The framework is applied to a major agricultural production region using field-scale data in conjunction with empirical models of land retirement and conservation tillage adoption, and a biophysical process simulation model for the environmental benefits of carbon sequestration and reduction in soil erosion.

Keywords: Conservation Reserve Program, land retirement, working land.

1 Introduction

Managing agricultural land for the production of conservation services in addition to agricultural commodities has had a long tradition in the United States. Efforts to control soil erosion date back to the dust bowl days of the 1930s when cost share programs were used to pay part of the costs of structures that reduce erosion. More recently, wildlife habitat, open space, and carbon sequestration have been identified as important environmental benefits attributed to agricultural conservation efforts, and, since the mid-1980s, the focus has changed from cost share programs that affect how land is worked to compensation for completely retiring land from production. This switch in focus is clearly reflected in conservation spending. In the last two decades, public funding of agri-environmental programs has nearly tripled, with programs that retire environmentally sensitive land from crop production accounting for more than 85 percent of Federal conservation expenditures (Claassen, 2003). The Conservation Reserve Program (CRP), the largest land retirement program with an annual budget about \$1.6 billion, currently enrolls about 10 percent of the country's cropland.

In what may signal a major shift back towards working land management programs, the 2002 farm bill reverses the trend towards land retirement funding with a much larger increase for conservation programs on working land (\$11 billion over 10 years) than for land retirement programs (\$3 billion for the CRP and the Wetlands Reserve Program). In addition, the legislation initiated a new working land program — the Conservation Security Program (CSP). The CSP represents a fundamental change from previous working

land programs in that it goes beyond the notion of cost sharing for structural improvements to fully compensating farmers for the opportunity cost of changing practices (Claassen et al., 2001). Thus, the CSP can be interpreted as a true “green” subsidy program. While details concerning implementation of the program are still in progress at this writing (USDA-NRCS, 2004a), it appears that farmers will be offered a set of payment options for the adoption of various conservation practices such as reduced tillage, improved nutrient management, and establishment of buffer strips.

There are a number of influences prompting this refocusing of conservation efforts on working lands. First, working land accounts for the vast majority of agricultural land; environmental advocates have come to appreciate that if significant environmental benefits are going to accrue from the agricultural sector, they will have to occur in conjunction with active production. Second, international pressure to separate farm support payments from production levels has generated an active interest in redefining farm support payments in terms of green subsidies that would fit under the “green box” of the World Trade Organization (WTO) agreement (Claassen et al., 2001). Third, while land retirement programs have produced a significant amount of environmental benefits, they have done so at a fairly high cost; changing practices on working land may be a more cost-effective approach.

This latter point provides the primary motivation for the present research. Compared to land retirement, the adoption of conservation practices on working land may seem to be more cost-effective, as the opportunity cost of conservation on working land is lower given that it continues to provide agricultural products. However, the benefits of conservation practices on

working land are also likely to be smaller. For example, in general, conservation tillage on cropped land would not reduce nutrient runoff as much as retiring the land completely from production. Thus, whether conservation practices on cropped land will be more cost-effective than land retirement is an empirical question that may depend on both the specific conservation practices adopted as well as the characteristics of the land. In addition, the efficiency of a working land program will also depend upon the details of how it is implemented (which practices are included, whether environmentally sensitive land is targeted, whether existing adopters of conservation practices are eligible, etc.) and how it is implemented vis a vis other conservation programs, such as the CRP.

In this study, we investigate the efficiency of working land conservation programs relative to land retirement programs. We begin by providing a theoretical framework for analyzing the trade-offs of conservation through working land and through land retirement. Given a policy objective of maximizing environmental benefit for a given conservation budget, we derive the optimal split of spending on conservation of working land vs. retiring land from production. Then, we examine the combined implementation of the programs when the share of funding is pre-fixed, as in the 2002 Farm Bill. Following the theoretical framework, we develop empirical economic models of conservation practice adoption and land retirement and integrate them with a biophysical environmental model to conduct regional policy simulations based on field-scale data. We study a variety of different ways in which the two types of conservation programs could be jointly implemented including simultaneous vs. sequential implementation of the programs with

a pre-fixed budget allocation.

In our empirical application, we initially focus on the environmental benefit of carbon sequestration. We also present results for soil erosion, but motivate and discuss our model throughout in terms of carbon. While soil erosion has long been a major concern in agriculture, the focus on carbon is motivated by the substantial interest that agricultural sequestration has generated recently (Pautsch et al.; Antle and McCarl; Antle et al., Kurkalova, Kling, and Zhao 2003b; Lewandrowski et al.; Choi and Sohngen) including its official place in trading on the Chicago Climate Exchange and the continued call for consideration of cost-effective means for reducing atmospheric greenhouse gas concentrations. Further, carbon sequestration has already been identified as one of the important benefits to be targeted by working land programs (USDA-NRCS, 2004b). Given our interest in carbon sequestration and soil erosion, it is natural to choose conservation tillage as the working land practice to study because of its well-known effects on these two environmental indicators (see, e.g., Lewandrowski et al.).¹

Our research builds on previous work related to the sequestration of carbon in agricultural soils and land retirement. The focus of existing carbon sequestration literature, including the examples previously mentioned, has primarily been the estimation of carbon sequestration potential and its cost or the implementation of carbon sequestration programs. A number of

¹While conservation tillage is included in major working land programs (such as the CSP and Environmental Quality Incentives Program [EQIP]), we do not attempt to model these programs exactly, but more generally focus on the trade-offs between conservation benefits from placing a parcel in conservation tillage versus retiring the land from production.

studies have also investigated the environmental benefits and efficiency characteristics of land retirement programs (Reichelderfer and Boggess; Smith; Babcock et al. 1996, 1997; Feather, Hellerstein, and Hansen; Wu; Khanna et al.). Despite the sizable literature on agricultural conservation programs, no study to our knowledge has investigated the quantitative trade-offs between conservation through land retirement and conservation on working land. Neither has any research studied the efficiency implications of how these two programs are implemented and thereby compete for the enrollment of land parcels.

2 Theoretical framework

Suppose there are N parcels of land which are currently cropped. The size of parcel i is denoted as \bar{x}_i . Within each parcel, land is assumed to be homogeneous. The government provides incentives to farmers to promote conservation practices a_i on the parcels. There are two methods of conservation for each parcel: retiring land from production (LR) or adopting some conservation practice on working land (WL), such as conservation tillage. Thus, we assume $a_i = wl$, or $a_i = lr$.

With the adoption of a_i , environmental performance on parcel i will be improved. The amount of improvement, which we refer to as environmental benefit of a_i , is denoted as $q_i^{a_i}$ per acre, which can be some measure of a single environmental indicator such as erosion, nutrient runoff, carbon sequestration, or an index of multiple environmental indicators. The compensation a farmer requires for adopting a_i is denoted as $p_i^{a_i}$ per acre, which

is the farmer's opportunity cost of adopting a_i .

