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An Analysis of the Effects of Uncertainty and Irreversibility on Farmer Participation in the Conservation Reserve Program

Murat Isik and Wanhong Yang

A real options model is developed to examine the determinants of farmer participation in the Conservation Reserve Program (CRP). This study contributes to the literature by developing a framework for ex post analysis of uncertainty and irreversibility. It extends the applications of real options models to analyze farmer participation in the CRP. The model incorporates land and owner attributes, and determines whether uncertainty and irreversibility affect the probability of participation. Option values play a significant role in farmer decisions to retire land by reducing the probability of participation. These results have implications for the design and implementation of conservation programs.

Key words: conservation, CRP, farmer participation, land rental payments, option values, uncertainty

Introduction

The Conservation Reserve Program (CRP), established in 1985, aims at protecting the nation's most environmentally sensitive cropland. In this voluntary land retirement program, farmers and ranchers enter into 10- to 15-year contracts with the U.S. Department of Agriculture to take environmentally sensitive cropland out of production. In exchange, landowners receive annual rental payments and cost-share assistance for establishing conservation practices to improve soil, water, and wildlife resources. Since the mid-1990s the CRP has enrolled land through a bidding process, in which contracts are accepted based on a soil-specific maximum acceptable bid cap determined in advance of enrollment and an Environmental Benefit Index (EBI) composed of a set of environmental criteria.[1] Each bidder knows the bid cap and how scores in the environmental categories of the EBI are calculated before a bid is submitted. Submitted bids are then ranked based on the EBI relative to costs, and selections of CRP contracts are made from these rankings.

The CRP has gained rapid acceptance within the agricultural community and the general public. Land in the CRP increased from slightly over 2 million acres in 1986 to

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Murat Isik is assistant professor, Department of Agricultural Economics and Rural Sociology, University of Idaho; Wanhong Yang is assistant professor, Department of Geography, University of Guelph. The authors thank two anonymous reviewers for their helpful comments and suggestions.

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[1] The bid cap is locally determined by soil productivity, local cash rental rates, and maintenance costs for conservation uses on the CRP land within each county. The EBI is comprised of six environmental factors: wildlife, water quality, erosion, enduring benefits, air quality, and state or national conservation priority area. Eligible acreage devoted to certain conservation practices, such as riparian buffers, filter strips, or grass strips, may be enrolled at any time under the continuous signup and is not subject to competitive bidding.

about 34 million acres in 2003 [U.S. Department of Agriculture/Farm Service Agency (USDA/FSA, 2003)]. As the nation's largest agri-environmental program, the CRP has made significant contributions in improving the quality of the natural environment in the United States (Ribaudo, 1990; Feather, Hellerstein, and Hansen, 1999). However, there also are various concerns regarding the rationale in determining land rental payments, enrollment in some states, and the program's environmental effectiveness (Claassen et al., 2001; U.S. General Accounting Office, 2002). For example, the CRP has had limited success in promoting cropland conversion to more permanent uses (Schatzki, 1998).[2] Additionally, some states in the Northeast region experienced relatively low enrollment rates in the CRP during the 1990s (USDA/FSA, 2003). As of October 2001, the CRP was not very effective in targeting environmentally sensitive land, and enrollment in many states was very low in the continuous CRP (U.S. General Accounting Office, 2002, p. 14). Clearly, it is very important to examine the factors affecting farmer participation in the CRP. An understanding of these motivating factors could be helpful to policy makers in improving the design and implementation of such crucial conservation programs and their cost-effectiveness.

This research problem, however, is complex. Farmers' participation decisions in the CRP involve various sources of uncertainty, irreversibility, and some leeway in the timing of participation. With CRP participation, farmers face a decision between uncertain farming income, which may be caused by fluctuating crop prices and yields, and uncertain program payments from one signup period to the next, which is associated with possible changes in government policies. Land rental payments received by farmers from the CRP are related to the returns from agriculture or cash rental rates, and could change from one signup to the next because of changes in agricultural and environmental policies, profitability of agriculture, and cash rental markets. For example, historical data on the CRP payments in Illinois counties show that the average fluctuation in land rental payments was about 18.6% between 1988 and 2002 (USDA/FSA, 2003), while the returns from agricultural production fluctuated about 22.5% between 1950 and 2002. This variability of the CRP payments is also observed at the national level. Average payments increased from $52/acre in 1988 to $78.80/acre in 2001, while the rental rates fluctuated between 5.5% and 24.7% annually across the United States (USDA/FSA, 2003).[3]

Moreover, under the terms of the CRP fixed-period participation contract, farmers must make an irreversible decision to enroll in the CRP. However, farmers are given the option of delaying enrollment decisions to learn more about economic conditions and government policies before making this irreversible decision. Although farmers who participate in the program are entitled to receive guaranteed annual payments over the program participation period, by delaying their participation decision and exercising the option to enroll later, they could receive different annual payment amounts in a future signup period. By waiting, farmers could also observe what the bids were. Additionally, the initial conversion costs (i.e., establishing conservation practices) are sunk. Thus, the option to retire land is valuable because uncertainty and irreversibility of the CRP, as

[2] Stavins and Jaffe (1990) point out that only 32–69% of the landowners in the Mississippi Delta convert land when it is optimal according to the net present value rule, suggesting the presence of factors not accounted for in their decision making.

[3] Some parts of the observed variability in the rental payments at the county level and at the state level could be due to the types of land parcels bid into the program each year. Although we found similar fluctuations of the rental rates at the watershed level, a more accurate representation of the variability would be to determine the fluctuations at the soil type level.

well as the ability to delay decision making, are important factors influencing participation decisions in the CRP.

