Integrating Farmer Decision Making to Target Land Retirement Programs

Wanhong Yang and Murat Isik

This study develops a model to examine the impacts of uncertainty about crop production and irreversibility of program participation on determining land rental payments and least-cost land retirement targeting in the Conservation Reserve Enhancement Program (CREP). Results show that under risk aversion only, the marginal cost of abatement and the average land rental payment are less than those under risk neutrality. However, under uncertainty and irreversibility, the marginal cost of abatement and the average land rental payment are considerably higher than those under risk neutrality or risk aversion only. It is important to incorporate uncertainty and irreversibility into the design of land rental payments and in determining participation constraints.

Key Words: Conservation Reserve Enhancement Program, irreversible decision, land retirement, rental payments, targeting, uncertainty

Since 1990, the Conservation Reserve Program (CRP) has been gradually moving toward a multifaceted environmental improvement program through the introduction of an environmental benefit index (EBI)[1] [U.S. Department of Agriculture/ Farm Service Agency (USDA/FSA), 1997]. With a bidding system, the CRP targets the retirement of cropland that exhibits high environmental benefits relative to economic costs (Feather, Hellerstein, and Hansen, 1999). In addition, the continuous CRP and the Conservation Reserve Enhancement Program (CREP) have been established to encourage land retirement for specific conservation practices such as filter strips and riparian buffers, and in areas of environmental significance.[2] The continuous CRP and the CREP accept submitted contracts as long as the contracts address important conservation needs such as proposing conservation practices on the land to be retired or locating in the program definition area. Furthermore, ample program payments, including annual rental payments and additional incentive payments, are provided to encourage program participation (Smith, 2000). As a result, program payments in the continuous CRP and the CREP are considerably higher than the local soil rental rates. For example, the average Illinois CREP payment from 1998 to 2002 was $158 per acre, in contrast to the average soil rental rate of $108 per acre in the CREP program area [USDA/FSA, 2003; Illinois Department of Natural Resources (IDNR), 1999]. While this pattern can be explained by additional incentives for promoting conservation practices contributing more environmental benefits in the continuous CRP and the CREP, a critical policy question remains: Are the considerably higher program payments economically justifiable?

Theoretically, rental payments in the land retirement programs should be designed to compensate the losses of farmers' expected returns from crop production on the land to be retired. However, the determination of land rental payments required for participation is complicated for several reasons. First, farmers make their participation decisions under uncertainty about cropping returns due to fluctuations of crop yields and output prices.

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[1] The EBI is composed of six environmental factors: wildlife, water quality, erosion, enduring benefits, air quality, and state or national conservation priority area.

[2] The continuous CRP is different from the general CRP and provides producers the opportunity to enroll acreage in specific conservation practices and areas year-round. The CREP is a joint federal-state program to address environmental problems of state significance. Enrollment is usually conducted under the continuous CRP with incentives from both federal and state governments.

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Second, participation in land retirement programs requires farmers to enter into 10- to 15-year binding contracts with the USDA. Program participants are allowed to terminate their contracts before the expiration date only if they reimburse all government payments received—including rental payments, cost-share payments, and incentive payments, plus interest and a liquidating cost calculated as 25% of the annual rental payments times the number of acres being terminated[3] (Scott, 2003). Furthermore, farmers who exit the program will lose their investments on establishing conservation covers and must bear additional costs for converting conservation covers into cropland.

From an economic perspective, participation in land retirement programs involves an irreversible decision because such a decision is very costly to reverse (Dixit and Pindyck, 1994). Hence, the land rental payments required for participation depend on how farmers make their participation decisions. Understanding the role of uncertainty and irreversibility in determining land rental payments, and consequently in targeting of a least-cost land retirement program, is an important policy question that needs to be addressed.

The purpose of this study is to develop a model for examining the impacts of alternative farmer decision making on determining land rental payments and least-cost land retirement targeting in conservation programs. By taking into account uncertainty about crop production and irreversibility of program participation, the model analyzes the implications of designing appropriate land rental payment schemes that compensate farmers' losses of expected returns from crop production on the land to be retired. The model is empirically applied to an agricultural watershed in the Illinois CREP region, and relevant policy implications are discussed.

From a social planner's perspective, the typical decision problem in land retirement programs is to select a small set of land to be retired from a large set of eligible land in order to achieve specified environmental objectives while minimizing program payments. In addressing this decision problem, a number of studies have proposed a targeting approach for improving the cost-effectiveness of such programs. It has been shown that the CRP benefits could be improved through better targeting based on off-site benefits (Ribaudo, 1986, 1989; Heimlich and Osborn, 1993) or benefit-to-cost criteria (Babcock et al., 1996, 1997). While these studies examined CRP targeting at the regional or national level, Khanna et al. (2003) developed a watershed-level land retirement targeting scheme to identify land parcels for retirement for achieving water quality objectives at least costs. However, the costs of land retirement in these studies are typically represented by foregone cropping returns which are estimated based on crop yields, output prices, and production costs. In particular, when assessing the cost-effectiveness of land retirement programs, none of these studies examined how farmers make their participation decisions.