For a given conservation budget, B , suppose the policy objective of an incentive program is to maximize environmental benefits. In deciding the best use of the conservation budget, it is convenient to consider two decisions to be made for each parcel: (1) the best practice for the parcel (a_i); and (2) given the chosen practice, a_i , how much of the parcel (x_i) to enroll. Depending on how the budget B is divided between the two programs, we consider two cases. In Case A, the share of funding between WL and LR is optimized. In Case B, the share of funding is fixed, presumably by some political process. We first discuss Case A.

2.1 Case A: Optimal share of funding

In this case, the share of funding between WL and LR is endogenously determined. In other words, policymakers are free to enroll parcels to maximize environmental benefits with the only constraint being that they do not exceed the total conservation budget. Thus, the share of funding for each program is the outcome of the combined enrollment policy.

The first step is to choose the practice on each parcel. In this case, the practice chosen for a parcel i is based on the following rule: if $\frac{q_i^{lr}}{p_i^{lr}} > \frac{q_i^{wl}}{p_i^{wl}}$, then $\hat{a}_i = lr$; otherwise, $\hat{a}_i = wl$. In other words, for each parcel i , the practice resulting in a higher marginal benefit per dollar is chosen. Given this practice choice, the second decision is how much of the parcel to enroll into the program.²

²We have simplified the optimization problem by making it sequential, solving first for a_i and then optimally choosing x_i , conditional on a_i . In fact, there are cases in which

Mathematically, for given a_i , the policymakers' problem is

$$\max_{x_i} \sum_i x_i q_i^{a_i} \quad (1a)$$

$$s.t. \quad \sum_i x_i p_i^{a_i} = B. \quad (1b)$$

$$0 \leq x_i \leq \bar{x}_i. \quad (1c)$$

Here x_i is the acreage from parcel i enrolled in a conservation program for a_i , $x_i \in [0, \bar{x}_i]$. Using λ as the Lagrangian multiplier of the budget constraint (1b), then, the optimal \hat{x}_i , for given a_i , is determined by the following conditions (throughout the paper, the superscript “ $\hat{\cdot}$ ” indicates the optimal solutions):

$$\text{if } p_i^{a_i} \left[\frac{q_i^{a_i}}{p_i^{a_i}} - \hat{\lambda} \right] < 0, \quad \text{then } \hat{x}_i = 0; \quad (2a)$$

$$\text{if } p_i^{a_i} \left[\frac{q_i^{a_i}}{p_i^{a_i}} - \hat{\lambda} \right] > 0, \quad \text{then } \hat{x}_i = \bar{x}_i; \quad (2b)$$

$$\text{if } p_i^{a_i} \left[\frac{q_i^{a_i}}{p_i^{a_i}} - \hat{\lambda} \right] = 0, \quad \text{then } \hat{x}_i \in [0, \bar{x}_i]. \quad (2c)$$

Intuitively, $\frac{q_i^{a_i}}{p_i^{a_i}}$ is the (marginal) benefit per dollar from parcel i when conservation practice a_i is chosen and $\hat{\lambda}$ is the marginal cost of the program due to limited funding. Thus, according to (2), given a_i , a parcel will be chosen as long as its marginal benefit is greater than the marginal cost.

Heuristically, Case A can be implemented as follows: for each parcel i , choose the maximum potential environmental benefit per dollar which is this strategy will not yield the least-cost allocation, as full optimization could require the re-allocation of previously assigned parcels between WL and LR as the budget changes. However, such a program would be difficult or impossible to implement in practice. Further, this additional complexity is unnecessary given our focus on comparison of WL and LR under fixed budgets.

just the higher of $\frac{q_i^{lr}}{p_i^{lr}}$ and $\frac{q_i^{wl}}{p_i^{wl}}$; rank these potential environmental benefits from the highest to the lowest; and then enroll parcels from the top of the ranking until the total budget is exhausted. If $\frac{q_i^{wl}}{p_i^{wl}} \geq \frac{q_i^{lr}}{p_i^{lr}}$ for all i , then all parcels should be enrolled in WL. On the contrary, if $\frac{q_i^{wl}}{p_i^{wl}} < \frac{q_i^{lr}}{p_i^{lr}}$ for all i , then all parcels should be enrolled into LR. However, if $\frac{q_i^{wl}}{p_i^{wl}} \geq \frac{q_i^{lr}}{p_i^{lr}}$ is not true for all i , then it will be optimal to enroll some into LR and some into WL.

The optimal choice of parcels is illustrated in Figures 1 and 2. In both figures, as in Figures 3 through 6 of this paper, the parcels are sorted by $\frac{q_i^{wl}}{p_i^{wl}}$ in descending order. Thus, in all figures, the curve for $\frac{q_i^{wl}}{p_i^{wl}}$, the blue (solid) curve, is always downward sloping. The value of $\frac{q_i^{lr}}{p_i^{lr}}$ is also plotted in these figures. Thus for each parcel there are two points on the figures, one along the monotonically downward sloping WL curve and the other at its associated point on the LR curve. The shape of the curve for $\frac{q_i^{lr}}{p_i^{lr}}$, the black (dashed) line, depends on the correlation of $\frac{q_i^{wl}}{p_i^{wl}}$ and $\frac{q_i^{lr}}{p_i^{lr}}$: if they are highly correlated, then $\frac{q_i^{lr}}{p_i^{lr}}$ will tend to follow a similar downward trend. However, if land that yields high benefits per dollar in WL does not also provide high benefits per dollar in LR, $\frac{q_i^{lr}}{p_i^{lr}}$ may display quite a different pattern from $\frac{q_i^{wl}}{p_i^{wl}}$.

Figure 1 illustrates a case where neither $\frac{q_i^{wl}}{p_i^{wl}}$ nor $\frac{q_i^{lr}}{p_i^{lr}}$ dominates the other for all parcels. The curves have been drawn for a situation in which the benefits per dollar are positively correlated in general. As shown in the figure by the red (bold) highlighted part of the curves, some parcels, i.e., parcels from $N_{(1)}$ to $N_{(n1)}$ and from $N_{(n2)}$ to $N_{(n3)}$, are optimally selected for WL, while some parcels, i.e., parcels from $N_{(n1)}$ to $N_{(n2)}$ and from $N_{(n3)}$ to $N_{(n4)}$, are optimally selected for LR. The remainder of the parcels are selected for neither of the programs. In contrast, Figure 2 displays a case

where $\frac{q_i^{wl}}{p_i^{wl}}$ is higher than $\frac{q_i^{lr}}{p_i^{lr}}$ for all parcels. Thus, all selected parcels, i.e., parcels from $N_{(1)}$ to $N_{(n)}$, are enrolled for WL, as shown by the highlighted part of $\frac{q_i^{wl}}{p_i^{wl}}$. This case is representative of the situation in our empirical study. The common aspect in both figures is that the highlighted parts of the curves are the higher of $\frac{q_i^{wl}}{p_i^{wl}}$ and $\frac{q_i^{lr}}{p_i^{lr}}$. That is, for each parcel selected, the practice that provides the highest environmental benefit per dollar is chosen.

The value of the benefit per dollar of the last parcel chosen, corresponding to the lowest point on the red (bold) highlighted parts of the curves (e.g., $\frac{q_n^{wl}}{p_n^{wl}}$ in Figure 2), represents the marginal benefit of the given conservation budget ($\hat{\lambda}$). The inverse of this value can be interpreted as the marginal cost of obtaining the resulting level of the environmental benefit, a result we exploit in the empirical section.