The purpose of this study is to develop a model of decision making to examine the factors affecting farmer participation in the CRP under uncertainty. The model incorporates uncertainty and irreversibility characteristics of CRP participation to estimate the probability of participation. The empirical application examines the extent to which uncertainty and irreversibility affect the probability of farmer participation in the CRP by taking into account land benefits, land characteristics, and owner attributes. The results from this analysis have implications for the design and implementation of conservation programs, and development of estimates of environmental program performance.

Several earlier studies have examined the factors affecting farmer participation in the CRP, post-CRP land use decisions, and wetland reserve programs using discrete choice models. Various factors affecting farmer participation in the CRP were identified. Socioeconomic variables such as farm tenure and farmer age, economic factors such as returns and bid cap, soil erosion rate, and location of counties have been found to influence the probability of farmer CRP participation (Shoemaker, 1989; Konyar and Osborn, 1990; McLean, Hui, and Joseph, 1994; Skaggs, Kirksey, and Harper, 1994; Kalaitzandonakes and Monson, 1994; Cooper and Osborn, 1998). Likewise, participation in wetlands reserve programs is affected by similar factors such as land and owner attributes (Parks and Kramer, 1995). However, these studies assume deterministic decision making, and therefore do not take into account uncertainty and irreversibility associated with CRP participation.

Farmer participation in the CRP is analogous to technology adoption decisions under uncertainty. When technology adoption involves an irreversible decision and the decision maker can wait to learn more about the value of technology or economic conditions, value of waiting may exist, which delays investment decisions (Dixit and Pindyck, 1994). Although a growing body of literature has recently applied the theory of investment under uncertainty to analyze the adoption of agricultural technologies (e.g., Isik, 2004; Isik, Khanna, and Winter-Nelson, 2001; Carey and Zilberman, 2002), land use change (e.g., Schatzki, 1998; Capozza and Li, 1994; Geltner, Riddiough, and Stojanovic, 1996), and entry-exit decisions (e.g., Isik et al., 2003), the theory of irreversible investment has seldom been used as a basis of econometric models for ex post analysis of uncertainty and irreversibility.

In this study, we examine whether option values affect farmer decision making by developing a behavioral econometric model. Thus, this study extends the existing literature on CRP participation by taking into account uncertainty and irreversibility of CRP participation based on a real options model. It contributes to the literature by incorporating uncertainty and irreversibility of the CRP in estimation of the participation probabilities. This analysis also extends the literature on the empirical applications of real options models by providing a framework for ex post analysis of uncertainty and irreversibility.

The Theoretical Model

A risk-neutral farmer's participation decision in the CRP is examined under uncertainty about crop returns and land rental payments. The returns from agricultural production at time T are denoted by $\pi_T(q; \eta)$, where q is the land quality and η represents farmer characteristics that influence profitability of crop production (such as age). The returns from crop production are uncertain due to uncertainty about output prices, crop yields, and weather conditions. The farmer has the option to participate in the CRP and can receive an annual rental payment, $V_T(q; \eta)$, for program participation at time T. Land rental payments to be received could also be uncertain because of possible changes in returns from agricultural production, cash rental rates, the EBI, or agricultural policies from year to year. In particular, there exists uncertainty about the future prospect of environmental policies regarding which instruments to use in controlling nonpoint pollution. The farmer who decides to enroll in the program must enter into a $\overline{T}$-year contract. This nature of the CRP characterizes the irreversibility effect of the participation decision.

The farmer who participates in the CRP is responsible for a portion of the total restoration costs, $(1 - \lambda)K(q)$. The farmer receives the remaining restoration costs, $\lambda K(q)$, as incentive payments for participation. It is assumed there is no uncertainty about the restoration costs. The expected present value of the foregone agricultural returns from crop production plus the restoration costs is defined as the opportunity costs of participation in the CRP, which is used to determine the minimum rental rate required for participation.

Farmer Participation in the CRP Under Uncertainty

We assume that π and V evolve according to the following stochastic processes (as in Capozza and Li, 1994; Schatzki, 1998; Isik, Khanna, and Winter-Nelson, 2001; Carey and Zilberman, 2002):[4]

$$d\pi = \alpha_\pi \pi dt + \sigma_\pi \pi dz_\pi \tag{1}$$

and

$$dV = \alpha_V V dt + \sigma_V V dz_V, \tag{2}$$

where dz is the increment of a Wiener process with mean zero and unit variance, α is the drift parameter, σ is the volatility in the drift parameter, and $E(dz_\pi dz_V) = \gamma dt$. The parameter γ represents the covariance between changes in π and V. Uncertainty associated with π and V could be correlated due to the common shocks affecting both returns from agricultural production and land rental payments received by farmers. Several studies have noted that returns from agricultural production or output prices can be represented by a geometric Brownian motion (Isik, Khanna, and Winter-Nelson, 2001; Schatzki, 1998; Carey and Zilberman, 2002). It is reasonable to assume that rental payments are related to the returns from agriculture and can be conveniently represented by the same stochastic process.

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[4] Geometric Brownian motion is chosen to preserve analytical clarity and ensure tractability in the theoretical model as well as to develop an econometric model for cross-sectional data. This hypothesis is consistent with most theoretical and empirical models assessing option values. We also tested this hypothesis. The augmented Dickey-Fuller tests reported later in table 2 do not reject a random walk for agricultural returns for the data used in the empirical application. However, the time series of rental rate data is too short for these tests to be conclusive. General conclusions on the effects of uncertainty still hold when rental payments follow an alternative stochastic process (Dixit and Pindyck, 1994; Dixit, 1993; Schatzki, 1998).

