ABSTRACT

BRIMLOW, JACOB NATHANIEL. The Determinants and Effects of Enrollment in the USDA Conservation Reserve Program. (Under the direction of Dr. Paul L. Fackler and Dr. Roger H. von Haefen.)

This dissertation is a series of three essays exploring the determinants and effects of enrollment in the United States Department of Agriculture's (USDA) Conservation Reserve Program (CRP). The CRP is the United States' largest federal conservation program, currently enrolling over 34 million acres of productive cropland. The CRP pays landowners to idle productive cropland by replacing crops with approved covers such as native grasses or trees. The CRP has a large and wide-ranging impact on both CRP and non-CRP land through its effects on farm profits and farm and non-farm economies, and enlightened CRP policy requires understanding of the determinants of CRP enrollment as well as the magnitude of its effects.

In the first essay I use a stochastic dynamic programming framework to construct an options model of CRP enrollment that characterizes landowner decisions to enroll in the CRP in terms of a threshold value of current agricultural returns. The model predicts changes in enrollment choices due to differences in market uncertainty and individual-specific risk aversion, and to changes in policy variables such as the length of CRP contracts and the frequency of sign-ups. The model predicts that landowner decisions to enroll in the CRP are significantly affected by variables absent from previous options models, and provides more realistic counterfactual policy analysis that provides policy makers with *ex ante* insight into possible changes to the CRP.

In the second essay I estimate the determinants of CRP enrollment using a parcel-level empirical model and Minnesota farmland data. The parcel-level data represent a significant improvement in data resolution over previous studies. I address specification concerns by including non-CRP government payments and a uniquely comprehensive index of land productivity, and use a censored normal regression framework to accommodate censoring in the participation data. All model specifications suggest a negative and statistically significant association between CRP enrollment and land productivity at the parcel level.

In the third essay I estimate the effect of the CRP on county land values to gain insight into the sign and magnitude of the effects of CRP enrollment on CRP and non-CRP land. I present a new estimation strategy designed to overcome the confounding effects of unobserved land characteristics that affect both CRP and land value. I use landowner estimates of county-level land value reported during the 1997 Census of Agriculture and county CRP bidding and enrollment data from CRP Sign-up 15 in 1997. My results are encouraging, suggesting that the estimation strategy is able to significantly reduce endogeneity bias, and suggest that the effects of CRP enrollment are positive and potentially large.

The Determinants and Effects of Enrollment in the USDA Conservation Reserve Program

by
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DEDICATION

To my family,

especially my parents.

BIOGRAPHY

Born unexpectedly early on May 30, 1974, in the biggest little city in Nevada, Jake Brimlow was raised in the foggy forests of the northern California coast. In 1998, after a decadent undergraduate career, Jake graduated from California State University, Chico with a Bachelor of Arts in Economics. Yet to realize his passion for agricultural and environmental economics, Jake worked for several years in the hospitality industry and as an acquisitions officer in a small capital company.

A nagging interest in conducting original research and teaching at the college level forced Jake to pursue graduate education. He accepted a National Needs Fellowship through the United States Department of Agriculture in 2003 for graduate study at North Carolina State University. During his time at NCSU, Jake taught undergraduate courses and spent summers in Washington, D.C. and Bozeman, Montana pursuing both professional and personal interests, sometimes in that order. He was stung by a scorpion fish on a Caribbean island, witnessed the thrill of victory and agony of defeat at Carter Finley stadium, and was given a graduate school beatdown. Jake also spent considerable time enjoying North Carolina barbeque, southern drawls, and fireflies.

Most recently, Jake has been refining his teaching skills as a Visiting Instructor in the Department of Economics at Wake Forest University, but he can also be found cycling, hiking, cooking, and traveling whenever possible. Jake will continue his academic career by returning to Northern California and his alma mater as an Assistant Professor in the College of Agriculture at California State University, Chico.

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Chapter 1

Introduction

Offering payments for voluntary land use restrictions has become a popular way of conserving ecosystem services from agricultural land. The ecosystem services provided by conserved agricultural land include habitat, air and water quality enhancements, and carbon sequestration. The 2007 Farm Bill authorized payments to secure over 40 million acres in voluntary land use restrictions. The largest federal conservation program, the United States Department of Agriculture's (USDA) Conservation Reserve Program (CRP), currently enrolls over 34 million acres (roughly the size of Wisconsin) of productive cropland. The CRP pays landowners to idle productive cropland by replacing crops with approved covers such as native grasses or trees. CRP payments are public purchases of ecosystem services, including crop production capacity and habitat conservation, from private landowners. The budget of the CRP is larger than the US Environmental Protection Agency's Superfund program; the CRP paid enrolled landowners over $1.8 billion for contracts active in 2008 [USDA, 2007]. This dissertation is a series of three essays exploring the determinants and effects of enrollment in the CRP.

There is evidence that the CRP has had mixed success in meeting its enrollment and environmental outcome goals [Claassen et al., 2001, Yang et al., 2005]. Predicting landowner decisions to enroll in the CRP is difficult because of the complexity of the enrollment decision, which includes stochastic agricultural prices, irreversible and postponable enrollment, and uncertainty about eligibility requirements, sign-up dates, and the existence of the CRP. Previous studies provide deterministic and stochastic models of landowner decisions to enter CRP, and some provide *ex-post* empirical estimates of the determinants of enrollment [Plantinga et al., 2001, Parks and Schorr, 1997, Konyar and Osborn, 1990, Cooper and Osborn, 1998, Brimlow, 2009, Isik and Yang, 2004]. Considering the evidence and the size of the CRP, research providing *ex-ante* information about landowner responses to counterfactual CRP policy changes would be valuable. Even when comparable policies exist, the lack of data on counterfactual policy impacts and the complexity of the problem often prohibit empirical predictions about landowner responses to changes in the CRP.

In Chapter 2 I use a stochastic dynamic programming framework to construct an options model of CRP enrollment that characterizes landowner decisions to enroll in the CRP in terms of a threshold value of current agricultural returns. The model predicts changes in enrollment choices due to differences in market uncertainty and individual-specific risk aversion, and to changes in policy variables such as the length of CRP contracts and the frequency of sign-ups. The options approach to modeling the CRP enrollment decision is desirable because it accounts for market and institutional uncertainty, and for the irreversible and postponable nature of the enrollment decision. When calibrated using parameter values found in the literature, the model predicts that landowner decisions to enroll in the CRP are significantly affected by variables absent from previous options models including risk aversion, mean-reverting agricultural returns, and uncertain CRP sign-up frequency. Further, the model provides more realistic counterfactual policy analysis of contract lengths and payment levels that provides policy makers with *ex ante* insight into possible changes to the CRP.

Understanding the determinants of CRP enrollment is important for policy decisions as well as for the estimations of the effects of CRP enrollment on CRP and non-CRP land. Previous empirical studies indicate that land quality, payments, and landowner characteristics affect CRP enrollment decisions [Konyar and Osborn, 1990, Parks and Schorr, 1997, Parks and Kramer, 1995, Isik and Yang, 2004, Goodwin and Smith, 2003]. The estimates, however, were generated in studies that differ in geographic location, empirical approach, and qualitative results, offering little to no consensus. Motivated by a parcel-level structural model of landowner enrollment in the CRP, in Chapter 3 I estimate the determinants of CRP enrollment using a parcel-level empirical model and data on Minnesota farmland parcels. The parcel-level data represent a significant improvement in data resolution over previous studies, allowing the determinants of enrollment in the CRP to be estimated closer to the resolution at which those decisions occur. I address specification concerns by including non-CRP government payments and a uniquely comprehensive index of land productivity, and use a censored normal regression framework to accommodate censoring in the participation data. All model specifications suggest a negative and statistically significant association between CRP enrollment and land productivity at the parcel level.

Considering its size, the costs and benefits of CRP enrollment may be large, and include effects on both CRP and non-CRP acreage. The CRP provides yearly, per acre payments to landowners in return for idling productive cropland, so the program can affect enrolled land value directly through payments to enrolled landowners. Changes in land use patterns, farming economies, commodity prices, and ecosystem service flows induced by the CRP generate additional, and potentially more significant, positive or negative CRP enrollment effects [Sullivan et al., 2004, Wu, 2000, Roberts and Bucholtz, 2005, Claassen et al., 2001]. Asset valuation theory predicts that economic profits or losses generated by CRP enrollment will be reflected in enrolled land values, but obtaining estimates of the effects of CRP enrollment using comparisons of land values is difficult. Because I do not observe the counterfactual world where the CRP does not exist, I cannot observe what land values would have been in the absence of the CRP. Consequently, estimation of the effect of CRP involves imperfect comparisons of, for example, the value of land where CRP enrollment is *more* prevalent to the value of land where CRP enrollment is *less* prevalent. These comparisons, however, may not be valid because of unobservable land quality characteristics that affect both land value and CRP enrollment.

In Chapter 4 I estimate the effect of the CRP on county land values to gain insight into the sign and magnitude of the effects of CRP enrollment on CRP and non-CRP land. I present a new estimation strategy designed to overcome the confounding effects of unobserved land characteristics that affect both CRP and land value. My estimation strategy uses the CRP's sign-up mechanism to construct variation in CRP enrollment that is independent of the confounding land characteristics that have led to counterintuitive results in previous studies. I use landowner estimates of county-level land value reported during the 1997 Census of Agriculture and county CRP bidding and enrollment data from CRP Sign-up 15 in 1997. My results are encouraging, suggesting that the estimation strategy is able to significantly reduce endogeneity bias. The standard errors are high, but my estimates suggest that the direct and spillover effects generated by marginal increases in the share of county land enrolled in the CRP are positive and potentially large.

Chapter 2

An Options Model of Enrollment in the Conservation Reserve Program

2.1 Introduction

The largest federal conservation program, the United States Department of Agriculture's (USDA) Conservation Reserve Program (CRP), paid over $1.8 billion in 2008 for contracts implementing 30 approved practices aimed at reducing soil erosion, enhancing water quality, and expanding and improving wildlife habitat and wetlands [USDA, 2007]. The CRP provides payments to landowners to idle productive cropland by replacing crops with approved covers such as native grasses or trees for ten to fifteen years. Landowners are voluntarily idling over 34 million acres of cropland under active CRP contracts, a land area roughly the size of Wisconsin.

The CRP was established in 1986 primarily as a supply and erosion control program, but amendments have transformed it into a program focused on the preservation of environmental services from cropland. The environmental benefits generated by the CRP are estimated to outweigh its costs [Feather et al., 1999], but there is evidence that the CRP has had mixed success in meeting its enrollment and environmental outcome goals [Claassen et al., 2001, Yang et al., 2005]. As an evolving and voluntary environmental program, the success of the CRP relies on understanding landowner decisions to enroll. Previous studies provide deterministic and stochastic models of landowner decisions to enter CRP, and some provide *ex-post* empirical estimates of the determinants of enrollment [Plantinga et al., 2001, Parks and Schorr, 1997, Konyar and Osborn, 1990, Cooper and Osborn, 1998, Brimlow, 2009, Isik and Yang, 2004]. Considering the evidence and the size of the CRP - the yearly CRP budget is larger than that of the EPA's Superfund program - research providing *ex-ante* information about landowner responses to counterfactual CRP policy changes would be valuable.

Stochastic agricultural prices, irreversible and postponable enrollment, and uncertainty about eligibility requirements, sign-up dates, and the continuation of the CRP combine to create a complex decision problem. Even when comparable policies exist, the lack of data on counterfactual policy impacts and the complexity of the problem often prohibit empirical predictions about landowner responses to changes in the CRP. This chapter constructs a model that characterizes landowner decisions to enroll in the CRP in terms of a threshold value of current agricultural returns. The model predicts changes in enrollment choices due to differences in market uncertainty and individual-specific risk aversion, and to changes in policy variables such as the length of CRP contracts and the frequency of sign-ups. Using a stochastic dynamic programming framework, I construct a model that accounts for market and institutional uncertainty, and for the irreversible and postponable nature of the CRP enrollment decision, to provide insight into enrollment under varying market conditions and counterfactual policy scenarios.

The chapter proceeds as follows: the next section describes the stochastic dynamic control framework used to characterize landowner decisions to enroll in CRP; this is followed by a section establishing base case parameter values and an analysis of the sensitivity of decisions to different individual-specific and market parameters; the next section explores the effects of variables chosen by CRP policymakers including the length of contracts and the frequency of sign-ups; the final section concludes and offers thoughts for future work.

2.2 CRP Enrollment Model

2.2.1 Modeling Context

The importance of including the effects of uncertainty, irreversibility, and the ability to wait in models of land value and land use is well established in the literature [Titman, 1985, Quigg, 1993, Parks, 1995, Collins and Hanf, 1998, Forsyth, 2000, Plantinga and Lubowski, 2002, Schatzki, 2003]. Titman [1985] demonstrates the importance of viewing use rights as irreversible options on real assets in a model of urban land prices that explains the presence of vacant lots in downtown Los Angeles. Clark and Reed [1988] find that uncertainty affects the value of vacant land proportionally more than that of developed land due to the remaining option to develop. Quigg [1993] analyzes property values in Seattle, finding empirical support for an *option premium* where delayed development is possible and uncertainty is present. Cunningham [2006] finds similar evidence that uncertainty creates an option premium and that options increase land prices on Seattle's rural/urban fringe. The importance of option values in agricultural land prices is shown by Plantinga and Lubowski [2002], who find evidence that option values are capitalized into agricultural land values in the U.S.

The real options framework has also been applied to rural land use decisions. Conrad [1997] examines the value of an old growth forest using a model in which the future value of timber is known but non-timber amenity values evolve according to a geometric Brownian motion process. Forsyth [2000] uses a mean reverting process to show that the results of Conrad's model are sensitive to the specification of the stochastic process driving amenity value. Wiemers and Behan [2004] employ a real options model to explain the observed reluctance of farmers to switch to forestry in Ireland, and Behan et al. [2006] use the model to motivate an empirical analysis of the response of Irish farmers to a national farm forestry incentive program. Property value and development decision impacts of impending land use regulation are examined by Riddiough [1997], who finds that credible threats of regulatory takings lead to substantial decreases in property value and increase the probability of development. Malchow-Moller et al. [2004] investigate adjacency constraints in forest harvest decisions using a stylized two-sided optimal stopping model, finding that uncertainty significantly increases the cost of adjacency constraints to landowners. Schatzki [2003] uses an options model to incorporate the effects of uncertainty and sunk costs on landowner decisions to convert land from agriculture to forestry. Under different assumptions about the process governing agricultural and forestry returns, including geometric Brownian motion and mean-reversion, the author finds empirical evidence that the value of the option to convert affects the level of returns at which landowners choose to convert between uses.

On the urban fringe, conservation programs compete with both development and farm uses. Tegene et al. [1999] and Brimlow et al. [2008] use options analysis to examine landowner decisions to voluntarily enroll in land conservation programs when there is an amenity return to land and development is a competitive alternative. Their models include stochastic returns to development and deterministic amenity flows and conservation payments.

Much of the land eligible and likely to enroll in the CRP is rural cropland with low development value. In this case, conservation program payments compete with uncertain agricultural production returns. The decision facing rural landowners between uncertain agricultural production returns and certain payments from a conservation program such as the CRP has not been explored to the same extent as decisions in the presence of development pressure. Isik and Yang [2004] motivate an empirical analysis of the determinants of CRP enrollment using a two-factor real options model with stochastic agricultural returns and CRP payments. The authors find that the option value associated with the irreversible, postponable decision to enter the CRP is a significant determinant of enrollment decisions. In this chapter, I present a model that differs from Isik and Yang [2004] in several ways. First, CRP payments are treated as fixed, but the model accounts for non-continuous CRP sign-ups and the positive probability that the CRP may be discontinued. Second, the model accounts for the fact that landowners who enroll in the CRP regain the ability to enroll or to produce in agriculture when their contract period ends; the value of this opportunity in the future may be large, and will vary with the length of a CRP contract. The model presented below values the future choice to enroll in CRP or produce in agriculture, allowing analysis of the effect of CRP contract length, a policy choice variable, on the value of the future option to enroll. Third, the model incorporates risk aversion. Theoretical and empirical work recognize the importance of including risk attitudes in characterizations of conservation enrollment decisions [Latacz-Lohmann and Van der Hamsvoort, 1997, Williams et al., 2009], and Isik [2004] and Isik and Khanna [2003] incorporate risk aversion into options models and landowner choices to adopt site specific technologies. Risk aversion is likely to play an important role in CRP enrollment decisions because the decision to enroll involves swapping an uncertain payment (agricultural returns) for a certain one (CRP).

2.2.2 Model

Landowners bid to enroll in the CRP by offering to place eligible land in an approved conservation practice in return for yearly, per-acre payments. Payments are limited by soil-specific maximums and remain fixed after being set at the beginning of each contract. In general, eligibility for the CRP requires that 1) landowners own and operate the land they offer, 2) land has been cropped in three of the five years prior to enrollment, and 3) land meets an environmental criteria set by the Farm Service Agency (FSA).

Landowners make decisions that maximize the utility received from land over available land-use strategies. Denoting yearly, per-acre CRP payments R, the decision facing landowners when CRP sign-ups occur is to enroll in the CRP for R dollars per year for a binding[1] contract period of h years, or to delay the enrollment decision and continue to collect a stochastic return A, where A represents the net returns to an acre of agricultural land. I assume A follows the mean-reverting Ornstein-Uhlenbeck (O-U) process

$$dA = \theta(\bar{A} - A)dt + \sigma dW,$$

where $\theta > 0$ is the rate of mean reversion, $\bar{A}$ is the long-run mean of the net agricultural returns, σ is the diffusion parameter, and dW is an increment of a standard Wiener process. In contrast to the non-stationary Geometric Brownian Motion process used for agricultural returns in previous studies (made, in part, because of its analytical tractability [Isik, 2001, Isik and Khanna, 2003, Schatzki, 2003]), the O-U process is stationary: agricultural returns tend toward the long run mean, $\bar{A}$. A mean-reverting process is an appropriate representation of net returns from agriculture if supply responses to market shocks in agricultural markets are sufficient to force agricultural returns toward a long run mean. Schatzki [2003] and Isik and Yang [2004] cannot reject the null hypothesis of non-stationarity using augmented Dickey-Fuller tests, but Schatzki [2003] notes that data requirements likely render the tests inconclusive. Bessembinder et al. [1995] find empirical evidence of expected mean reversion in the term structure of agricultural futures prices. Evidence suggests that the choice of stochastic process is an important determinant of the quantitative implications of options models of land use, but that qualitative results are generally consistent across processes [Schatzki, 2003, Insley, 2002, Isik, 2001].

I characterize landowner decisions to enroll in CRP in terms of a threshold of

[1] Early exit from the CRP is expensive; landowners must repay all payments received, and incur additional penalties.

agricultural returns, A^*, at which landowners will choose to retire land from agriculture to enroll in the CRP for a known payment of R per year. When a sign-up occurs, landowners will continue in agriculture if the observed return is greater than the threshold, $A > A^*$, and enroll in the CRP if $A \leq A^*$. I develop a stochastic dynamic programming model to find A^* for a given CRP payment by considering the value of agricultural land under three scenarios: (1) the CRP is available and a sign-up is occurring, (2) the CRP is available but a sign-up is not occurring, and (3) the CRP has been discontinued. In the first scenario, landowners face an immediate decision between conservation and agriculture. They can choose to enroll in an h year CRP contract for R per year, or they can choose to wait, continuing to collect the uncertain agricultural return, A, and holding the option to enroll in the CRP in the future. The second and third scenarios differ by the existence of the option to enroll; if the CRP exists, the value of land is increased by the value of the opportunity (but not the requirement) to enroll in CRP [Dixit and Pindyck, 1994].

I incorporate two additional sources of uncertainty due to the institutional structure of the CRP: the timing of sign-ups and the existence of the CRP. There are two types of CRP enrollment, continuous and general, with different eligibility criteria and enrollment mechanisms. Continuous sign-ups target high priority land and land use practices, and landowners who meet continuous sign-up eligibility criteria can enroll at any time without competition. General sign-ups, which enroll the vast majority of CRP acreage - over 30 million of the 34.7 million total acres enrolled in CRP in 2008 were enrolled in general sign-ups - have broader eligibility criteria, but occur less frequently, and enrollment is competitive. Since 1990, bids entered during general CRP sign-ups have been scored and ranked by the FSA according to five environmental factors and one cost factor, composing the Environmental Benefits Index (EBI).[2] Acres enrolled through continuous sign-ups do not go through the same competitive EBI bidding process as acres enrolled during general sign-ups [USDA, 2007].

[2] Appendix A contains brief descriptions of the six EBI factors.

I use a Poisson process with intensity η to represent uncertainty about CRP sign-ups. Therefore, the probability a sign-up occurs by time t is $1 - e^{-\eta t}$. Higher values of η correspond to more frequent sign-ups, and large η approximate nearly continuous enrollment. In addition to reflecting expectations about the frequency of CRP sign-ups, the intensity η could also be thought of as reflecting individual landowners' expectations about their eligibility for the CRP; possible revision of CRP program goals creates uncertainty about the characteristics and location of land targeted by the CRP enrollment mechanism.

The second source of institutional uncertainty is that the CRP may be discontinued due to changes in budgets, politics, or federal conservation priorities. I use a second Poisson process with intensity λ to govern the probability the CRP is discontinued; increases in λ increase the probability that the CRP will be discontinued. I assume landowners who enter the CRP receive payments for the duration of the contract length, h, even if the CRP is discontinued, but uncertainty about CRP sign-ups and enrollment availability affect the decisions of landowners by increasing the expected cost of waiting and decreasing the expected value of the option to re-enroll in the CRP after completing an h year contract.

Let $V(A)$ be the value of an acre of land when the CRP program exists but a sign-up is not occurring, and assume landowners receive utility from monetary returns to agriculture or the CRP according to a utility function denoted by $U(.)$. Assuming landowners discount the future at rate r, the required return on land, $rV(A)$, must equal the flow rate of return, U(A), plus the rate of change of the expected value of $V(A)$ over time, $dE[V(A)]/dt$, to prevent arbitrage opportunities. Therefore, $V(A)$ satisfies the Bellman equation

$$
\begin{aligned}
rV(A) &= U(A) + dE[V(A)]/dt \\
&= U(A) + \theta(\bar{A} - A)V'(A) + \frac{\sigma^2}{2}V''(A) + \\
&\qquad \lambda(V_0(A) - V(A)) + \eta(\max(V_C(A,R) - V(A), 0)), \qquad (2.1)
\end{aligned}
$$

where V_0 is the value of the land when the CRP does not exist, and V_C is the value of land when it is enrolled in the CRP. The first three terms on the right side of equation 2.1 are the utility derived from the the flow rate of A, $U(A)$, and the expected change in $V(A)$ due to the dynamics of A, a consequence of Ito's Lemma [Pindyck, 1991]. The additional terms, $\lambda(V_0(A) - V(A))$ and $\eta(\max(V_C(A,R) - V(A), 0))$, account for changes due to the possibility that the CRP is discontinued or a sign-up occurs, respectively. Each term is found by multiplying the intensity of the event (CRP sign-up occurs, CRP discontinued) by the value of the land after the event occurs minus the value before the event occurs. For example, the value of the land if a CRP sign-up occurs is the value of the land if it is enrolled in the CRP or the value if it is not, whichever is larger, $\max(V_C(A,R), V(A))$. The value of the land if a CRP sign-up is not occurring is V(A). The intensity driving CRP sign-ups is η, so the appropriate term for including sign-up uncertainty in the Bellman equation is $\eta(\max(V_C, V) - V)$ $= \eta(\max(V_C - V, 0))$.