By adding up the spending on all selected parcels for practice a_i , we obtain the optimal funding for practice a_i , denoted as \hat{B}^{a_i} . That is,

$$\hat{B}^{wl} = \sum_{\{i: \hat{x}_i \geq 0, \hat{a}_i = wl\}} \hat{x}_i p_i^{wl}; \quad (3a)$$

$$\hat{B}^{lr} = \sum_{\{i: \hat{x}_i \geq 0, \hat{a}_i = lr\}} \hat{x}_i p_i^{lr}; \quad (3b)$$

$$B = \hat{B}^{wl} + \hat{B}^{lr} = \sum_{\{i: \hat{x}_i \geq 0\}} \hat{x}_i p_i^{\hat{a}_i}. \quad (3c)$$

2.2 Case B: Exogenously fixed share of budget allocation

Suppose the shares of funding for the WL and LR programs are pre-fixed exogenously: for some $0 \leq \theta \leq 1$, the funding for LR is $\bar{B}^{lr} = \theta B$, and the funding for WL is $\bar{B}^{wl} = (1 - \theta)B$. There are two ways policy could

be implemented in this case. The first is the simultaneous implementation of the programs. That is, policymakers could enroll parcels for either LR or WL to maximize environmental benefits, as long as \bar{B}^{lr} and \bar{B}^{wl} are not exhausted. Once one budget is exhausted, then remaining parcels can only be enrolled for the other practice. We call this Case B(i). The second method is the sequential implementation of the programs, where parcels are first selected for the LR (or WL) program to maximize the environmental benefits from that program given \bar{B}^{lr} (or \bar{B}^{wl}). Then, parcels are selected for the WL (LR) program from among the remaining parcels, given \bar{B}^{wl} (or \bar{B}^{lr}), to maximize the environmental benefits. We call this Case B(ii).

At first blush, implementation of the land retirement and working land conservation programs as specified in the 2002 farm bill appear most analogous to Case B(i) since they have separate funding and agricultural land can be enrolled in either of the programs. However, given that the CRP started enrolling land in the middle 1980s when there were few incentive payments for working land, Case B(ii) may be a more apt comparison. Thus, we think both cases are interesting.

2.2.1 Case B(i): Simultaneous implementation of programs

This case is the same as problem (1) except that there are separate budget

constraints for the LR and the WL programs, for any given a_i :

$$\max_{x_i} \quad \sum_i x_i q_i^{a_i} \quad (4a)$$

$$s.t. \quad \sum_i x_i p_i^{lr} = \bar{B}^{lr}, \quad (4b)$$

$$\sum_i x_i p_i^{wl} = \bar{B}^{wl}. \quad (4c)$$

$$0 \leq x_i \leq \bar{x}_i. \quad (4d)$$

Using λ^{lr} and λ^{wl} as the Lagrangian multipliers of (4b) and (4c), respectively, we have

$$\text{if } p_i^{a_i} \left[\frac{q_i^{a_i}}{p_i^{a_i}} - \hat{\lambda}^{a_i} \right] < 0, \quad \text{then } \hat{x}_i = 0; \quad (5a)$$

$$\text{if } p_i^{a_i} \left[\frac{q_i^{a_i}}{p_i^{a_i}} - \hat{\lambda}^{a_i} \right] > 0, \quad \text{then } \hat{x}_i = \bar{x}_i; \quad (5b)$$

$$\text{if } p_i^{a_i} \left[\frac{q_i^{a_i}}{p_i^{a_i}} - \hat{\lambda}^{a_i} \right] = 0, \quad \text{then } \hat{x}_i \in [0, \bar{x}_i]. \quad (5c)$$

Conditions in (5) are the same as those in (2), except that in the former the Lagrangian multipliers are for a given a_i because of the separate budget constraint for each a_i . As in Case A, for a given a_i , if the marginal benefit $\left(\frac{q_i^{a_i}}{p_i^{a_i}}\right)$ is greater than the marginal cost $(\hat{\lambda}^{a_i})$, then the parcel will be enrolled in the program for a_i . When there is funding left for both practices, the practice with higher $\frac{q}{p}$ is selected for the parcel. However, once the funding allocated for one practice is exhausted, then there is only one choice of practice for all remaining parcels.

Intuitively, Case B(i) can be implemented as follows. First, determine the maximum potential environmental benefits per dollar for each parcel, just as in Case A. Second, rank all parcels based on these benefits and

enroll parcels from the top until one of the pre-fixed budget is exhausted. Third, when one of the budgets is exhausted, say, \bar{B}^{lr} is exhausted first at parcel k , then $\hat{\lambda}^{lr} = \frac{q_k^{lr}}{p_k}$. Rank the parcels not yet enrolled based on $\frac{q_i^{wl}}{p_i}$. Finally, enroll from the top until \bar{B}^{wl} is exhausted, say, at parcel l . Then $\hat{\lambda}^{wl} = \frac{q_l^{wl}}{p_l}$. (If \bar{B}^{wl} is exhausted first, adjust steps 3-4 accordingly.)

Figures 3 and 4 illustrate the optimal selection of parcels in this case. In Figure 3, the parcels ranked before $N_{(n2)}$ provide higher environmental benefits per dollar under WL. However, with relatively limited funding for WL, only some of them, parcels from $N_{(1)}$ to $N_{(n1)}$, are enrolled in WL. After that, parcels are selected only if their environmental benefits per dollar under LR are higher than a threshold level, regardless of their effectiveness in providing environmental benefits under WL. The inefficiency as a result of pre-fixed funding is shown by points where the highlighted sections of the curves, for example, parcels from $N_{(n1)}$ to $N_{(n2)}$ and from $N_{(n3)}$ to $N_{(n4)}$, are not the higher of the two curves. Similarly, in Figure 4, all enrolled parcels would optimally be in WL. However, enrolled parcels after $N_{(n1)}$ are placed into LR.

2.2.2 Case B(ii): Sequential implementation of programs

Without loss of generality, suppose parcels are first selected for the LR program to maximize environmental benefits within the constraint of \bar{B}^{lr} . Then, a similar selection process is used for the WL program among the remaining parcels within the constraint of \bar{B}^{wl} . Mathematically, we have

the following two sequential problems. First,

$$\begin{aligned} & \max_{x_i} \quad \sum_i x_i q_i^{lr} \\ \text{s.t.} \quad & \sum_i x_i p_i^{lr} = \bar{B}^{lr}, \text{ and } 0 \leq x_i \leq \bar{x}_i, \end{aligned}$$

then, denoting the set of parcels chosen for the CRP as Ω^{lr} ,

$$\begin{aligned} & \max_{x_i} \quad \sum_{i \notin \Omega^{lr}} x_i q_i^{wl} \\ \text{s.t.} \quad & \sum_i x_i p_i^{wl} = \bar{B}^{wl}, \text{ and } 0 \leq x_i \leq \bar{x}_i. \end{aligned}$$

It is straightforward to see the solutions to the problems. Intuitively, at the first stage, sort parcels by $\frac{q_i^{lr}}{p_i^{lr}}$, then select parcels from the top until \bar{B}^{lr} is exhausted. At the second stage, sort the remaining parcels by $\frac{q_i^{wl}}{p_i^{wl}}$, then choose parcels from the top until \bar{B}^{wl} is exhausted.