Appropriate assessment of the cost-effectiveness of land retirement programs requires incorporating farmer decision making into the social planner's land retirement targeting. Several studies have examined the impacts of farmers' risk attitudes on the required land rental rates for program participation. Hope and Lingard (1990) concluded that increases in the degree of risk aversion would make land retirement more attractive to farmers for the set-aside program in the United Kingdom. This finding implies lower program premiums would be acceptable for high risk-averse farmers. Consistently, several other studies also found that in the set-aside program, additional incentives could generate more land retirement for high risk-averse farmers (Fraser, 1991; Roberts, Froud, and Fraser, 1996). However, risk aversion would not justify why the land rental payments in the continuous CRP or the CREP are considerably higher than the soil rental rates.

Considering uncertainty about crop production and irreversibility of program participation is important in analyzing the required land rental payments and the cost-effectiveness of land retirement programs because farmers' participation in the programs is similar to the technology adoption decision under uncertainty. Studies on investment under uncertainty show that decision makers could delay their investment decisions to learn more about the value of technology or economic conditions before making irreversible decisions (Dixit and Pindyck, 1994). A number of studies have recently applied the theory of irreversible investment in analyzing the adoption of agricultural technologies (e.g., Purvis et al., 1995; Isik, Khanna, and Winter-Nelson, 2001; Carey and Zilberman, 2002).

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[3] The Federal Agriculture Improvement and Reform (FAIR) Act of 1996 allowed participants with contracts signed before 1995 to withdraw from the CRP without penalty. However, certain environmentally sensitive CRP acres were ineligible for early termination. The purpose was to release those CRP acres that contributed less environmental benefits through the sign-ups with soil erosion criteria.

In this investigation, we extend the application of the theory of irreversible investment to examine the implications of farmer decision making for participation in land retirement programs under uncertainty. A framework is developed for assessing the impacts of uncertainty about crop production and irreversibility of program participation on determining land rental payments and least-cost land retirement targeting. The theoretical framework is laid out in the next section, followed by a description of the empirical applications and data. The results of the empirical applications are then presented. The paper ends with our conclusions and a discussion of policy implications.

The Theoretical Model

The model is based on the social planner's decision problem in targeting least-cost land retirement in an agricultural watershed. Land parcels are identified to achieve an off-site pollution abatement goal while minimizing program costs in terms of land rental payments to farmers. Assume a watershed has N eligible land parcels, and each parcel is of size X_i acres, where $i = 1, ..., N$. All other land parcels in the watershed are assumed to be unchanged in the land retirement program. For simplicity, we consider only off-site sediment abatement as the environmental benefit achieved by land retirement. The off-site sediment abatement refers to the reduction of sediment delivered from fields to the nearest waterway in agricultural watersheds.

The off-site sediment abatement per acre due to the proportion of land parcel i taken out of crop production is denoted by $S(C_i, O_i)$, where C_i indicates land characteristics which include land use, land quality, distance to the water body, and other attributes, and O_i indicates the impacts of off-site sediment generation from other land parcels in the same surface runoff channel. The off-site sediment abatement is defined as the difference in off-site sediment loading between when the land parcel is in crop production and when it is in the land retirement program. The off-site sediment abatement due to retiring of a land parcel depends not only on the soil characteristics and land use of that parcel, but also on the volume of runoff flowing in from upslope parcels; this volume in turn depends on land use decisions and site-specific characteristics of upslope parcels (Khanna et al., 2003).

The social planner needs to compensate farmers' losses due to the retirement of agricultural land from crop productions. Let $R(C_i \mid \eta)$ be the minimum necessary per acre land rental payment to be provided to farmers for compensating their losses of expected returns on land parcel i from land retirement, depending on their decision-making criteria (η). Alternative farmer decision-making criteria that determine participation constraints in the program are discussed below, along with their implications for designing incentive mechanisms to induce farmer participation in the land retirement program.

The Social Planner's Decision Problem

The social planner's problem is to identify land parcels to be retired to achieve a given level of sediment abatement ($\bar{A}$) in an agricultural watershed while minimizing the total cost of the program in terms of land rental payments.[4] Let θ_i be the proportion of land parcel i to be retired.[5] The model is represented as follows:

$$(1) \quad \min_{\theta_i} \sum_{i=1}^{N} \theta_i X_i R(C_i \mid \eta)$$

subject to:

$$(2) \quad \sum_{i=1}^{N} \theta_i X_i S(C_i, O_i) \geq \bar{A},$$

$$(3) \quad 0 \leq \theta_i \leq 1, \quad \forall i.$$

The Lagrangian of the optimization model can be written as:

$$(4) \quad L = \sum_{i=1}^{N} \theta_i X_i R(C_i \mid \eta) + \lambda \left\{ \bar{A} - \sum_{i=1}^{N} \theta_i X_i S(C_i, O_i) \right\} + \sum_{i=1}^{N} \mu_i (\theta_i - 1),$$

where λ and μ_i are the Lagrange multipliers associated with (2) and (3), respectively ($\lambda \geq 0$). The first-order conditions are as follows:

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[4] The social planner's problem could also be formulated as the maximization of environmental benefits subject to a budget constraint. However, the budget constraint is typically set at the national, state, or regional level. In a specific watershed, the budget constraint is unknown because program funds are not further allocated at the watershed level. Therefore, we model the social planner's problem as minimizing program costs subject to the environmental objectives set by the programs.