The value of the land when the CRP does not exist, V_0, is the expected value of the utility derived from a perpetual flow of agricultural returns,

$$V_0(A) = E\left[\int_0^\infty e^{-rt}U(A_t)\,dt | A_0 = A\right].$$

The value of land when enrollment occurs, V_C, is a combination of the present discounted value of the utility derived from the h-year stream of CRP payments and the present discounted value of the expected value of land when the landowner exits the CRP in h years,

$$\begin{aligned}V_C(A,R) &= (1-e^{-rh})\frac{U(R)}{r} + \\ &\qquad e^{-rh}\left((1-e^{-\lambda h})E\left[V_0(A_{t+h})|A_t=A\right]\right) + \\ &\qquad\quad e^{-rh}\left(e^{-\lambda h}E\left[V(A_{t+h})|A_t=A\right]\right), \qquad (2.2)\end{aligned}$$

where $U(R)$ is the utility derived from CRP payments, $E\left[V_0(A_{t+h})|A_t\right]$ is the expected value of the land h periods from the date of enrollment if the CRP is discontinued during the h-period contract, $E\left[V(A_{t+h})|A_t\right]$ is the expected value of the land h periods from the date of enrollment if the CRP is still active when the contract ends, and $1-e^{-\lambda h}$ and $e^{-\lambda h}$ are the probabilities the program is discontinued or not discontinued within h periods, respectively. The probabilities are dictated by the Poisson process driving continuation of the CRP and are increasing in both λ and h. I assume that discontinuation of the CRP halts new sign-ups, but does not stop payments to landowners already enrolled.[3]

Equation 2.1 contains a utility function to incorporate the effects of subjective landowner risk preferences on CRP enrollment decisions. Landowners face uncertainty regarding agricultural returns, the existence of CRP, and the frequency of CRP sign-ups, and enrolling in the CRP involves trading uncertain returns from agriculture for certain payments from the CRP. Landowner risk preferences are therefore likely to play an important role in CRP enrollment decisions; all else equal, risk averse landowners will prefer more certain outcomes. Stochastic dynamic programming models can incorporate market risk using risk-adjusted rates of return in place of discount rates [Dixit and Pindyck, 1994], but doing so does not account for landowners' subjective risk aversion. Including a utility function increases the flexibility and

[3]My model does not contain switch costs associated with CRP. Landowners may incur costs to set up conservation practices on their land, and may experience costs associated with returning land to production at the end of a CRP contract. For simplicity, I have not included lump-sum costs associated with entry and exit, but they could be added without changing the structure of the model.

scope of the model and allows analysis of the effect of subjective risk preferences.

Landowners will enroll in the CRP if the value of enrolled land, $V_C(A, R)$, is greater than the value of land not enrolled, $V(A)$, so the decision can be described as

$$\begin{array}{ll} \text{enroll in CRP} & \text{if } V_C(A,R) > V(A). \\ \text{do not enroll} & \text{otherwise.} \end{array}$$

The functional form of the value function when the CRP exists but a sign-up is not occurring, $V(A)$, is not known in closed form, so I use a numerical approximation of $V(A)$ to explore the characteristics of landowner decisions to enroll in the CRP. I use a collocation method, which approximates $V(A)$ for nodal values of A using $V(A) \approx \phi(A)c$, where $\phi(A)$ is a vector of basis functions, and c is an unknown parameter vector. I choose the piece-wise family of basis functions based on the fact that $V(A)$ is not likely to be smooth at the threshold value of A, and approximate $V(A)$ using n nodal values of A over a bounded approximation space. For each value of A, approximating $V(A)$ involves finding the unknown parameter vector c that solves the root-finding problem

$$\begin{array}{l} [(r+\lambda)\phi(A) - \theta(\bar{A} - A)\phi'(A) - \frac{\sigma^2}{2}\phi''(A)]c \\ \qquad -U(A) - \lambda V_0(A) - \eta(\max(V_C(A,R,c) - \phi(A)c, 0)) = 0, \end{array}$$

where

$$V_C(A,R,c) = (1-e^{-rh})\frac{U(R)}{r} + e^{-rh}\left((1-e^{-\lambda h})E\left[V_0(A_{t+h})|A_t\right] + e^{-\lambda h}E\left[V(A_{t+h})|A_t\right]\right).$$

Discontinuation of the CRP, governed by the Poisson jump process with intensity λ, changes the value of land to V_0. This can be thought of as an exogenously imposed change in regime, with the value function in the new regime, V_0, independent of the value of the land when CRP exists. V_0 will satisfy

$$\begin{aligned} rV_0(A) &= U(A) + dE[V_0(A)]/dt \\ &= U(A) + \theta(\bar{A} - A)V_0'(A) + \frac{\sigma^2}{2}V_0''(A), \end{aligned}$$

and can be approximated for each value of A by solving for unknowns d in

$$r\phi(A)d = U(A) + \theta(\bar{A} - A)\phi'(A)d + \frac{\sigma^2}{2}\phi''(A)d, \quad (2.3)$$

where again $\phi(A)$ are piece-wise linear basis functions, and V_0 is approximated over the approximation space using n nodal values of A.

The value of land enrolled in the CRP, $V_C(A, R, c)$, depends on the expected values of V and V_0 h periods in the future, $E\left[V(A_{t+h})|A_t\right]$ and $E\left[V_0(A_{t+h})|A_t\right]$, respectively. I approximate the integrals representing the expected future values using numerical quadrature. I approximate $E\left[V_0(A_{t+h})|A_t\right]$ using

$$E\left[V_0(A_{t+h})|A_t\right] \approx \sum_{i=1}^{m} w_i f(z_i|A_t, h)\phi(z_i)d, \quad (2.4)$$

where m is the order of approximation, z_i and w_i are quadrature nodes and weights chosen using Simpson's rule,[4] $\phi(z)$ are piece-wise linear basis functions evaluated at the m nodes of A representing A_{t+h}, and $f(A_{t+h}|A_t, h)$ is the transition density of A. The O-U process is Gaussian; the transition density of A is normally distributed as

$$f(A_{t+h}|A_t, h) = N(\bar{A} + e^{-\theta h}(A - \bar{A}), (1 - e^{-2\theta h})\frac{\sigma^2}{2\theta}).$$

Because V_0 is independent of V, the d are known from equation 2.3, so $E\left[V_0(A_{t+h})|A_t\right]$ is known. I approximate the expected future value of land when CRP exists, $E\left[V(A_{t+h})|A_t\right]$,

[4] V_0 is a smooth, continuous function, so Simpson's rule is sufficient and computationally inexpensive. The nodes, z are evenly spaced across the interval of approximation for A. The number of nodes necessary to achieve sufficient accuracy varies from case to case; Miranda and Fackler [2002] provide a review of numerical quadrature rules and computational methods.

using

$$E\left[V(A_{t+h})|A_t\right] \approx \sum_{i=1}^{m} w_i f(z_i|A_t, h)\phi(z_i)c,$$

where variables are defined as above.

Inserting my approximations of V_0 into equation 2.2.2 leaves an equation that can be solved for the values of c that provide the best approximation of V. Using the optimized values of c, I find A^*, the threshold agricultural return at which landowners would choose to enter the CRP for a given set of parameter values, agricultural return, A, and CRP payment, R, using

$$\begin{array}{ll} \text{enroll in CRP} & \text{if } (1-e^{-rh})\frac{U(R)}{r}+ \\ & e^{-rh}\left((1-e^{-\lambda h})\sum_{i=1}^{m} w_i f(z_i|A_t=A,h)\phi(z_i)d\right)+ \\ & e^{-rh}\left(e^{-\lambda h}\sum_{i=1}^{m} w_i f(z_i|A_t=A,h)\phi(z_i)c\right) > \phi(A)c, \\ \text{do not enroll} & \text{otherwise.} \end{array}$$

2.3 Analysis

The response of A^* to variation in model parameter values informs policy analysis and offers insight into how landowner decisions may differ across space. I establish a base case by solving for A^* over a range of CRP payment offers, R, using a set of calibrated parameter values. I then explore the sensitivity of CRP enrollment decisions to individual-specific and market parameters, and predict the effects of changes in policy variables including the length of contracts and the frequency of sign-ups. For reference, table 2.1 lists the model parameters and values for the base case and sensitivity analysis.

2.3.1 Base Case Parameters

I establish a base case by calibrating model parameters using available estimates from the literature and institutional details of the CRP. For simplicity, I normalize

Table 2.1: Parameter Values: Base Case/Range

Parameter	Description	Base Case/Range
R	annual per-acre CRP payment	1 / 0.5 - 1.5
$\bar{A}$	mean per-acre net ag. return	1
θ	rate of mean reversion	0.4 / 0.2 - 3
σ	ag. return volatility	0.3 / 0.1 - 0.5
r	discount rate	0.05 / 0.03 - 0.07
γ	coefficient of absolute risk aversion	1.2 / 0.1 - 3
h	CRP contract years	15 / 1 - 30
λ	Poisson intensity, CRP existence	0.02 / 0.001 - 0.1
η	Poisson intensity, sign-up frequency	0.7 / 0.1 - 3

the long run expected flow of returns to agricultural land, $\bar{A}$, to one. Yearly, per-acre payments from CRP, R are scaled to represent proportions of the mean agricultural return, $\bar{A}$. By solving A^* over a range of R from 0.75 to 1.25, I illustrate landowner enrollment decisions when the payments offered by CRP are above, equal to, and below the mean agricultural return, $\bar{A}$. Following Schatzki [2003], Isik and Yang [2004], and Yang and Isik [2004], I set the base discount rate at five percent. I begin with a CRP contract length of 15 years.

Net agricultural returns, A, are determined by the difference between agricultural prices and production costs. The volatility of crop returns and production costs vary across time and by crop, and are at least partially determined by farm policy [Crain and Lee, 1996]. Schatzki [2003] estimates the volatility of a geometric Brownian motion process driving net agricultural returns in Georgia of $0.1-0.2$, and yearly crop price standard deviations reported by the Chicago Board of Trade range between 0.05 and 0.68 for corn, soybeans, and wheat between 1980 and 2007 [CBT, 2009]. Because it is governed by an O-U process, the diffusion of agricultural returns, σ, is related to the long run standard deviation of A by $SD(A) = \sigma\sqrt{\frac{1}{2\theta}}$, where θ is the rate of mean reversion, so standard deviations can be multiplied by $\sqrt{2\theta}$ to convert them to estimates of σ. I use $\sigma = 0.3$ for the base case.

The rate of mean reversion of agricultural returns, θ, determines the persistence of shocks to agricultural prices and production costs. Because I describe agricultural net returns using an Ornstein-Uhlenbeck process, the half-life of a shock to A is $ln(2)/\theta$, where θ is the rate of mean reversion. Bessembinder et al. [1995] use the term structure of futures prices to estimate that approximately one third of a shock to the spot price of wheat is expected to be reversed within a year. This corresponds with a rate of mean reversion near 0.4, which I use as the base case value of θ.[5]

Landowners face uncertainty regarding the existence of the CRP program and the frequency of general CRP sign-ups. The Poisson intensities λ and η can be converted into estimates of the probability that the CRP is discontinued or a CRP sign-up occurs before time t, respectively, using 1 - $e^{-\lambda t}$ and 1 - $e^{-\eta t}$. The Farm Bill provides the CRP with its budget, and a new Farm Bill is passed by Congress about once every five years. Shifting priorities and politics make both funding and eligibility rules uncertain, and farmers likely consider both when making CRP enrollment decisions. For the base case, I set $\lambda = 0.02$, implying that landowners expect a two percent chance the availability of the CRP will change within a year, and a ten percent chance that it will change within five years.

The frequency of CRP sign-ups is governed by η; lower values of η correspond to less frequent sign-ups, potentially increasing the cost of waiting to enroll by not allowing landowners the chance to sign-up at an optimal time. For the base case I use $\eta = 0.7$, indicating that landowners expect a fifty percent chance they will have the opportunity to enroll in the CRP within a year, and a ninety percent chance they

[5]Schatzki [2003] uses an Ornstein-Uhlenbeck process with an assumed rate of mean reversion of 0.25 for agricultural returns; my sensitivity analysis includes this value.

will have an opportunity to enroll within four years.

Because A can take negative values, the utility function must be defined and well behaved for values of A less than one. I use the exponential utility function, a constant absolute risk aversion (CARA) utility function,[6]

$$U(A) = a - be^{-A\gamma}, \tag{2.5}$$

where increased risk aversion is reflected by increased γ, and a and b can be used to scale the function. The exponential utility function will accept negative values of A, and setting $a, b = 1$ causes $U(0) = 0$, and $U(A)$ approaches 1 as A approaches ∞. For $A < 0$, $U(A)$ is not bounded below by negative one, so large negative values of $U(A)$ are possible. For exponential utility, the Arrow-Pratt measure of absolute risk aversion is constant, $-U''(A)/U'(A) = \gamma$. Calibrating γ requires consideration of the scale of A. Because I normalize A to one, previous estimates of the coefficient of absolute risk aversion for farmers must be adjusted accordingly [Raskin and Cochran, 1986]. Adjusted estimates of agricultural landowner risk preferences described by exponential utility in Buccola [1982], Ramaratnam et al. [1986], and Love and Buccola [1991] suggest setting γ between 0.8 and 1.8; I use 1.2 for the base case.

Figure 2.1 illustrates A^* for CRP payment offers, R, between 0.75 and 1.25, over an approximation space for A [7] of [-1, 3], using the base case parameter values: $\bar{A} = 1$, $\theta = 0.4$, $\sigma = 0.3$, $\lambda = 0.01$, $\eta = 0.7$, $\gamma = 1.2$, $r = 0.05$, and $h = 15$. The solid line in figure 2.1 plots the maximum agricultural return, A^*, at which landowners would choose to enroll for a given CRP payment offer, R. For each value of R, an

[6]Saha et al. [1994] find that CARA utility may not be an appropriate representation of landowner preferences; qualitative differences due to the inclusion of risk aversion is the primary reason I include a utility function in the model, and I leave exploration of alternative utility functions to future work.

[7]I base the size of the approximation space on the distribution of A. Because A is governed by an O-U process, the long run standard deviation of A is $\sigma\sqrt{\frac{1}{2\theta}}$, implying a long run standard deviation of 0.34 for the base case parameter values. I chose the approximation space [-1, 3] to includes 4 long run standard deviations above and below the mean for most of the parameter combinations used in the analysis.

agricultural return equal to or below A^* induces enrollment. For example, the base case threshold of A^* in figure 2.1 indicates that a CRP payment offer of one would induce enrollment only if the agricultural return were less than or equal to 0.92. For a 10 percent higher CRP payment offer ($R = 1.1$), a current return equal to 1.16 or less would induce enrollment.

The dashed line in the figure illustrates points where the agricultural return is equal to the CRP payment offer ($A = R$). When the solid line is above the dashed line, $A^* > R$, and for some values of A landowners would be willing to accept a CRP payment offer below the current agricultural return. For example, $A^* = 1.16$ when the CRP payment offer is $R = 1.1$, implying that if the observed agricultural return were 1.16, landowners would be willing to enroll in CRP for a payment below 1.1. Figure 2.1 shows that the difference between A^* and R depends on the value of R; as R increases above 1, the difference between A^* and R increases. For values of R below one, A^* falls farther below R, implying that when $R < 1$, landowners will only enroll in the CRP if observed agricultural values get much lower than the CRP payment offer. This relationship between A^* and R remains fairly consistent as parameter values vary, and is largely explained by the mean reverting nature of agricultural returns.

The model's implications can be interpreted slightly differently to concentrate on policy considerations. Comparing where the threshold for A^* crosses a given value of A shows the lowest CRP payment offer that would induce enrollment at that value of A. For example, if $A = \bar{A} = 1$, the base case model predicts that the minimum payment required to induce enrollment is approximately $R = 1.03$. As the A^* threshold moves, the minimum R required to induce enrollment will change. The long run standard deviation of A for the base case parameters is 0.34, so the long run 95 percent confidence interval for A is 1 +/- 0.67. This interval is useful for long run policy considerations. In the base case, if A^* is below 1.67 for a given CRP payment of R, policy makers setting future enrollment guidelines could expect the average landowner to enroll in the CRP in the long run because there is a 95 percent chance A will be below A^* at some point in the long run. This implies that higher values of R for which A^* is above 1.67 have nearly the same probability of inducing enrollment by the average landowner in the long run, but increase overall program costs.

In the next two sections, I test the sensitivity of the model's predictions to changes in the base case parameter values to conduct numerical comparative statics and explore the effects of alternate policy scenarios. Two responses of the A^* threshold to parameter changes are common. First, the threshold may shift up or down, indicating a change in A^* at all levels of R. If the threshold shifts up, for example, landowners will enroll in the CRP at higher current values of A at any value of R, making it more likely that landowners will enroll for a given value of R. The second reaction is a rotation of the A^* threshold, often occurring near the point where the CRP payment offer equals the long run mean of agricultural returns, $\bar{A}$ ($R = \bar{A} = 1$. A rotation of the threshold counter-clockwise around one indicates that A^* is rising for $R > 1$ (enrollment becomes 'more likely' for values of R greater than $\bar{A}$), and falling for $R < 1$ (enrollment becoming less likely for values of R lower than $\bar{A}$).

2.3.2 Comparative Statics

Evidence suggests that the volatility of agricultural prices, and therefore agricultural returns, varies across crops [Crain and Lee, 1996, Schatzki, 2003, CBT, 2009]. Combined with likely variation in input prices and crop yield volatility, this variation implies that enlightened CRP policy will be based on an understanding of how enrollment responds to varied market conditions. I do not characterize the distribution of spatial variation, but sensitivity analysis of θ and σ offers insight into how CRP enrollment decisions vary for landowners facing different market volatilities. Figures 2.2 and 2.3 show enrollment thresholds for the base case as well as $\sigma = 0.1$ and $\sigma = 0.5$. The two figures show the importance of risk aversion in the model. The model predicts that increases in volatility increase A^* at all CRP payment levels, but only when landowners exhibit risk aversion. In sharp contrast to figure 2.2, figure 2.3 shows that when landowners are risk neutral,[8] an increase in σ from 0.3 to 0.5 *decreases* A^* at all potential values of R.

For the base case volatility of $\sigma = 0.3$, figure 2.2 shows that risk aversion decreases the CRP payment offer required to induce enrollment when A is equal to its long run mean of one. A risk averse landowner would only require a payment offer of $R \approx 1.03$ to enroll, while a risk neutral landowner would require $R \approx 1.07$.

Marginal or sensitive land, such as riparian zones and wetlands, and land with steep slopes and high erosion rates, are targeted for CRP enrollment through financial incentives and special enrollment considerations. The model suggests that if any of these land types have more variable returns, they are more likely to be enrolled in the CRP in the first place. This may offer a possible explanation for anecdotal and empirical evidence that the CRP is more costly than originally estimated [Parks and Kramer, 1995] and may be overpaying for conservation [Kirwan et al., 2005, Yang et al., 2005].

Figure 2.2 shows that values of A^* are higher at all CRP payment offers when landowners are risk averse. If landowners are risk averse, models failing to account for generate values of A^* that are too low. Estimates in Raskin and Cochran [1986], Buccola [1982], Ramaratnam et al. [1986], and Love and Buccola [1991] suggest setting γ between 0.8 and 1.8. Figure 2.4 shows the base case of $\gamma = 1.2$ along with $\gamma = 0.1$ to illustrate low risk aversion, and $\gamma = 3$ to illustrate high risk aversion. Increasing risk aversion increases A^* for all values of R, consistent with the interpretation that risk averse landowners prefer certain CRP payments over uncertain option values and agricultural returns.

The rate of mean reversion of agricultural returns, θ, depends on the type of

[8] To achieve risk neutrality, the utility function was replaced with U(A) = A. This corresponds to a very low value of the risk aversion parameter, γ.

shocks that dominate agriculture return variation, as well as on market responses to those shocks. Just as agricultural return volatility varies across space, mean reversion is likely to vary. For example, if shocks with only seasonal impacts are the primary determinants of shocks to net returns to agriculture, the rate of reversion will be high. Figure 2.5 shows the enrollment threshold for the base case, for $\theta = 3$, giving shocks a half-life of three months, and for $\theta = 0.2$, giving shocks a half-life of three and a half years. The rotation of the thresholds is significant, reflecting that the effect of a change in the rate of mean reversion on A^* depends on whether the CRP payment offer is above or below the long run mean of agricultural returns. Generally, an increase in the rate of mean reversion increases A^* for higher $R > \bar{A}$, and decrease A^* for lower $R < \bar{A}$. When landowners expect agricultural returns to revert to $\bar{A}$ quickly, they are less likely to enroll in CRP when R is less than $\bar{A}$, and more likely to enroll if R is greater than $\bar{A}$.

The potential behavioral implications of changes in the rate of mean reversion are affected by the influence of θ on the long run standard deviation of agricultural returns. The long run standard deviation of A is $SD(A) = \sigma\sqrt{\frac{1}{2\theta}}$, so the 95 percent confidence interval for A when $\theta = 3$ is 1 +/- 0.24 compared to 1 +/- 0.67 in the base case when $\theta = 0.4$. When the rate of mean reversion is high ($\theta = 3$), A^* falls above the long run 95 percent confidence interval for A when R is above 1.04. In contrast, A^* does not fall above the confidence interval for A until R is above about 1.1 in the base case. Figure 2.5 shows that different rates of mean reversion can imply significantly different long run probabilities of CRP enrollment.

Figure 2.6 shows the sensitivity of A^* values to changes in the discount rate, r. Overall, A^* is relatively insensitive to changes in the discount rate. Increases in r have a small affect on the willingness of landowners to take CRP payments below $\bar{A}$, increasing A^* at low values of r.

2.3.3 CRP Program Variables

CRP payment levels are set according to program goals, and the success of an increasingly targeted CRP requires understanding the characteristics of targeted land and predictions about the responses of landowners to the institutional structure of the program. To provide maximal conservation per taxpayer dollar, policymakers can adjust the length of CRP contracts, the frequency of CRP sign-ups, and enrollment eligibility criteria to ensure payments to landowners are minimized.

The CRP primarily enrolls land in contracts with durations of 10 - 15 years. As the CRP has become an increasingly environmental program, temporary CRP contracts have been criticized as insufficient to meet the program's stated conservation goals. Presumably, contract lengths could be set with several competing goals in mind, including regulatory burden and enrollment costs. Figure 2.7 shows that not only the magnitude, but the *sign* of the effect of changes in h on A^* depend on R. Shorter contract lengths increase the value of A^* for low values of R, but decrease A^* for high values of R. For example, when $R = 0.8$, $A^* = 0.76$ when $h = 1$ but only 0.36 when $h = 15$. Longer contracts force landowners to lock in payments below the long run mean of agricultural returns, so when R is below the long run mean of A, the current value of A must be quite low to induce enrollment.

The CRP currently uses continuous and general sign-ups to enroll landowners in the program. Continuous enrollments are more exclusive, and are generally used by the CRP to enroll the most environmentally sensitive lands. Setting the Poisson intensity governing the frequency of sign-ups, η, equal to three implies that landowners are almost certain they will be able to enroll in the CRP within a year (95 percent chance a sign-up will occur within a year), approximating continuous enrollment. Figure 2.8 allows comparison of the model predictions when $\eta = 3$ with the base case of $\eta = 0.7$, corresponding to a 50 percent chance of a sign-up within one year, and the case of $\eta = 0.1$, where landowners expect only a one in ten chance a sign-up will occur within one year. The figure shows that the frequency of sign-ups has a significant effect on A^*; when landowners expect only a ten percent chance a sign-up will occur within a year, A^* increases to 1.16 from the base case value of 0.92 for a CRP payment equal to one. When sign-ups are fairly continuous, A^* is lower for all values of R, indicating that when landowners anticipate they will have another chance to sign-up in the near future, they are less likely to enroll for each value of the CRP payment offer. Stated in terms of the minimum CRP payment offer sufficient to induce enrollment for a current agricultural return of $A = 1$, landowners would enroll if $R = 0.96$ when enrollment is less frequent ($\eta = 0.1$), but would require $R = 1.10$ to enroll if sign-ups were relatively continuous ($\eta = 3$).