Figures 5 and 6 illustrate the choice of parcels, when parcels are first selected for LR. Again, the optimal choices are the bold (red highlighted) portions of the curves. In both figures, given that some parcels (for example, parcels from $N_{(n1)}$ to $N_{(n2)}$) are first selected into LR, they are no longer available for WL. As a result, given two parcels j and k , with $\frac{q_j^{wl}}{p_j^{wl}} > \frac{q_k^{wl}}{p_k^{wl}}$ and $\frac{q_j^{wl}}{p_j^{wl}} > \frac{q_j^{lr}}{p_j^{lr}}$, parcel k may be chosen for WL, while parcel j is chosen for LR. For example, in Figure 5, comparing parcels ranked immediately after $N_{(n1)}$ and parcels ranked immediately after $N_{(n2)}$, the former has higher benefits per dollar under WL than the latter under WL. Moreover, the former also provides a higher benefit per dollar under WL than under LR. However, the former is not chosen for WL, while the latter is.

2.2.3 Inefficiency of fixed share budget allocations

There are two types of inefficiency arising from the fixed-share of funding between the programs: the sub-optimal choice of parcels and the sub-optimal choice of practices. In Case B(i), consider as an example the case where $\frac{q_i^{wl}}{p_i^{wl}} \geq \frac{q_i^{lr}}{p_i^{lr}}$ for all i . In Figure 4, suppose, in the optimal allocation, parcels ranked from $N_{(1)}$ to $N_{(n)}$ should be chosen for WL. With the fixed-share budget allocation and simultaneous implementation of the programs, however, parcels from $N_{(n2)}$ and $N_{(n)}$ are left out of the program and parcels from $N_{(n3)}$ to $N_{(n4)}$ and from $N_{(n5)}$ to $N_{(n6)}$ are inappropriately included in the program. In addition, parcels from $N_{(n1)}$ to $N_{(n2)}$ are selected for the wrong practice (LR instead of WL). Similarly, for Case B(ii) as illustrated in Figure 6, parcels ranked from $N_{(n3)}$ and $N_{(n)}$ are left out of the program and parcels from $N_{(n4)}$ to $N_{(n5)}$ and from $N_{(n6)}$ to $N_{(n7)}$ are inappropriately included in the program. The wrong practice is chosen for parcels from $N_{(n1)}$ to $N_{(n2)}$.

While both cases of B may result in an efficiency loss relative to Case A, it is not clear *a priori* which of the two is more inefficient because both are second-best programs. However, Case B(ii) is less efficient than B(i) in the following sense: in Case B(i), for a given practice, a parcel with higher $\frac{q^a}{p^a}$ will be chosen before a parcel with lower $\frac{q^a}{p^a}$, unless, for $a' \neq a$, the former is chosen for a' . However, this is not necessarily the case for Case B(ii). One final point of comparison can also be made between B(i) and B(ii): if the optimal budget shares are chosen, then simultaneous implementation of the programs (B(i)) will yield the optimal allocation. This is not the case for the sequential implementation (B(ii)). However, this does not necessarily mean

that sequential implementation is inferior to simultaneous implementation when the budget share is not optimal.

When the prices of WL and LR are the same and equal to one and all the parcels are of the same size, the area under each curve represents the total benefit potential from the corresponding practice.³ Again, we use Figures 4 and 6 as examples. In both cases, the lost benefit from omitted parcels and the use of the wrong practice on the selected parcels are shaded with a “-” sign and the benefit from inappropriately included parcels are shaded with a “+” sign. Thus the net loss in benefit is the difference between the two shaded areas. As previously discussed, whether Case B(i) or B(ii) will have larger loss of benefits is an empirical question: depending on the distribution of parcels in terms of benefit per dollar under each practice, the difference of the shaded areas in Figure 4 may be larger or smaller than that in Figure 6.

3 Study region, data, and empirical models

The empirical analysis is conducted for the state of Iowa, which had over 1.9 million acres enrolled in land retirement programs (primarily the CRP) in 2003 and the largest number of such contracts among all 50 states. Iowa also ranks first in total contract value; more than 11 percent of the national CRP rental payments go to acreage in the state totaling some \$192 million in 2003 (USDA-FSA).

As noted in the introduction, we focus our empirical application primar-

³When the prices are not equal to one or the parcels vary in size, then the shaded area has to be resized to accurately reflect the magnitude of benefits.

ily on carbon sequestration benefits of conservation programs because of the substantial interest drawn recently to carbon sequestration in agricultural soils both in the policy arena and in science and economics research. We also estimate soil erosion benefits because soil erosion has been a major environmental concern in agriculture for a long time. Iowa soils have been identified as a large potential source of carbon sequestration (Lal; Brenner et al.; Paustian et al.) and the state is part of the region where soil erosion is particularly high (CENR).

In modeling the conservation practice of land retirement, we assume establishment of grass cover on the land taken out of production. While other resource-conserving land covers are also possible, the grass covers have been by far the most commonly used on the land retired through CRP (see, e.g., USDA-FSA). Of the working land practices, we chose that of conservation tillage, the practice eligible for most of working land conservation programs. Furthermore, conservation tillage is a natural choice for our empirical analysis as it is known to provide significant soil erosion benefits and has the highest potential for storing carbon in the soils among all working land conservation practices (Lewandowski et al.).

The primary data source used in the analysis is the latest available National Resource Inventory (NRI) (USDA-NRCS, 1997). The NRI provides information on the natural resource characteristics of the land, cropping history, and farming practices used by producers on some 13,225 physical points in the study area. Since the data are statistically reliable for state and multi-county analysis of non-federal land (Nusser and Goebel), they are representative of the agricultural land in Iowa. The major unit of our anal-

ysis is an NRI point, which is treated as a producer with a farm size equal to the number of acres represented by the point, on average approximately 1,100 acres.

3.1 Empirical models of economic costs

To estimate the costs of adopting conservation tillage for every NRI point in the analysis, p_i^{wl} , $i=1, \dots, 13225$, we draw on the work of Kurkalova, Kling, and Zhao (2003a), which provides empirical estimates of a reduced form, discrete-choice adoption model for conservation tillage in Iowa. The underlying economic model begins with the standard assumption that a farmer will adopt conservation tillage when net returns from the practice exceed the returns from the alternative, conventional tillage practice, adjusting for differences in risk. Specifically, a farmer will choose conservation tillage when $\pi_1 > \pi_0 + P$, where π_1 is the net returns to farming using conservation tillage, π_0 is the net returns to conventional tillage, and P is a risk premium needed for adoption of conservation tillage, a practice that is generally believed to exhibit greater yield variability than conventional tillage methods.