[5] It is possible to assume that θ_i is a binary decision variable, taking the value of one if a parcel participates and zero if it does not. Since it is theoretically possible to enroll some proportions of a parcel to the program, θ_i is not restricted to be one or zero in the theoretical model.

$$(5)\quad \frac{\mathrm{M}L}{\mathrm{M}\theta_i}\ '\ X_iR(C_i{*}\eta)\ \&\ \lambda X_iS(C_i, O_i)\ \%\ \mu_i\ \$\ 0,$$

$$\text{and}\quad \frac{\mathrm{M}L}{\mathrm{M}\theta_i}\theta_i\ '\ 0,\quad œ\, i.$$

After rearrangement, (5) can be written as:

$$(6)\quad \lambda X_iS(C_i, O_i)\ \&\ X_iR(C_i{*}\eta)\ \#\ \mu_i,\quad œ\, i.$$

On the left-hand side of equation (6), the marginal cost of sediment abatement λ, multiplied by sediment abatement $X_iS(C_i, O_i)$ from the retirement of land parcel i, represents the social benefits of land retirement. The term $X_iR(C_i \mid \eta)$ could be considered as the costs of the retirement of land parcel i to the government. The difference between the two, μ_i, indicates the net social benefits provided by land parcel i if retired. Because the marginal cost λ is a constant at a given sediment abatement constraint, equation (6) also implies that a land parcel with a higher benefit-to-cost ratio, $S(C_i, O_i)/R(C_i \mid \eta)$, would be selected for land retirement.

An important issue in solving the above social planner's problem is to identify an incentive mechanism which induces farmer participation in the land retirement program. Most previous studies consider $R(C_i \mid \eta)$ as the opportunity cost of crop production or losses of cropping returns on the land parcel to be retired. However, land rental payments required for participation in the program, $R(C_i \mid \eta)$, could also depend on how farmers make their participation decisions in the land retirement program and their risk preferences. Thus, solving the decision problem in (1)–(3) requires incorporating farmer decision making into the model, which determines participation constraints. In other words, the social planner must establish the appropriate value of $R(C_i \mid \eta)$ that will make farmers indifferent between participating in the land retirement program and continuing their risky farming operations.

We now incorporate alternative farmer decision making (represented by η) into (1) and analyze implications of those decision-making scenarios for the marginal cost of sediment abatement. The expected returns from the land currently in crop production depend on various factors such as land characteristics and how farmers make their participation decisions. Given uncertainty about crop production and irreversibility of program participation, $R(C_i \mid \eta)$ would depend not only on the opportunity costs of crop production, but also on the farmer's decision-making criteria (η). If the farmer is risk neutral, $R(C_i \mid \eta)$ is the expected returns from crop production on the land parcel to be retired, i.e., $R(C_i \mid \eta) = ER(C_i)$.

If the farmer were risk averse, he or she would reduce the variability of returns by participating in the land retirement program and would require less for land retirement. To determine the minimum rental payments required for participation, it is assumed for simplicity that the utility function is represented by a negative exponential function, $U =\ !\, e^{!\phi R}$, where ϕ is the absolute risk-aversion coefficient. With a negative exponential utility function and normally distributed $R(C_i)$, the certainty equivalent of expected returns under risk aversion for X_i acres of land is represented by

$$\theta_iX_iER(C_i)\ \&\ \frac{\phi\theta_i^2X_i^2}{2}\operatorname{Var}(R),$$

where $\operatorname{Var}(R)$ is the variance of the returns and

$$\frac{\phi\theta_i^2X_i^2}{2}\operatorname{Var}(R)$$

is the risk premium. Thus, under risk aversion, $\theta_iX_iR(C_i \mid \eta)$ will be replaced by

$$\theta_iX_iER(C_i)\ \&\ \frac{\phi\theta_i^2X_i^2}{2}\operatorname{Var}(R)$$

in solving the social planner's decision problem given in (1).[6]

When the irreversibility of program participation is taken into account, farmers would require the rental payment to be at least $\Gamma ER(C_i)$ to compensate their losses of cropping returns for participation in the land retirement program, where $\Gamma > 1$ is the option value multiplier (see the appendix for further details). The extent to which uncertainty and irreversibility affect the farmer participation depends on the value of Γ (Dixit and Pindyck, 1994). Thus, uncertainty and irreversibility cause farmers to be compensated at least $\Gamma ER(C_i)$ in order to participate in the land retirement program, and therefore $R(C_i \mid \eta) = \Gamma ER(C_i)$ in (1).