In practice, most CRP enrollment is accomplished in general sign-ups governed by the Environmental Benefits Index (EBI) bidding mechanism; landowners submit bids that are scored and ranked according to the EBI and enrollment is determined by whether a landowner's EBI score falls above the threshold set by the Farm Service Agency. This generates uncertainty for landowners about the likelihood of successful CRP enrollment. In addition, funding and enrollment targets for the CRP are set by policymakers whose actions are uncertain. Funding for the CRP comes from the US Farm Bill, which is renewed about once every five years. The intensity governing the frequency of CRP sign-ups can be interpreted as capturing landowner expectations about their enrollment eligibility. Interpreted this way, figure 2.8 suggests that if landowners are uncertain about their future eligibility, the CRP payment required to induce enrollment for a given agricultural return will be lower.

The Poisson intensity, λ, incorporates uncertainty regarding the existence of the CRP. Figure 2.9 predicts a strong relationship between enrollment and landowner expectations about the existence of the CRP. When λ is very low, landowners are nearly certain the program will persist and they will have enrollment opportunities in the future. This certainty also increases the expected value of the option to enroll in the CRP in the future, increasing the opportunity cost of enrollment. For $\lambda = 0.001$, which decreases the probability the CRP will be discontinued in a year to nearly zero, a payment of approximately 1.05 is required to induce enrollment when $A = 1$, compared to approximately 1.03 in the base case. As λ increases, values of A^* rise or remain constant for all values of R, indicating that landowners are more likely to enroll for a given payment of R when they expect a higher probability that the CRP will be discontinued and will not be available to them in the future. Setting $\lambda = 0.02$ implies an expected probability of 10 percent that the CRP will be discontinued in a year, and the payment required to induce enrollment when $A = 1$ falls to near one.

Figures 2.8 and 2.9 illustrate the relative insensitivity of A^* to changes in η and λ at low values of R. For CRP payment offers well below the mean agricultural return of one, low values of A^* reflect that mean reverting agricultural returns make landowners unlikely to choose to lock in the low CRP payment in favor of waiting. That is, for low values of R, landowners do not expect to choose to enroll, so the frequency of sign-ups and existence of the CRP are less relevant to landowners, and the impact of changes in η and λ are reduced.

2.4 Conclusion

The model presented in this chapter provides insight into landowner decisions to enroll in the CRP under varying market conditions and counterfactual policy scenarios. Incorporating market and institutional uncertainty, risk aversion, and the irreversible and postponable nature of CRP enrollment decisions in a single model captures more of the realities of landowner decisions to enroll in the CRP than previous models, and significantly affects the model's implications. The base case parameter values predict that for a CRP payment offer equal to the long run mean of agricultural returns, landowners would enroll in the CRP if the current agricultural return was at or below 92 percent of it's long run mean value. Equivalently, if current agricultural returns are at their long run mean of one, a CRP payment offer of 1.04 or greater would induce enrollment.

The introduction of risk aversion through an exponential utility function has important effects on the model's predictions, indicating that previous models ignoring risk aversion may provide misleading results. In particular, introducing risk aversion reverses the predicted effects of increases in the volatility of agricultural returns on the threshold value for CRP enrollment. Without risk aversion, the model predicts that landowners are less likely to enroll in the CRP for a given CRP payment offer when the volatility of agricultural returns increases. When landowners are risk averse, the effect is reversed; risk averse landowners are more likely to enroll when uncertainty increases. The model predicts that the potential error from ignoring risk aversion is significant; the payment predicted to induce enrollment is 10 percent higher when risk aversion is included.

Modeling agricultural returns as a mean reverting process rather than geometric Brownian motion illustrates the potential impact of mean reversion for CRP policy makers. When agricultural returns are mean reverting, the value of agricultural returns at which landowners would choose to enroll in the CRP for a given standing payment offer depend on whether the offer is above or below the long run mean of agricultural returns. When agricultural returns are highly mean reverting, threshold values increase rapidly as CRP payment offers rise above the long run mean of agricultural returns, and fall rapidly as payment offers falls below the long run mean. This predicts that enrollment in the CRP will be more sensitive to the proximity of CRP payment offers to mean agricultural returns as mean reversion increases. Because the rate of mean reversion influences the long run standard deviation of agricultural returns, including mean reversion in the model also illustrates that landowners' long run enrollment responses to CRP payment offers may be significantly different depending on the rate of mean reversion.

The model incorporates two institutional characteristics absent from previous models: non-constant sign-up, and the possibility that the CRP may be discontinued. Adjustments to both have significant impacts on the predictions of the model. The model predicts that the CRP payment required to induce enrollment when agricultural returns are at their long run mean decreases by 14 percent when the expected frequency of sign-ups decreases from nearly continuous to only a 25 percent chance that a sign-up will occur within three years. Because the intensity governing CRP sign-ups can also be viewed as governing landowner expectations about the frequency of their enrollment eligibility, this result predicts that eligibility uncertainty may have a significant effect on CRP enrollment and costs.

The model presented in this chapter is a step toward providing *ex ante* estimates of landowner decisions to enroll in CRP, but there are several aspects of the CRP policy problem not incorporated in the model that should be addressed in future work. In particular, the model does not address important spatial aspects of the policy environment, including the distribution of market and landowner characteristics across space, as well as the effect of market and non-market spillovers on landowner decisions. These considerations are likely important to understanding the landowner's decision problem [Parks, 1995, Wu and Lin, 2008].

An important next step to assessing the strength of the model's predictions and increasing its applicability is to calibrate the model and test its implications using data. Calibrating the model parameters to a specific agricultural market, location, and crop mix would allow the model's predictions to be tested against observed CRP enrollment behavior and inform model improvements.

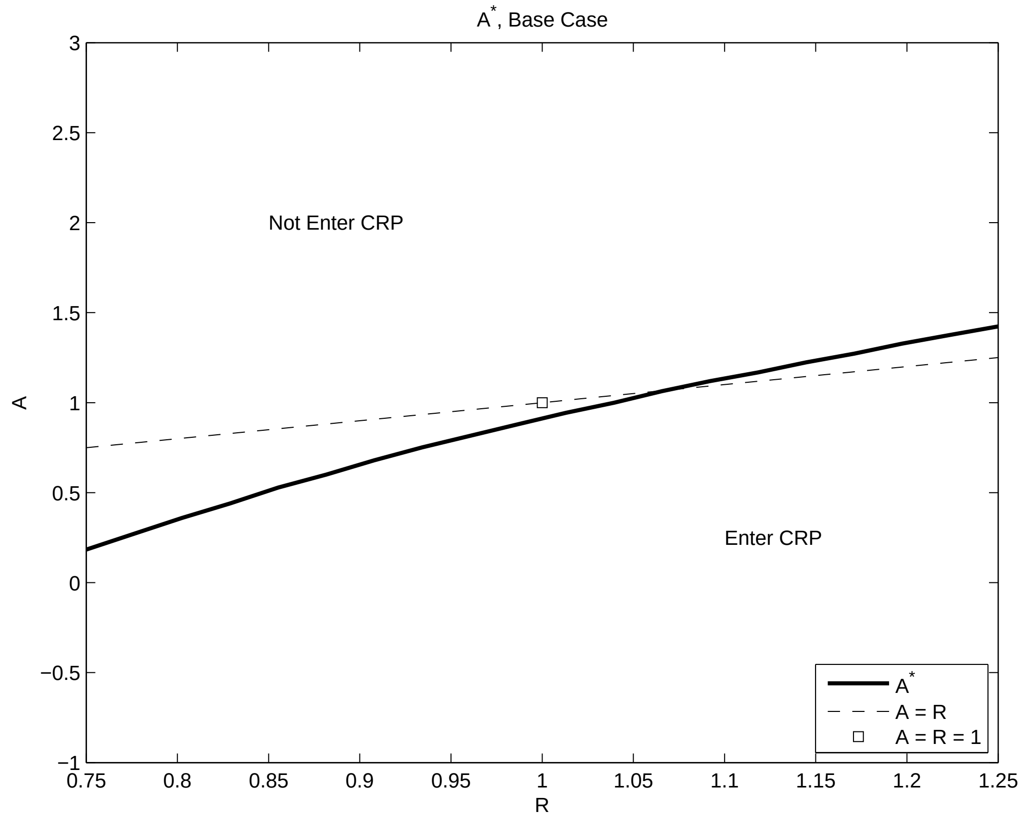

Figure 2.1: A^*, Base Case, 0.75 < R <1.25

Base case parameter values $\bar{A} = 1$, $\theta = 0.4$, $\sigma = 0.3$, $\lambda = 0.02$, $\eta = 0.7$, $\gamma = 1.2$, $r = 0.05$, and $h = 15$. Solid line shows the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) the solid line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

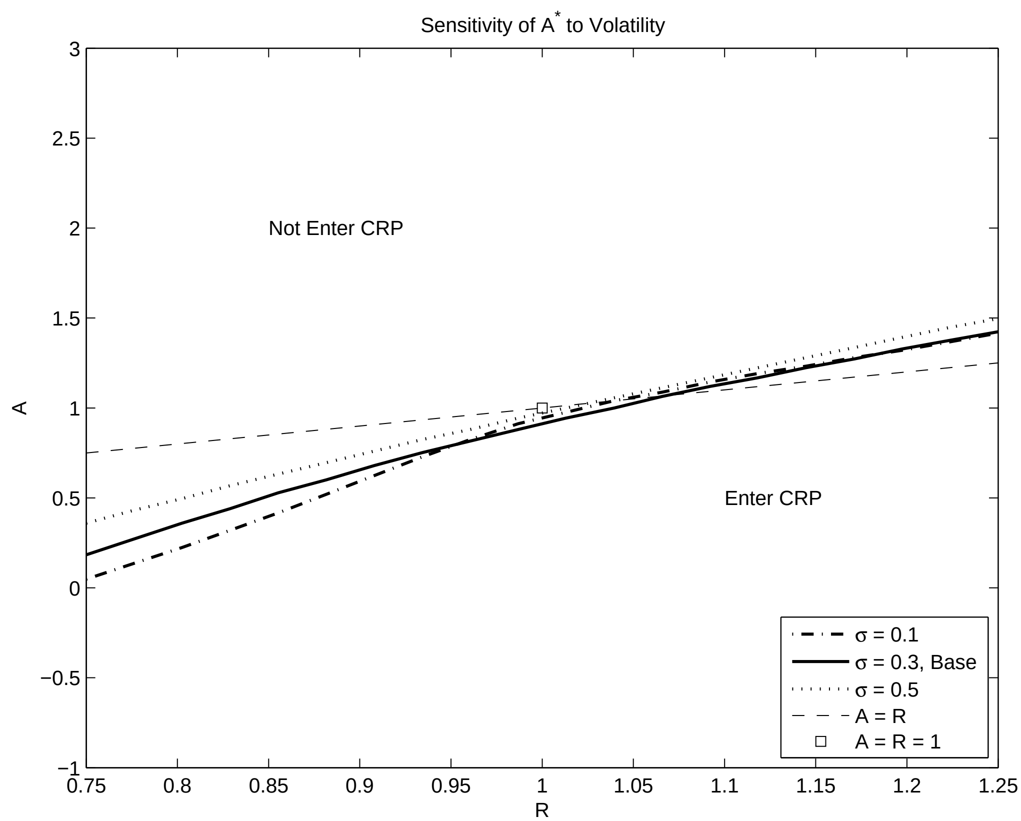

Figure 2.2: Enrollment Threshold, A^*, $\sigma = 0.1,\ 0.3,\ 0.5$.

Parameter values $\bar{A} = 1$, $\theta = 0.4$, $\lambda = 0.02$, $\eta = 0.7$, $\gamma = 1.2$, $r = 0.05$, and $h = 15$, 0.75 < R <1.25. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

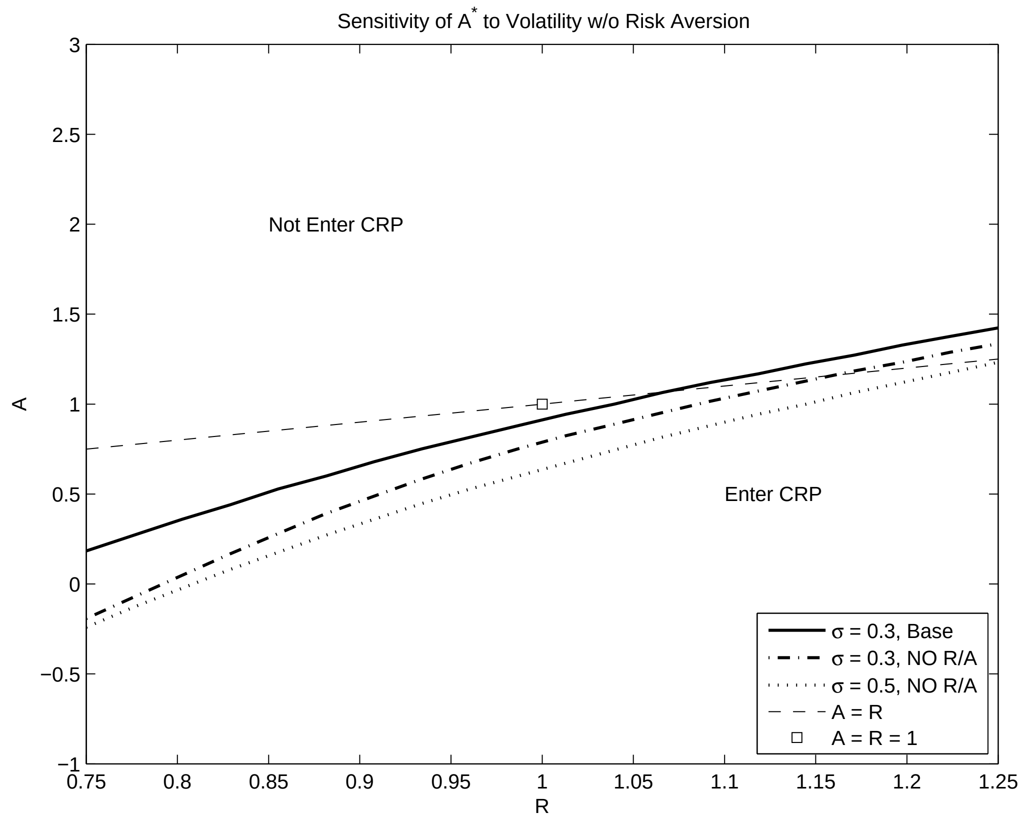

Figure 2.3: Enrollment Threshold, A^*, $\sigma = 0.3$, 0.3 w/o RA, 0.5 w/o RA.

Parameter values $\bar{A} = 1$, $\theta = 0.4$, $\lambda = 0.02$, $\eta = 0.7$, $\gamma = 1.2$, $r = 0.05$, and $h = 15$, $0.75 <$ R <1.25. 'NO R/A' refers to thresholds estimated with U(A) = A. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

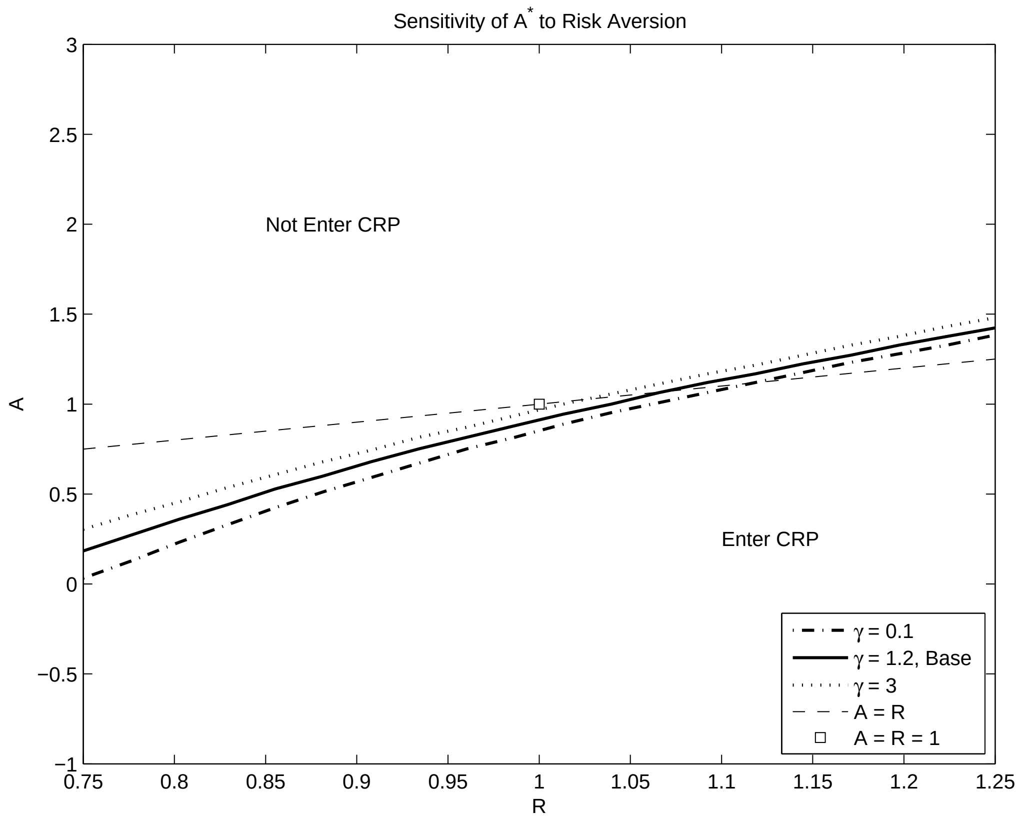

Figure 2.4: Enrollment Threshold, A^*, $\gamma = 0.1$, 1.2, 3.

Parameter values $\bar{A} = 1$, $\sigma = 0.3$, $\theta = 0.4$, $\lambda = 0.02$, $\eta = 0.7$, $r = 0.05$, and $h = 15$, $0.75 <$ R <1.25. 'NO R/A' refers to thresholds estimated with U(A) = A. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

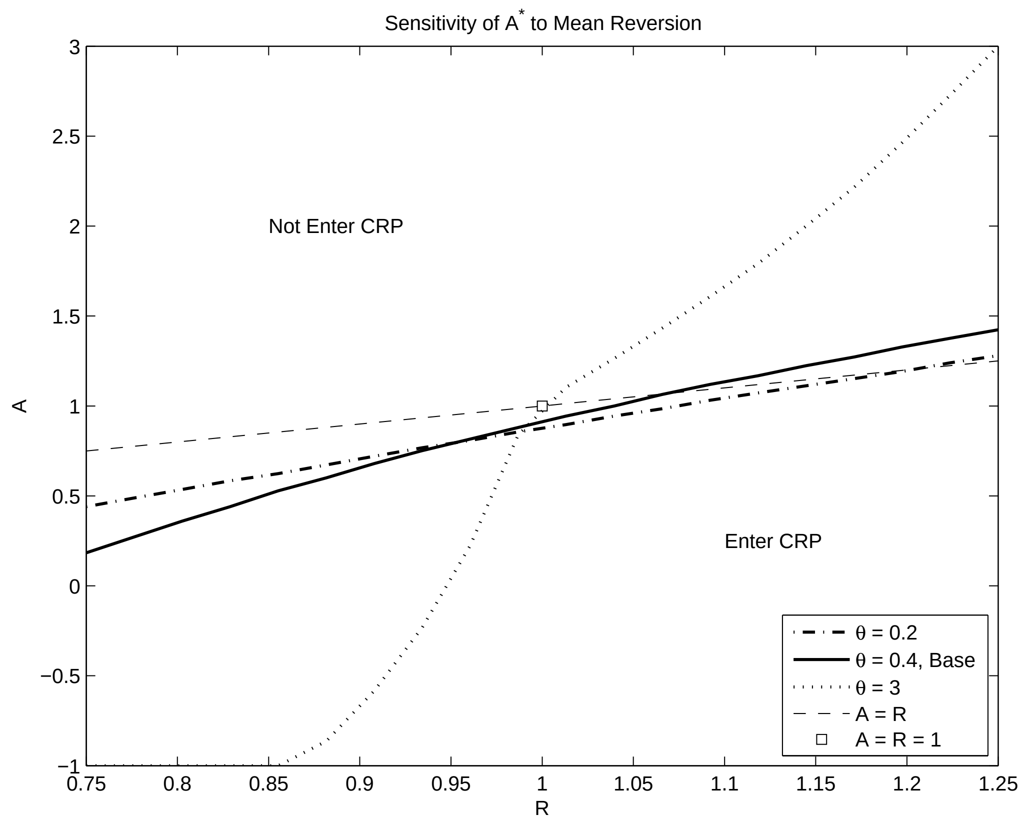

Figure 2.5: Enrollment Threshold, A^*, for $\theta = 0.2$, 0.4, 3.

Parameter values $\bar{A} = 1$, $\sigma = 0.3$, $\lambda = 0.02$, $\eta = 0.7$, $\gamma = 1.2$, $r = 0.05$, and $h = 15$, 0.75 < R <1.25. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

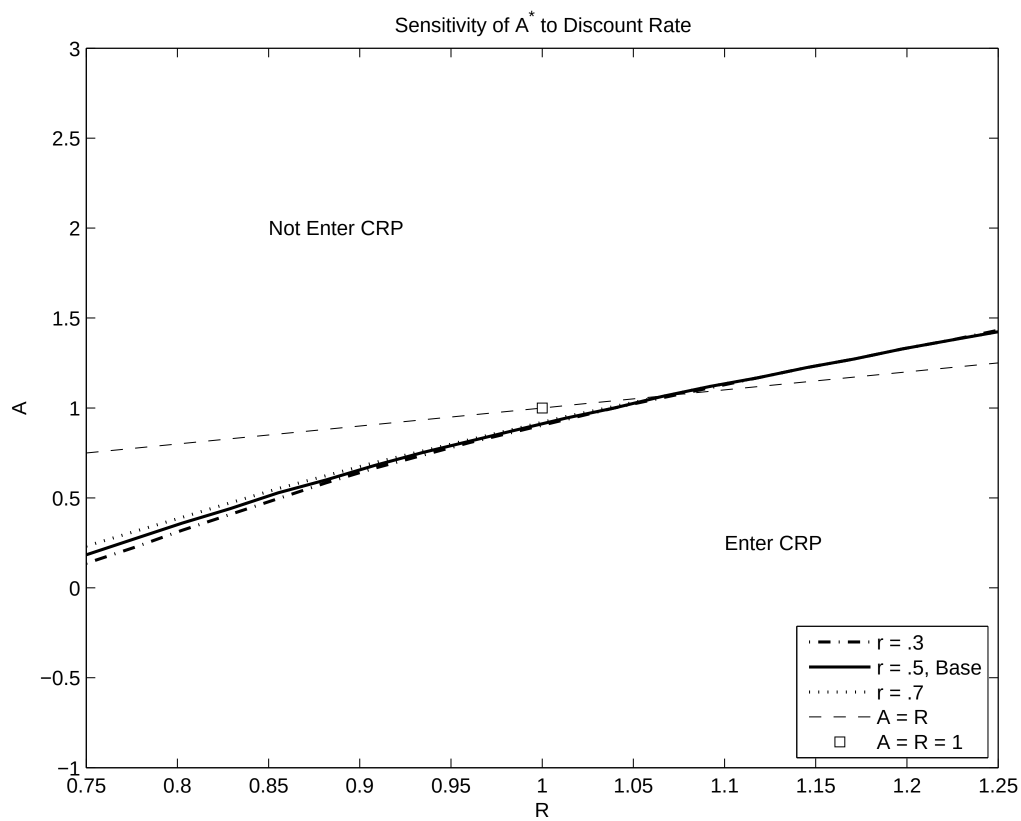

Figure 2.6: Enrollment Threshold, A^*, for $r = 0.03$, 0.05, 0.07.