Under the assumptions of a linear conservation tillage net returns function, $\pi_1 = \beta \mathbf{x}$, a premium function $P(\mathbf{z})$, a standard econometric error ε with a variance multiplier σ , and observable net returns to conventional tillage π_0 , the probability of adoption is estimated using standard discrete choice econometric methods on a sub-sample of 1992 NRI for Iowa as

$$\Pr[adopt] = \Pr[\pi_1 > \pi_0 + P + \sigma\varepsilon] = \Pr\left[\varepsilon \leq \frac{\beta\mathbf{x}}{\sigma} - \frac{\pi_0}{\sigma} - \frac{P(\mathbf{z})}{\sigma}\right]$$

where β is a vector of parameters and \mathbf{x} and \mathbf{z} are explanatory variables. Details on the variables, definitions of the data, and parameter estimates are provided in Kurkalova, Kling, and Zhao (2003a).

The re-estimation of this model on the 1997 NRI data is not possible as the tillage choice data are not available in the latest NRI. To circumvent this problem, we calibrate the model by introducing additive 1997 year shift parameters in the conservation tillage net returns function, and find the values of these additional parameters via equating the 1997 NRI-sample-predicted state-average conservation tillage adoption rate to that reported by the Conservation Technology Information Center (CTIC) for corn and soybeans separately. That is, the model used with the 1997 NRI has the form

$$\Pr[adopt] = \Pr \left[\varepsilon \leq \frac{\beta \mathbf{x} + \alpha_c \delta_c + \alpha_s \delta_s}{\sigma} - \frac{\pi_0}{\sigma} - \frac{P(\mathbf{z})}{\sigma} \right],$$

where the additional variables α_c and α_s are the 1997 year shift parameters and the δ_c (δ_s) is the indicator variable taking on the value of one if the NRI point is under corn (soybean) production and zero otherwise. This adjusted model is used to estimate the cost of adopting conservation tillage at every 1997 NRI point in the analysis. Then, the subsidy needed to induce new adoption is

$$p_i^{wl} = \max \left\{ \hat{P}_i + (\pi_{0i} - \hat{\pi}_{1i}), 0 \right\},$$

where the “hat” over a variable denotes the estimate, i.e.,

$$\hat{P}_i = \hat{P}(\mathbf{z}_i), \quad \hat{\pi}_{1i} = \hat{\beta} \mathbf{x}_i + \hat{\alpha}_c \delta_{ci} + \hat{\alpha}_s \delta_{si}.$$

To estimate the cost of land retirement at each point, p_i^{lr} , $i=1, \dots, 13225$, we follow the approach of Smith, who measured the opportunity cost of land

retirement via the cropland cash rental rate.⁴ The Iowa State University Extension Service provided county-level data on cropland cash rental rates for low-, average-, and high-quality land together with the percentages of total county cropland in these three categories (ISU Extension). Under the assumption that the cropland cash rental rate is a monotonic function of corn yield potential, we estimated piece-wise linear functions that relate the yield potential to the cash rental rate and used the functions to estimate the cash rental rate of every NRI point in the study. The functions were estimated separately for each of the 99 Iowa counties to account for possible rent differences that may exist due to land uses alternative to agriculture. The details of the rental rate function estimation are provided in the Appendix.

3.2 Empirical model of environmental benefits

The environmental benefits, carbon sequestered and soil erosion reduction are estimated at each of the NRI data points using the Environmental Policy Integrated Climate (EPIC) model version 3060 (Izaurrealde et al.).⁵ EPIC has been extensively tested and validated for predicting environmental bene-

⁴Babcock et al. (1996, 1997) used the observed CRP rental rate in their analysis of contract renewals. This approach is not suitable for our purposes since the observed CRP rental rate data would not be representative of costs for land not currently enrolled. Since generally the CRP land is of lower quality than the land not in the program, this truncation would likely result in underestimating the average opportunity cost of land retirement. An alternative approach was employed by Khanna et al., who directly estimated the net returns to keeping land in production. Our information is not detailed enough to follow this approach.

⁵Earlier versions of EPIC were called Erosion Productivity Impact Calculator (Williams).

fits under a wide range of conditions, including data collected in Iowa (King, Richardson, and Williams; Chung et al. 1999, 2002). 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. At each of the data points, three 30-year simulations were run: the first assuming conventional tillage, the second assuming conservation tillage, and the third assuming LR with a grass cover. The NRI database provides baseline soil, landscape, crop rotation, and other input data for the simulations.

Conservation tillage is defined as any tillage system that leaves at least 30 percent of the surface covered with crop residue and thus can be implemented in a variety of ways. Since the specific information on tillage and other farming practices is not provided in the NRI database, we use the information provided by a statistically designed survey of farms in the area, the Cropping Practices Survey (USDA). For every surveyed farm, we constructed detailed records of tillage and fertilizer practices, specifically noting the number and timing of tillage operations and tillage implements used and the number, timing, and mode of fertilizer applications together with the quantities of the nutrients applied. These records formed a representation of the distribution of farming practices in the study area, separated by the two tillage categories, conventional and conservation. For every NRI point, we randomly assigned a practice from the distributions depending on whether the point is assumed to be in conventional or conservation tillage. In this setting, modeling a switch of the farm from conventional to conservation tillage results in a replacement of the earlier assigned practice with the one

randomly drawn from the other distribution.

3.3 Environmental benefit accounting and payment

The estimated environmental benefit of a conservation program varies with the choice of baseline. Two possible baselines are potentially interesting: one that counts benefits in excess of conventional agricultural practices on all lands, and one that counts the benefits only relative to the actual practice in place before a program is implemented. Two accounting schemes are studied to reflect these two baselines. In the first, the environmental benefits are measured against the environmental condition that would occur under conventional tillage. That is, the benefits, which we refer to as total benefits, are computed as the differences between the appropriate EPIC outputs under LR (or conservation tillage) and conventional tillage (regardless of whether the parcel was already under conservation tillage).

In the second accounting method, benefits are measured against the current state of the world which includes some adoption of conservation practices. In other words, the benefits, which we refer to as new benefits, are computed as the differences between the appropriate EPIC outputs under LR (or conservation tillage) and the 1997 tillage predicted from the tillage adoption model in the absence of any subsidies.

A second feature of a conservation program that will affect its cost effectiveness is whether current adopters are eligible for payment or whether only those induced to adopt by the presence of the program receive payment. In our study, we present results on two combinations of benefit accounting and payments: (1) the “new benefit” scheme under which only new benefits and

new adopters are eligible for payments; and (2) the “total benefit” scheme under which total benefits and all adopters are eligible for payments.⁶

Table 1 provides summary statistics for the simulation data.

4 Results

We begin with the “new benefit” scheme as we consider this the most interesting and relevant in terms of social efficiency. As discussed later, the results of the “total benefit” scheme are qualitatively quite similar. First, we present estimates of the new-carbon marginal cost curves under three alternative assumptions about availability of conservation programs: 1) only the LR program is available, 2) only a WL program is available, or 3) both LR and WL programs are available and policymakers are free to offer them without a pre-fixed budget split between the programs. As can be seen from Figure 7 summarizing the supply curves, the LR program is the more expensive option for sequestering carbon over most of the range of benefits. However, since per-acre LR program benefits are generally higher than those for the WL program, the maximum carbon benefit obtainable with the LR program alone is much higher than what can be obtained from a WL program alone.