Marginal Cost of Sediment Abatement Under Alternative Models

Under risk neutrality only, the condition for least-cost land retirement is given by $\lambda X_iS(C_i, O_i)\ !\ \mu_i\ \#\ X_iER(C_i)$. The marginal cost of sediment abatement

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[6] Note that these results are conditional on the assumption of a negative exponential utility function and normally distributed $R(C_i)$.

under risk neutrality is denoted as λ^{RN}. Under risk aversion only, the condition for least-cost land retirement is represented by

$$\lambda X_i S(C_i, O_i) \,\&\, \mu_i$$
$$\# \left[X_i ER(C_i) \,\&\, \phi\theta_i X_i^2 \mathrm{Var}(R) \right].$$

The marginal cost of sediment abatement under risk aversion is defined as λ^{RA}. Because $\mathrm{Var}(R) > 0$, then $\lambda^{RN} > \lambda^{RA}$. Under uncertainty and irreversibility, the condition for the least-cost land retirement is given by $\lambda X_i S(C_i, O_i) \; ! \; \mu_i \,\#\, \Gamma X_i ER(C_i)$. The marginal cost of sediment abatement under uncertainty and irreversibility is denoted as λ^{IR}. Because $\Gamma > 1$, then $\lambda^{IR} > \lambda^{RN} > \lambda^{RA}$.

Based on these results, when only risk aversion is considered in land retirement programs, the marginal cost of sediment abatement is less than that under risk neutrality, and this would lead to lower program costs in terms of land rental payments. However, when irreversibility of program participation is considered, the marginal cost of abatement is higher than that under risk neutrality or risk aversion only.

In addition to the marginal cost of abatement, solving the above model empirically would generate total costs of the program and the least-cost land retirement patterns. It is reasonable to expect that eligible land parcels in an agricultural watershed are heterogeneous. How land heterogeneity, in conjunction with uncertainty and irreversibility, impacts on determining the changes in the magnitude of land rental payments and the least-cost land retirement pattern is an empirical question to be examined further.

Empirical Applications and Data

We develop an empirical model to apply the above theoretical model to the Otter Creek Watershed in Fulton County, situated in the Illinois Conservation Reserve Enhancement Program (CREP) region. The Illinois CREP is a supplementary program of the CRP for improving water quality in the Illinois River Basin. With a budget of about \$500 million, the program aims at retiring 232,000 acres of cropland for 15 to 30 years in order to achieve environmental objectives such as reducing sediment loading by 20% and nitrate loading by 10% in the Illinois River and its tributaries. To accomplish these goals, the Illinois CREP limits enrollment primarily to a narrow buffer zone adjacent to rivers and streams, 85% of which are to be selected from riparian areas (defined as the 100-year floodplains of the Illinois River and its tributaries, streams, and wetlands). The remaining 15% could be selected from highly erodible cropland adjacent to enrolled riparian areas (Khanna et al., 2003).

The Otter Creek Watershed is comprised of 68,314 acres of land, of which 47% is cropland, 25% is grassland, 25% is woodland, and the remaining 3% is urban, water, and miscellaneous land. The watershed is also relatively flat, with 71% of the land having less than 5% slope. We partitioned the watershed into 300-by-300 foot parcels (2.07 acres per parcel), resulting in about 33,000 parcels for the entire watershed. This parcel size is consistent with actual CREP enrollment contracts in the study area, where the size of the smallest land parcels enrolled in the program is about two acres. Because the Illinois CREP is essentially a buffer program in which cropland on floodplains or adjacent sloping land is eligible, we define cropland within a 900-foot buffer of water bodies as eligible land in the empirical model—which is consistent with the definition established under CREP. This leads to 4,691 eligible land parcels or 9,710 acres, representing 30% of the total cropland in the watershed.

The on-site erosion and off-site sediment generated by eligible land parcels are estimated with the Agricultural Nonpoint Source Pollution (AGNPS) model, a hydrologic model widely applied to simulate movements of sediment and nutrients in agricultural watersheds. The AGNPS model requires five parameters at the watershed level and 23 parameters at the parcel level[7] (Young et al., 1994; Young, Onstad, and Bosch, 1995). In this study, the model incorporates a typical five-year storm event with 3.73 inches of rainfall within 12 hours, based on rainfall data from Huff and Angel (1989). Remote sensing data (IDNR, 1996) are used to identify land use in each land parcel. Elevation data (U.S. Geological Survey, 1997) are used to create flow paths or channels that direct runoff from upland parcels to the nearest water body. Soil erodibility factor, texture, and hydrologic soil group are derived from

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[7] The five parameters at the watershed level are watershed name, cell area, total number of cells, precipitation, and rainfall energy-intensity value. The 23 parameters at the parcel level are cell number, flow direction, receiving cell number, channel indicator, runoff curve number, slope, slope length, slope shape, channel slope gradient, channel side slope, Manning's roughness coefficient, soil texture, soil erodibility, cropping management factor, conservation practice factor, surface condition coefficient, fertilization application level, fertilization incorporation level, chemical oxygen demand factor, point source indicator, erosion from other sources, terrace impoundments, and feedlots.

Table 1. Summary Statistics of Eligible Land in the Illinois Otter Creek Watershed

Variable	Mean	Std. Deviation	Minimum	Maximum
Distance from Water Bodies (feet)	392.2	242.2	150.0	750.0
Slope (%)	3.3	2.8	0.5	21.0
Soil Erodibility Factor	0.39	0.06	0.04	0.49
Upland Sediment Inflow (tons/acre)	4.0	6.3	0.0	132.9
On-Site Erosion (tons/acre)	12.2	13.3	0.3	161.7
Quasi-Rent ($/acre)	145.2	29.7	31.0	215.7
Total No. of Eligible Land Parcels	4,691.0			
No. of Eligible Acres	9,710.4			
Total Sediment Loading (tons)	29,996.3			

soil data obtained from the Illinois Natural Resources Conservation Service (1996).