To illustrate the impacts of uncertainty and irreversibility, we first determine the minimum rental rate required by a farmer to participate in the CRP using the net present value (NPV) rule. Under the NPV rule, the farmer should participate in the CRP if the expected present value of the land rental payment to be received is greater than or equal to the expected present value of the foregone returns from crop production plus the restoration costs. The present value of the expected land rental payment that can be received over the $\overline{T}$-year CRP contract at year T (with $\alpha_V = 0$) is specified as:

$$R(V_T) = E\int_T^{\overline{T}+T} V_t e^{-\rho t}\,dt = \frac{V_T(1 - e^{-\rho\overline{T}})}{\rho},$$

where V_T is the annual land rental payment to be received at year T, and ρ is the discount rate. The expected present value of the foregone agricultural revenues plus the restoration costs at year T is given by:

$$C(\pi_T, K) = \frac{\pi_T(1 - e^{-(\rho-\alpha_\pi)\overline{T}})}{(\rho - \alpha_\pi)} + (1 - \lambda)K.$$

Thus, under the NPV rule which ignores the uncertainty and irreversibility of the CRP, the farmer will enroll in the CRP at year zero if at least $C(\pi_0, K)$ is received for participation, i.e.,

$$R(V_0) \geq C(\pi_0, K), \quad \text{or} \quad V_0 \geq \frac{\rho C(\pi_0, K)}{(1 - e^{-\rho\overline{T}})}.$$

In other words, $C(\pi_0, K)$ can also be considered as the farmer's willingness to accept for participation in the CRP. Under the NPV rule, this value would also correspond to the minimum amount the farmer bids for participation.

When the farmer has the option to delay the participation decision in the CRP, the present value of the expected land rental payment to be received, $R(V_T)$, changes from one signup period to the next with the changes in V_T, i.e., $R(V_T)$ at year 2 is equal to $V_2(1 - e^{-\rho\overline{T}})/\rho$, and it can be characterized with the same stochastic process given in (2). By delaying participation decisions and keeping the opportunity to participate in the program in the future, the farmer could obtain a different stream of rental payments, $R(V_T)$, in future CRP signup periods.

We now incorporate uncertainty and irreversibility of the CRP into the farmer's participation decision and determine the rental rates required to participate in the CRP using dynamic optimization techniques. The farmer will face the same participation decision after the contract is expired. The farmer chooses enrollment year T that maximizes the net present value of returns subject to (1) and (2) as:

(3) $$F(V, \pi) = \max_T E\big[R(V_T) - C(\pi_T, K)\big].$$

Use of dynamic programming then reveals the following critical value of the land rental payment to be received over $\overline{T}$ years ($R(V_T^*)$) at which it is optimal to enroll in the CRP (refer to the appendix for additional computational details and discussion):

(4) $$R(V_T^*) = \left(\frac{\beta}{\beta - 1}\right) C(\pi_T, K),$$

where $\beta > 1$ is the larger root of $0.5(\sigma_V^2 - 2\gamma\sigma_V\sigma_\pi + \sigma_\pi^2)\beta(\beta - 1) + (\alpha_V - \alpha_\pi)\beta - (\rho - \alpha_\pi) = 0$. Equation (4) can be rewritten as

$$V_T^* = \left(\frac{\beta}{\beta - 1}\right)\frac{\rho C(\pi, K)}{(1 - e^{-\rho\bar{T}})}$$

to represent the annual threshold rental payment in which the farmer is indifferent between enrolling and maintaining the land in agriculture.[5] This value would represent the minimum rental rate required for participation or the farmer's willingness to accept for participation in the CRP under uncertainty and irreversibility. Thus, the threshold rental payment would correspond to the minimum amount the farmer bids to participate in the CRP under uncertainty.[6]

The participation decision under uncertainty and irreversibility requires the present value of the rental payment to be received, $R(V_T)$, to be greater than the expected present value of the foregone returns from crop production plus the restoration costs, $C(\pi_T, K)$, by a factor of $\beta/(\beta - 1) > 1$. The magnitude of this factor determines the extent to which uncertainty and irreversibility of the CRP affect the participation decision. The option-value multiplier $\beta/(\beta - 1)$ increases if the expected growth in π (α_π) increases or if the expected growth in the present value of rental payment (α_V) decreases. The multiplier will decrease if ρ or γ increases. Holding their variances fixed, a greater covariance between changes in π and $R(V_T)$ implies less uncertainty over their ratio, hence a reduced incentive to wait for participation. The option-value multiplier also increases if the volatility in π and/or $R(V_T)$ increases.

The critical value of the land rental payment required for participation in the CRP given in (4) can be written as

$$R(V_T^*) = \frac{C(\pi_T, K)}{\beta - 1} + C(\pi_T, K).$$

This expression indicates the farmer requires the land rental payments to be greater than the expected returns from crop production plus the restoration costs by $C(\pi_T, K)/(\beta - 1) > 0$, in order to participate in the CRP. This value, $C(\pi_T, K)/(\beta - 1)$, can be considered as the value of waiting to participate in the CRP in the future. Under uncertainty and irreversibility, the value of waiting is added to the opportunity costs of participation because the farmer gives up the option to participate in the program in the future. These results extend the literature by incorporating uncertainty and irreversibility of the CRP into the participation decision. Ignoring uncertainty and irreversibility of the CRP participation decision would overestimate the probability of farmer participation in the CRP.

Empirical Application

The empirical application of the theoretical model focuses on farmer participation decisions under uncertainty and irreversibility of the CRP to develop an econometric model for cross-sectional data. The empirical model identifies various factors that may influence

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[5] When there is no uncertainty about V [and therefore $R(V_T)$], the critical value of the land rental payment is $R(V_T^*) = ((\beta_2 - 1)/\beta_2)C(\pi_T, K)$, where $\beta_2 < 0$ is the smaller root of $0.5\,\sigma_\pi^2\beta(\beta - 1) - \alpha_\pi\beta - \rho = 0$.

[6] In actual implementation of the program, however, the bids submitted by the farmer could be modified depending on the EBI of the land and the soil-specific bid caps set.

farmers' decisions to enroll in the CRP. Participation by landowners in the CRP is measured using the proportion of county cropland offered to the CRP. Each county is analyzed as a representative farm possessing the average characteristics of that county. The factors affecting participation probabilities in the CRP are examined using the proportions of the land offered to the CRP in counties considered.