When both programs are available, the marginal cost curve follows the WL supply curve at the lower levels of carbon benefits, which is the consequence of the WL being the less expensive option at these benefit levels.

⁶Both schemes are interesting and relevant for policymakers as some argue that it would be unfair and impractical not to pay current adopters. Further, without payment current adopters might reverse their adoption in order to be considered new adopters.

However, at the higher levels of benefits, between 2.7 million and 4.5 million metric tons (MT) of new carbon, the combined policy marginal cost curve is lower than the two single-practice marginal cost curves. At the benefit levels above 4.5 million MT of carbon, the combined program's marginal cost exceeds that of the LR program only. This is because some of the parcels that could have provided higher benefits in the LR program have been already enrolled in the WL program. Notwithstanding the fact that the marginal costs are higher for the combined program at high output levels, the total costs are lower. For example, at around 5 million MT of carbon the marginal costs are \$386/MT vs. \$324/MT for the combined and LR programs, respectively, but the associated total costs are \$601 million vs. \$868 million.

The effects of a pre-fixed budget split on the amounts of new carbon benefits obtainable are investigated at the funding level of \$100 million a year, which constitutes about a 50 percent increase from the current conservation program funding received in Iowa. As can be seen from Table 2, the optimal allocation of this funding between WL and LR programs would mean 99.6 percent of the budget spent for the WL program. However, if the WL budget share is fixed at approximately 10 percent, which is the current national percentage of working land conservation programs in the USDA conservation programs, (Claassen, 2003), the amount of carbon obtainable is much lower, around 1.9 vs. 2.8 million MT/year under the combined program. Interestingly, this amount depends very little on whether the simultaneous or sequential program implementation is followed. As the WL budget share increases to the 50 percent projected nationally by 2007 (Claassen, 2003),

the amount of carbon obtainable increases to 2.5 million MT/year. Figure 8 depicts the carbon benefits obtainable with the pre-fixed budget split as the proportions of the maximum carbon obtainable under the combined policy with no pre-fixed budget split for various WL budget shares.⁷ As the WL budget share increases towards the optimal share of 99.6 percent, the proportion increases towards one.

With the “total carbon” scheme, the location of the three marginal cost curves relative to each other is qualitatively similar to the “new carbon” scheme. Figure 9 provides the curves for the total carbon benefits, i.e. measured relative to the case of conventional tillage. We assume that policymakers are paying a minimum of \$10/acre for new and current adoption of conservation tillage. The two schemes also show similar qualitative results in Figure 8.

When erosion is used as an environmental indicator, we obtain results similar to those for carbon sequestration. Thus, we present just an example. Figure 10 provides the marginal cost curves for the total erosion benefits under the same minimum payment arrangement as that for carbon sequestration in Figure 9. This similarity of the two environmental indicators is probably due to the positive correlation of the two indicators. Without this positive correlation, the results may differ.

⁷The curve is drawn for the simultaneous allocation; the curve for the sequential allocation is similar and not presented.

5 Conclusions and additional discussion

In this paper, we develop a formal framework for assessing the tradeoffs between two conservation programs that compete for the same parcels of land: the complete retirement of land from production (as done for almost 20 years in the CRP) versus a change in farming practices on working land (as proposed in the latest farm bill). We study the efficiency properties of alternative approaches to implementing these two competing policies including a combined policy with no pre-fixed budget allocation, and two pre-fixed budget allocation scenarios where parcels are chosen into the conservation programs either sequentially or simultaneously.

We empirically apply the theoretical framework for the case of conservation tillage on working land relative to land retirement when the environmental benefit of concern is carbon sequestration in agricultural soils. We found that WL is more cost-effective relative to conservation through LR in our study area over most of the range of the potential carbon sequestration levels. Only at very high levels of carbon sequestration would it be cost effective to have enrolled land into an LR program instead of a WL program. Of particular note in our empirical results is the magnitude of the efficiency losses due to the pre-fixing of conservation budgets, regardless of whether a simultaneous or sequential implementation strategy is followed.

It is important to recognize that the qualitative empirical results found here may not hold for other regions of the country, as the cost of retiring agricultural land in Iowa is one of the highest in the nation (USDA-FSA) and the carbon sequestration potential of land retirement may be higher in

other parts of the country (Paustian et al.). Further, conclusions regarding the superior cost-effectiveness of WL may easily be reversed for other environmental benefits, although for soil erosion in this study region there were no significant qualitative differences in the conclusions.

Numerous aspects of the work undertaken here deserve additional consideration. Extension of the analysis to multiple environmental benefits would be valuable, as would the extension to multiple conservation programs with pre-fixed budget allocations.

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Table 1. Summary statistics for simulation data

Variable	<i>Land Retirement</i>			<i>Working Land Conservation</i>		
	Min [*]	Average	Max [*]	Min [*]	Average	Max [*]
Cost, \$/acre	77.89	120.32	153.05	0.42	7.06	27.89
New carbon, tons/acre	0.04	0.31	0.65	0.03	0.16	0.34
Total carbon, tons/acre	0.21	0.53	0.91	0.30	0.39	0.55
Total erosion reduction, tons/acre	1.36	2.84	5.06	1.32	2.74	4.85

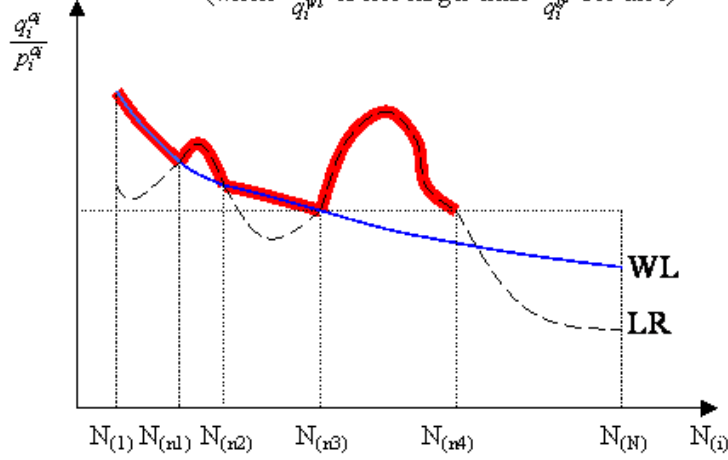
*Min of county averages, and Max of county averages.

Table 2. New carbon benefits and average costs under alternative budget allocations for a \$100 million/year budget

Budget allocation	Carbon Million MT/year	Average cost \$/MT/year
Optimal, 99.6% to WL	2.8	35.6
Simultaneous, 10% to WL	1.9	53.7
Sequential, 10% to WL	1.8	54.7
Simultaneous, 50% to WL	2.5	39.7
Sequential, 50% to WL	2.5	39.8

**Figure 1. Parcels and practices selected
—optimal share of funding**

(when $\frac{p_i^{wl}}{q_i^{wl}}$ is not larger than $\frac{p_i^{lr}}{q_i^{lr}}$ for all i)



$N_{(i)}$: the i^{th} ranking parcel when parcels are sorted by $\frac{q_i^{wl}}{p_i^{wl}}$.