All other AGNPS parameters are obtained from the USDA's *National Engineering Handbook* (1972) and the USDA/Soil Conservation Service (1986) publication "Urban Hydrology for Small Watersheds." Through consultation with University of Illinois hydrologists, input data for all AGNPS input parameters were adjusted to assure compatibility with the conditions characterizing the study area. The AGNPS model run shows that a typical five-year storm event (3.73 inches of rainfall within 12 hours) would cause about 30,000 tons of sediment to be loaded into water bodies in the watershed, given existing patterns of land use.

Summary statistics for the eligible land parcels in the watershed are reported in table 1. The land parcels differ considerably in their distance from water bodies, slope, erodibility index, upland sediment inflow, and on-site erosion. The distance from water bodies reflects the position of all eligible land parcels within the watershed. The eligible land parcels within the watershed have an average distance from water bodies of 392 feet. These parcels are relatively flat, with an average slope of 3.3%. However, relative landscape variations still exist, with slopes ranging from 0.5% to 21%. The soil erodibility factor (K) varies between 0.04 and 0.49, with an average of 0.39, which represents a modest erodibility condition. The amount of upland sediment inflow varies from 0.0 to 133 tons per acre, with an average of four tons per acre. While some parcels generate as little as 0.3 tons on-site erosion per acre, others could generate on-site erosion as high as 162 tons per acre. The average on-site erosion rate is 12 tons per acre.

A difficulty in estimating off-site sediment abatement achieved by retired land parcels is accounting for the interdependence of land parcels when determining off-site sediment abatement benefits. In order to solve this problem, we consider flow chains within the eligible region (i.e., comprised of cropland within a 900-foot buffer of water bodies) as decision units, and each flow chain consists of at most three 300-by-300 parcels.[8] Of the runoff channels covering the watershed, 2,594 channels contain eligible cropland within 900 feet of water bodies.

It is assumed each land parcel is either retired or in crop production, and all eight (= 2^3) possible alternative land retirement options for each flow chain within a surface runoff channel are defined as follows: *CCC*, *GCC*, *CGC*, *CCG*, *GGC*, *CGG*, *GCG*, and *GGG*, where *C* denotes crop production and *G* denotes land retirement with grass cover.[9] Land uses of all other parcels outside the eligible region are assumed to be unchanged in the land retirement program. Note that the three-parcel chains in the buffer region are linked to the inland watershed so that runoff and sediment transport from upland parcels beyond the eligible region are tracked and incorporated into the sediment transport process within the eligible region.

The AGNPS model is run for the eight land retirement options to obtain off-site sediment abatement

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[8] Land parcels in a watershed constitute a flow network based on hydrology. However, it is very difficult to use the network structure in an optimization model. In order to make the optimization model operational while considering the connection of land parcels in the flow structure, we organize land parcels in the buffer area into linear flow chains through the Geographic Information System (GIS). Within the linear flow chains, the same land parcel only appears once. The formulation of linear flow chains has the advantage of avoiding conflicting land use types while examining different land retirement options in the buffer area. Furthermore, the connection between land parcels is still retained because land use changes will be put back into GIS to run the AGNPS hydrologic model. Sediment abatement is defined as the reduction of sediment at the end of each flow chain or delivered to the water body.

[9] For example, *GCG* indicates the first and third parcels from a water body are in grass cover, and the second parcel is in crop production.

for each flow chain and each land retirement option, designated by A_{mp}, where $m = 1, ..., M$ denotes flow chains in the eligible region and p denotes the eight land retirement options. While the off-site sediment abatement for each parcel is still dependent on its own characteristics and upslope runoff in the same runoff channel, by changing decision-making units from the land parcels to the flow chains, we circumvent the computational difficulties arising from the interdependency of individual land parcels in determining off-site sediment abatement as characterized in the theoretical model.

Corresponding cropping returns are obtained for the eight land retirement options in each flow chain, denoted as R_{mp}. The estimation of cropping returns is based on a crop budget model (University of Illinois, FaRM Laboratory, 1995). Within the model, a typical 700-acre farm with corn-soybean rotation and reduced tillage is assumed. The returns are defined as total revenue minus total variable costs, which include machinery use, fertilizer and pesticide costs, crop insurance premium, and interest paid for capital. Crop yield information based on soil productivity is obtained from Olson and Lang (1994). The machinery use costs in terms of maintenance, repair, and fuel and labor costs are estimated from a machinery program developed by Siemens (1998). The use of fertilizers, pesticides, and other chemicals is based on the *Illinois Agronomy Handbook* (Illinois Cooperative Extension Service, 1999). The crop insurance premium is calculated using data from the USDA's Risk Management Agency (1999). The 5% interest rate reflects the average loan rates in 1998.

Based on the above justification, cropping returns are estimated for each soil type and then assigned to eligible land parcels through GIS. The eligible land is highly productive in nature, with an average return of \$145 per acre. However, as shown in table 1, significant differences in productivity exist across the land parcels. The minimum return is \$31 per acre, while the maximum is \$216 per acre.