Parameter values $\bar{A} = 1$, $\sigma = 0.3$, $\theta = 0.4$, $\lambda = 0.02$, $\eta = 0.7$, $\gamma = 1.2$, and $h = 15$, 0.75 < R <1.25. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

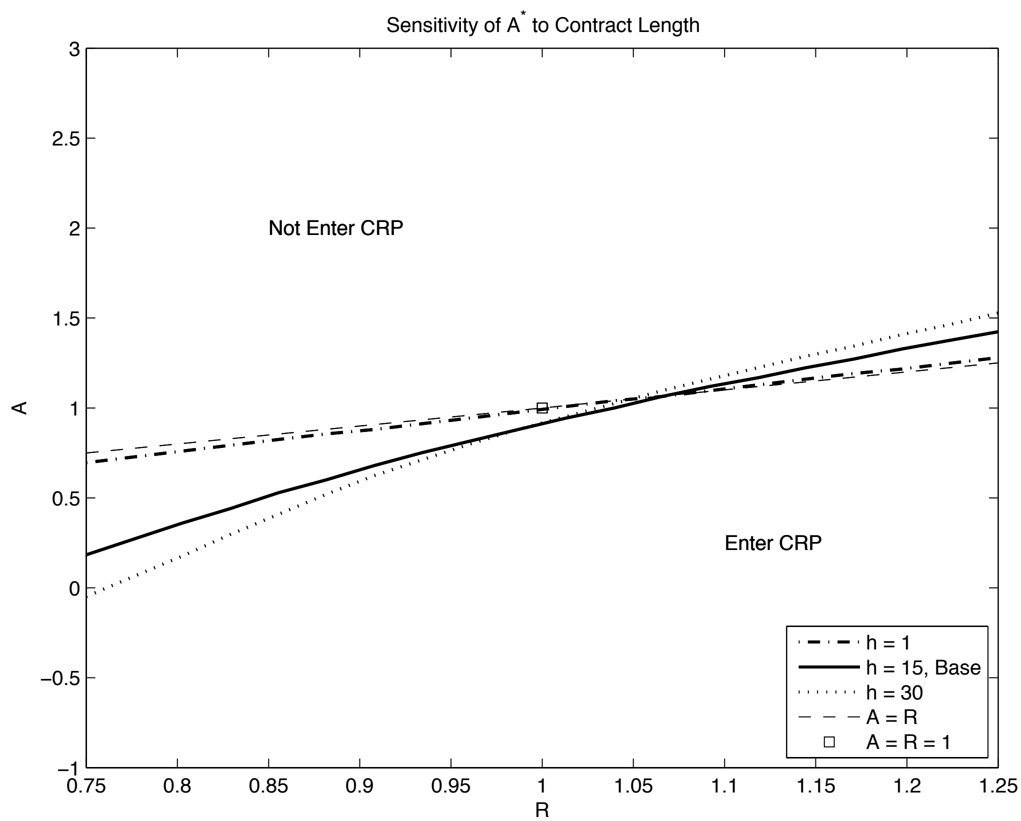

Figure 2.7: Enrollment Threshold, A^*, $h = 1$, 15, 30.

Parameter values $\bar{A} = 1$, $\sigma = 0.3$, $\theta = 0.4$, $\gamma = 1.2$, $\eta = 0.7$, $\lambda = 0.02$, and $r = 0.05$, 0.75 < R <1.25. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

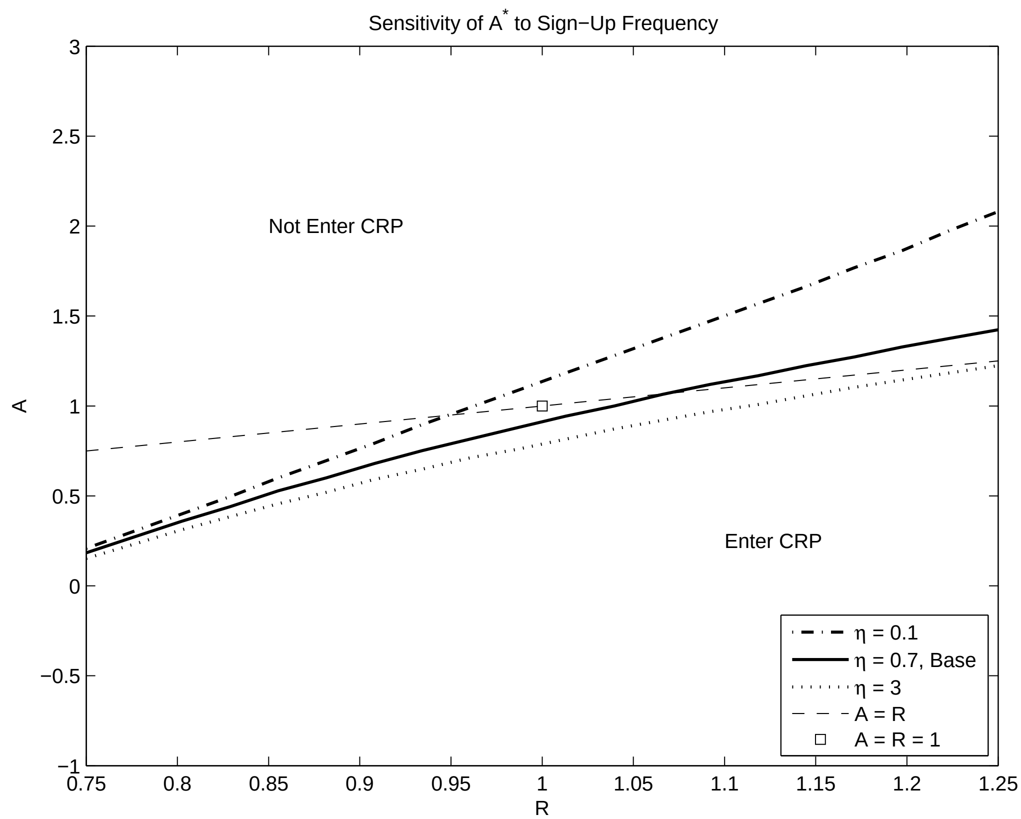

Figure 2.8: Enrollment Threshold, A^*, $\eta = 0.1$, 0.7, 3.

Parameter values $\bar{A} = 1$, $\sigma = 0.3$, $\theta = 0.4$, $\lambda = 0.02$, $\gamma = 1.2$, $r = 0.05$, and $h = 15$, 0.75 < R <1.25. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

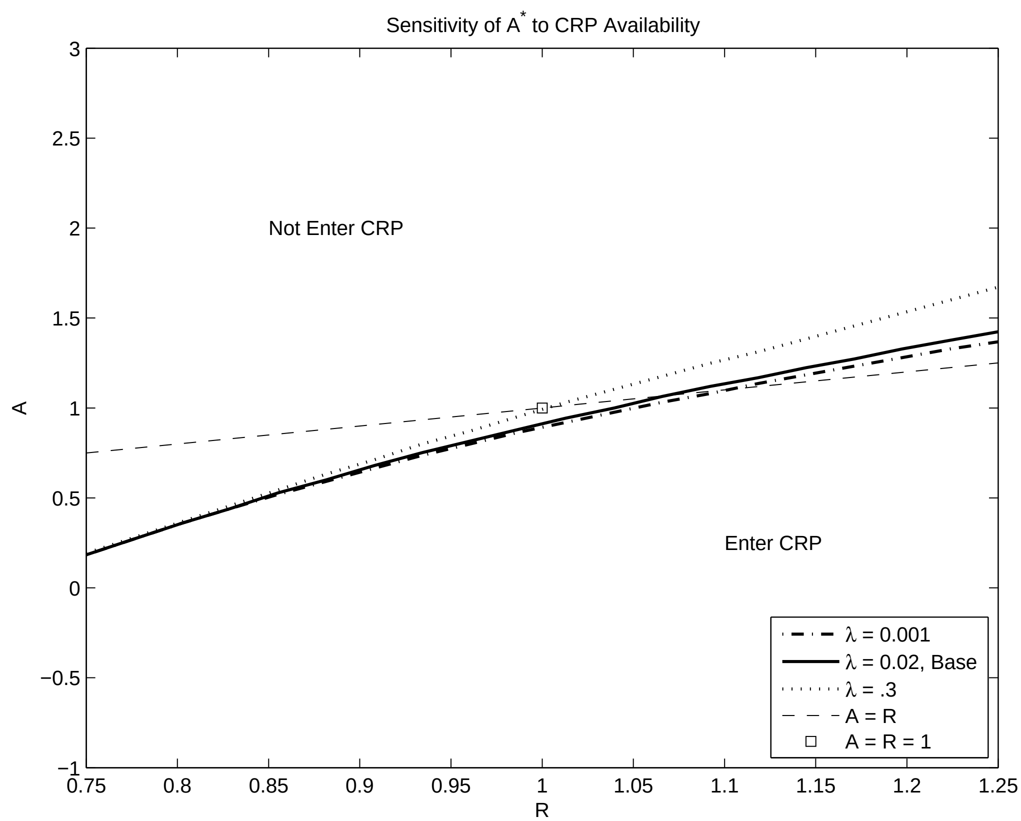

Figure 2.9: Enrollment Threshold, A^*, $\lambda = 0.001$, 0.02, 0.3.

Parameter values $\bar{A} = 1$, $\sigma = 0.3$, $\theta = 0.4$, $\gamma = 1.2$, $\eta = 0.7$, $r = 0.05$, and $h = 15$, 0.75 < R <1.25. Solid lines show the maximum agricultural return, A, for which a landowner would accept the corresponding CRP payment offer, R, to enroll in CRP. For combinations of A and R below (above) each line a landowner would (would not) enroll in the CRP. Dashed line illustrates points at which the agricultural return and CRP payment offer are equal. The square on the dashed line shows where $A = R = 1$.

Chapter 3

Determinants of Voluntary Conservation: The USDA Conservation Reserve Program

3.1 Introduction

In this chapter, I find that parcel-level increases in land productivity and non-conservation government payments are associated with decreased enrollment in the United States Department of Agriculture's Conservation Reserve Program (CRP). The result adds a robust parcel-level estimate to a mixed literature by addressing mis-specification and censoring in CRP enrollment data. The CRP is one of the United States' largest land conservation programs. The CRP distributes about $1.8 billion a year in payments to conserve over 36 million acres of agricultural land [U.S. Department of Agriculture, 2006]. Market and non-market benefits of the CRP include improvements in air and water quality, which enhance recreation value and decrease industrial operations costs, and improvements in bird and other wildlife habitats, which enhance hunting and wildlife viewing. Freshwater recreation, pheasant hunting, and wildlife viewing benefits directly attributed to CRP were estimated at $464 million annually by the USDA Economic Research Service. However, Shoemaker [1989] and Kirwan et al. [2005] have found evidence that payments for CRP enrollment may exceed private opportunity costs, raising questions about the ability of the CRP to maximize conservation per program dollar, and generating discussions about alternative enrollment mechanisms. These discussions highlight a need for agreement regarding the drivers of CRP enrollment.

Previous empirical studies indicate that land quality, payments, and landowner characteristics affect CRP enrollment decisions [Konyar and Osborn, 1990, Parks and Schorr, 1997, Parks and Kramer, 1995, Isik and Yang, 2004, Goodwin and Smith, 2003]. These effects, however, were generated in studies that differ in geographic location, empirical approach, and estimation results, offering little to no consensus. These studies use Major Land Resource Area (MLRA)[1] and county-level data that allow estimation of the effects of erodibility, productivity, landowner characteristics, and CRP bid cap and payment variables on CRP enrollment. The inclusion of CRP bid caps and payment variables as explanatory variables may explain the weak and counterintuitive results found in previous work because CRP metrics can be highly correlated with land characteristics. The auctions literature suggests that institutional changes are needed to increase the cost-effectiveness of the CRP auction mechanism [Vukina et al., 2008, Cason and Gangadharan, 2004, Kirwan et al., 2005]. A firm understanding of the degree to which different factors influence landowner decisions to enroll in the CRP would be helpful in assessing possible improvements to the CRP auction mechanism.

Motivated by a parcel-level structural model of landowner enrollment in the CRP, I estimate the determinants of CRP enrollment using a parcel-level empirical model and Minnesota farmland data. The parcel-level data represent a significant improvement

[1]Major Land Resource Areas generally encompass several thousand acres characterized by particular patterns of soils, geology, climate, water resources, and land use. An MLRA may be one continuous area or several separate nearby areas. There are 204 MLRAs in the United States, ranging in size from less than 500,000 acres to more than 60 million acres.

in data resolution, allowing the determinants of enrollment in the CRP to be estimated at the same resolution those decisions occur. I address specification concerns by including non-CRP government payments and a uniquely comprehensive index of land productivity, and use a censored normal regression framework to accommodate censoring in the participation data.

3.2 The USDA's Conservation Reserve Program

The USDA's Conservation Reserve Program (CRP) is a voluntary land use restriction program originally established in 1985 "to assist owners and operators in conserving and improving soil, water, and wildlife resources on their farms by converting highly erodible and other environmentally sensitive cropland and marginal pasture to long-term resource conserving covers." The CRP was established as a supply control program, but amendments in 1990, 1996, and 2002 have transformed it into an environmental program with 30 approved practices aimed at reducing soil erosion, enhancing water quality, and expanding and improving wildlife habitat and wetlands. CRP achieves its conservation goals primarily through $10-15$ year contracts that pay landowners to convert productive cropland to alternative covers such as native grasses or forest.

Since 1990, the majority of enrollment in the CRP has been governed by a bidding system based on the Environmental Benefits Index (EBI). A landowner's EBI score summarizes five environmental factor scores and a cost factor score. The environmental factors reflect the history of the CRP as an erosion control program as well as the current environmental focus: wildlife, water quality, erosion, enduring benefits, and air quality.[2] The scores from environmental factors are added to the following cost factor that penalizes higher proposed rents and requests for cost share assistance:

[2] A brief description of the EBI categories are provided in the appendix.

$$CostFactor = \omega(1 - r/HIGH)) + 10(1 - s) + Min(15, r^m - r). \qquad (3.1)$$

In equation 3.1, r is the rental rate proposed by the landowner, r^m is the parcel's soil-based maximum rental rate,[3] $HIGH$ is the highest soil specific rental rate allowed for all bids received, ω is a scaling parameter set by the government after all bids are submitted, and s=1 if the farmer chooses to request cost share assistance, and 0 otherwise.[4] The first term in equation 3.1 gives landowners more EBI points for proposing low rental rates, with the value of ω determining the weight of the cost factor in the overall EBI score.[5] The second term in equation 3.1 gives landowners a 10 point bonus if they do not request cost share assistance.[6] The final term in equation 3.1, added for sign-up 16 in 1997, adds one point to a landowner's score - up to 15 - for every dollar they bid below the maximum allowed, r^m. The maximum yearly rental rates allowed are determined by a formula that uses the relative productivity of soils within each county, the prevalence of the three most prominent soil types on the subject parcel, and the average county dryland cash rent. The rental rate proposed by each landowner determines the annual payments received over the life of a CRP contract if the bid is accepted; rental rates are not adjusted during the contract period. Bids are ranked nationally according to EBI score, and after each general sign-up period has ended, the FSA determines a national EBI score cutoff, and enrolls qualifying contracts USDA [2007].[7]

General[8] CRP sign-ups begin with a bidding period during which eligible landowners submit bids to receive cost share and yearly rental payments in return for installing

[3]Bidding rules require that $r \leq r^m$.

[4]Some notation is borrowed from Kirwan et al. [2005]

[5]The scale parameter ω has been constant at 125 since sign-up 15.

[6]The government typically pays half the cost of establishing the proposed conservation practice if landowners request cost share assistance.

[7]No information about how EBI cutoffs are determined is released by FSA, but presumably they are set in accordance with program goals and budgets.

[8]There are two types of CRP enrollment: general and continuous. The vast majority of CRP contracts fall under general enrollment, with continuous sign-ups being targeted at specialized areas and practices.

conservation practices on land for 10−15 year contract periods. Eligibility is determined by active ownership and operation of land offered for enrollment; landowners are required to own and operate the land they offer, and to have cropped the land in several years prior to enrollment. Bids are collected by the Farm Service Agency (FSA) and ranked according to EBI score. After bids have been collected, the FSA determines an EBI score threshold; landowners submitting bids that exceed the threshold EBI score are enrolled in the CRP and paid their proposed rental rate.

3.3 Review of Existing Evidence

The institutional structure of the CRP under the EBI scoring system, along with shortcomings of previous studies, informs estimation of the determinants of enrollment. The EBI score explicitly links land characteristics that affect the opportunity cost of enrolling in CRP and land productivity to the likelihood of acceptance and the CRP payment received. Previous researchers have estimated the effects of soil erodibility and productivity on enrollment in CRP in models that also include CRP rental rates, government payments, and landowner characteristics, with mixed results. A summary of these studies is presented in table 3.1, and described below.

Konyar and Osborn [1990] use data aggregated to Major Land Resource Area's (MLRA) and Weighted Two-Stage Least Squares to estimate a discrete choice model of the effects of differential land use returns, land value, farm size, landowner tenure and age, and land erodibility on CRP enrollment in the first 3 sign-ups in 1986. The authors find results consistent with their *a priori* expectations: 1) the proportion of land enrolled in the CRP increases when land is less productive and alternatives to cropping are less likely to compete with returns to CRP; and 2) larger farms, older farmers, and farmers with less tenure enroll a smaller proportion of land in CRP.

Parks and Kramer [1995] and Parks and Schorr [1997] use grouped logit estimation at the county level. Parks and Kramer [1995] examine the impact of land benefits, land attributes, and owner attributes on national county-level participation in CRP wetland restoration practices. The authors find that increases in net agricultural benefits and net CRP benefits (rental rate) are associated with decreased and increased participation, respectively. However, increased land quality, expected to be strongly associated with decreased participation, is found to be positively associated but statistically insignificant. Increased government payments, expected to increase opportunity costs and decrease participation,[9] are associated with increases in participation. Parks and Kramer postulate that the counterintuitive land quality result may be due to non-linear land quality impacts being modeled linearly, and that increased government payments proxy for landowner awareness of federal programs. Ownership of land and older age are associated strongly with increased participation; the result for age conflicts directly with Konyar and Osborn [1990]. Parks and Schorr [1997] conduct a county-level analysis of CRP participation in the Northeast. The authors' main finding is that the CRP does not affect landowner decisions in metropolitan[10] counties, likely because payments from the CRP were not large enough to induce landowners to forgo development. This result highlights the possible importance of considering development options when estimating determinants of CRP enrollment. Parks and Schorr [1997] also find that 'hobby farms,' small farms owned and operated for pleasure rather than business, influence enrollment in metropolitan counties. In a study similar in spirit to Parks and Kramer [1995] and Parks and Schorr [1997], Esseks and Kraft [1988] use data from the midwest and find a negative relationship between participation in the first four CRP sign-ups and income from farming, and a positive relationship between CRP participation and the percentage of land with erodible soils.

Isik and Yang [2004] provide the only study explicitly estimating the impact of uncertainty and irreversibility on participation in the CRP. The authors condition

[9] Acres placed in the CRP are not eligible for government payments.

[10] Counties considered metropolitan statistical areas by the Census of Population taken by the U.S. Department of Commerce, Bureau of Census.

on a set of explanatory variables similar to that in Parks and Kramer [1995] and Parks and Schorr [1997], with the addition of a variable accounting for the value of "real options"[11] forfeited by landowners when they choose to enter the CRP. Isik and Yang find that irreversibility and uncertainty play a significant role in landowner decisions to enter the CRP; as option values increase, participation decreases. This study reinforces the importance of controlling for variables that affect option values such as proximity to urban areas.

Also working with CRP enrollment prior to 1990, Plantinga et al. [2001] use county data and linear regression to estimate CRP supply functions for nine U.S. regions. As in Parks and Kramer [1995] and Parks and Schorr [1997], Plantinga et al. [2001] find that increases in program payments and decreases in land capability tend to increase participation in the CRP, although their results are not consistent in all regions. Increases in population density and median household income are found to decrease participation. Goodwin and Smith [2003] use county-level data between 1982 and 1992 to estimate a set of simultaneous equations describing CRP participation, soil erosion, crop insurance participation, conservation effort, and fertilizer usage. The authors find an expected result - increases in CRP rental rates are associated with increased participation - but report several statistically significant results that have signs that conflict with previous work. Increases in cost share assistance are associated with decreased participation, more erodible soil is associated with decreased participation, and increases in government payments, one of the opportunity costs of CRP participation, are associated with increased participation.

Roberts and Lubowski [2007] include an estimation of CRP participation in a study of CRP contract expiration between 1995 and 1997. Several variables found to be significant in other studies, including prime soil and erodibility, are insignificant in Roberts and Lubowski's model, but this may be explained by the fact that the model

[11] See Dixit and Pindyck [1994] for a description of real options, and Brimlow et al. [2008] for an application of real options models to land conservation decisions.

is the first stage in a two-stage selection model, and may be over-specified due to the authors' attempt to capture selection bias. Coefficients with statistical significance, such as changes in government payments, have the expected signs.

Before 1990, 33.9 million acres were enrolled in the CRP under 10-year contracts, so the vast majority of early CRP contracts were set to begin to expire around 1996. Contracts written before 1990 were not subject to the competitive EBI bidding process, and many landowners were likely being paid significantly more than their opportunity costs. Consequently, several studies focused on the determinants and effects of land use choices made by landowners facing the decision to return their land to non-conservation uses or to compete to re-enter the CRP [Cooper and Osborn, 1998, Johnson et al., 1997, Skaggs et al., 1994, Kalaitzandonakes and Monson, 1994]. The studies of re-enrollment decisions use survey and land use data, and are broadly consistent with the literature covering initial CRP enrollment: land characteristics such as productivity and location are the primary drivers of land use decisions [Kalaitzandonakes and Monson, 1994, Cooper and Osborn, 1998, Johnson et al., 1997], with increases in land productivity or market value decreasing the likelihood of reenrollment. Landowner characteristics and conservation motives are included in Cooper and Osborn [1998] and Kalaitzandonakes and Monson [1994], but are not found to significantly affect landowner decisions when land characteristics are included in the models.

If payments exceed the private opportunity cost of restriction, landowners enrolled in CRP may be earning windfall profits, providing motivation for policy makers to examine the enrollment process and consider making changes to the bidding structure of the program. The auctions literature has investigated how landowner bids submitted under the CRP's EBI auction mechanism shed light on the motivations of participants, and how well the bidding structure forces landowners to reveal the true opportunity cost of enrollment [Vukina et al., 2008, Cason and Gangadharan, 2004, Kirwan et al., 2005]. Vukina et al. [2008] analyze farmer bids to enter the

CRP and find that farmers value the environmental benefits of the CRP, especially when those benefits increase the future productivity of their land. This suggests that the EBI auction mechanism may be rewarding farmers, through higher EBI scores and increased probability of acceptance, for actions they may have undertaken anyway. Kirwan et al. [2005] estimate the difference between willingness to pay and willingness to accept in the CRP. Their estimates indicate that landowners were paid 10-40% more than a rent that would just compensate them for adopting conservation practices. This premium could represent windfall gains to landowners, but could also represent payment required to convince landowners to reveal private information and enroll in CRP, reimburse landowners for transactions costs, or compensate for the value of lost land use options.

The results of previous studies of enrollment in the CRP informs the estimation conducted in this paper. Previous studies find that land characteristics are the primary driver of enrollment in the CRP, but estimates of the sign and magnitude of the effects are mixed: the literature reports contradictory effects of erodible soil and higher non-CRP government payments, and several studies find that land quality has an insignificant effect on CRP enrollment. Analysis of the literature suggests that the mixed and sometimes counterintuitive results may be due in part to specification errors, because factors influencing landowner participation in CRP are often the same factors determining CRP program metrics such as the maximum allowable rental rate. Parks and Kramer [1995] find that the proportion of land in Land Capability Classes (LCC) I and II has an insignificant effect on participation in the CRP. Because land in LCC's I and II is the most productive land, a higher proportion of land in LCC's I and II indicates higher opportunity costs and, therefore, would be expected to decrease CRP enrollment. The Parks and Kramer result is less surprising once it is considered that the the maximum rental rate allowed by the CRP, largely determined by the productivity of land in the region, is also included in the regression. Misspecification introduced by the correlation between maximum CRP rental rates and LCCs could explain the unexpected result, and this example illustrates the importance of considering the CRP enrollment process when estimating the determinants of CRP enrollment, and of carefully selecting explanatory variables to avoid misspecification. I address specification concerns by including only non-CRP government payments and a uniquely comprehensive index of land productivity in my regressions, and use a censored normal regression framework to accommodate censoring in the participation data.