**Figure 2. Parcels and practices selected
—optimal share of funding**

(when $\frac{p_i^{wl}}{q_i^{wl}}$ is larger than $\frac{p_i^{lr}}{q_i^{lr}}$ for all i)

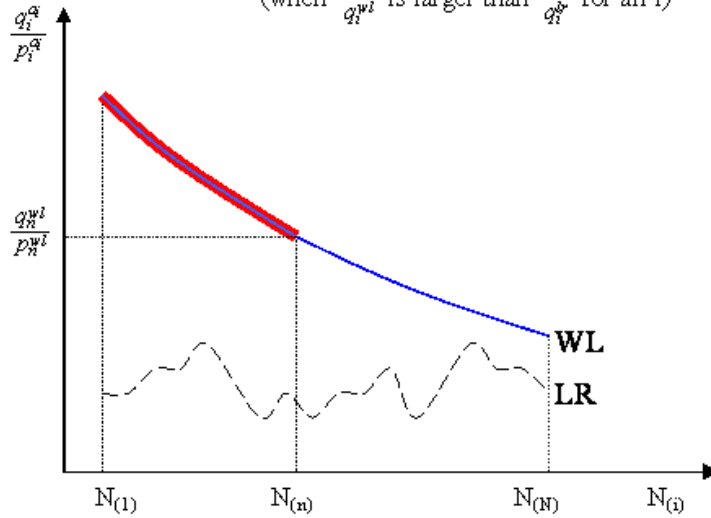


Figure 3. Parcels and practices selected
—fixed share of funding, simultaneous implementation

(when $\frac{P_1^{wl}}{q_1^{wl}}$ is not larger than $\frac{P_1^k}{q_1^k}$ for all i)

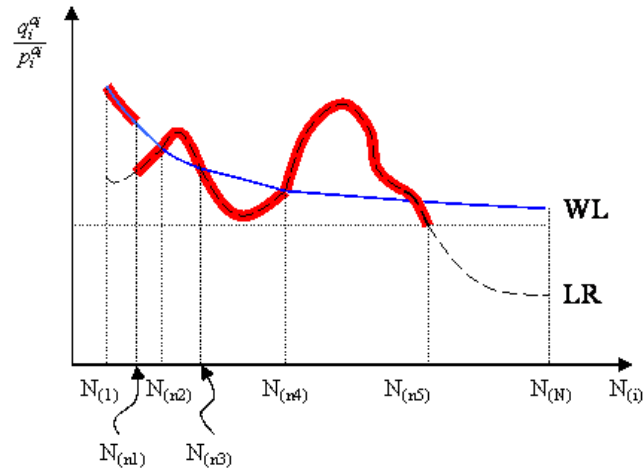


Figure 4. Parcels and practices selected
—fixed share of funding, simultaneous implementation

(when $\frac{P_1^{wl}}{q_1^{wl}}$ is larger than $\frac{P_1^k}{q_1^k}$ for all i)

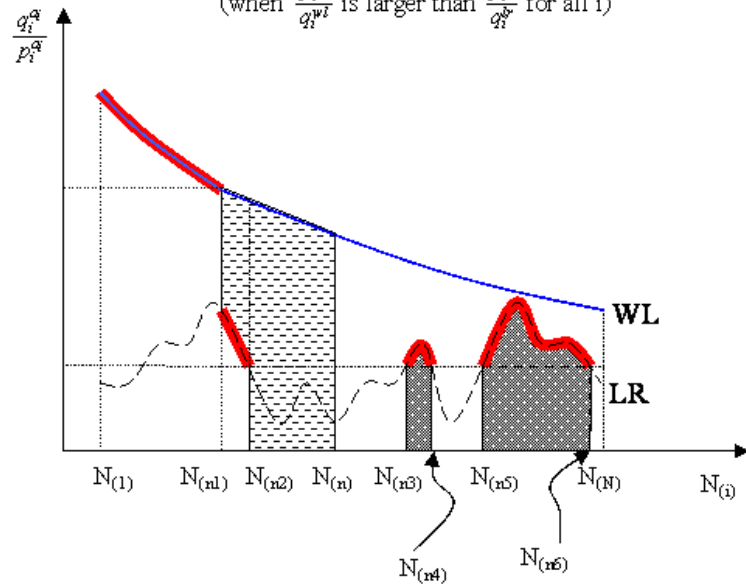


Figure 5. Parcels and practices selected
—fixed share of funding, LR first implemented

(when $\frac{p_i^{wl}}{q_i^{wl}}$ is not larger than $\frac{p_i^k}{q_i^k}$ for all i)

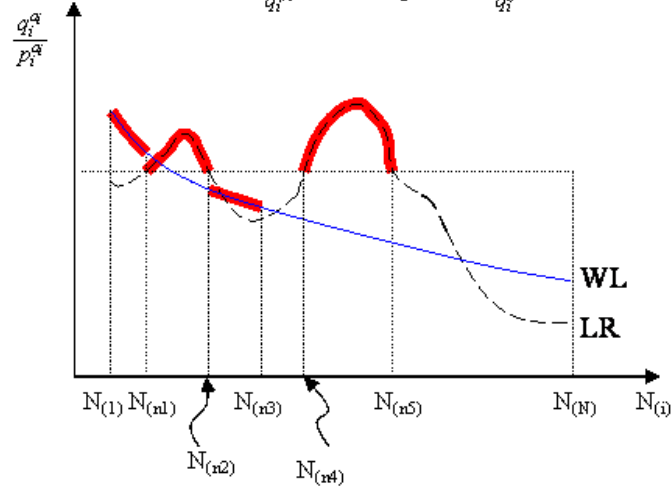


Figure 6. Parcels and practices selected
—fixed share of funding, LR first implemented

(when $\frac{p_i^{wl}}{q_i^{wl}}$ is larger than $\frac{p_i^k}{q_i^k}$ for all i)

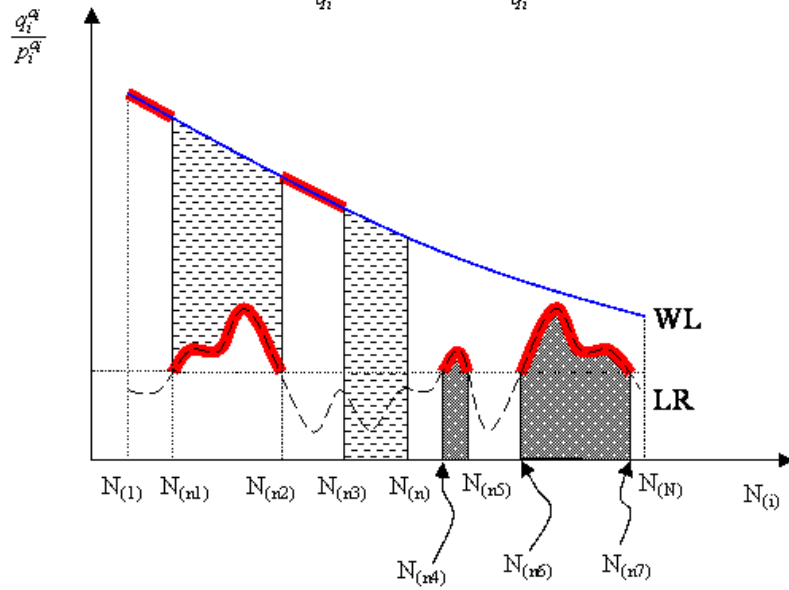


Figure 7. New carbon marginal cost curves under alternative conservation programs