The theoretical model shows the estimation of expected returns depends on two key parameters: risk-aversion coefficients (ϕ), and the factor that affects the magnitude of uncertainty and irreversibility (Γ). There is no consensus regarding the magnitude of risk-aversion coefficients (ϕ) in the literature (e.g., Babcock, Choi, and Feinerman, 1993; Weersink, Dutka, and Goss, 1998). For this analysis, two alternative risk-aversion coefficients were chosen—low risk aversion at 0.005 and high risk aversion at 0.01—consistent with the range of risk-aversion coefficients evaluated by Lambert (1990).

The variance of the returns is estimated for each land parcel based on the sample of all eligible land parcels. The variances of the returns for each flow chain and land retirement option are standardized by coefficient of variation (CV). In this study, CV ' 0.38, which is estimated from the cropping returns data for Fulton County, Illinois [USDA/National Agricultural Statistics Service (NASS), 2001]. Thus, the rental rate required for retiring an acre of land from crop production for flow chain m and land retirement option p under risk aversion is

$$\left[R_{mp} \,\&\, \frac{\phi}{2}\,(CV\,(\,R_{mp})^2\right].$$

Using the returns received by farmers in Fulton County, we also estimated the irreversibility factor,

$$\Gamma \;'\; \left(\frac{\beta \,\&\, 1}{\beta}\right),$$

where $\beta < 0$ is the smaller root of $0.5\sigma^2\beta(\beta \,!\, 1) \,!\, \alpha\beta \,!\, \rho \;'\; 0$ (see the appendix). The drift parameter α is estimated as $\alpha \;'\; \mu + (0.5)\sigma^2$, where μ is the mean of the series $\ln(R_{t+1}/R_t)$, and σ is the standard deviation of the series (Forsyth, 2000). A 5% discount rate is assumed in the estimation of β. Using historical data on the average crop returns from corn and soybean productions over the period 1950–2000 in Illinois (USDA/NASS, 2001), intermediate parameters are estimated, such as $\ln(R_{t+1}/R_t)$, μ, σ, and β, and the irreversibility factor $\Gamma \;'\; 1.45$ is obtained for Fulton County.[10] The minimum land rental rate required to participate in the CREP under uncertainty and irreversibility is then represented as ΓR_{mp}.

As noted earlier, the decision unit is defined as a flow chain instead of single land parcels. The social planner's problem is to select a land retirement option p in each flow chain m to achieve the 20% off-site sediment abatement goal (}) in the watershed, i.e.,

$$\underset{m\,'\,1}{\overset{M}{j}}\;\underset{p\,'\,1}{\overset{8}{j}}\;A_{mp}\;\$\;\bar{A},$$

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[10] The value of Γ could vary across heterogeneous soil characteristics, and therefore across R_{mp}. Because we do not have the historical data at the soil type level in this county, and because the study area is relatively small, for simplicity we assume the value of Γ is, on average, the same for all land parcels considered here.

Table 2. Characteristics of Land Retirement Under Different Scenarios of Risk Aversion and Irreversibility

	SCENARIOS			
Variable	Certainty	Low Risk Aversion	High Risk Aversion	Uncertainty and Irreversibility
Number of Parcels Enrolled	451	448	539	451
Land Enrolled (acres)	933.6	927.4	1,115.7	933.6
Percentage of Overlapping Parcels Compared to Certainty Case (%)	—	98	72	100
Total Cost of Abatement[a] ($)	114,492.4	102,460.5	86,330.8	166,013.9
Average Cost of Abatement ($/ton)	19.1	17.1	14.4	27.7
Marginal Cost of Abatement ($/ton)	35.6	31.9	25.6	51.6
Average Payment to Farmers ($/acre)	122.6	110.5	77.4	177.8

[a] Total cost of abatement is represented by the total rental payments made to farmers to retire their land.

while minimizing the program costs with respect to land rental payments compensating the losses of expected returns on the land parcels to be retired. The model ranks flow chains and associated land retirement options based on their benefits in terms of sediment abatement to their cost ratios, and chooses flow chains from the highest benefit-to-cost ratio until the sediment goal is met. This model is solved for each scenario of risk aversion and irreversibility to obtain marginal cost of sediment abatement, total cost of the program, and the least-cost land retirement pattern in the watershed.

Results

The empirical model is run for different scenarios of alternative farmer decision-making and participation constraints to identify least-cost land retirement patterns for achieving the 20% sediment abatement goal in the Otter Creek Watershed. The results are presented in table 2. In the base scenario under risk neutrality and no irreversibility, 451 land parcels or 934 acres of cropland must be retired in order to achieve the 20% off-site sediment abatement in water bodies of the watershed. The targeted acreage for land retirement is about 10% of the eligible land in the watershed. The program cost in terms of land rental payments for compensating farmers' cropping return losses is about $114,000 per year. The marginal cost of sediment abatement is $36 per ton, and the average land rental payment that should be provided to farmers in the watershed is $123 per acre.

When farmers are assumed to be risk averse or face an irreversible decision of participating in conservation programs, the required land rental payments for compensating farmers' losses of expected cropping returns are different depending on the scenarios of risk aversion and irreversibility. When only risk aversion is considered in modeling farmer participation, the program cost in terms of land rental payments is less than under the scenario of risk neutrality. This is because risk-averse farmers require less compensation for their losses of expected cropping returns compared to risk-neutral farmers.