3.4 Theory

Below I introduce a parcel-level structural model of landowner decisions to enter the CRP to illustrate the expected effect of land characteristics on CRP enrollment decisions, and to motivate my empirical analysis. I assume that landowners are profit maximizers, so they accept land use restrictions only when expected returns under restriction exceed returns without restriction.[12] Further, I assume that conservation program payments are broken into constant annual per acre payments that do not vary over the life of the contract and compensate landowners for transactions costs.

Figure 3.1 plots the yearly value of productive acreage, net of production costs (net productivity), for each of two farmland properties of the same size. Acreage of each parcel is arrayed from least to most productive along the horizontal axis, with the size of each full parcel represented by $\bar{A}$. The net productivity of a parcel of land can be written

[12] While nonpecuniary returns are not included in the estimation section, returns under restriction could include pecuniary returns as well as nonpecuniary returns due to conservation preference or bequest motive. Anderson and King (2004) and Vukina, Zheng, Marra, and Levy (2008) find that landowners do not place considerable weight on the public benefits of conservation; landowners participate in conservation programs if the private benefits of participation (monetary compensation, personal satisfaction, etc.) outweigh the private opportunity costs (foregone income, option values). Therefore, a model of landowner participation in the CRP that accounts for the primary sources of private benefits and costs is likely sufficient.

$$NP_i = a_0 + a_1' \cdot \mathbf{z_i} + a_2 \cdot A, \tag{3.2}$$

where z_i is a vector of variables that shift net productivity, i indexes parcels, and A is acres. Parcel 1 is assumed to have higher net productivity than parcel 2 (due to the values in z_2 relative to z_1), so NP_1 lies above NP_2.[13] Because land is arrayed from least to most productive along the horizontal axis, the net productivity of the first acre in each parcel is less than the net productivity of the last acre; the model being developed here allows for land quality that is heterogeneous both within and across parcels.

If a conservation program offers landowners a constant yearly per acre payment to retire land from production, they will restrict acres, from least to most productive, until the payment just offsets the opportunity cost of restriction. In Figure 3.1, the opportunity cost of restriction for each property is represented by its net productivity curve. If a yearly payment of $\bar{c}$ is offered, Parcel 1 will be unrestricted because the value of the annual per acre payment is below the net productivity of the parcel's least productive acre. For parcel 2, $\bar{c}$ is greater than the net productivity of all acres up to A^*, so some of the acreage in parcel 2 is offered for restriction. In general, landowners will restrict all, some, or none, of parcel acreage, depending on parcel productivity and program payments.

With the introduction of the EBI bidding system in 1990, offering land for participation in the CRP was an increasingly strategic decision by landowners, and the structural model presented here can be viewed as representing those decisions. As discussed above, landowners choose the land they offer (A^*), the conservation practices they will adopt, and the rental rate they request ($\bar{c}$). Evidence of strategic behavior of landowners found by Shoemaker [1989], Cason and Gangadharan [2004], and Kirwan et al. [2005] indicate that the exogenous characteristics of a parcel of land will affect

[13] The parcels are assumed to share values for the parameters a_0, a_1, and a_2.

the joint determination of the conservation practices adopted, the amount of land offered for conservation, A^*, and the yearly rental rate, $\bar{c}$.

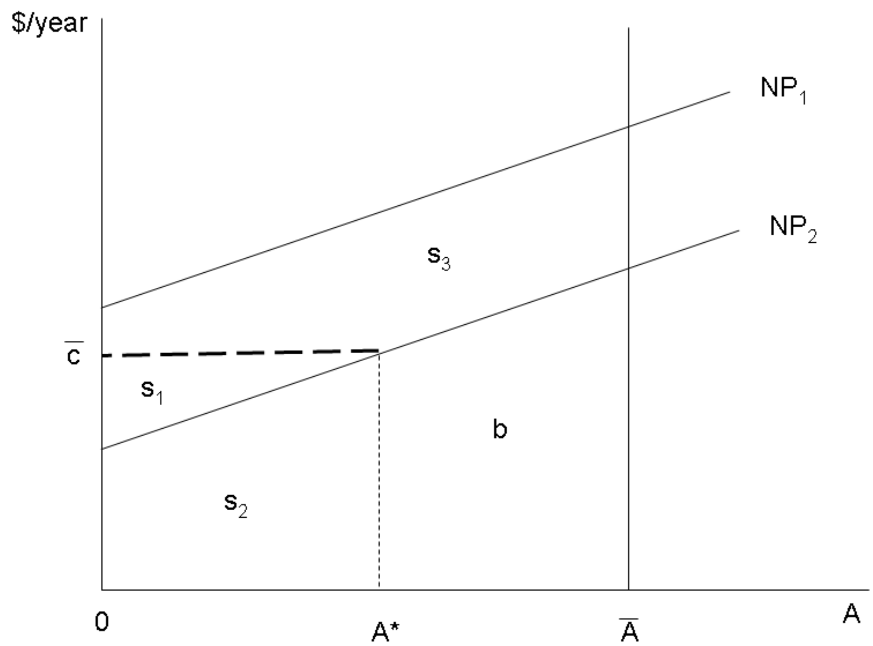

Figure 3.1: Conservation Payments and Land of Varying Productivity

It is well understood that land characteristics affect land use choices [Lichtenberg, 1989, Plantinga, 1996], and the studies discussed above [Skaggs et al., 1994, Parks and Kramer, 1995, Parks and Schorr, 1997] have found evidence that landowner characteristics (age, tenure) also impact land use decisions. It could be argued that the model presented here should be modified to accommodate landowner characteristics. The parcel-level data I use in this study does not include landowner attributes, and aggregated measures such as county-level census information would not yield enough variation to justify their use. Roberts and Lubowski [2007] address this issue by appealing to equilibrium sorting a la Tiebout [1956]: heterogeneous individuals sort into different locations, and characteristics of individuals are mapped to the characteristics of land and to prices in equilibrium. This implies that landowner characteristics are ultimately endogenous, and should not be included in the analysis. I will appeal to this argument here, omitting landowner characteristics from the model and estimation.

3.5 Estimation

3.5.1 Empirical Model

The main implication of the structural model presented above is that the amount of land enrolled in a conservation program will decrease as the net productivity of that land - representing the private opportunity cost of restriction - rises. In Figure 3.1, the quantity of enrolled land, A^*, is determined by the intersection between the conservation payment, $\bar{c}$, and net productivity, so enrollment is determined by

$$A^* = \frac{\bar{c} - a_0 - a_1 \cdot \mathbf{z}}{a_2}. \tag{3.3}$$

This enrollment equation can be estimated using

$$A^* = \alpha_0 + \alpha_1 \cdot \mathbf{z} + \alpha_{\mathbf{2}} \cdot \bar{\mathbf{c}} + \eta \tag{3.4}$$

to identify model parameters and gain insight into the behavior of optimizing landowners. The structural model of figure 3.1 shows that landowners owning land of very high or very low productivity would enroll less than zero or more than the total acreage in the parcel if they could. Therefore, at the parcel level, enrollment is censored from below by zero, or from above by the acreage of each parcel. A two-sided censored normal model is used to estimate equation 3.4 to accommodate fixed lower and varying upper censoring points. The two-sided censored normal model is:

$$A_i^* = \alpha' \mathbf{x_i} + \eta_\mathbf{i}$$

where A_i^* is the latent dependent variable of acres enrolled in CRP. The vector $\mathbf{x_i}$ contains independent variables such as productivity and CRP payments, α is the vector of parameters to be estimated, and the η_i are residuals assumed to be independently and normally distributed, $\eta \sim N(0, \sigma^2)$. The observed dependent variable, A_i, can be represented as

$$\begin{aligned} A_i &= \quad 0 \quad\quad \text{if} \quad A_i^* \leq 0 \\ &= \alpha' \mathbf{x_i} + \varepsilon \quad \text{if} \quad A_i < A_i^* < \bar{A} \\ &= \quad \bar{A} \quad\quad \text{if} \quad A_i^* \geq \bar{A}, \end{aligned}$$

where $a_i = 0$ and $b_i = \bar{A}$ are the upper and lower censoring points for each observation, respectively. In my data, I use zero as the lower censoring point, and the total cropland acreage in each parcel as the upper censoring point. Following Maddala (1983), the parameters β are estimated by maximizing the likelihood function

$$L(\alpha, \sigma) = \prod_{A_i=0} \Phi\left(\frac{-\alpha' \mathbf{x_i}}{\sigma}\right) \prod_{A_i=A_i^*} \frac{1}{\sigma}\phi\left(\frac{A_i - \alpha' \mathbf{x_i}}{\sigma}\right) \prod_{A_i=\bar{A}} \left(1 - \Phi\left(\frac{\bar{A} - \alpha' \mathbf{x_i}}{\sigma}\right)\right),$$

where Φ and ϕ are the normal distribution and density function, respectively. The two-sided Tobit model results if the upper and lower censoring points are constant across observations.

How censored normal regression coefficients are interpreted depends on the purpose of the estimates. For data that are always censored, as is the case for CRP enrollment data (negative enrollment or enrollment above the maximum size of the parcel are never observed), impacts on the censored population are relevant. Following Greene [1997], marginal effects on the censored dependent variable in a two-sided censored normal model are obtained using

$$\frac{\partial E[A_i|\mathbf{x}_i]}{\partial \mathbf{x}_i} = \alpha \times \Pr(0 \leq A_i^* \leq \bar{A}) = \alpha[\Phi((\bar{A} - \alpha^{'}\mathbf{x}_i)/\sigma) - \Phi((-\alpha^{'}\mathbf{x}_i)/\sigma)], \qquad (3.5)$$

where 0 and $\bar{A}$ are the upper and lower censoring points, respectively. A two-sided censored normal model is used to estimate equation 3.4.

3.5.2 Data

Estimating equation 3.4 requires parcel-level data for CRP enrollment, per-acre CRP payments, and variables likely to shift the net productivity of land, such as soil productivity and non-CRP government payments. Data for Minnesota farm parcels were obtained from Dr. Steve Taff at the University of Minnesota Department of Applied Economics. The University of Minnesota maintains a substantial database of arms-length sales data for all land types. Data from a pooled cross section of sales occurring between 2002 and 2006 were used for this estimation. The data include information about land characteristics (productivity, size, tillable acreage), location, and acres enrolled in the CRP at the time of sale.[14] As of September 30, 2006, Minnesota contained nearly 1.8 million of the 36.8 million acres enrolled nationally in the CRP. The acreage is concentrated in the western and southern parts of the state where agriculture is a prevalent land use. Although enrollment data for this analysis comes from both general and continuous CRP sign-ups, the vast majority of Minnesota's CRP acreage, 1.4 million acres, entered the program through the general sign up process, and 1.6 million acres falls into the Prairie Pothole Conservation Priority Area (CPA).[15] I exclude parcels with no tillable acreage, and parcels with

[14] Taff [2004] and Taff and Weisberg [2007] utilize this set, but the data used in this paper were updated with sales through 2006.

[15] Parcels in National Conservation Priority Areas, such as the Prairie Pothole, receive bonus points during contract sign ups because they have been deemed more sensitive by the USDA.

less than 35 acres that contain structures.[16]

The CRP places productive acreage under conservation restriction, so the dependent variable is constructed using only the tillable acreage of each parcel. Models are estimated using the level and log of tillable acreage enrolled, as well as the proportion of tillable acreage enrolled, as the dependent variable. If *tillacre* represents the total tillable acreage in a parcel, and *crp* represents the number of acres in each parcel restricted by CRP, tillable acreage enrolled in CRP is calculated as $\min[tillacre, crp]$, and the proportion of tillable acreage enrolled as $\min[\frac{crp}{tillacre}, 1]$.[17] The dependent variable is considered to be censored from below if the parcel is not enrolled in CRP,[18] and censored from above if the parcel is fully enrolled.

In equation 3.4, the vector $\mathbf{z}$ contains variables that affect the net productivity of land. For this estimation, Minnesota's Crop Equivalency Rating (CER), non-CRP government payments, and fixed effects for county and region are included in $\mathbf{z}$.[19] Minnesota's measure of productivity, the Crop Equivalent Rating (CER), is a broad proxy for land productivity. According to the Agricultural Extension Service of the University of Minnesota, CERs reflect the net economic return per acre of soil when the soil is used for cultivated crops, permanent pasture, or forest, whichever provides the highest net return. The CER for each parcel is computed using soil, climate, and management variables, and provides a relative ranking of parcels on a scale of

[16] This addresses the issue of hobby farms, noted by Anderson and Weinhold [2005], where farmland is used as a place of residence but not actively farmed due to landowner preference. Landowners who live on hobby farms have a preference for untilled land, and would be expected to enroll more land in CRP because they receive payments for idling land they plan to idle anyway.

[17] The acreage enrolled in CRP exceeded the tillable acreage in 42 of 288 parcels. For all but 5 of the parcels enrolled in CRP, CRP exceeded tillable acreage by less than 20 acres; the mean was 10 acres. The CRP enrollment in these parcels likely exceeded tillable acreage because of measurement error or the enrollment of wildlife habitat under the continuous CRP.

[18] This assumes that for parcels not enrolled in CRP, the value of the least productive acre is higher than the payment the landowner could receive from CRP. This assumption could be violated if county acreage caps restricted enrollment, if landowners submitted bids that were not accepted, or if landowners did not know about the CRP. If all observations with no enrollment are thrown out, the coefficient estimates reported below decrease in value, but are qualitatively the same.

[19] Time dummies are not included in the estimation because productivity and government payments are independent of the year of sale.

1 (lowest) to 100 (highest). CER data are computed by individual counties, and were not available for every observation; over 4000 sales in 41 counties, including 288 CRP-restricted parcels, had CER data and are used for this analysis.[20] Using CER data to proxy for productivity introduces measurement error for at least two reasons. First, CER values were calculated in some parts of Minnesota as early as 1972, and the majority were computed in the 1980s, so recent changes in a parcel's relative or absolute productivity will not be reflected in the measure. Second, CERs are computed using the distribution of soils on each parcel, but only one number is recorded for each parcel. This means each parcel's CER is an average across the parcel, and does not provide information about the distribution of productivity across acres. Measurement error will bias the coefficient estimate on CER downward in the estimation of equation 3.4. CER is a parcel specific rating of property productivity, so the model of figure 3.1 predicts that increases in CER will decrease the proportion of a property enrolled, *ceteris paribus.*

Non-CRP government payments are also included in the estimation. Non-CRP government payments and subsidies to agricultural land represent a cost of CRP enrollment because enrolling land in CRP decreases the acreage eligible for these types of payments. Non-CRP government payment data were not included in the sales dataset. County average per-acre direct government payments in Minnesota over the years 1993-2000 were obtained from FINBIN, an online farm financial database that gathers data using individual farm surveys, and average government payments to land managed primarily for corn were used.[21] County fixed effects cannot be used in conjunction with the county averages for non-CRP government payments, so National Agricultural Statistical Service (NASS) region dummies were constructed for use as

[20]A comparison between parcels with CER data and parcels without showed that parcels with CER data sold for higher average per acre prices. This could reflect the value of the productivity information to sellers, or to a systematic difference in the types of properties for which CERs are recorded. If parcels with CER data are systematically different from parcels without, the results of this estimation will only be applicable to similar types of parcels.

[21]Minnesota farmers in the study region generally rotate corn and soybean crops.

fixed effects in models that include non-CRP government payments. The model of figure 3.1 predicts that higher non-CRP government payments will decrease CRP enrollment. However, non-CRP payments are based on agricultural productivity, and are correlated with CER.[22] For this reason, models are run with and without this variable.

CRP rental payments to individual parcels, $\bar{c}$ in equation 3.4, were not available. The structural model suggests that CRP payments are an important determinant of participation, but the CRP sign-up process, discussed in section 2, may make their inclusion unnecessary or even problematic. Payments from the CRP are designed to compensate landowners for foregone crop profits, and the maximum allowable rental rate increases with the productivity of land. Therefore, excluding payment information may be acceptable for at least two reasons: first, the maximum rent paid in each county is used to determine the cost factor for each bid, so county fixed effects may capture some of the variation in payments; second, payments are determined by both landowner choice and the relative productivity of the land offered for restriction, so CER is likely correlated with CRP payments, and inclusion of both could confound estimation results. This latter point may explain some of the weak and counterintuitive results found in studies that include measures of productivity as well as CRP payment information.

Summary statistics for the data used are presented in table 3.2.

3.5.3 Results

Table 3.3 reports results for censored normal regressions of the level of acres enrolled in CRP on productivity and other variables, and table 3.4 reports results for regressions using the log of acres enrolled. The log specification is preferred if marginal increases in the productivity of additional acres of land decline with increased acreage. The coefficient on *CER*, the relative productivity of each parcel, is negative and statis-

[22]The simple correlation coefficient between the two variables in the data is 0.45.

tically significant across both models and all specifications, indicating that increased productivity is associated with decreased enrollment. The result is consistent with intuition and the structural model presented above. Plugging the mean value for each of the explanatory variables into equation 3.5, the coefficient estimate under the log specification (table 3.4) when county fixed effects are included implies that a one unit increase in *CER* decreases acres enrolled by approximately 0.73 percent, *ceteris paribus*. Thus, a one standard deviation change in productivity results in about a 9.5 percent change in enrollment. In the log specification, the coefficient on county average non-CRP government payments is negative and significant when NASS region fixed effects are not included. The estimate implies that a one dollar increase in government payments reduces enrollment by approximately 0.43 percent, or that a one standard deviation change reduces enrollment by around 3 percent. When NASS region fixed effects are included, the coefficient estimate remains negative but is no longer statistically significant. The negative relationship between government payments and enrollment is consistent with the interpretation that government payments increase the opportunity cost of restriction, decreasing CRP enrollment.

The proportion of tillable acres enrolled was also used as the dependent variable to estimate equation 3.4. Using the proportion of tillable acres enrolled imposes the requirement that the first and last acre of large and small parcels with the same CER have the same productivity. With fixed censoring points, the censored normal model becomes a two-sided Tobit, as described above. This alternative model specification estimates smaller marginal effects of productivity and non-CRP government payments on enrollment, but the sign and significance of the estimates remain the same. Results are reported in table 3.5. Again using equation 3.5 and the mean values of the explanatory variables, the coefficient estimates for Model 2 in table 3.5 imply that a one unit increase in productivity decreases the proportion of land enrolled by approximately 0.0014. The coefficient on government payments indicates that a one dollar increase in government payments reduces the proportion enrolled by approximately 0.0007. The effect of non-CRP government payments is again statistically significant only in the absence of NASS region fixed effects.

The estimations show a significant negative relationship between land quality and CRP enrollment; selection into CRP is made based partially on productivity as measured by *CER*. The result is robust to model specification, and is obtained despite the likely presence of measurement error, which would bias the estimate downward (toward zero).

3.6 Conclusion

I find that increases in parcel net productivity have a negative and significant effect on the proportion of land enrolled in the USDA's Conservation Reserve Program. The result adds a robust parcel-level result to mixed empirical evidence that has important policy implications. My finding that increases in non-CRP government payments decrease CRP enrollment is evidence of non-trivial interaction between USDA Farm Bill programs. The strongly significant association between enrollment and productivity has important implications for testing the hypothesis that CRP confers windfall rents to enrolled landowners advanced by Kirwan et al. [2005], among others. One way to test for the existence of windfall rents is to estimate the difference in land value between land enrolled and not enrolled in CRP. This approach has been used in several studies of the CRP and other conservation programs [Anderson and Weinhold, 2005, Nickerson and Lynch, 2001, Taff, 2004, Taff and Weisberg, 2007], and mixed and counterintuitive results have been reported. Selection bias will confound regressions of land value on CRP enrollment if CRP is enrollment is driven by factors that also affect land value. Therefore, my finding that CRP enrollment is significantly affected by land productivity, a strong determinant of land value, indicates that selection bias must be considered. Incomplete consideration of selection bias may explain the mixed results in previous studies of the effect of enrollment in conservation programs on land value.

Table 3.1: Literature Summary: Determinants of Participation in the CRP

	Estimation Method	**Data Aggregation**	**Higher Land Quality**	**Erodible Soil**	**Higher CRP Rental Rate**	**Higher non-CRP Government Payments**	**Larger Farms (Hobby Farm)**	**Higher Population Density**	**Longer Tenure**	**Older Landowner**	**Own Land**	**Option Value**
Konyar and Osborne 1990	Weighted OLS	MLRA	-	+	+	-	-	n/a	+	-	n/a	n/a
Parks and Kramer 1995	Grouped Logit	county	?	n/a	+	+	n/a	n/a	n/a	+	+	n/a
Parks and Schorr 1997	Grouped Logit	county	-	n/a	+	n/a	-	n/a	n/a	n/a	n/a	n/a
Esseks and Kraft 1988		county	-	+	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Plantinga, et al. 1990	OLS	county	-/?	n/a	+/?	n/a	n/a	-	n/a	n/a	n/a	n/a
Goodwin and Smith 2003	Bootstrapped 2SLS	county	n/a	-	+	+	n/a	n/a	n/a	n/a	n/a	n/a
Isik and Yang 2004	Grouped Logit	county	-	n/a	+	-	n/a	n/a	n/a	+	+	-
Roberts and Lubowski 2007	2SLS	farm/county	?	?	+/?	-/?	n/a	n/a	n/a	n/a	n/a	n/a

Notes: +, -, ? are used to indicate positive, negative, and insignificant effects, respectively. If results were mixed, / is used to separate the effects.

