# Assessing Cost-effectiveness of the Conservation Reserve Program (CRP) and Interactions between CRP and Crop Insurance

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**Abstract:** We examine U.S. Conservation Reserve Program (CRP) enrollment design while accounting for CRP's interactions with the federal crop insurance program. We find that the current CRP is not cost-effective despite its intent to balance benefits and costs. Based on CRP contract-level data, we show that adopting a cost-effective enrollment design and incorporating crop insurance subsidies into CRP's Environmental Benefits Index would significantly increase all of CRP acreage, environmental benefits, and savings on crop insurance subsidies while leaving government outlay unchanged. Large geographical re-distributions of CRP acreage would also occur. We further investigate the cost-effective design's robustness to CRP benefit mis-specifications.

**Keywords**: Conservation Reserve Program, Cost-effectiveness, Crop Insurance, Environmental Benefit Index

**JEL Classification:** Q18, Q24, Q38, H23

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## I. INTRODUCTION

Conservation effectiveness when facing resource constraints is a central theme in the environmental conservation literature. Cost-benefit analysis has been advocated as a basic tool to enhance conservation effectiveness (Ando and Mallory 2012; Murdoch et al. 2010; Arrow et al. 1996). This article focuses on the Conservation Reserve Program (CRP), the largest land retirement program supported by the United States federal government. It shows that CRP's effectiveness can be significantly enhanced by appropriate use of cost-benefit targeting and by accounting for interactions between CRP and federal crop insurance program (FCIP), the largest U.S. agricultural commodity subsidy program.

The CRP is a voluntary program that pays farmers to retire environmentally sensitive land from active production and plant it with grass or trees for a contract period of 10-15 years (Stubbs 2013). The program was first authorized in the Food Security Act of 1985 and enrollment reached 33.9 million acres in 1990, which accounted for about 8% of the country's total cropland. Enrollment in CRP ranged from 30 to 37 million acres between 1990 and 2011, but has declined to about 23.5 million acres as of November 2015 due to the favorable market environment for cropping and the subsequent reduction of CRP acreage cap in the 2008 and 2014 Farm Bills. The current annual program outlay is about $2 billion (Farm Service Agency (FSA) 2014). CRP is generally considered to have succeeded in providing multiple environmental benefits including soil, water, wildlife, and other natural resources (Feather, Hellerstein, and Hansen 1999; FAPRI-UMC 2007; Wu and Weber 2012).

The CRP currently faces serious challenges. In light of strong demand for agricultural commodities as well as pressure to reduce the federal budget deficit, the 2014 Farm Bill provided legislation to reduce the maximum amount of land that can be kept in CRP from the

32 million acres to 24 million acres by 2018. Commencing about 2007, a higher crop price environment also implies that farmers will require higher rental payments to enroll their land into CRP, which will result in higher program outlays and hence dull the program's political appeal (Hellerstein and Malcolm 2011). These new challenges heighten the need for a CRP enrollment mechanism designed to achieve maximum environmental benefit for any given federal government budget outlay.

In this article we examine the environmental and budgetary implications of different CRP enrollment designs in the context of the program's interactions with FCIP. FCIP insures more than 280 million acres of land with an annual average liability worth about $95 billion in 2015 (Risk Management Agency (RMA) 2015). It supports farmers mostly through premium subsidies which have averaged about 60 percent of total premiums paid in recent years. It also includes significant amount of administration and operating costs paid to approved private insurance companies (Shields 2015). FCIP is predicted to cost about $8.9 billion per year over 2013-2022, making it the most expensive agricultural commodity program. It has been heavily criticized and is under intense scrutiny (USGAO 2012 and 2015; Goodwin and Smith 2014).

CRP and FCIP can interact. The enrollment design currently used in CRP as of 2014 is targeted at removing cropland from production if the land performs sufficiently well according to the program's Environmental Benefits Index (EBI). Throughout this paper we refer to the EBI design used in CRP as of 2015 as the current EBI design.[i] Factors entering the current EBI include wildlife impacts, water quality, air quality, erosion propensity, and carbon sequestration potential. Enrollment cost factors are also included where, *ceteris paribus*, land that commands higher rental payment will perform worse on the index and so is less likely to be accepted for enrollment. Omitted from the current EBI, however, is the crop insurance subsidy reduction that would occur were the land removed from production.[ii] To underscore the omission's significance, in some regions average crop insurance premium subsidies amount to significant percentages of CRP rents and even cropland cash rents. Table 1 shows that in North Dakota the state-average crop insurance subsidies were about 70% of CRP rent and 50% of land cash rent over 2008 to 2014. Even in Iowa, where land is fertile and has high rent, average crop insurance subsidy can be as high as 20% of average CRP rent in some years. This indicates that some land could be taken out of production at very small budgetary cost to the government. That is, when crop insurance subsidies on a land tract are close to its CRP rent then the saved crop insurance subsidies through enrolling the land into CRP can largely offset its CRP payment.