Equation (4) defines the threshold rental payment required for participation in the CRP. The farmer's choice to restore a tract of agricultural land to the CRP depends on whether the annual land rental payment to be received is higher than the threshold rental payment defined by:

$$V_i^* = \left(\frac{\beta}{\beta - 1}\right)\frac{\rho C_i(\pi, K)}{(1 - e^{-\rho \overline{T}})}. \tag{5}$$

Let $V_i^*(C, K, \beta)$ describe the per acre threshold land rental payment relevant to county i. This threshold is expected to be lower than the exogenously determined soil-specific bid caps for farmers who participate in the program. While the threshold may not be observed, it is possible to observe the land uses on the land tract and some attributes of the tract which may indicate its suitability for devotion to agricultural production or the CRP. The land use observed is an indication of whether its opportunity costs of the crop production plus restoration costs are above or below the threshold rental payment. Measurable attributes relevant to the unobservable land rental thresholds may include components of land benefits, soil quality indicators, socioeconomic variables, the CRP participation benefits, and the bid cap.

The probability of some parcels drawn from county i, with observable characteristics $\mathbf{x}_i$, has a probability of enrolling (P_i), which is defined as the probability that $V_i = g(\mathbf{x}_i\delta)$ is greater than the unobservable threshold V_i^*. Here, $V_i = g(\mathbf{x}_i\delta)$ is a rental payment index and measures the expected rental payment to be received by lands with attributes $\mathbf{x}_i$. The vector is specified so that the probability of land with attributes $\mathbf{x}_i$ drawn randomly from the land base enrolled in the CRP in county i is $P_i = \Pr\{V_i^* \le g(\mathbf{x}_i\delta)\}$, where δ is the parameter vector to be estimated. This probability is bounded by zero and one.

The relationship between V_i and P_i is assumed to form a logistic cumulative distribution function:

$$P_i = \Pr\left\{V_i^* \le g(\mathbf{x}_i\delta)\right\} = \frac{1}{1 + e^{-g(\mathbf{x}_i\delta)}}. \tag{6}$$

We solve (6) for $g(\mathbf{x}_i\delta)$ to approximate the probability with the proportion of land acres offered to the CRP in county i, f_i. Minimum χ^2 methods in grouped data are then used to estimate the probability of participation (Maddala, 1987) as follows:

$$\ln\left(\frac{f_i}{1 - f_i}\right) \cong \ln\left(\frac{P_i}{1 - P_i}\right) + \frac{(f_i - P_i)}{P_i(1 - P_i)} \cong g(\mathbf{x}_i\delta) + u_i, \tag{7}$$

where f_i is the proportion of land acres offered to the CRP in county i. The grouping was done across producers with eligible lands, following Parks and Kramer (1995).

The parameters δ in (7) are estimated using observations on f_i, the proportion of acres offered to the CRP in county i. This is consistent with the approach used by Parks and Kramer (1995) in their study of the Wetlands Reserve Program. A linear function of parameters is estimated—i.e., $g(\mathbf{x}_i\delta) = \mathbf{x}_i\delta + u_i$. Maddala's correction was used for the heteroskedasticity exhibited by u_i in grouped logit models. Note that $\mathbf{x}_i$ also includes the parameters of the value of waiting. Although this method does not explicitly allow quantifying the impact of the value of waiting on the participation probabilities, it illustrates the extent to which this value affects the participation probabilities by adding β or β/(β − 1) as an independent variable in the regression. These parameter estimates allow the probability of participation in the CRP to be estimated for each county and quantify the impacts of uncertainty and irreversibility of the CRP on the participation decisions. However, the estimated coefficients are insufficient to show direct impacts of variables on participation probabilities. Therefore, the elasticities of probability for some of the explanatory variables are also estimated. These elasticities show the percentage change in the probability of participation associated with a 1% change in an explanatory variable considered. The elasticity of probability for variable j in county i is obtained as:

$$\varepsilon_{ij} = \frac{\partial P_{ij}}{\partial x_{ij}} * \frac{x_{ij}}{P_{ij}},$$

where P_{ij} is defined by (6).

We use a two-step procedure described by Wooldridge (2002, p. 474) to test the possibility of endogeneity of some of the variables used in the estimation of (7). This procedure determines whether some of the variables are endogenous and/or whether endogeneity has any effect on consistency of their estimate. To determine whether the variable x_2 is endogenous, we first run the ordinary least squares regression x_2 on other independent variables and save the residual (v). Next, (7) is re-estimated with the residual v included as an additional independent variable. We then test the null hypothesis that x_2 is exogenous in the estimated model by determining whether the coefficient on v is equal to zero.

Data

The model developed above is applied to farmer participation in the CRP in Illinois using data from 100 counties. In Illinois, 811,926 acres of land were contracted under the CRP between 1986 and 1993. From 1996, the earliest contracts started to expire and caused fluctuations of the CRP acreage. In 1997, the active Illinois CRP contracts had 732,345 acres (Illinois Agricultural Statistics Service, 2001). With increasing enrollment in recent years, Illinois CRP land reached 944,944 acres by 2002, representing about 3.4% of the cropland in Illinois. The CRP pays an annual rental rate based on the rental value of the land, and 50% of the costs of establishing grasses or trees on the land enrolled.

Farmer participation in the CRP is measured using the proportion of the eligible cropland offered to the CRP. These cross-section data are merged at the county level with the economic data and farmer characteristics in Illinois counties. Descriptive statistics of the data used in the estimation are presented in table 1. The probability of participation is estimated using the average county-level data. To be eligible for CRP participation, the land must be: (*a*) cropland that was planted or considered planted to an agricultural commodity on hydric soils, or (*b*) marginal pastureland suitable for practices such as riparian buffers, filter strips, grassed waterways, shelterbelts, or field windbreaks. Eligible land data are obtained from the 1997 National Resources Inventory [USDA/ Natural Resources Conservation Service (NRCS), 1997].