Table 3.2: Summary Statistics for all Parcels and Parcels Enrolled in CRP

Variable	Obs	Mean	Std. Dev.	Min	Max
All Parcels					
Tillable Acreage in CRP	4528	3.02	16.51	0	207
Crop Equivalency Rating (CER)	4528	66.47	13.53	5	99
Cty Ave Govt Pay 1993-2000	4528	23.63	7.11	1.39	36.91
Total Acreage in Parcel	4528	114.54	85.21	1	1360
Total Tillable Acreage in Parcel	4528	100.82	78.72	1	1278
Parcels Enrolled in CRP					
Tillable Acreage in CRP	288	47.41	46.79	1	207
CER	288	56.23	12.20	5	85
Cty Ave Govt Pay 1993-2000	288	20.07	7.01	1.39	36.31
Total Acreage in Parcel	288	142.88	100.88	14	687
Total Tillable Acreage in Parcel	288	116.48	88.99	5	601

Table 3.3: Censored Normal Estimation Results - Acres Enrolled in CRP

	Model 1	Model 2	Model 3	Model 4
CER	-3.437***	-2.987***	-3.139***	-2.979***
	(-11.41)	(-8.66)	(-10.17)	(-9.34)
Cty Ave Gov't Pay			-1.636***	-1.277*
			(-3.21)	(-1.84)
Constant	35.323**	-77.730***	52.749***	53.712**
	(2.30)	(-2.83)	(3.22)	(2.42)
Cty Fixed Effects	N	Y	N	N
NASS Fixed Effects	N	N	N	Y
N	4528	4528	4528	4528
Sigma	117.186***	102.950***	117.169***	113.975***
	(17.93)	(18.26)	(17.93)	(17.97)
Log–Likelihood	-2214.742	-2082.169	-2209.415	-2187.070
Chi–Squared	193.003	458.147	203.657	248.346

Note: t-stats in parentheses; * p< 0.1, ** p< 0.05, *** p< 0.01

Table 3.4: Censored Normal Estimation Results - Log of Acres Enrolled in CRP

	Model 1	Model 2	Model 3	Model 4
CER	-0.207***	-0.180***	-0.186***	-0.179***
	(-10.95)	(-8.38)	(-9.64)	(-8.94)
Cty Ave Gov't Pay			-0.111***	-0.070
			(-3.51)	(-1.61)
Constant	1.874**	-4.959***	3.039***	2.320*
	(1.97)	(-2.93)	(3.00)	(1.68)
Cty Fixed Effects	N	Y	N	N
NASS Fixed Effects	N	N	N	Y
N	4528	4528	4528	4528
Sigma	7.320***	6.414***	7.292***	7.141***
	(17.16)	(17.40)	(17.18)	(17.21)
Log–Likelihood	-1545.888	-1414.325	-1539.475	-1518.878
Chi–Squared	183.430	446.556	196.257	237.451

Note: t-stats in parentheses; * $p< 0.1$, ** $p< 0.05$, *** $p< 0.01$

Table 3.5: Tobit Estimation Results - Proportion of Tillable Acres Enrolled

	Model 1	Model 2	Model 3	Model 4
CER	-0.040***	-0.036***	-0.037***	-0.035***
	(-11.15)	(-8.84)	(-10.05)	(-9.33)
Cty Ave Gov't Pay			-0.018***	-0.010
			(-3.06)	(-1.29)
Constant	0.439**	-0.811**	0.629***	0.243
	(2.50)	(-2.55)	(3.35)	(0.71)
Cty Fixed Effects	N	Y	N	N
NASS Fixed Effects	N	N	N	Y
N	4528	4528	4528	4528
Sigma	1.337***	1.196***	1.337***	1.321***
	(16.58)	(16.79)	(16.58)	(16.59)
Log–Likelihood	-1109.563	-984.158	-1104.704	-1086.917
Chi–Squared	197.523	448.333	207.240	242.815

Note: t-stats in parentheses; * p< 0.1, ** p< 0.05, *** p< 0.01

Chapter 4

Overcoming Endogeneity: The USDA Conservation Reserve Program and Agricultural Land Values

4.1 Introduction

Offering payments for voluntary land use restrictions is a popular way of conserving ecosystem services such as wildlife habitat, air and water quality enhancements, and carbon sequestration on agricultural land. The 2007 Farm Bill authorized payments to secure over 40 million acres in voluntary land use restrictions. The largest federal conservation program, the Conservation Reserve Program (CRP), currently enrolls over 34 million acres of productive cropland, paying enrolled landowners over $1.8 billion for contracts active in 2008 [USDA, 2007]. In addition to providing payments to enrolled landowners, the CRP has the potential to affect CRP and non-CRP land through its effects on ecosystem services and local economies. Costs and benefits generated by the CRP are relevant for assessing the outcome of current CRP policy and informing future CRP policy decisions.

Asset valuation theory predicts that land values incorporate present and future returns to land, so land values will capture many market effects and some non-market effects of the CRP. Understanding the magnitude of changes in land value due to CRP could be useful for quantifying the effects of the program and guiding federal conservation policies, but its empirical measurement will be dependent on the scale of value measurements. For example, value measurements can be taken at the parcel level, or at more aggregate levels.

At the parcel level, effects of the CRP that accrue to enrolled land, including CRP payments and hunting revenues, will be reflected in changes in the value of CRP enrolled parcels. The CRP pays landowners yearly rental payments to idle productive cropland by replacing crops with approved covers such as native grasses or trees. Additionally, CRP land provides potentially valuable ecosystem services such as wildlife habitat that generate revenues for landowners who can charge for hunting or recreation access. Landowners will enroll in the CRP only if the net present value of land enrolled in the CRP is greater than the expected net present value of land in all alternative uses at the time of enrollment. This suggests that the effect of CRP on enrolled land value at the time of enrollment is likely positive. Real estate listings in the prairie pothole region of the upper Midwest suggest this is the case; listings enthusiastically advertise CRP contracted acres and their historical hunting revenues.

At the community or county level, changes in ecosystem service flows and farming economies induced by the CRP may also have significant effects that will extend to both CRP and non-CRP land values [Sullivan et al., 2004, Wu, 2000, Roberts and Bucholtz, 2005, Claassen et al., 2001]. The USDA Economic Research Service (ERS) estimates that freshwater recreation, pheasant hunting, and wildlife viewing benefits directly attributed to CRP are worth $464 million annually. Some of these benefits will support and grow local hunting and tourism economies, increasing land values in affected areas. In the prairie pothole region, conservation of waterfowl habitat not only generates revenues for CRP enrolled landowners, but the money spent by visitors supports local gas stations, hotels, and restaurants.

In contrast, it is also possible that CRP enrollment negatively affects local land values. In areas with high CRP enrollment, businesses that supply farming equipment, fertilizer, and feed suffer if CRP enrollment reduces the size of the local farm economy. In principal, high levels of CRP enrollment could decrease land values, but current empirical evidence suggests negative effects are probably limited. In 2004, the ERS drafted a report responding to concerns that high levels of CRP enrollment were causing declines in population and employment in rural farming communities. The report found evidence that areas with high CRP enrollment had low and declining levels of population and employment, but that the trends began *prior* to the introduction of the CRP in 1986, and did not appear to be significantly altered by the program [Sullivan et al., 2004].

Finally, CRP enrollment could have far reaching affects on agricultural land values through its effects on commodity prices. CRP contracts prohibit agricultural production on 10 percent of the productive cropland in the United States, representing a significant decrease in the supply of cropland acreage and crops. Increases in commodity prices created by reduced supply would increase the value of all cropland acreage producing the affected commodities. Commodity prices are sensitive to relatively small changes in productive acreage, so even small percentage fluctuations around the 34 million acres of land enrolled in the CRP has the potential to generate substantial price effects.

4.1.1 Measuring Land Values Under CRP

Effects of the CRP at different scales are reflected by different measurements of land values; e.g., county level data reflect overall effects, while parcel level data reflect effects on enrolled land. An ideal estimate of the effects of CRP on land values would involve measurements of changes in land value at the individual parcel as well as a more aggregated level, using both estimates to determine the magnitude of the effects accruing separately to CRP and non-CRP land. Unfortunately, data that link detailed CRP enrollment information with land characteristics and value are unavailable, limiting analysis to aggregate scales.

Measuring the effect of CRP on land value is also complicated by the fact that direct comparisons of the per-acre value of a county's farmland when the CRP exists to the per-acre value of the same farmland when the CRP does not exist are not possible. This challenge requires estimating the effect of CRP using comparisons of, for example, the value of land in counties where CRP enrollment is *more* prevalent to the value in counties where CRP enrollment is *less* prevalent. If comparison counties are similar in all ways except the prevalence of CRP enrollment, differences in land value between counties can be interpreted as *caused* by the CRP. However, if counties differ in ways that affect both land value and CRP enrollment, land value differences will be combinations of differences caused by the CRP and differences not caused by the CRP, and the effect of CRP enrollment will be confounded.

Further complications for measuring the effects of the CRP on land value arise due to enrollment incentives generated by the CRP itself. The strong negative relationship between CRP enrollment and land quality is a natural consequence of the CRP enrollment and landowner profit maximization. Since 1990, the Farm Service Agency (FSA) has enrolled a majority of CRP acreage using the Environmental Benefits Index (EBI). Landowners submit bids to the FSA consisting of a land area, cover practice, and requested yearly rental payment. The FSA uses the EBI to score and rank bids, and sets a threshold score for acceptance after all bids are received.

The EBI scoring mechanism induces correlation between land quality and CRP enrollment by giving higher scores to landowners offering to enroll land with particular characteristics and for requesting lower yearly rental payments and cost share assistance. In general, landowners with lower quality land will be more willing to increase their EBI score by lowering their required rental rate. Higher EBI scores for landowners willing to reduce their rental rate because they have lower quality land makes it more likely that low quality land is accepted into the program. Further, many of the land characteristics rewarded by the EBI, such as high erodibility, are associated with decreased productive value Miranowski and Hammes [1984] and Palmquist and Danielson [1989]. This negative association between CRP enrollment and land quality has been empirically identified in several previous studies [Sullivan et al., 2004, Parks and Schorr, 1997, Plantinga et al., 2001, Brimlow, 2009].

Because land values are determined largely by land quality, the data presented in table 4.1 further suggest the negative relationship between land quality and CRP enrollment. In 1997, the year of the data used in this chapter, US counties that had more than 5 percent of farmland enrolled in the CRP had a mean per-acre value almost $600 lower than counties with between zero and 5 percent enrolled. The table illustrates the challenge of identifying the effect of the CRP on land value: the data could be showing decreases in land value *caused* by CRP enrollment, or reflecting that low quality land tends to enroll in the CRP, or both.

In practice, a significant portion of the land quality differences driving landowner decisions to enroll in the CRP and land value is private information held by landowners, and land quality data that capture potentially observable variation are often not available. This makes constructing comparisons between counties that are similar in all respects except CRP enrollment difficult, and results in regression estimates that suffer from omitted variables bias. The negative correlation between land quality and CRP enrollment will likely cause estimates to be too low. This is consistent with previous negative estimates of effect of CRP enrollment on land value Goodwin and Smith [2003], Taff and Weisberg [2007]. Profit maximizing landowners are expected to enroll in the CRP only if the present value of enrollment exceeds the expected present value of not enrolling, but the empirical evidence does not support the hypothesis that the direct effect of CRP payments is positive.

4.1.2 A New Approach to Estimating the "CRP Effect"

In this chapter, I present a new approach to estimating the effect of increased CRP enrollment on county land values. My estimation strategy uses regression analysis with two unique strategies that allow me to measure differences in CRP enrollment while controlling for confounding differences in land characteristics between counties. For this chapter I focus on county-level land values that capture the direct effect of CRP rental payments on parcels enrolled in the program as well as the effect on both CRP and non-CRP land of other changes such as increases in tourism.

The first strategy I use is to limit my analysis to a small range of EBI scores near the threshold for acceptance. Focusing on this narrow EBI range has two benefits. First, because EBI scores and land characteristics are correlated, counties with very different EBI scores are likely to have dramatically different land quality and other characteristics. As discussed above, land quality differences will confound effects of the CRP in predictable ways. In contrast, land within a narrow EBI range will be more similar, reducing the potential for unobserved land characteristics to confound estimates of the effect of the CRP on county land values.

The second advantage is that small differences in EBI scores around the threshold for acceptance can generate significant variation in CRP enrollment. This follows from the sharp discontinuity created by the EBI threshold: bids with scores below the threshold, whether by one point or a hundred points, are rejected by the program. Similarly, bids with EBI scores above the threshold, whether by one point or a hundred, are accepted. The discontinuity allows me to compare differences in CRP acreage shares that stem from small differences in EBI scores around the threshold of acceptance.

Heterogeneous landowner characteristics help ensure that counties with similar land characteristics will have bids that receive different EBI scores and therefore have different shares of land accepted into the program. The EBI mechanism allows individual landowners to affect their score through choices of land type, cover, and required payments. This allows landowners with different expectations about the EBI threshold, for example, to submit bids with different EBI scores even if their land has identical characteristics. Landowner expectations about the EBI threshold may differ for reasons such as experience from previous sign-ups or the advice of a county FSA agent. Financial hardship, environmental preferences, bequest motives, or other circumstances could also affect landowners' decisions to adjust their EBI score. Importantly, differences in EBI scores generated by landowner expectations or circumstances are often independent of land quality. In this way, counties with similar land characteristics near the EBI threshold can have different shares of land accepted into the program for reasons that will not confound estimates of the effect of the CRP.

The second strategy I use to account for land quality differences between counties is to compare counties with similar shares of land bidding to enter the CRP near the EBI threshold. Empirical evidence and the EBI bidding mechanism suggest that, on average, counties with lower land quality will have higher shares of land bidding to enroll in the CRP. This suggests that counties with lower land quality will have higher shares of land bidding to enter the CRP near the threshold. Narrowing analysis to a small range of EBI scores near the cutoff for acceptance without controlling for the share of land bidding decreases differences between counties reflected by EBI scores, but does not eliminate differences captured by the share of land bidding to enter the CRP. Therefore, comparing counties with similar shares of land bidding to enroll further controls for variation in land quality.

Finally, I restrict my comparisons to differences in land value *at the time of enrollment*. Landowner decisions to enter the CRP are based on expectations about how the net present value of land enrolled in the CRP compares to the net present value of land not enrolled. If landowners' *ex ante* expectations about what will happen during their enrollment are incorrect, the true return to CRP enrollment will be different than expected. This would change the effect of CRP enrollment measured as a difference in land values over time. For example, landowners who enroll in the CRP prior to unexpected increases in commodity prices will likely underestimate the CRP payments necessary to make enrolling in the CRP profitable. This discrepancy has the potential to cause land enrolled in the CRP to be less valuable than similar land not enrolled in the CRP. Differences between *ex ante* expectations and *ex post* reality due to broad price, environmental, or population changes may not average out over time, and may significantly contribute to the effect of CRP on land value over time. To avoid these confounding temporal effects, I define the "CRP Effect," as the effect of the CRP on county land values *at the time of enrollment*.

I proceed under the assumption that counties with similar shares of farmland bidding to enter the CRP in a narrow range of the EBI score cutoff are, on average, similar in all other respects as well. This implies that differences in land values associated with differences in CRP enrollment that stem from small EBI score variations around the threshold of acceptance are caused by CRP. Before estimating the CRP Effect, I present the data and provide some evidence to support the assumption that counties with different CRP enrollment stemming from small EBI variations around the threshold of acceptance are in fact similar. After exploring the sources of correlation between land quality and CRP enrollment, I provide a brief description of the regression estimation. My estimates of the CRP Effect are followed by a discussion of the implications of my estimation strategy for the CRP and other conservation policies.

4.2 Data

In this chapter I use county-level data for the 1737 US counties that submitted bids to enter the CRP during "general"[1] sign-ups in 1997. The data include several

[1]There are two types of CRP enrollment: general and continuous. The vast majority of CRP acreage is enrolled in general sign-ups; over 30 million of the 34.7 million total acres enrolled in CRP in 2008 were enrolled in general sign-ups. Continuous sign-ups target high priority areas and land

measures of county land values derived from the 1992 and 1997 Census of Agriculture as well as EBI scores and shares of county land bidding to enter and enrolled in the CRP provided by the USDA Economic Research Service (ERS). To limit my estimates to the effect of CRP on land values *at the time of enrollment*, I pair county-level farmland value data from 1997 with CRP enrollment and bidding data from CRP general sign-up 15 in the same year.[2]

I use two measures of county farmland value in my estimations: mean value per acre and acre-weighted median value. Both value measures include all farmland acres in each county, and are not restricted to acres enrolled in the CRP or to acres falling in a particular EBI score range. The Census of Agriculture questionnaire asks farmers to estimate the value of the land and buildings on their farms. The farmer estimates are used by the USDA to construct county-level total and per acre "value of land and buildings" statistics for publication in the Census of Agriculture. The 1992 and 1997 county mean per-acre value used in this chapter is the sum of the estimated values reported by each farm in the county divided by the total land in farms in the county. The acre-weighted median value is not reported in the Census of Agriculture, and was provided by the ERS. The acre-weighted median farmland value in each county is found by ordering farms in the county from lowest to highest per-acre value of land and buildings, and then recording the value per acre of the farm that contains the middle farmland acre in the county. In a county with ten thousand acres of farmland, the acre-weighted median is the value per acre of the farm that contains the five thousandth acre when farms are ordered from lowest to highest per-acre value.

Table 4.2 summarizes land values from the full sample of 1737 counties receiving bids to enroll in the CRP in 1997. The table show that the mean value per acre of

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use practices, and acres enrolled during continuous sign-ups do not go through the same competitive Environmental Benefits Index(EBI) bidding process as acres enrolled during general sign-ups [USDA, 2007].

[2]Sign-up 15 occurred in the spring of 1997, and the Census of Agriculture questionnaire is sent out at the end of each census year, so land values reported by farmers for the 1997 Census of Agriculture will reflect CRP enrollments from sign-up 15.

farmland varies widely. Hunterdon County, New Jersey has the highest mean value per acre, 7,245 dollars, and Garfield County, Montana has the lowest, 107 dollars. The mean is 1,242 dollars. The acre-weighted median has a lower mean, 1,065 dollars, and a smaller standard deviation of 684 dollars compared to 769 dollars for the average per-acre value. Distributions of land values are generally positively skewed. The lower mean value for the acre-weighted median reflects the fact that the statistic is less affected by extremely high values in each county.

For naive regressions of land value on total CRP enrollment, I use total county CRP enrollment shares in 1993 and 1998 provided by the ERS. Land value data are measured at the end of the year in which the census is taken, but total county CRP enrollment data are measured by the ERS at the beginning of each year. Therefore, 1993 and 1998 CRP enrollment levels correspond to land value measures from 1992 and 1997, respectively. Table 4.3 reports summary statistics for counties with zero, zero to 5, and over 5 percent of farmland acres enrolled in the CRP at the end of 1997, respectively. The majority of counties with CRP acres have a share of farmland enrolled between 0 and 5 percent (the mean is 0.043 and the standard deviation 0.045), and Bailey County, Texas tops the list with over thirty percent of farmland enrolled. The negative correlation between CRP enrollment and land value is illustrated in table 4.3. The changes in the mean of the average per-acre county land value across the three enrollment bins are considerable: the value falls from 1,883 to 1,393 dollars when enrollment share rises from zero to between zero and five percent, and then from 1,393 to 880 dollars for enrollment greater than five percent. Average value per-acre has a consistently higher mean and standard deviation than the acre-weighted median across the enrollment share bins.

The ERS provided aggregate CRP bidding statistics from general sign-up 15, including acres accepted and rejected grouped according to how far each bid's EBI score fell from the national acceptance cutoff. Table 4.2 reports that the average per-acre CRP rental rate paid to accepted acres in sign-up 15 was about fifty dollars, with a standard deviation of 21, and the highest per-acre rental payment was 122 dollars paid to a landowner in Douglas County, Illinois.

The shares of each county bidding to enter and accepted into the CRP within a small EBI range of the cutoff correspond to sign-up 15 only, and do not reflect cumulative CRP enrollment in each county in 1997. I compute the share of farmland bidding to enter and accepted into the CRP by dividing acres bid and acres accepted by the total farmland acres in each county, respectively. Micro-census data providing individual CRP bid location and other information are confidential; the data were provided by the USDA Economic Research Service after aggregating individual bid data up to the county level. Denoting the EBI score for bid j in county i as EBI_{ij}, and the EBI cutoff by $\overline{EBI}$, and defining δ such that $(\overline{EBI} - \delta) < EBI_{ij} < (\overline{EBI} + \delta)$ places EBI_{ij} within a 'narrow' range of $\overline{EBI}$, the share of land accepted into the CRP, $Accept_i$, is

$$Accept_i = \frac{\sum_{j=1}^{N_i} d_{ij} \cdot bid_{ij}}{Acres_i}, \quad \text{for } (\overline{EBI}) < EBI_{ij} < (\overline{EBI} + \delta), \tag{4.1}$$

where bid_{ij} is the number of acres in bid j in county i, N_i is the number of bids, $Acres_i$ is the number of acres of farmland in county i, and d_{ij} is a random variable that equals one if bid j in county i is accepted by the CRP (its EBI score was above the threshold for acceptance) and zero otherwise. The share of land in county i bidding to enter the CRP near the EBI threshold, Bid_i, is

$$Bid_i = \frac{\sum_{j=1}^{N_i} bid_{ij}}{Acres_i}, \quad \text{for } (\overline{EBI} - \delta) < EBI_{ij} < (\overline{EBI} + \delta).$$

4.2.1 Comparing Similar Counties Near the EBI Threshold

The shares of county land bidding to enter and enrolled in the CRP can be used to assess the viability of my assumption that counties with similar shares bidding to enter the CRP in a narrow range of the EBI cutoff are, on average, similar in all ways except the share of land accepted. In table 4.4 I compare the average pre- and post-sign up 15 characteristics for two sub-groups of counties: 1) counties that had over two-thirds of their bids within 10 points of the threshold accepted, and 2) counties that had less than one-third of their bids within 10 points of the threshold accepted.

To construct the sub-groups, I compute the proportion of the share of county land bidding to enter the CRP that is accepted within 10 points of the EBI threshold,

$$ProportionAccepted_i = Accept_i/Bid_i, \quad \text{for } (\overline{EBI} - 10) < EBI_{ij} < (\overline{EBI} + 10).$$

In table 4.4, High Acceptance counties are those with $ProportionAccepted > 2/3$, and Low Acceptance counties are those with $ProportionAccepted < 1/3$.

Table 4.4 shows that restricting analysis to bids falling within 10 points of the EBI threshold leads to similar average characteristics across the High and Low Acceptance groups. By construction, the two groups have very different proportions accepted in sign-up 15. However, t-tests fail to reject the hypothesis that the two groups have the same mean *prior* to sign-up 15 in 1997.

The lower section of table 4.4 reports statistics for the High and Low Acceptance counties taken *after* CRP sign-up 15. Comparisons of land value measures between the two groups after sign-up 15 provides an estimate of the average effect of CRP enrollment within 10 points of the EBI threshold on land value in High and Low Acceptance counties. Results show that both per acre mean and acre-weighted median values are lower for the High Acceptance group than for the Low Acceptance groups, but the differences are not statistically significant.

The comparisons of High and Low Acceptance counties in table 4.4 provide estimates of the average effect of discrete differences in CRP enrollment within a narrow range of the EBI cutoff for acceptance. However, CRP enrollment is a continuous variable, and a regression framework is more appropriate for estimating the effect of marginal changes in CRP enrollment on county land values.

4.3 Correlation Between Unobserved Land Quality and CRP Enrollment

4.3.1 Structural Model of Parcel Enrollment

The parcel level structural model presented in Chapter 3 is useful for exploring how parcel level CRP enrollment decisions are related to land quality, and the potential effects of those enrollment decisions on parcel level land values; for convenience, I reproduce the model here, with slight notational modifications. Figure 4.1 plots the yearly value of productive acreage, net of production costs (net productivity), for each of two farmland properties of the same size. Acreage of each parcel is arrayed from least to most productive along the horizontal axis, with the size of each full parcel represented by $\bar{A}$. The net productivity of a parcel of land can be written

$$NP_j = a_0 + a_1' \cdot \mathbf{z_j} + a_2 \cdot A, \tag{4.2}$$

where z_j is a vector of variables that shift net productivity, j indexes parcels, and A is acres. Parcel 1 is assumed to have higher net productivity than parcel 2 (due to the values in z_2 relative to z_1), so NP_1 lies above NP_2.[3] Because land is arrayed from least to most productive along the horizontal axis, the net productivity of the first acre in each parcel is less than the net productivity of the last acre; the model being developed here allows for land quality that is heterogeneous both within and across parcels.

If the CRP offers landowners a constant yearly per acre payment to retire land from production, they will enroll acres, from least to most productive, until the

[3]The parcels are assumed to share values for the parameters a_0, a_1, and a_2.

payment just offsets the opportunity cost of enrollment. In Figure 4.1, the opportunity cost of enrollment for each property is represented by its net productivity curve. If a yearly payment of $\bar{c}$ is offered, Parcel 1 will not enroll any acreage because the value of the annual per acre payment is below the net productivity of the parcel's least productive acre. For parcel 2, $\bar{c}$ is greater than the net productivity of all acres up to CRP^*, so some of the acreage in parcel 2 is offered for enrollment. In general, landowners will enroll all, some, or none, of parcel acreage, depending on parcel productivity and program payments.

In the absence of the CRP, the total yearly return to a farmland parcel is the sum of the net productivities of each acre: this is the area under the net productivity (NP) curve for each of the two parcels in figure 4.1. For example, the yearly value of parcel 2 is $(s_2 + b)$. Facing an available payment of $\bar{c}$ per acre, a profit maximizing owner of parcel 2 would want to enroll any acre for which the payment from CRP would exceed the expected net productivity of that acre: CRP^* acres for total payments of $s_2 + s_1$ per year.[4] This increases the yearly value of parcel 2 from $(s_2 + b)$ to $(s_2 + b) + s_1$. The increase in the value of parcel 2 over an identical parcel not enrolled in the CRP is s_1 per year, the area of the triangle below the conservation payment line and above the net productivity of land not enrolled in the CRP.