In the low risk-aversion scenario (table 2), 448 land parcels or 927 acres of cropland need to be retired to achieve the 20% sediment abatement goal, which is similar to the land retirement acreage under the risk-neutrality scenario. However, the program cost in terms of land rental payments (approximately $102,000) is less than that under risk neutrality (about $114,000). Correspondingly, the marginal cost of sediment abatement is $32 per ton, and the average land rental payment to farmers is $111 per acre.

Under the scenario of high risk aversion (table 2), 539 land parcels or 1,116 acres of cropland must be retired in order to achieve the 20% sediment abatement goal. While the land retirement acreage is increased by 20% compared to the risk-neutrality scenario, the program cost decreases by 25% (about $86,000 per year). The corresponding marginal cost of sediment abatement is $26 per ton, and the average payment to farmers is $77 per acre.

Because the risk premium could vary across heterogeneous land parcels, land retirement patterns under risk aversion are different from those under risk neutrality (table 2). In the scenario of low risk aversion, 11 land parcels, or 2% of the targeted land parcels, are not overlapping with the targeted land parcels in the risk-neutrality case. In contrast, under the high risk-aversion scenario, the number of non-overlapping parcels rises to 153, or 28% of the total selected parcels in the watershed. This spatial shift is explained by a change in the benefit-to-cost ratios of eligible land parcels when the risk-aversion factor is considered, and the land retirement is moved toward those land parcels having higher benefit-to-cost ratios.

Under uncertainty and irreversibility, land retirement patterns are similar to those under the risk-neutrality scenario (table 2) because the irreversibility factor scales up the rental payments required to participate in the program. As a result, the program cost in terms of rental payments to be provided to farmers increases considerably ($178 per acre compared to $123 per acre). Under uncertainty and irreversibility, the land retired consists of 451 land parcels, identical to the scenario under risk neutrality. However, the total cost of the program under uncertainty and irreversibility reaches about $166,000 per year, which is 45% higher than the cost under the scenario of risk neutrality only. The corresponding marginal cost of sediment abatement is $52 per ton. As expected, the total cost of land retirement and marginal cost of abatement under uncertainty and irreversibility are also considerably higher than those under risk aversion only.

These results may provide a justification for the considerably higher program payments in the continuous CRP or the CREP. For example, in Fulton County where the Otter Creek Watershed is located, the average soil rental rate was $87 per acre in 1998 for the five-year Illinois CREP. However, the actual average CREP program payments in 1999, 2000, and 2001 were $142, $152, and $167 per acre, respectively, representing increases ranging from 63% to 92% (USDA/FSA, 2003). Although the actual program payments are considerably higher than the average soil rental rate, these payments are below the average land rental payment estimated under the scenario of uncertainty and irreversibility ($178 per acre, table 2). This finding indicates that when the irreversibility of the program participation decision is considered, the actual CREP land rental payments are reasonable in compensating the losses of farmers' expected cropping returns.

Implications of a Uniform Bid Cap in the Scenario of Uncertainty and Irreversibility

While a bidding cap is currently not applicable to the continuous CRP or the CREP, the empirical model is also applied to examine the implications of a uniform bidding cap for land retirement programs. It is important to examine the potential policy implications of introducing such a land rental instrument for the continuous CRP or the CREP. Typically in regular CRP sign-ups, a soil-based bid cap is set at the county level and land parcels with higher EBI scores relative to costs of bids would be accepted to the program. Apparently, the bid cap could be set differently depending on the alternative farmer decision-making criteria examined above. Then, an important question to consider would be how a uniform bid cap determined assuming risk neutrality would work when farmers actually make their participation decisions under uncertainty of crop production and irreversibility of program participation.

We first determine a uniform bid cap required to achieve the 20% sediment abatement goal in the watershed assuming farmers are risk neutral. A heuristic procedure is built into the least-cost targeting model to identify the uniform bid cap which would induce land retirement in order to achieve the 20% sediment abatement goal. The land rental payment is the minimum of the bid cap and estimated cropping returns. In the beginning a low bid cap is set, land parcels with cropping returns below the cap are selected, and the sediment abatement achieved by these parcels is summarized. The bid cap is increased by small increments until the environmental goal in the watershed is achieved. The model indicates a uniform rental rate of $140 per acre would achieve the 20% sediment abatement by enrolling farmlands with the expected returns at or below $140 per acre.

We examine the impacts of this uniform bid cap set assuming risk neutrality when farmers actually make an irreversible decision of land retirement under uncertainty. The uniform bid cap under the risk-neutrality scenario is applied to the scenario of uncertainty and irreversibility to identify land parcels that would be retired, and the sediment abatement and the cost of abatement are estimated. As a result, 493 acres of cropland are selected for retirement. The achieved sediment abatement is 2,579 tons, which is only 42% of the 6,000-ton abatement target (table 3).