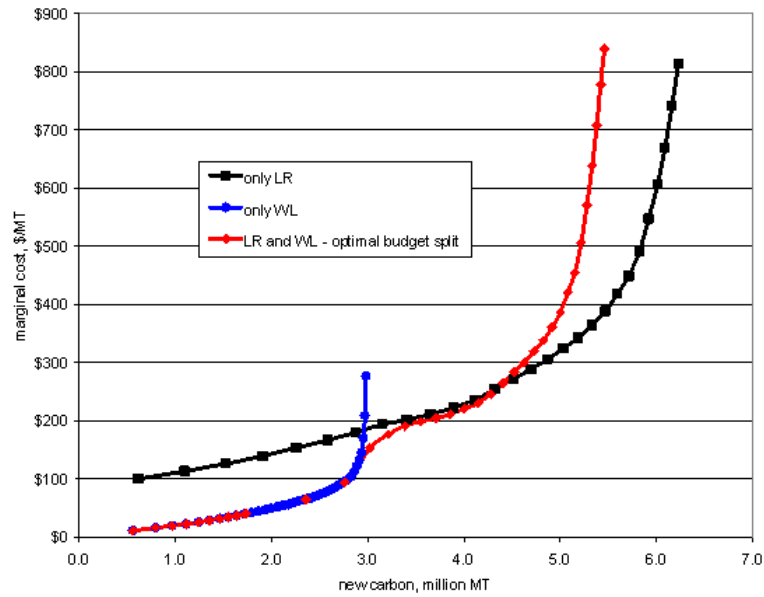


Figure 8. Relative efficiency of fixed-share budget allocation (\$100 million total budget)

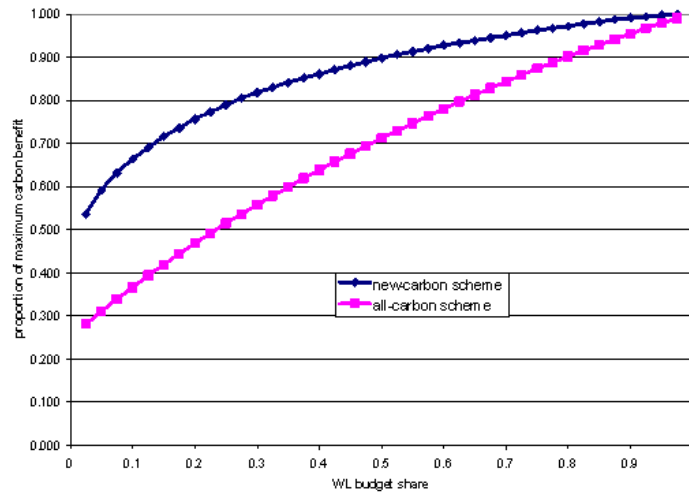


Figure 9. Total carbon marginal cost curves under alternative conservation programs

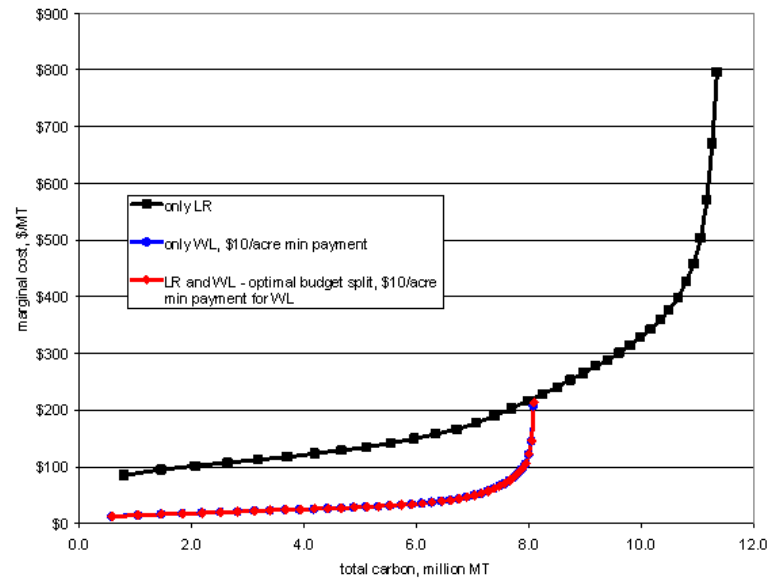
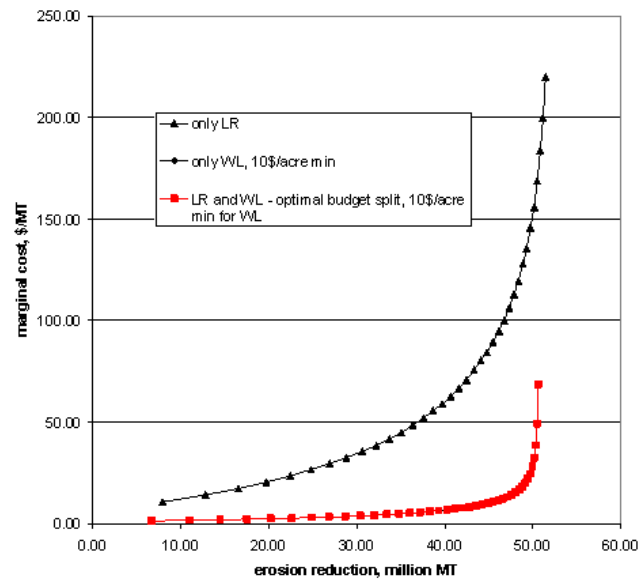


Figure 10. Total erosion reduction marginal cost curves under alternative conservation programs



* Note: in Figures 9 and 10, the "Only WL" and "LR and WL" curves are nearly identical

Appendix

The rental rate function expresses the cash rental rate as the function of the corn yield potential of the land parcel. To estimate the corn yield potential of each NRI point, we used EPIC to simulate 30 years of corn-soybean rotation under normal weather conditions. The 15-year average of the predicted corn yield was used as the measure of the corn yield potential of the point. Next, all the points in the county were rank-ordered from the lowest to the highest by the corn yield potential and assigned to the low-, medium-, and high-quality class based on the percentages of the total county cropland in these three categories (Figure A1). The midpoints of the classes were assigned the corresponding cash rental rates reported in ISU Extension, r_{low} , r_{med} , and r_{high} , respectively. The endpoints of the yield distribution in the county, x_{min} and x_{max} , were assigned the rental rate values 20 percent lower than the low-quality land rental rate and 20 percent higher than the high-quality land rental rate, respectively. The resulting 5 points (3 midpoints of the corresponding classes and 2 endpoints) were connected by linear pieces to form the piece-wise linear cash rental rate function. Since by construction the corn yield potential of any point in the county falls between x_{min} and x_{max} , the resulting function allows estimation of the cash rental rate for any point in the county.

Figure A1. Construction of rental rate function