In figure 4.1, the quantity of land enrolled in each parcel, CRP^*, is determined by the intersection between the conservation payment, $\bar{c}$, and net productivity, so enrollment decisions are made based on land characteristics as

$$CRP^* = \frac{\bar{c} - a_0 + a_1 \cdot \mathbf{z}}{a_2}. \tag{4.3}$$

This can be represented using the regression equation

$$CRP^* = \alpha_0 + \alpha_1 \cdot \mathbf{z} + \alpha_{\mathbf{2}} \cdot \bar{\mathbf{c}} + \eta, \tag{4.4}$$

[4]Profit maximizing landowners would also consider any costs or benefits not due directly to CRP payments. To simplify the presentation here, I assume these are zero.

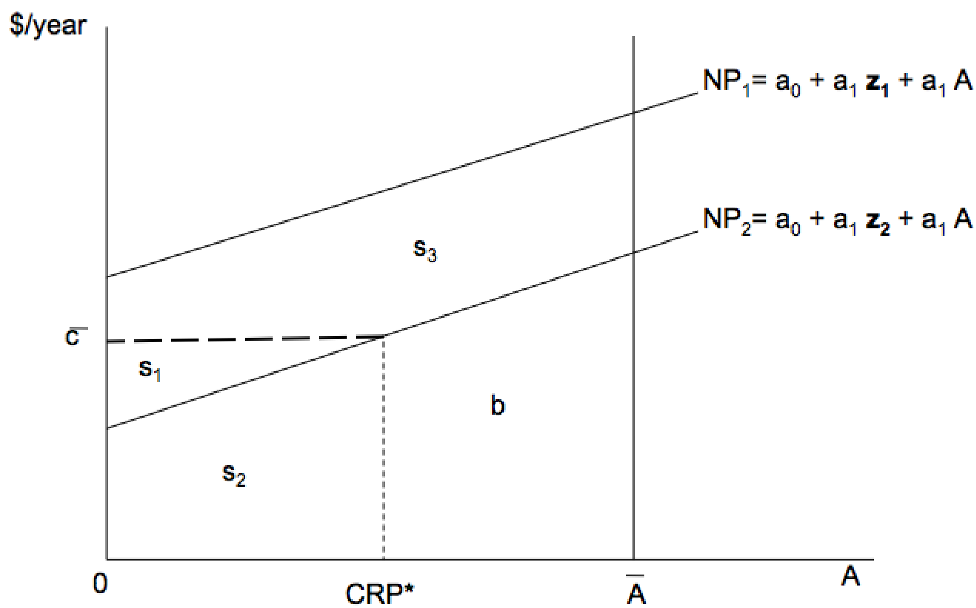

Figure 4.1: Conservation Payments and Land of Varying Productivity

which assumes that CRP enrollment is a function of variables in **z** such as land productivity, and an error, η, that captures determinants of CRP enrollment due to variables not included in **z**.

Previous studies measure the CRP Effect at the parcel level by estimating γ_2 in a regression of land value on a set of explanatory variables,

$$Value_j = \gamma_1 + \gamma_2 \cdot CRP^*_j + \mathbf{Controls_j'}\boldsymbol{\gamma_3} + \nu_j, \tag{4.5}$$

where $Value_j$ is the value of parcel j, $\mathbf{Controls_j}$ is a vector of variables thought to influence the value of parcel j such as productivity and location, and ν_j contains the effects on land value of variables not explained by CRP enrollment or variables in $\mathbf{Controls_j}$.

Landowners with scores near the expected EBI cutoff can trade future profit for a higher probability of acceptance by lowering the per-acre payment they request. As discussed above, landowners with lower quality land will be more willing to trade profit for higher probability of acceptance, inducing correlation between CRP enrollment and observed and unobserved land quality characteristics. When CRP enrollment is correlated with unobserved land quality, ν and η will be correlated. This induces correlation between CRP_j^* and ν_j,

$$E[CRP_j^* \cdot \nu_j | \mathbf{Controls_j}] \neq \mathbf{0},$$

and leads to selection bias in estimates of the CRP Effect, γ_2 [Heckman, 1979].

Selection bias may offer some insight into the "counterintuitive" [Taff, 2004, Taff and Weisberg, 2007] negative estimates of the association between CRP enrollment and land value obtained in the literature. The model of figure 4.1 indicates that because landowners base CRP enrollment decisions on the opportunity cost of production, they are likely to enroll less productive land in CRP. Evidence suggests this is the case: Vukina et al. [2008] find evidence that landowner expectations of future productivity increases due to CRP enrollment are reflected in bidding decisions, and Allen and Vanderever [2003] find that participants cite other factors influencing the value of land, including reductions in soil erosion, increases in wildlife hunting and viewing opportunities, improvements in air and water quality, more scenic landscapes, and increased future income potential. Parks and Schorr [1997], Plantinga et al. [2001], and Brimlow [2009] provide empirical estimates of the correlation between decreases in CRP enrollment and increases in Land Capability Class (LCC) and other measures of land productivity. If less productive land is being enrolled in CRP, and decreases in productivity driving enrollment are incompletely observed,

$$E[CRP_j^* \cdot \nu_j | \mathbf{Controls_j}] \leq \mathbf{0},$$

and estimates of the CRP Effect will be biased downward.

The problem of selection bias can be illustrated conceptually by returning to figure 4.1. If the price of a single parcel is not observed when the parcel is both enrolled and not enrolled in the CRP, the CRP Effect can only be determined using parcels that are otherwise similar to the enrolled parcel but not enrolled in the CRP. Assume that the two parcels in figure 4.1 are similar, but that one parcel has enrolled in the CRP due to a difference in productivity unobserved by the researcher.[5] In a regression model such as equation 4.5, the CRP Effect is recovered by holding constant any differences between the parcels other than CRP enrollment. Failing to completely control for the difference leads to results confounded by the unobserved yearly difference $s_1 + s_3$. Enrolling in CRP increases value by s_1 per year for years in which the restriction is in place, but the decrease s_3 per year is recovered in the comparison.

Several approaches have been taken to deal with selection bias in estimates of the effects of voluntary conservation programs on land value, with unsatisfying results. Nickerson and Lynch [2001] and Anderson and Weinhold [2005] take a two-step approach to account for selection bias in parcel-level models of participation in conservation programs. In the first stage, a probit regression of the enrollment decision (0,1) on explanatory variables is used to account for selection into the program, and to construct a hazard term that reflects the likelihood a parcel will be restricted. In the second stage, the effect of the program is estimated including the hazard term as an explanatory variable.[6] Taff and Weisberg [2007] attempt to account for selection in CRP enrollment using a quasi-experimental matching procedure, matching parcels enrolled in CRP with parcels not enrolled based on observed characteristics. None of the attempts report satisfying results: neither Nickerson and Lynch [2001] nor Anderson and Weinhold [2005] find the hazard term to be significant, indicating selection is

[5]Other differences, such as location, can be described in a similar fashion, but productivity is used in the illustration because it represents a likely source of unobservable selection bias.

[6]There is no exclusion restriction in the model; the author's rely on the non-linearity of the hazard term for identification.

not systematically correlated with property value or the bias is not identified, and the matching procedure in Taff and Weisberg [2007] is done in-sample and on observable variables only, and fails to eliminate the selection bias suspected by the authors.

4.3.2 The CRP and the Environmental Benefits Index (EBI)

The Environmental Benefits Index (EBI) offers further insight into the strong negative correlation between CRP enrollment and land quality. Since 1990, "general"[7] CRP enrollments have enrolled acres using the EBI. General CRP sign-ups begin with a bidding period during which eligible landowners submit bids to receive cost share and yearly rental payments in return for installing conservation practices on land for ten to fifteen year contract periods. Eligibility for the CRP is determined by active land ownership; landowners are required to own and operate the land they offer, and to have cropped the land in three of the five years prior to enrollment. Bids are collected by the Farm Service Agency (FSA) and ranked according to EBI score. After all bids to enroll are collected, the FSA determines an EBI score threshold, and landowners submitting bids that exceed the threshold are enrolled in the CRP and paid their proposed rental rate.

A landowner's EBI score is a combination of scores achieved in five environmental categories and one cost category.[8] The environmental factors reflect the history of the CRP as an erosion control program as well as the current environmental focus: wildlife, water quality, erosion, enduring benefits, and air quality. The environmental EBI scores are added to a cost factor that penalizes higher proposed rents and requests for cost share assistance according to

[7]There are two types of CRP enrollment: general and continuous. The vast majority of CRP acreage is enrolled in general sign-ups; over 30 million of the 34.7 million total acres enrolled in CRP in 2008 were enrolled in general sign-ups. Continuous sign-ups target high priority areas and land use practices, and acres enrolled during continuous sign-ups do not go through the same competitive EBI bidding process as acres enrolled during general sign-ups [USDA, 2007].

[8]A brief description of the EBI categories are provided in the appendix.

$$CostFactor = \omega(1 - r/HIGH) + 10(1 - s) + Min(15, r^m - r), \qquad (4.6)$$

where r is the rental rate proposed by the landowner, r^m is the parcel's soil-based maximum rental rate,[9] $HIGH$ is the highest soil specific rental rate allowed for all bids received nationally, ω is a scaling parameter set by the government after all bids are submitted, and s=1 if the farmer chooses to request cost share assistance, and 0 otherwise.[10]

Equation 4.6 has several characteristics that contribute to correlation between land quality and CRP enrollment. The first term in the equation is larger when the rental rate requested by a landowner is low relative to the highest rate allowed nationally, $HIGH$. Maximum yearly rental rates allowed for each bid, r^m, are determined by a formula that uses the relative productivity of soils within each county, the prevalence of the three most prominent soil types on the subject parcel, and the average county dryland cash rent. This implies that landowners' requested rental rate may be limited because they have low valued land. The weighting parameter ω is set by the FSA and determines if and how much of a bonus is given to landowners requesting relatively low rental rates, whether because they choose to or because their bids are limited by low r^m. The scale parameter ω has been constant at 125 since sign-up 15.

The second term in equation 4.6 gives landowners a 10 point bonus if they do not request cost share assistance, [11] and the final term in equation 4.6, added for sign-up 16 in 1997, adds one point to a landowner's score - up to 15 - for every dollar they bid below the maximum allowed for their specific parcel, r^m. If a landowners bid is accepted, the rental rate requested in the bid determines the annual payments received over the life of the contract; rental rates are not adjusted during the contract period. On average, landowners with lower quality land will be more willing to forgo

[9] Bidding rules require that $r \leq r^m$.

[10] Some notation is borrowed from Kirwan et al. [2005]

[11] The government typically pays half the cost of establishing the proposed conservation practice if landowners request cost share assistance.

cost share assistance or decrease their requested rental rates, causing lower valued land to be enrolled in the program.

4.4 Estimating the CRP Effect

4.4.1 Standard County Level Regression

To illustrate the regression I use to estimate the CRP Effect I begin with a county-level specification of equation 4.5,

$$Value_i = \gamma_1 + \gamma_2 \cdot CRP_i + \mathbf{Controls_i'}\gamma_3 + \nu_i, \tag{4.7}$$

where $Value_i$ is the per acre land value in county i, CRP_i is the share of county land enrolled in the CRP, the vector $\mathbf{Controls_i}$ contains other variables affecting land value such as land quality and location, and the regression error, ν_i, contains variation due to unobserved or omitted variables not accounted for by CRP_i or $\mathbf{Controls_i}$. The coefficient on the share of county land enrolled in the CRP, γ_2, measures the marginal effect of increases in CRP enrollment on per acre land value in county i, holding the variables in $\mathbf{Controls_i}$ constant.

For estimates of γ_2 to be unbiased, CRP enrollment must be conditionally independent of variables in the regression error, ν_i. This can be written as the conditional independence assumption

$$E[CRP_i \cdot \nu_i | \mathbf{Controls_i}] = \mathbf{0}; \tag{4.8}$$

when the variables in $\mathbf{Controls_i}$ are held constant, the share of land enrolled in the CRP must not be correlated with variables in the regression error, ν_i. Because land characteristics that have a large influence on both land value and CRP enrollment, such as land quality, are often unobserved, achieving the conditional independence described in equation 4.8 is difficult in practice. If equation 4.8 is violated estimates of γ_2 will suffer from omitted variables bias.

As discussed above, the strong negative correlation between CRP enrollment and land quality observed in the literature [Sullivan et al., 2004, Parks and Schorr, 1997, Plantinga et al., 2001, Brimlow, 2009], along with incentives present in the EBI enrollment mechanism suggest that unobserved land quality differences are negatively correlated with CRP enrollment. This suggests that

$$E[CRP_i \cdot \nu_i | \mathbf{Controls_i}] < \mathbf{0}, \tag{4.9}$$

which would result in estimates of γ_2 that are biased downward.

4.4.2 An Alternative Regression Approach

I attempt to overcome the confounding effects of unobserved land characteristics using a regression based on the same implicit identification method as equation 4.7 - compare land values between otherwise similar counties with different levels of CRP enrollment - but that uses a different method of controlling for unobserved differences in land quality and other characteristics. Rather than using variables such as Land Capability Class to control for differences in land quality between counties, I restrict comparisons to counties with similar shares of land bidding to enter the CRP within a narrow range of the EBI threshold.

My approach uses two unique methods of controlling for confounding differences in county land characteristics. First, I restrict analysis to county acreage contained in bids falling within a narrow range of the EBI score cutoff. As discussed above, EBI scores are correlated with land characteristics, so focusing on counties with bids receiving similar EBI scores limits variation in land quality and other characteristics that could confound estimates of the CRP Effect.

The second control method is to include the share of land in each county bidding to enter the CRP with EBI scores near the cutoff for acceptance. On average, counties with lower quality land will have a higher share of land bidding to enter the CRP near the threshold for acceptance. This is a natural consequence of the EBI enrollment mechanism, discussed above. The share of land bidding to enter the CRP serves as a proxy for observable and unobservable land quality characteristics, capturing additional confounding correlation between land characteristic and CRP enrollment.

Focusing on a narrow range of EBI scores near the cutoff for acceptance allows me to compare counties with similar characteristics (as a consequence of being in the narrow EBI range) but different levels of CRP enrollment. Because of the discontinuity of enrollment at the EBI threshold, within a narrow range of the EBI cutoff, small differences in EBI scores generate significant variation in CRP enrollment.[12]

Heterogeneous landowner characteristics generate EBI score differences that lead to different levels of CRP enrollment for counties with similar land characteristics. Landowners are able to adjust their EBI scores through choices of rental rate and conservation practice; for example, equation 4.6 shows that landowners can increase their EBI scores by 10 points by forgoing cost share assitance. From the standpoint of a landowner submitting a bid to enroll in the CRP, acceptance into the program is a Bernoulli trial, where the expected probability of being accepted (success) varies with EBI score. Near the unknown EBI cutoff, the probability of acceptance expected by each landowner approaches .5, maximizing the variance of the trial and causing landowners to treat the trial as random. Facing a random trial, landowners adjust their EBI scores according to their individual expectations or information about the EBI cutoff and their willingness to trade lower rental rates for higher expected proba-

[12]Thistlethwaite et al. [1960] originally demonstrated that program assignment based on a known, deterministic function of a continuous forcing or selection variable could be used to identify the causal effect of program enrollment. Their framework, Regression Discontinuity (RD) design, requires that enrollment (in/out) is fully dictated by the selection variable. Bid-level data linking land value, EBI score, and CRP acceptance are confidential, so the direct treatment/outcome relationship based on EBI score cannot be established. There is not a direct county-level analog to a bid-level RD design to estimate the CRP Effect, because observed enrollment is a share of total county farmland acreage, and observed per acre land values are averages of the values of county acres enrolled and not enrolled in CRP. A more thorough description of RD design and its limitations for estimating the CRP Effect using county level data is provided in the appendix.

bility of acceptance. This makes EBI scores a function of land characteristics as well as individual landowner characteristics.

In sufficiently narrow ranges of the EBI,[13] EBI variation due to heterogeneous landowner characteristics may dominate EBI variation due to land value. Near the EBI cutoff for acceptance, this generates variation in acceptance into the CRP that is effectively random with respect to confounding land characteristics. This implies that counties with similar land characteristics and shares bidding to enroll in the CRP near the EBI threshold can have different shares of land accepted into the CRP.

I implement my estimation strategy using the regression equation

$$Value_i = \beta_1 + \beta_2 \cdot Accept_i + \beta_3 \cdot Bid_i + \mathbf{X_i'}\boldsymbol{\beta_4} + \epsilon_i, \tag{4.10}$$

where $Accept_i$ and Bid_i are the shares of farmland in county i accepted and bidding to enter the CRP within a narrow range of the EBI cutoff for acceptance, as defined in section 2, and $\mathbf{X_i}$ is a vector of additional control variables such as state fixed effects included to reduce the variance of ϵ.

The conditional independence assumption necessary to obtain unbiased causal estimates of the CRP Effect, β_2, using equation 4.10 is

$$E[Accept_i \cdot \epsilon_i | Bid_i, \mathbf{X_i}] = 0; \tag{4.11}$$

if the share of land accepted into CRP near the EBI cutoff, $Accept_i$, is uncorrelated with unobserved land characteristics affecting land value conditional on Bid_i and the control variables in $\mathbf{X_i}$, equation 4.10 will provide unbiased estimates of the CRP Effect.

Higher EBI scores increase the probability of acceptance, so whether a bid is accepted into the CRP is correlated with the size of the bid through land quality.

[13]What represents a sufficiently narrow EBI range is open to argument; I will test the sensitivity of my results to changes in the EBI range.

Recalling that bid_{ij} is a bid to enroll in the CRP submitted by parcel j in county i, and d_{ij} is a dummy variable equal to one if bid_{ij} has an EBI score above the threshold for acceptance and zero otherwise, this implies

$$E[d_{ij} \cdot bid_{ij}] \neq 0.$$

Correlation between d_{ij} and bid_{ij} can induce correlation between acceptance into the CRP and unobserved components of land quality. This correlation has the potential to bias estimates of the CRP Effect. However, I assume that heterogeneous landowner characteristics make acceptance into the CRP random with respect to ϵ conditional on bid_{ij} within a narrow range of the EBI threshold. The assumption is

$$E[d_{ij} \cdot \epsilon_i | bid_{ij}, \overline{EBI} - \delta < EBI_{ij} < \overline{EBI} + \delta] = 0. \tag{4.12}$$

The negative relationship between CRP enrollment and land productivity observed in the literature [Parks and Schorr, 1997, Plantinga et al., 2001, Brimlow, 2009], supported by the strong negative correlation between the share of land enrolled in CRP and farmland value in table 4.1 leads me to expect that counties with low land value will submit more bids and attempt to enroll a higher share of land in CRP near the EBI threshold. This implies that both Bid_i and $Accept_i$ are correlated with ϵ. However, including Bid_i to control for the correlation between $Accept_i$ and ϵ_i induced through equation 4.1, the assumption described by equation 4.12 implies that

$$E[Accept_i \cdot \epsilon_i | Bid_i] = 0;$$

in a narrow range of the EBI score, the share of county i accepted into the CRP is independent of unobserved variation in land quality after accounting for the share of the county bidding to enter the CRP. Therefore, β_2 in equation 4.10 will be an unbiased estimate of the CRP Effect.

In the following section I present estimations of the CRP Effect using equation 4.10. I include state fixed effects in the control vector, $\mathbf{X_i}$, to reduce the variance of my regression error and improve the precision of my estimates. I also estimate the CRP Effect using a first-differenced specification of equation 4.10.

4.4.3 Results

If restricting analysis to bids within a small range of the EBI threshold for acceptance allows landowner beliefs, information, and circumstances to be the dominant determinant of CRP enrollment, $Accept_i$ will be a conditionally exogenous measure of CRP enrollment. The strategy predicts that bias in estimates of the CRP Effect should decrease as the EBI range narrows because variation in EBI scores due to heterogeneous landowner characteristics increases relative to the variation due to land characteristics. Table 4.5 reports estimates of the CRP Effect based on my preferred model specification and varied EBI intervals (+/- δ). The dependent variable is the difference in the acre-weighted median value between 1992 and 1997, and the model includes state fixed effects. The coefficient on the share of acres accepted into the CRP within δ of the EBI threshold is the CRP Effect, and is the first row of estimates in table 4.5. The table shows that estimates of the CRP Effect are sensitive to the width of the EBI band; the sign is consistently positive, but the magnitude increases markedly as the EBI band is narrowed.

Without large effects to non-CRP land, the point estimates in table 4.5 seem implausibly large. Because I estimate the CRP Effect using county data comprised of farmer estimates of land and buildings, my estimates include expected CRP effects on non-CRP land. If the effects of CRP enrollment on local economies are large or affect a large area, the estimates are more plausible. Potential effects of CRP enrollment on non-CRP land include hunting and wildlife viewing; CRP contracts used to preserve prairie pothole wetland areas attract hunters who pay for rights to hunt on the land, and often support local businesses.

The estimated coefficient on the share of acres bidding to enter CRP within δ of the EBI threshold is included to capture correlation between CRP enrollment and characteristics affecting land value. This correlation is induced in part by landowner self-selection into the CRP. The second row in table 4.5 shows that the coefficient estimates on the share of farmland bidding to enter the CRP are consistently negative and significant, and become more negative as the EBI band is narrowed. The coefficient estimates seem to confirm that inclusion of Bid_i captures at least some of the negative correlation between CRP enrollment and land value seen in the data in tables 4.1 and 4.2.

My preferred model uses the change in the acre-weighted median land value as the dependent variable. Empirical evidence shows a negative correlation between CRP acreage and land value, indicating that acres enrolled in the CRP are typically at the lower end of the land value distribution in each county. Because it is less influenced by value changes at the high end of the distribution in each county, the change in the acre-weighted median value used in my preferred model provides variation more suitable to identifying the CRP Effect. Using the *change* in the acre-weighted median value between 1992 and 1997 eliminates the influence of time-invariant contributors to land value. The determinants of agricultural land value are many and varied, and their estimation alone is a contentious literature [Goodwin et al., 2003]. Using the difference specification controls for time-invariant land characteristics that are not central to the identification strategy and may increase the error variance. In the difference specification, $Accept_i$ and Bid_i remain as originally defined, so the change in value regression is not a complete first-differencing of equation 4.10.

Because the enrollment data I use in this chapter are limited to acreage within a narrow range of the EBI threshold and do not measure overall CRP acreage, the first-differenced specification of equation 4.10 could be confounded if, after controlling for other variables in the regression, $Accept_i$ does not explain changes in overall CRP acreage during the period from 1992 to 1997. Although it is by far the largest, sign-up 15 is one of several sign-ups occurring during the time period, so it is possible that *changes* in CRP enrollment are not well represented by new enrollment in sign-up 15. Table 4.6 reports the results of regressions of changes in CRP enrollment from 1992 to 1997 on $Accept_i$ and controls. Regression coefficients are near 1 for all EBI ranges, suggesting that $Accept_i$ provides a good instrument for CRP enrollment changes between 1992 and 1997.

In general, my coefficient estimates, reported in table 4.5, have large standard errors. Only one of the estimates of the CRP Effect is statistically significant. Collinearity between $Accept_i$ and Bid_i, along with restrictive EBI score intervals likely contribute to the lack of precision. The correlation coefficient between $Accept_i$ and Bid_i varies between 0.91 and 0.97, depending on the width of the EBI range. This correlation increases the standard errors of my estimates, but the use of $Accept_i$ and Bid_i together is central to my identification strategy. Restricting estimation to small intervals around the EBI threshold for acceptance is also a crucial component of my identification strategy, but the decreasing amount of information contained in smaller EBI intervals may increase the standard errors of my estimates. I attempted to maximize the precision of my estimates using state fixed effects and by using acre-weighted median land value and differenced land value measures as dependent variables.