Table 1. Descriptive Statistics of the Variables Used in the Estimation

Variable	Mean	Standard Deviation
Proportion of Land Offered to the CRP	0.046	0.042
Bid Cap ($/acre)	93.970	21.048
Value of Crops Sold ($/acre)	275.950	73.636
Crop Production Costs ($/acre)	171.690	52.379
Government Payments ($/acre)	16.459	22.575
Environmental Benefit Index (EBI)	209.600	19.095
Proportion of Land in Land Capability Classes (LCCs) I or II	0.422	0.023
Proportion of Cropland Idle	0.094	0.009
Average Age of Operator (years)	53.560	1.395
Proportion of Land Operated by Full- or Part-Time Owners	0.838	0.073
$\beta/(\beta - 1)$	1.525	0.812

Data on the land acres offered to the CRP from 100 Illinois counties during signup #18 of the CRP were obtained from the Farm Service Agency (USDA/FSA, 2003). The average bid cap for each county and the average EBI of each county were also obtained from the Farm Service Agency. The bid cap influences the rental rates and participation decision of farmers (Shoemaker, 1989). The EBI also plays a role in determining suitability of the land for enrollment in the CRP. The EBI depends on six environmental factors and a cost component. The environmental factors are determined based on the following point system: wildlife habitat benefits, 0–100 points; water quality benefits, 0–100 points; on-farm benefits, 0–100 points; long-term benefits, 0–50 points; air quality benefits, 0–35 points; and conservation priority area, 0–25 points. The cost component of the EBI for signup #18 includes 15 points for requested rental payment relative to the maximum acceptable payment for soils offered, 10 points if no cost-share for cover establishment is requested, and up to 125 points depending on the per acre rental payment requested with a formula [$125 * (1 - R/165)$, where R is the rental rate bid]. Prior to selection of contracts, the total environmental component and the cost component of the EBI are reweighted. To avoid endogeneity associated with the cost component in the estimations, only the total environmental component of the EBI is used in our analysis.

Under CRP participation, an economic decision is made to forego the use of environmentally sensitive lands for agricultural purposes. The opportunity cost of CRP participation is made up of crop net returns and farm program payments. Data related to the agricultural opportunity costs are obtained from the *1997 U.S. Census of Agriculture* [USDA/National Agricultural Statistics Service (NASS), 1999]. Crop revenues per acre consist of the value of crops sold in a county. Crop costs per acre include the costs of seed, fertilizer, chemicals, petroleum, electricity, labor, and other customwork costs. Per acre government payments other than the CRP payments received by farmers are also considered as opportunity costs of crop production.

Land quality indices for each county include the proportion of land in Land Capability Classes (LCCs) I and II, and the proportion of the land idle. These measures are obtained from the 1997 National Resources Inventory (USDA/NRCS, 1997), which defines the land quality for producing crops. LCCs I and II represent well-suited land for crop production.

The vector η for a county includes characteristics of land users in the county. The proportion of idle land is also included as a measure of land quality. Farmer characteristics for a county from the *1997 U.S. Census of Agriculture* (USDA/NASS, 1999) include the average age of the farm operators and proportion of the area operated by full- or part-time owners in the county.

We determine whether the profits can be represented with a geometric Brownian motion using the augmented Dickey-Fuller (1981) unit root test:

$$\Delta\pi_t = \phi_0 + (\phi_\pi - 1)\pi_{t-1} + \phi_t t + \sum_{k=1}^{N} \phi_k \Delta\pi_{t-k} + \varepsilon_t, \tag{8}$$

where N is the number of lags selected on the basis of the likelihood-ratio test. A unit root test is conducted by comparing the sum of squared residuals from the unrestricted version in (8) and a restricted regression with $\phi_\pi = 1$ and $\phi_t = 0$ using an F-test. The estimated F-statistic is found to be lower than the critical value (p-value is 0.39). The results of a τ-test on the coefficients $\phi_\pi - 1$ and ϕ_t are reported in table 2. Both tests fail to reject the null hypothesis of nonstationarity. These results validate the assumption of a geometric Brownian motion.

To estimate the uncertainty parameter (β) in (4), historical data on crop returns and average historical rental payments received by participants in a county are used. The values of β for each county in Illinois are estimated using the real returns and rental payments received by farmers. The drift parameter is estimated as $\alpha_\pi = m + (0.5)\sigma_\pi^2$, where m is the mean of the series $\ln(\pi_{t+1}/\pi_t)$, and σ_π is the standard deviation of the series (Forsyth, 2000).

Because the profit shocks may have both transitory and permanent components, the standard deviation is dissected into permanent and transitory standard deviation (uncertainty) components. To isolate these components of total uncertainty, we use the decomposition technique developed by Hall and Mishkin (1982) and expanded by Carroll (1991). Only the permanent component of the standard deviation is used in the analysis. Using historical data on average crop returns (crop yields and output prices) from corn and soybean productions over the period 1950–2002 in Illinois (USDA/NASS, 2003), the values of α_π and σ_π are estimated for each county in Illinois. Similarly, the values of α_V and σ_V are obtained using the historical rental payments data available between 1988 and 2002 in each county in Illinois (USDA/FSA, 2003). Correlation between α_π and σ_π is also estimated for each county. A 5% discount rate is assumed in the estimation of β.

Results

Table 3 presents the parameters of the estimated grouped logit models for farmer participation in the CRP in Illinois counties. To quantify the impacts of uncertainty and irreversibility of the CRP on the probability of participation, two alternative models are estimated: Model I in which β is used as an independent variable, and Model II in which $\beta/(\beta - 1)$ is used as an independent variable. Two alternative models are estimated to illustrate the robustness of the impacts of uncertainty and irreversibility on the participation decisions. An increase in β reduces the option-value multiplier $\beta/(\beta - 1)$, thereby corresponding to a reduction in the degree of uncertainty and irreversibility.