Furthermore, the omission of crop insurance subsidies in the calculation of EBI may also affect the geographical configuration of enrolled acres. A cursory inspection of any CRP enrollment map shows high concentration of enrolled acres in the Southern Corn Belt, the Eastern Dakotas, Montana, the Southern Great Plains and parts of the Palouse (FSA 2013). These are in the main marginal cropland regions where CRP enrollment costs are low and benefits may be high. Regions with more marginal land tend to have higher insurance premiums per acre which implies higher premium subsidies per acre given that subsidy is proportional to premium (USGAO 2015). Therefore, all else equal, the incorporation of subsidy savings will increase the competitiveness of offers from marginal land to be enrolled in CRP. These observations highlight the importance of taking crop insurance subsidies into account when designing CRP enrollment policies. Although program fund sources differ, federal taxes spent and saved have equal weight when calculating the budget deficit. Moreover, were saved crop insurance subsidies included in the index then incentives for optimal land allocation would be strengthened because the inclusion would mitigate potential dissonance across the suite of agro-environmental policies.

Large literatures have examined the efficiency of the CRP and FCIP separately whereas interactions between these two programs from a CRP enrollment design perspective have received little attention. Since CRP's inception in 1985, the efficiency of its land enrollment designs and associated environmental and economic impacts have attracted scrutiny. Reichelderfer and Boggess (1988) and Ribaudo (1989) argue that CRP enrollment design used in the first nine signups basically maximized acres enrolled.[iii] Babcock et al. (1996, 1997) compare three enrollment designs under a budget constraint: (a) enrolling land with highest benefit-to-cost ratio; (b) enrolling land with lowest costs among eligible land (akin to enrollment design for the first nine signups); and (c) enrolling land with highest environmental benefits among eligible land regardless of costs. Wu, Zilberman, and Babcock (2001) study how these alternative designs are preferred by different interest groups. However, none of these studies have considered the cost-effectiveness of the current EBI design. Although Hellerstein, Higgins, and Roberts (2015) focus on the cost-effectiveness of the current EBI design, they mainly investigate effects of setting a maximum CRP payment rate (i.e., bid cap) on the cost-effectiveness of CRP by applying auction theory and economic experiments, which is not a focus in this paper. On the other hand, most of the considerable body of research on U.S. crop insurance has focused on issues related to product design, rate-setting, and farmers' participation decisions (e.g., Goodwin 2001; Sherrick et al. 2004; Norwood, Roberts, and Lusk 2004). A few studies have focused on the land use impacts of FCIP (e.g., Young, Vandeveer, and Schnepf 2001; Goodwin, Vandeveer, and Deal 2004; Lubowski *et al.* 2006; USGAO 2007; Miao, Hennessy, and Feng 2012, 2014). Goodwin and Smith (2003) investigate the offset effect of crop insurance on CRP-induced soil erosion reduction. However, none of these studies consider interactions between CRP enrollment design and FCIP.

To our best knowledge, this article is the first study that examines the cost-effectiveness of the current EBI design while accounting for the interactions between CRP and FCIP. We show that, although it tries to balance environmental benefits with rental costs, the current EBI is not cost-effective. The current EBI can be interpreted as an effort to maximize net benefit per acre targeted where benefits measured in index points are assumed to be commensurable with land rental rates. By contrast, a cost-effective enrollment criterion requires benefit-cost ratio targeting so that environmental benefit per dollar spent is maximized. Benefit-cost ratio targeting is widely used for analysis of programs and regulations (e.g., Mishan and Quah 2007). Therefore, we identify a cost-effective EBI and examine how crop insurance savings can be included in the current EBI design and also in this cost-effective EBI. We then simulate the environmental and budgetary consequences of alternative EBI designs by using contract-level CRP offer data in Signup 26 (conducted in 2003) and Signup 41 (conducted in 2011) across the contiguous United States. Data were obtained from the FSA of the U.S. Department of Agriculture (USDA). We select these two signups because crop prices, and hence crop insurance subsidies, were much higher in 2011 than in 2003. The large differences between insurance subsidies in these two years provide an opportunity to assess the impacts of incorporating crop insurance subsidies over a wide range of values.

The results based on the two signups suggest that adopting a cost-effective enrollment design and incorporating crop insurance subsidies into EBI would result in significant increases in CRP acreage, total environmental benefits, and savings on crop insurance subsidies while leaving government outlay unchanged. For example, had the cost-effective targeting enrollment design been adopted and insurance subsidies been accounted for in Signup 41 then the government could have enrolled about 50% of offered acres in that signup at zero real cost, defined as nominal CRP payment minus saved insurance subsidies. Under cost-effective targeting, CRP acreage and payments would increase in the Great Plains and the Southeastern states but would decrease in the Midwest.