The sediment abatement achieved under uncertainty and irreversibility is significantly lower than the program goal. Based on these results, if a uniform bid cap is designated without considering uncertainty and irreversibility, then applying the policy instrument would not achieve the program

Table 3. Impact of a Uniform Bid Cap Under Risk Neutrality on Land Retirement and Cost of Abatement Under Irreversibility

Variable	Uncertainty and Irreversibility
Uniform Bid Cap Under Risk Neutrality ($/acre)	140.0
Land Enrolled (acres)	492.7
Abatement Achieved (tons)	2,579.2
Percentage of Abatement Target Achieved (%)	42.1

goal. Otherwise, the uniform bid cap must be raised. These findings provide insights for setting appropriate levels of bidding caps for inducing farmers' participation in land retirement programs. The results also imply that conservation programs like the CREP do not impose bid caps because they encourage farmer participation by providing additional incentives in order to meet the program goals.

Conclusions and Policy Implications

This study has examined the impacts of alternative farmer decision making on determining land rental payments and least-cost land retirement targeting in agricultural conservation programs. It takes into account uncertainty about crop production and irreversibility of program participation to analyze the economic incentives necessary for inducing farmer participation in land retirement programs. The model is empirically applied to the Conservation Reserve Enhancement Program (CREP) in the Otter Creek Watershed in Illinois.

In achieving the 20% sediment abatement goal in the watershed, results show the marginal cost of sediment abatement and the average land rental payment under risk aversion are less than those under risk neutrality. However, when the irreversibility of program participation is considered, the marginal cost of sediment abatement and the average land rental payment are considerably higher than those under scenarios of risk neutrality or risk aversion only. Furthermore, the model results indicate that if a bidding system were introduced, a uniform bid cap determined under the assumption of risk neutrality would achieve far less sediment abatement than the program goal when it is applied to the scenario of uncertainty and irreversibility.

The success of land retirement programs highly depends on appropriate design of land rental payment instruments to compensate the losses of farmers' expected returns. Statistics reveal the land rental payments in the continuous CRP or the CREP are considerably higher than the local soil rental rates. When irreversibility of the land retirement program participation is considered, the findings of this analysis suggest the land rental payments needed for inducing farmers' participation in the program should be higher than the payments specified under the assumption of risk neutrality only. Furthermore, if a bidding system were implemented, the uniform bid caps determined with the assumption of risk neutrality only would not be attractive to many farmers who make the program participation decision under uncertainty and irreversibility. Consequently, the bid caps need to be raised in order to encourage more farmers to participate in the program.

The results have implications for the design of policy instruments in land retirement programs. Given the uncertainty about crop production and irreversibility of program participation, incentive payments in addition to the land rental payments based on local land markets would be provided to farmers to account for the value of waiting. Currently, only continuous sign-ups in the CRP or the CREP offer additional incentives to farmers for implementing conservation practices that provide more environmental benefits such as filter strips and buffers, or for retiring land in areas of environmental significance. In light of our modeling results, it would be useful to reexamine the bidding system and payment levels of regular sign-ups in the CRP.

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Appendix: Modeling Farmer's Participation Decision in the Land Retirement Program

We model a risk-neutral farmer's participation decision in the land retirement program under uncertainty and irreversibility. Let V be the annualized present value of the rental rate over the participation period to be determined, which induces the farmer's participation in the land retirement program. V is assumed to be stochastic, and evolves according to the following geometric Brownian motion process:

$$dR = \alpha R dt + \sigma R dz, \qquad \text{(A1)}$$

where dz is the increment of a Wiener process with mean zero and unit variance, α is the expected growth rate, and σ is the volatility in the growth rate. A number of studies have shown that returns from agricultural production or output prices can be represented by a geometric Brownian motion process (Purvis et al., 1995; Isik, Khanna, and Winter-Nelson, 2001; Carey and Zilberman, 2002).

In this paper, a geometric Brownian motion is chosen to preserve analytical clarity and ensure tractability. This hypothesis is consistent with most theoretical and empirical models assessing option values. General conclusions about the effects of uncertainty on decision making still hold when returns may follow an alternative stochastic process (Dixit and Pindyck, 1994).

The farmer's decision problem is to maximize the net returns from participation in the land retirement program by choosing an optimal time t subject to (A1) as:

$$F(R) = \underset{t}{\mathrm{Max}}\, E(V_t - R_t). \qquad \text{(A2)}$$

Dynamic optimization techniques are used to derive the optimal participation rule. The Bellman equation is $\rho F(R)dt = E[F(R)]$, where ρ is the discount rate. Using Ito's lemma to expand the right-hand side of this expression, $F(R)$ can be shown to satisfy $0.5(\sigma^2 R^2 F_R) + \alpha R F_R - \rho R = 0$. This differential equation is solved with respect to the boundary conditions: $F(0) = 0$, $F(R) = V - R$, and $F_R(R) = -1$.

Following Dixit and Pindyck (1994), we obtain the threshold return to be received at which it is optimal to participate at year zero:

$$V_0^* = \Gamma R_0, \text{ where } \Gamma = \left(\frac{\beta - 1}{\beta}\right) > 1,$$

with $\beta < 0$ being the smaller root of $0.5\sigma^2\beta(\beta - 1) - \alpha\beta - \rho = 0$. The magnitude of this factor determines the extent to which uncertainty and irreversibility affect the participation decision. This factor increases with an increase in σ and/or a decrease in α. This decision rule requires the farmer to be compensated at least ΓR_0 to participate in the land retirement program today.