Table 2. Results of Dickey-Fuller Unit Root Test for Nonstationarity of Profit

Variable	Parameter Estimate	τ-Statistic	Variable	Parameter Estimate	τ-Statistic
ϕ_0	5.392	4.562	ϕ_2	-0.013	-0.271
$\phi_\pi - 1$	-0.915	-2.015	ϕ_3	0.025	0.537
ϕ_t	-0.009	-2.189	ϕ_4	0.059	1.291
ϕ_1	0.003	0.061			

Note: Critical values for the τ-statistic at the 5% and 10% significance levels are 2.4 and 2.8, respectively (Dickey and Fuller, 1981).

Table 3. Grouped Logit Model Parameter Estimates for Proportion of County Land Offered

	MODEL I		MODEL II	
Variable	Parameter Estimate	Elasticity of Probability	Parameter Estimate	Elasticity of Probability
Constant	-14.970*** (1.672)		-9.678*** (2.588)	
Bid Cap ($/acre)	0.037*** (0.002)	3.122	0.027*** (0.002)	2.724
Value of Crops Sold ($/acre)	-0.005*** (0.001)	-0.559	-0.007*** (0.004)	-0.741
Crop Production Costs ($/acre)	0.002* (0.001)	0.262	0.004** (0.002)	0.352
Government Payments ($/acre)	-0.002* (0.001)	-0.239	-0.002* (0.001)	-0.161
Environmental Benefit Index (EBI)	0.009*** (0.001)	0.956	0.006*** (0.001)	0.648
Proportion of Land in LCCs I or II	-0.518*** (0.102)		-0.548*** (0.109)	
Proportion of Cropland Idle	0.030** (0.014)		0.040** (0.018)	
Average Age of Operator (years)	0.041*** (0.012)		0.048*** (0.015)	
Proportion of Land Operated by Full- or Part-Time Owners	6.896*** (1.265)		5.393*** (0.248)	
β	0.102*** (0.012)	5.866	—	—
$\beta/(\beta - 1)$	—	—	-0.027*** (0.008)	-2.359
R^2	0.826		0.830	
Log Likelihood Function	-160.2		-160.1	

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses are standard errors.

The coefficients of both β and $\beta/(\beta - 1)$ are found to be statistically significant at the 1% level, indicating that an increase in uncertainty and irreversibility of the CRP participation decisions represented by a decrease in β or an increase in $\beta/(\beta - 1)$ leads to a decrease in the participation probabilities. The elasticity of probability with respect to $\beta/(\beta - 1)$ is found to be relatively high (-2.36). These results are consistent with findings of other empirical research examining the effects of option values on land use decisions (Schatzki, 1998; Capozza and Li, 1994; Geltner, Riddiough, and Stojanovic, 1996). Based on the results of our analysis, option values play an important role in farmer decisions to retire land, and decrease the probability of farmer participation in the CRP. From these findings, farmers would require a premium over agricultural profits to enroll in the CRP.

This analysis also examines the impacts of various economic factors and socioeconomic variables on the participation probabilities. In both models given in table 3, all the variables considered here are statistically significant. As expected, the bid cap has positive impacts on the participation decisions. The CRP contracts are accepted based on a bid cap which is calculated in advance of enrollment. The bid cap is included to explain participation decisions because it influences the rental rates received and participation decisions of farmers. The probability is elastic with respect to the rental bid. The respective elasticities of the bid cap for Models I and II are 3.12 and 2.72.

An increase in agricultural benefits from crop production is expected to decrease the probability of participation in the CRP because it increases the opportunity costs of participation in the program. In the model, this corresponds to increases in the value of crop production or decreases in the crop production costs. The negative coefficients for the value of crop production and the positive coefficients for the production costs (table 3) are consistent with these interpretations. These findings suggest increases in the value from crop production and/or decreases in the production costs will likely reduce the probability of participation in the CRP. However, the probabilities are found to be inelastic with respect to the value of crop production and the production costs. The respective estimated elasticities of the value of crop production for Models I and II are -0.56 and -0.74, and the corresponding estimated elasticities of probability with respect to the production costs are 0.26 and 0.35.

Government payments are also included as a measure of the opportunity costs of enrollment in the CRP. The negative and statistically significant coefficient for this variable reveals that government payments received by farmers, other than the CRP payments, have a negative impact on the participation decision. This result is reasonable because these payments increase the opportunity costs of crop production, and therefore the opportunity costs of participation in the CRP. However, the participation probability is inelastic with respect to the government payments (table 3), with elasticities of probability found to be -0.24 in Model I and -0.16 in Model II.

As soil quality and environmental quality variables, proportion of the land in Land Capability Classes I and II, proportion of idle cropland, and the Environmental Benefit Index are included in the estimations. LCCs I and II measure the land's suitability for crop production. Higher proportions of land in these categories are expected to lower enrollment in the CRP. The negative coefficients for the proportion of LCCs I and II (table 3) are consistent with this interpretation. The positive coefficient for the proportion of cropland idle indicates that the higher the proportion of idle cropland in a county, the higher is the probability of CRP participation in that county. The idle cropland in a county may be an indicator of the environmental sensitivity of that county's land. Thus, an increase in a county's idle cropland increases the probability of farmer participation in the CRP.

The EBI is included as an environmental quality indicator of a county. Proportion of the land enrolled in the CRP in a county could depend on the EBI rankings of that county because the CRP contracts are selected by taking into account the EBI rankings of the land offered to the CRP. As observed in table 3, the coefficient on the EBI is positive and statistically significant at the 1% level in both models, showing that the higher the EBI, the higher is the probability of participation. This result is consistent with the actual implementation of the program in which contracts are accepted based on the EBI rankings relative to costs. The probability of participation is inelastic with respect to the EBI for both of the estimated models, as indicated by elasticities of 0.96 for Model I and 0.65 for Model II.