Tables 4.7 and 4.8 report estimates of the CRP Effect from naive specification of equation 4.7 as well as from several alternative specifications of equation 4.10 with the EBI range held constant at +/- 10. Table 4.7 reports estimates when the dependent variable is the log of 1997 farmland value per acre. The first two regressions in table 4.7 are based on a naive model that ignores the endogeneity of CRP enrollment, and regresses the total share of land enrolled in CRP in 1997 on total CRP enrollment in CRP in 1997. Coefficient estimates of the CRP Effect are negative and significant, reflecting the strong negative correlation between CRP enrollment and land value. The remaining three regressions in table 4.7 include $Accept_i$ as an independent variable. When $Accept_i$ is included alone, estimates of the CRP Effect will be unbiased only if

$Accept_i$ is *un*conditionally independent of all factors influencing land value. Regressing the natural log of county per-acre land value on the share of county land 'just accepted' reports a statistically significant negative CRP Effect estimate. I expect this estimate to be biased by correlation between $Accept_i$ and the regression error. Introducing the share of land 'just accepted and just rejected,' Bid_i, reverses the sign of the CRP Effect estimate, but the estimate is not statistically significant. The coefficient on Bid_i is statistically significant and negative in specifications with and without state fixed effects, reflecting that Bid_i is capturing the negative correlation between the level of CRP enrollment and per acre land value observed in the data.

The regressions in table 4.8 show that using acre-weighted median land values and the change in land value from 1992-1997 as dependent variables lead to modest decreases in standard errors compared to alternate specifications. These regressions also serve as a check of the sensitivity of my results to model specification. The dependent variable for the first two regressions is the log of average per-acre land value and the log of acre-weighted median value, respectively, while the remaining three regressions use difference specifications. Overall, my identification strategy yields estimates of the CRP Effect that have large standard errors and vary in magnitude across specifications. However, the consistently positive sign of estimates is encouraging; the method seems to offer significant improvement over previous analyses that likely suffer from selection bias.

County-level average data induce heteroskedasticity because the error variance of the model is a function of the number of acres in each county, $\epsilon_i \; N(\mu, \sigma^2/Acres_i)$. Heteroskedasticity can be reduced by weighting each observation by county farmland acres, $Acres_i$ [Wooldridge, 2003]. This ensures that counties with more acreage in farms carry more weight in the estimation, and generates efficient estimates of the CRP Effect. Estimates of weighted regressions are reported in table 4.9. The estimates from these specifications are qualitatively similar to estimations using the difference in mean value per acre and state fixed effects reported in table 4.7, but have slightly lower standard errors.

4.5 Conclusion

The USDA Conservation Reserve Program pays landowners to voluntarily preserve ecosystem services from agricultural land. The large federal program distributes over 1.8 billion dollars in payments per year, but the effects of the program on agricultural land values is poorly understood. Unbiased causal estimates of voluntary program effects require conditionally exogenous variation in program enrollment. This chapter presents a novel identification strategy that utilizes variation in CRP enrollment generated by the EBI enrollment mechanism to obtain variation in CRP enrollment conditionally exogenous of land characteristics driving land value. Estimates of the effect of CRP on county land values are sensitive to model specification and have large standard errors. However, the consistently positive sign of the estimates is inconsistent with previous counterintuitive estimates, suggesting that the identification strategy represents a significant step toward overcoming data limitations and bias induced by the endogeneity of CRP enrollment.

Estimates of the CRP Effect in this chapter also suggest that the effects of CRP enrollment may be large, indicating that large positive effects on local economies may exist. Insight into the existence of the effect of the CRP on non-CRP land is an advantage of estimating the CRP Effect using county level data. Estimates using farm-level data would not include these effects; if parcel level data become available, future work could estimate the CRP Effect with farm-level data, and comparisons of farm- and county-level estimates of the CRP Effect would provide insight into the relative size of the effects of CRP enrollment on non-CRP land.

My identification strategy may have broader applicability. In this chapter I estimated the effect of CRP enrollment on land values; other impacts of the CRP could be addressed, as well as other programs with similar enrollment mechnisms. For example, there is disagreement in the literature about whether the CRP causes landowners to bring previously idle land into production ("slippage"), offsetting the program's environmental benefits [Wu, 2000, Roberts and Bucholtz, 2005]. My identification strategy could be applied to measure the effect of CRP enrollment on changes in cropland acreage to provide estimates of "slippage" caused by the program. Global interest in climate change is generating interest in voluntary programs designed to curb environmentally destructive land use practices and offset carbon dioxide emissions. As programs grow larger, standardized enrollment mechanisms become necessary, and evaluation of the impacts of the programs will be required for policy decisions. The method presented in this chapter represents an alternative method of evaluating programs when data limitations and selection bias make other estimators impractical.

Table 4.1: 1997 US County Per-Acre Farmland Value by Share Accepted into CRP

		0<CRP≤5%	5%<CRP
Value/Acre 1997	Mean	**$1,399**	**$880**
	St Dev	**811**	**498**
Counties		1215	522

Notes: Data for the per-acre farmland value in US counties that entered bids to enroll in CRP is provided by the USDA Economic Research Service. The total number of counties entering bids in 1997 was 1737. A difference of means t-test assuming independent samples and unequal variance yields a value of 16.28, rejecting the hypothesis that the means are equal.

Table 4.2: Summary Statistics - Full Sample

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Average Value/Acre 1997	1,242	769	107	7,245	1,737
Acre-Weighted Median Value 1997	1,065	684	62	5,379	1,737
Diff in Ave Value/Acre 92-97	310	282	-1,389	1,835	1,737
Diff A-W Median Value 92-97	280	259	-911	1846	1,737
Ave Pay/Acre, Sign-up 15	50	21.5	0	122	1,737
Share enrolled in CRP 1997	0.043	.045	0	0.30	1,737
Acres Accepted Sign-Up 15	8,299	18,031	0	196,123	1,737
Share Accepted Sign-Up 15	0.021	0.031	0	0.221	1,737
Acres Bid Sign-Up 15	11,850	23,359	0.5	314,459	1,737
Share Bid Sign-Up 15	0.03	0.037	0	0.275	1,737

Table 4.3: Summary Statistics - by Share Enrolled in the CRP

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Share of 1997 Farmland Enrolled = 0%					
Average Value/Acre 1997	1,883	1,403	157	5,490	14
Acre-Weighted Median Value 1997	1,492	1,234	150	5,000	14
CRP Acres 1997	0	0	0	0	14
0% < Share of 1997 Farmland Enrolled ≥ 5%					
Average Value/Acre 1997	1,393	801	107	7,245	1,201
Acre-Weighted Median Value 1997	1,205	716	62	5,379	1,201
CRP Acres 1997	6,211	8,805	50	75,247	1,201
5% < Share of 1997 Farmland Enrolled					
Average Value/Acre 1997	880	498	155	3,722	522
Acre-Weighted Median Value 1997	732	423	99	3000	522
CRP Acres 1997	38,386	38,927	715	249,793	522

Table 4.4: County sub-groups before and after sign-up 15

	Full Sample n = 1737	High Acceptance n = 875	Low Acceptance n = 132	
Before Sign-up 15				
Farmland Value: mean $/acre, 1992	932 (609)	992 (22.08)	991 (47.69)	t = -0.02 df = 191
Farmland Value: median $/acre, 1992	784 (500)	820 (17.83)	847 (42.45)	t = 0.587 df = 180
Land in Farms: 1992	342,875 343,355	312,841 (11,768)	295,966 (18,522)	t = -0.77 df = 252
After Sign-up 15				
Farmland Value: 1997 $/acre	1,883 (1,483)	1,314 (27.57)	1,346 (68.53)	t = 0.44 df = 176
Farmland Value: median $/acre, 1997	1,065 (684)	1,113 (24.02)	1,174 (62.31)	t = 0.91 df = 172
Land in Farms: 1997	342,483 (342,203)	313,000 (11,807)	295,645 (18,522)	t = -0.79 df = 252

Notes: High Acceptance and Low Acceptance counties are determined by dividing the total share of county land accepted in sign-up 15 by the total share bidding to enter within a 10 point margin of the EBI threshold for acceptance. High Acceptance counties had two-thirds or more of their bids accepted, and Low Acceptance counties had less than one-third accepted. Shares are computed as the total farmland acreage bidding to enroll or accepted by the CRP divided by total farmland acres. The total number of counties entering bids to enroll in the CRP in sign-up 15 was 1737. Median $/acre is the value of the acre-weighted median in each county. Reported t statistics correspond to two-sample test that the means of high and low acceptance counties are equal assuming unpaired data and unequal variances.

Table 4.5: Preferred Model: CRP Effect by EBI Range, Sign-up 15

Variable		$\delta = 30$	$\delta = 20$	$\delta = 10$	$\delta = 5$
Share Accepted	349.1	1711*	2363	4770	5039
	(452)	(1026)	(1678)	(3638)	(6076)
Share Bid	-1203***	-2329***	-3038***	-5418***	-7408**
	(364.1)	(662.7)	(1022)	(2082)	(3305)
R^2	0.458	0.455	0.454	0.453	0.452

Notes: Standard deviations in parentheses, *** p<0.01, ** p<0.05, * p<0.1 Shares for each county are computed as the total farmland acreage bidding to enroll or accepted by the CRP during sign-up 15 divided by total farmland acres. The total number of counties entering bids to enroll in the CRP in sign-up 15 was 1737. δ dictates distance from the EBI range; inclusion in 'share bid' requires an EBI score a maximum of +/- δ from the EBI threshold, 'share accepted' requires an EBI score a maximum of + δ from the threshold. All models include state fixed effects.

Table 4.6: CRP Enrollment Share 1992-1997 on Accepted Share, Bid Share, and State FE

VARIABLES	
Accepted Sign-Up 15 ($\delta = 10$)	0.979**
	(0.411)
Accepted Sign-Up 15 ($\delta = 20$)	1.146***
	(0.187)
Accepted Sign-Up 15 ($\delta = 30$)	0.902***
	(0.113)

Notes: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1,
+/-δ is the range around EBI cutoff, N=1737.

Table 4.7: CRP Effect - Log of Farmland Value, 1997

Variable	(1)	(2)	(3)	(4)	(5)
CRP98_share	-4.779***	-2.722***			
	(0.349)	(0.228)			
Accepted (δ=10)			-33.74***	0.303	6.510
			(2.881)	(11.98)	(7.395)
Bid (δ=10)				-19.96***	-13.17***
				(6.817)	(4.233)
State FE	N	Y	N	N	Y
R^2	0.098	0.691	0.073	0.078	0.681

Notes: Standard errors in parentheses, N = 1737,
*** p<0.01, ** p<0.05, * p<0.1,
(+/-)δ is the range around EBI cutoff.
Dependent variable (1) - (5): log of 1997 average farmland value per acre.

Table 4.8: CRP Effect - Varied Specification

Variable	(1)	(2)	(3)	(4)
Accept ($\delta = 10$)	6.510	8.080	2368	4770
	(7.395)	(7.771)	(4151)	(3638)
Bid ($\delta = 10$)	-13.17***	-14.09***	-3770	-5418***
	(4.233)	(4.449)	(2376)	(2083)
State FE	Y	Y	Y	Y
R^2	0.681	0.695	0.400	0.453

Notes: Standard errors in parentheses, N = 1737,
*** p<0.01, ** p<0.05, * p<0.1,
(+/-)δ is the range around EBI cutoff.
Dependent variable:
(1) Log of average land value per-acre
(2) Log of acre-weighted median value
(3) Difference, 1992-1997 mean value per acre
(4) Difference, 1992-1997 acre-weighted median value

Table 4.9: CRP Effect - Weighted Regression

Variable	(1)	(2)	(3)	(4)
Accept ($\delta = 10$)	9.102	13.51	-724.1	2583
	(8.080)	(8.589)	(3025)	(2701)
Bid ($\delta = 10$)	-10.06**	-12.27**	-1037	-3337**
	(4.571)	(4.859)	(1711)	(1528)
State FE	Y	Y	Y	Y
R^2	0.681	0.695	0.400	0.453

Notes: Standard errors in parentheses, N = 1737,
*** p<0.01, ** p<0.05, * p<0.1,
(+/-)δ is the range around EBI cutoff.
Dependent variable:
(1) Log of mean per-acre value
(2) Log of acre-weighted median value
(3) Difference, 1992-1997 mean value per acre
(4) Difference, 1992-1997 acre-weighted median value

Chapter 5

Conclusion

This dissertation explores the determinants and effects of enrollment in the United States Department of Agriculture's (USDA) Conservation Reserve Program (CRP). The CRP is the largest federal conservation program, currently enrolling over 34 million acres of productive cropland. Annual CRP payments to enrolled landowners average over $1.7 billion, and represent public purchases of ecosystem services, including crop production capacity and habitat conservation, from private landowners. The CRP has a large and wide-ranging impact on both CRP and non-CRP land through its effects on farm profits and farm and non-farm economies, and enlightened CRP policy requires understanding of the determinants of CRP enrollment as well as the magnitude of its effects.

In Chapter 2 I present an options model that provides insight into landowner decisions to enroll in the CRP under varying market conditions and counterfactual policy scenarios. It incorporates market and institutional uncertainty, risk aversion, and the irreversible and postponable nature of CRP enrollment decisions, and includes institutional characteristics of the CRP that generate policy implications. For example, the model predicts that, for a given level of agricultural returns, landowners will require lower payments to enroll in the CRP as the expected frequency of CRP sign-ups decreases. The prediction of the model is consistent with current payment levels used to enroll landowners during the two types of CRP sign-ups: general and continuous. Continuous sign-ups are generally used by the USDA to target enrollment of small areas of environmentally sensitive land, and offer higher average payments. My options model in Chapter 2 predicts that higher payments during continuous sign-ups are necessary *because* of the continuous nature of the sign-ups, and may not reflect differences in the agricultural productivity of the enrolled land. If the continuous sign-up structure is required to secure land that has large environmental benefits, higher payments may be justified. However, if similar land could be enrolled during less frequent sign-ups, the cost to taxpayers of achieving the same level of conservation would decrease.

The model also predicts that landowner decisions to enroll in the CRP are relatively insensitive to CRP contract lengths when payments for enrollment are near the long run mean of agricultural returns. As the conservation focus of the CRP has shifted to include a greater breadth of ecosystem services, environmental groups have raised concerns that CRP contracts, typically lasting 15 years, are too short to provide meaningful habitat conservation. My model predicts that when CRP payments are at or near the long run mean of agricultural returns, decisions to enroll are insensitive to increases in contract length from 15 to 30 years. This implies that it may be possible for the CRP to secure longer contracts for nearly the same yearly per-acre payments.

There are additional aspects of the CRP policy problem not incorporated in the model I present in Chapter 2 that I leave for future work. The model does not address important spatial aspects of the policy environment, including the distribution of market and landowner characteristics across space. Additionally, the model does not account for potentially large effects of CRP enrollment on enrolled land not directly related to program payments, such as revenues generated by charging for hunting access. These additional considerations are likely important for understanding decisions to enroll in the CRP [Parks, 1995, Wu and Lin, 2008], and could be included in future versions of the model. Finally, calibrating the model to observed data is an important next step to assessing the strength of the model's predictions and increasing its applicability. The model's implications will vary by agricultural market, location, and crop mix. Calibrating the model to specific areas and crops would allow predictions to be tested against observed CRP enrollment behavior and inform model improvements.

In Chapter 3 I present estimates of the effect of agricultural productivity on CRP enrollment. Motivated by a parcel-level structural model of landowner enrollment in the CRP, my estimation addresses censoring in CRP enrollment data and addresses challenges of model misspecification using a uniquely comprehensive index of land productivity for farm parcels in Minnesota and county non-CRP government payments. Parcel-level data represent a significant improvement in data resolution, allowing me to estimate the determinants of CRP enrollment at the same resolution those decisions occur. I find a significant negative relationship between land productivity and CRP enrollment that adds a robust parcel-level estimate to a mixed literature.

The significant negative relationship between CRP enrollment and land productivity I find in Chapter 3 has implications for studies designed to evaluate the effects of program enrollment on CRP and non-CRP land. In addition to providing payments to enrolled landowners, the CRP has the potential to affect CRP and non-CRP land through its effects on ecosystem services and local economies. Asset valuation theory predicts that land values will capture many market effects and some non-market effects of the CRP. Therefore, estimating the magnitude of changes in land value caused by the CRP would be useful for quantifying the effects of the program and guiding federal conservation policies. However, estimating the effects of the CRP by measuring differences in land values requires comparisons between land that is similar in all ways except the level of CRP enrollment, and the correlation between CRP enrollment and land quality illustrated in Chapter 3 complicates estimates in practice. This is because a significant portion of the land quality differences that drive both land values and landowner decisions to enroll in the CRP is private information held by landowners, and land quality data that capture potentially observable variation are often not available. For example, linking the parcel level productivity data in Chapter 3 to more detailed CRP enrollment data (e.g., timing, payments) held by the USDA is not possible because of federal confidentiality agreements. Thus, constructing comparisons between land that is of similar quality is difficult, and failure to do so results in biased estimates of the effect of the CRP.

In Chapter 4 I present a new approach to estimating the effect of CRP enrollment on land values that focuses on land value differences generated by the acceptance into the CRP in a narrow range of the Environmental Benefits Index (EBI) cutoff for acceptance. Data confidentiality issues require me to focus on county-level effects. However, county level effects capture the direct effect of CRP rental payments on parcels enrolled in the program as well as the effect on both CRP and non-CRP land of other changes such as increases in tourism, and provide a good metric for assessing the local impact of the CRP.

The results of my estimations in Chapter 4 indicate that the new approach significantly reduces bias generated by unobserved variation in land quality, and that the CRP may have large positive effects on county land values. My estimates in Chapter 4 are likely too large to represent only effects accruing to CRP enrolled land, and suggest that the CRP may have large positive impacts on local economies. If parcel level data become available, future work could compare farm- and county-level estimates to provide insight into the relative size of the effects of CRP enrollment on non-CRP land.

The estimation approach I present in Chapter 4 may have broader applicability as well. First, it could be used to assess other effects of the CRP. For example, there is disagreement in the literature about whether the CRP causes landowners to bring previously idle land into production ("slippage"), offsetting the program's environmental benefits [Wu, 2000, Roberts and Bucholtz, 2005]. My identification strategy could be applied to measure the effect of CRP enrollment on changes in cropland acreage to provide estimates of "slippage" caused by the program. Further, the approach could be used to asses other programs with similar enrollment mechnisms. For example, there is increasing interest in voluntary programs designed to curb environmentally destructive land use practices and offset carbon dioxide emissions. Enrollment mechanisms such as the EBI become necessary as programs grow larger, and evaluation of the impacts of programs is required for policy decisions. The estimation approach I present in Chapter 4 represents an alternative when data limitations and selection bias make traditional program evaluation estimators impractical.

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APPENDIX

A Environmental Benefits Scoring Categories

EBI point scores are the sum of the point values earned in six EBI categories:

N1(Wildlife) - habitat cover, enhancement; bonus if in priority area (up to 100 points)

N2(Water Quality) - improvements to ground and surface water due to decreased erosion; bonus if in priority area (up to 100 points)

N3(Erosion) - weighted average of wind and water Erodibility Index (EI); based on 3 predominant soils (up to 100 points)

N4(Enduring Benefits) - points for establishing enduring cover (up to 50 points)

N5(Air Quality) - improvements to air quality due to decreased wind erosion; also includes carbon sequestration (up to 35 points)

N6(Cost) - based on landowner bid; bonus if bid is below max payment rate for region/practice) (weighted after sign-up)

B EBI Score and Regression Discontinuity Design

The Environmental Benefits Index (EBI) score used to determine enrollment admits the possibility of using a quasi-experimental framework to test the effect of CRP enrollment on land value. Regression Discontinuity (RD) design, originally introduced in the statistical literature by Thistlethwaite et al. [1960], has gained popularity in the economics literature for its ability to identify the effect of a treatment on an outcome of interest when the treatment is assigned based on a known, deterministic function of an observed, continuous 'forcing' or 'selection' variable.[1]. In RD design, the relationship between treatment and selection dictates that treatment is a discontinuous function of the selection variable, so the estimated treatment effect at the threshold value of the forcing variable is the difference between the intercepts of two, parallel regression lines, as shown in figure B.1.

In RD design, special attention is paid to the possibility of correlation between the selection variable and the outcome of interest. Correlation between the outcome and selection variable is separate from causal correlation between treatment and outcome, and could lead to biased and inconsistent estimates of the treatment effect. Typically, an assumption about the functional form of the relationship between the average outcome and the selection variable must be used to control for correlation not due to treatment Imbens and Lemieux [2008].[2] If correlation between the outcome and the selection variable is successfully controlled for, the 'randomized experiment' characteristic in a close vicinity of the cutoff for treatment remains intact, and the RD design can generate unbiased estimates of the treatment effect.[3]

The discontinuity of the EBI score at the acceptance threshold - a parcel bidding

[1]For a review of RD design and a current review of the practical and theoretical issues with its implementation, see Imbens and Lemieux [2008].

[2]Consistent estimation of requires that the functional relationship between the outcome variable and the selection variable is correctly specified. If the control function is continuous in the selection variable, identification of the treatment effect is possible due to the discontinuity of treatment.

[3]A commonly used method for controlling for correlation between selection and outcome is described in Heckman and Robb [1985].

to enter the CRP is enrolled if its EBI score exceeds the threshold value, and not enrolled otherwise - makes it appropriate as a selection variable for use in RD design if land in an arbitrarily small interval around the EBI cutoff has similar value. Because landowners do not know the EBI score required for acceptance before they submit their bids, EBI scores can be partially determined by heterogeneous landowner expectations and information.

Because the EBI score meets the requirements for a selection variable in RD design, the CRP Effect could be estimated using the model

$$Value_j = \pi_0 + \pi_1 \cdot EBI_j + \pi_2 k(EBI_j) + \pi_3 controls_j + \xi_j, \tag{B.1}$$

where EBI_j is the EBI score corresponding to the bid submitted to enter CRP by parcel j, $k(EBI_j)$ is a function to control for possible correlation between the EBI score and land value for parcel j,[4] $Value_j$. Unfortunately, the data necessary to implement a classic RD design to estimate the CRP Effect are not available. Data linking individual parcel bids and their EBI scores to specific geographic location, and therefore to land value, are confidential. There is no direct county-level analog to estimating the CRP Effect using a parcel-level RD design, because generating the randomized experiment requires that the EBI score value for each observation (i.e., county) fully dictate treatment (enrollment).

[4]Because the RD design only requires that the control function and treatment effect are continuous at the cutoff of the selection variable, semi-parametric relationships between the selection variable and the outcome of interest can be used to minimize the possibility of misspecification.

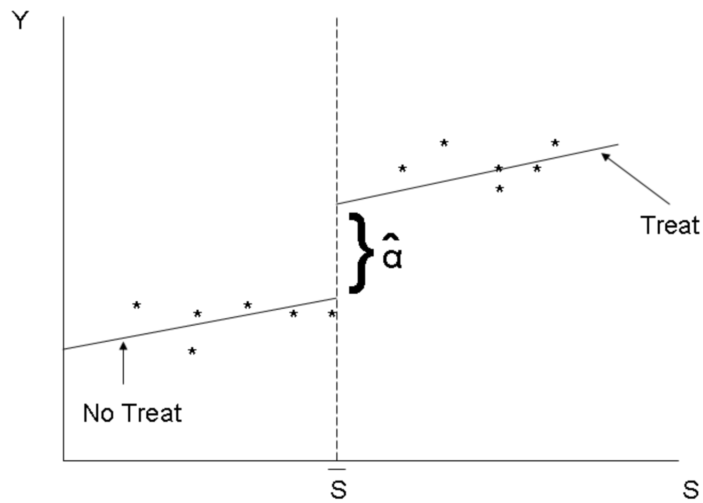

Figure B.1: Basic RD Design