The impacts of socioeconomic factors on the participation probabilities are also reported in table 3. Older farmers are expected to participate more in the CRP as a means of partial retirement. It is also reasonable to expect that counties with higher proportions of full- or part-time landowners have higher participation rates. These expectations are consistent with the results obtained from the estimated models, i.e., older farmers and higher proportions of land operated by part- or full-time owners have higher participation probabilities. These results are consistent with findings reported by other studies examining the factors affecting participation in the CRP and wetland reserve programs (McLean, Hui, and Joseph, 1994; Kalaitzandonakes and Monson, 1994; Parks and Kramer, 1995).

We tested the potential endogeneity of some of the variables used in the estimations of Model I and Model II. The estimated coefficients on the residuals for several independent variables are reported in table 4. The null hypothesis of exogeneity cannot be rejected for any of the variables tested. To test the stability of the option-value parameter in the estimated models, results of several alternative models are provided in table 5. We kept the parameter $\beta/(\beta-1)$ in the model and dropped some of the important variables from Model II to determine whether the sign and significance of the coefficient on this variable would change. These alternative models (Models III, IV, V, VI, and VII) found that the parameter estimates for $\beta/(\beta-1)$ are quite stable. The impact of uncertainty and irreversibility on farmer participation appears to be reasonably robust to alternative specifications.

Conclusions

This study has examined the factors affecting farmer participation in the CRP under uncertainty and irreversibility. It incorporates option values into land retirement decisions to determine whether uncertainty and irreversibility characteristics of the CRP affect the probability of participation. The empirical application of the model incorporates land benefits, land attributes, owner characteristics, and uncertainty associated with crop production and the CRP rental payments. The analysis contributes to the literature on CRP participation by incorporating uncertainty and irreversibility in estimation of the participation probabilities, and on the theory of irreversible investment under uncertainty by providing a framework for ex post analysis of uncertainty and irreversibility.

Results show that uncertainty and irreversibility of the CRP impact farmers' participation decisions. Option values play a significant role in farmer decisions to retire land and reduce the probability of farmer participation. Additionally, land benefits, land attributes, and farmer characteristics have significant impacts on the participation probabilities. The bid cap set has a positive impact on the CRP participation decision. Increases in production costs and/or decreases in crop revenues have positive impacts

Table 4. Endogeneity Tests for Selected Variables Used in the Estimations of Model I and Model II

	Model I		Model II	
Variable	Parameter Estimate	*P*-Value	Parameter Estimate	*P*-Value
Value of Crops Sold ($/acre)	-0.007 (0.010)	0.520	-0.006 (0.010)	0.562
Crop Production Costs ($/acre)	-0.002 (0.014)	0.875	-0.002 (0.014)	0.868
Environmental Benefit Index (EBI)	0.039 (0.035)	0.338	0.019 (0.037)	0.587
β	0.006 (0.010)	0.562	—	—
$\beta/(\beta - 1)$	—	—	-1.775 (1.872)	0.459

Note: Values in parentheses are standard errors.

Table 5. Grouped Logit Model Parameter Estimates of Alternative Specification of Model II for Proportion of County Land Offered

	Parameter Estimate				
Variable	Model III	Model IV	Model V	Model VI	Model VII
Constant	-9.315*** (1.561)	-12.087*** (1.669)	-9.562*** (1.678)	-9.964*** (1.659)	-3.008** (1.496)
Bid Cap ($/acre)	—	0.017*** (0.001)	0.017*** (0.002)	0.016*** (0.002)	—
Value of Crops Sold ($/acre)	-0.007*** (0.002)	—	-0.007*** (0.001)	-0.009*** (0.0005)	—
Crop Production Costs ($/acre)	0.005*** (0.001)	0.009* (0.005)	—	0.007* (0.004)	0.010*** (0.003)
Government Payments ($/acre)	-0.006** (0.003)	-0.004** (0.002)	-0.004** (0.002)	-0.002 (0.002)	-0.001 (0.001)
Environmental Benefit Index (EBI)	0.014*** (0.001)	0.006*** (0.001)	0.015*** (0.002)	—	—
Proportion of Land in LCCs I or II	-0.142 (0.109)	-0.521*** (0.104)	0.125 (0.110)	-0.192* (0.109)	-0.728*** (0.108)
Proportion of Cropland Idle	0.058*** (0.013)	0.075*** (0.015)	0.037** (0.016)	0.062*** (0.015)	0.077*** (0.012)
Average Age of Operator (years)	0.011 (0.009)	0.129*** (0.011)	0.022** (0.010)	0.054*** (0.012)	0.015 (0.009)
Proportion of Land Operated by Full- or Part-Time Owners	3.516*** (0.836)	4.773*** (0.856)	3.444*** (0.947)	3.324*** (0.924)	1.513 (0.922)
$\beta/(\beta - 1)$	-0.033*** (0.009)	-0.023** (0.010)	-0.030*** (0.009)	-0.029*** (0.009)	-0.018* (0.010)
R^2	0.69	0.71	0.71	0.66	0.62
Log Likelihood Function	-176.9	-177.6	-176.0	-180.1	-183.4

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses are standard errors.

on the decision to participate. Lands with higher EBI have a higher probability of participation. Counties with higher proportions of cropland suitable for crop production tend to have lower enrollment in the CRP. Counties with higher proportions of landowners have higher participation rates. Older farmers also tend to participate more in the CRP than younger farmers.

Public policies are increasingly relying on the use of land retirement and conversion programs to achieve environmental policy goals. The results from this study have implications for the design of conservation programs promoting shifts in behavior and development of estimates of environmental program performance. Program design should consider the effects of sunk costs to participants and uncertainty about outcomes on participation decisions. Incorporating uncertainty and irreversibility in analyzing conservation programs is important not only for the design of appropriate incentive payments, but also for examining costs and benefits of such programs. Success of land retirement programs depends on appropriate design of land rental payment and environmental benefit instruments as well as effectively targeting environmentally sensitive cropland.

While the CRP has made contributions in improving the quality of natural environments, it has not been very effective in targeting environmentally sensitive cropland (U.S. General Accounting Office, 2002, p. 14), and some states in the Northeast region have experienced relatively low enrollment rates. Supplementary programs such as the continuous CRP have also been established to target specific environmental concerns such as improving water quality and wildlife by offering additional financial incentives to landowners for establishing conservation practices (Smith, 2000). These programs are considered to be more effective than the general CRP in addressing environmental concerns. Nevertheless, as of October 2001, enrollment in these programs was very low in many states, accounting for less than 5% of the authorized CRP enrollment (U.S. General Accounting Office, 2002, p. 14). In environmentally sensitive regions, providing financial incentives in addition to the land rental payments to landowners would help increase participation in these programs. This is consistent with the recent changes made in the program design, which include offering additional economic incentives for landowners to enroll highly sensitive cropland.

The results from this investigation also underscore the importance of incorporating uncertainty and irreversibility into cost-benefit analyses of conservation programs. This inclusion is important because the option values affect participation probabilities, which would modify the cost-benefit analysis of the program. Incorporating option values into the cost-benefit analysis may provide more realistic assessments of policy performance.

The model of irreversible investment under uncertainty appears to explain farmer participation decisions in the CRP in a satisfactory way, both from an economic and a statistical point of view. The theory of irreversible investment under uncertainty may become a useful tool for empirical investigations of various economic and social problems. Up to now, it has been frequently used in ex ante simulations, but seldom as a basis of econometric models in ex post analysis of uncertainty and irreversibility. Further research in this area is needed to incorporate many important features of the theory of irreversible investment and various sources of uncertainty into the estimation of behavioral econometric models. Future research should also consider whether option values are likely to have an important role in other land use decision making and environmental performance evaluations.

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Appendix: Determination of Farmer's Optimal Annual Threshold Rental Payment

The farmer's participation decision in the CRP is modeled by determining the annual threshold rental payment at which it is optimal to participate in the CRP. Let V_0^* represent this threshold value, which triggers farmer participation at year zero. The value of the option to participate in the CRP ($F(V, \pi)$) depends on both π and V. Since there is no uncertainty about the restoration costs K, both π and $C(\pi, K)$ have the same parameters of a geometric Brownian process.

Dynamic optimization techniques are used to derive the participation threshold (as in Dixit and Pindyck, 1994). The Bellman equation is expressed as:

$$\text{(A1)} \qquad \rho F(V, \pi)dt = E[dF(V, \pi)].$$

Using Ito's lemma to expand the right-hand side (dF) of equation (A1), $F(V, \pi)$ can be shown to satisfy the following differential equation:

$$\text{(A2)} \qquad 0.5\left(\sigma_V^2 V^2 F_{VV} + 2\gamma\sigma_V\sigma_\pi V\pi F_{V\pi} + \sigma_\pi^2\pi^2 F_{\pi\pi}\right) + \alpha_V V F_V + \alpha_\pi \pi F_\pi - \rho F = 0,$$

where F_π and $F_{\pi\pi}$ are the derivatives of $F(V, \pi)$ to π. This partial differential equation is solved subject to the boundary conditions:

$$\text{(A3a)} \qquad F(V, \pi) = R(V) - C(\pi, K),$$

$$\text{(A3b)} \qquad F_V(V, \pi) = R_V(V) = \left(\frac{\left(1 - e^{-\rho\overline{T}}\right)}{\rho}\right),$$

$$\text{(A3c)} \qquad F_\pi(V, \pi) = C_\pi(\pi, K) = -1.$$

It is difficult to solve the partial differential equation in (A2) with respect to (A3) because it depends on both π and V. However, it would be easier to solve the problem in one dimension. Reducing the problem to one dimension leads to an ordinary differential equation and makes it possible to derive analytical results.

Assume that the optimal decision depends on the ratio, $v \equiv V/C(\pi, K)$. The value of the option should be homogeneous of degree 1 in (π, V). We then can write $F(V, \pi) = C(\pi, K)f(v)$, where f is the function to be determined. Differentiating $F(V, \pi)$ with respect to π and V, and substituting the related terms into (A2) leads to the following ordinary differential equation:

(A4) $$0.5\left(\sigma_V^2 - 2\gamma\sigma_V\sigma_\pi + \sigma_\pi^2\right)v^2 f_{VV}(v) + (\alpha_V - \alpha_\pi)v f_v(v)\beta - (\rho - \alpha_\pi)f(v) = 0.$$

This differential equation is solved with respect to a value-matching condition and two smooth-pasting conditions:

(A5a) $$f(v) = v\Bigg/\left(\frac{\left(1 - e^{-\rho\overline{T}}\right)}{\rho}\right) - 1,$$

(A5b) $$f(v) = 1\Bigg/\left(\frac{\left(1 - e^{-\rho\overline{T}}\right)}{\rho}\right),$$

(A5c) $$f(v) - v f_v(v) = -1.$$

Solving the partial differential equation in (A4) with respect to the boundary conditions given in (A5) leads to the threshold ratio of the land rental payment to the agricultural returns from crop production at which it is optimal to participate in the CRP program:

(A6) $$v^* = \frac{V_0^*}{C(\pi, K)} = \left(\frac{\beta}{\beta - 1}\right)\left(\frac{\rho}{\left(1 - e^{-\rho\overline{T}}\right)}\right).$$