In what follows we first outline a conceptual framework illustrating that the current CRP enrollment design is not cost-effective. Further, a cost-effective EBI design is proposed. Section III describes the simulation strategy and data used while Section IV reports simulation results. Section V discusses the development of EBI design and analyzes underlying motivations for the current EBI design from perspectives of transaction costs and political economy. It also analyzes the robustness of the current EBI and the cost-effective EBI when environmental benefits of offered land are not accurately measured. Section VI concludes with discussions regarding this study's implications and qualifications, and also regarding possible directions for future work.

## II. CONCEPTUAL FRAMEWORK

In this section we model CRP's enrollment mechanisms. To meaningfully model and assess the mechanisms, we need to first understand the goals that CRP is intended to achieve. When the CRP was first established in 1985, its major goal was to reduce soil erosion. For the first nine signups between 1986 and 1989, the program focused on quickly enrolling acres, not on maximizing environmental benefits, and its enrollment was consistent with maximizing total acreage for a given budget outlay (Reichelderfer and Boggess 1988; Ribaudo 1989). Commencing in 1990, multiple environmental factors were introduced and the concept of EBI was used in order to balance environmental gains with program costs. For general signups 10 through 13 over 1991-1995, land enrollment was intended to maximize environmental benefits per dollar of cost where the specific design of EBI was not disclosed (Osborn 1993; Jacobs, Thurman, and Marra 2014).

The current EBI design was created after the Federal Agriculture Improvement and Reform Act of 1996. In this design, CRP rental payments requested by farmers are added to environmental components after a linear transformation. For all enrolled acres, funding is mandatory, i.e., it is not subject to annual appropriation. For each CRP offer, the FSA assigns an EBI to it based on the offer's environmental benefits and rental payment requested by the landowner. Then all offers are ranked according to EBI and offers with EBI no less than the cut-off EBI will be enrolled into CRP. Here we focus on the efficiency of the current EBI design.

Let EEBI denote environmental benefits of an offer and $r_k$ denote the rent per acre requested in an offer for land tract *k*.[iv] EBI under the current CRP specification is as follows:

$$\text{EBI} = \text{EEBI} + f(r_k) + \text{extra bonus points}, \quad [1]$$

where $f(r_k)$ is a function of the requested rental rate, and the extra bonus points are a relatively small number reflecting whether the offer requests cost share or how much the requested rental rate is below the weighted average soil rental rate (WASRR) of the offered land. Under the current CRP implementation, $f(r_k)$ is set to be

$$f(r_k) = a \times \left(1 - \frac{r_k}{b}\right), \quad [2]$$

where parameters $a$ and $b$ are determined by the program administrator. Table 2 presents values of these two parameters, the maximum possible points for the cost components, EEBI, EBI, and the cut-off EBI points for acceptance in general signups over 1997-2011. For the general sign-up in 1997, $a = 190$ but has been 125 since then. The value of $b$ has increased gradually from 165 in 1997 to 220 in 2011. In addition, total available points for environmental benefits (i.e., maximum EEBI) accounted for 67-73% of total EBI points over 1997-2011 (Table 2). Such large percentages suggest that the current EBI puts more emphasis on environmental benefits than on program costs.

The EBI formulation in equations [1]-[2], as explained above, gives positive incentives for providing environmental services and negative incentives for requesting a high rental rate. Thus, it is an attempt to balance environmental benefits and program costs. A notable feature of the EBI in equations [1]-[2] is that it is a linear combination of costs and environmental benefits. We refer to this form of benefit targeting as "pseudo cost-effective targeting." The term "pseudo" is used here because benefits and costs are not necessarily measured in a common unit and the EBI is not necessarily a true measure of net benefits. Before demonstrating that "pseudo cost-effective targeting" is consistent with an optimization problem to be described below, we first introduce some notation. Define by $k \in \Omega \equiv \{1, 2, ..., K\}$ the $k^{\text{th}}$ parcel of land offered to CRP. Let $l_k$ denote the size of parcel *k*. The set of all subsets of $\Omega$ is written as $\mathscr{P}(\Omega)$. Environmental benefits arising from land retirement amount to $e_k$ per acre for parcel *k*. Therefore, if set $\boldsymbol{h} \subseteq \mathscr{P}(\Omega)$ is placed in CRP then environmental benefits amount to $\sum_{k \in \boldsymbol{h}} e_k l_k$. The optimization problem that induces the currently employed CRP enrollment design (i.e., "pseudo cost-effective targeting") can be written as:

**Optimization Problem 1** (OP1, pseudo cost-effective targeting): maximize environmental benefits with a linear adjustment of costs, subject to an acreage constraint. That is,

$$\begin{aligned} &\max_{\boldsymbol{h} \subseteq \mathscr{P}(\Omega)} \sum\nolimits_{k \in \boldsymbol{h}} l_k \times \left[ e_k + f(r_k) \right], \\ &\text{s.t.} \quad \sum\nolimits_{k \in \boldsymbol{h}} l_k \leq \overline{L}, \end{aligned} \qquad [3]$$

where $\overline{L}$ denotes the cap for total acreage enrollment, reflecting the fact that current CRP is constrained in acreage. Let $\lambda_1$ be the Lagrange multiplier representing the shadow value of acreage. Then the enrollment criterion for the *k*th parcel is

$$\begin{cases} \text{enroll if} & e_k + f(r_k) \geq \lambda_1; \\ \text{do not enroll if} & e_k + f(r_k) < \lambda_1. \end{cases} \qquad [4]$$

Comparing [4] with [1] and [2], we find that $e_k + f(r_k)$ is the same as the EBI (except for the minor extra bonus points) if we let EEBI be represented by $e_k$. In our analysis, we use EEBI to approximate environmental benefits from CRP land. We do so based on two rationales: (i) EEBI is carefully designed and used as a proxy for actual environmental benefits in the current CRP; (ii) using EEBI to measure CRP benefits is consistent with how the program values the different environmental factors.[v]

OP1 assumes that benefits $e_k$ and the transformation of rental rate, $f(r_k)$, are measured in comparable units such that summing the two terms is a meaningful operation. However, in the case of the current CRP, $e_k$ is represented by EEBI, an index based on points assigned to physical environmental benefits, and $f(r_k)$ is a linear transformation of the rental rate. Thus, in general, $e_k$ and $f(r_k)$ may not be measured in a common unit. For example in sign-up 41 held in 2011 water quality benefits have a maximum value of 100 points; the total points available for air quality were 45 points, and the transformation of rental rate was $f(r_k) = 125 - 125 r_k / 120$. Embedded in these points are weights that the program assigns to environmental factors. It is usually an involved task to estimate how CRP program costs and, especially, environmental benefits are valued by the society. Thus, in general $e_k$ and $f(r_k)$ will not be measured in a common unit.

In contrast with OP1, a standard optimization problem that is associated with maximizing environmental benefits for a given monetary budget can be formulated as follows:

**Optimization Problem 2** (OP2, cost-effective targeting): maximize environmental benefits subject to a budget constraint, i.e.,

$$\begin{aligned} \max_{\mathcal{k} \subseteq \mathcal{P}(\Omega)} & \sum_{k \in \mathcal{k}} l_k e_k, \\ \text{s.t.} & \sum_{k \in \mathcal{k}} l_k r_k \leq \bar{M}, \end{aligned} \qquad [5]$$

where $\bar{M}$ denotes the CRP budget constraint. With $\lambda_2$ denoting the Lagrange multiplier for the budget's shadow value, the enrollment criterion for the $k^{\text{th}}$ parcel is

$$\begin{cases} \text{enroll if} & e_k / r_k \geq \lambda_2; \\ \text{do not enroll if} & e_k / r_k < \lambda_2. \end{cases} \qquad [6]$$

In expression [6] the enrollment criterion is the ratio of benefit over cost. For any given budget, enrollment based on [6] will maximize environmental benefits achievable. Equivalently, for any given amount of benefits achieved, the required cost will be minimized. So we refer to enrollment based on this criterion as "cost-effective targeting." In contrast with the criterion in [4], that in [6] does not require $e_k$ and $r_k$ to be measured in a common unit, and should be a meaningful measure to use when comparing the cost-effectiveness of the parcels in providing environmental benefits. If we want to evaluate how CRP has performed for a given taxpayer expenditure, it is informative to measure program performance against the highest potential that could have been obtained. OP2 is also commonly used in economic analyses with direct policy implications (Feng et al. 2006). Moreover, as will be shown later, the impacts of incorporating crop insurance subsidies into the selection of CRP offers differ significantly depending on which optimization problem among OP1 and OP2 is used.

Now we study how saved crop insurance subsidies can be incorporated into the EBI. Because saved crop insurance subsidies due to CRP enrollment offset the federal budget outlays on the CRP program, a natural starting point to extend the current enrollment design is to subtract crop insurance subsidies from the rental rate when calculating the EBI. Let $s_k$ be the dollar amount of premium subsidies per acre for land parcel *k*. If we value a dollar that would have been paid in premium subsidies the same as a dollar spent on CRP rental payments, then we can subtract $s_k$ from $r_k$ when making enrollment decisions. Thus, if crop insurance subsidies were to be accounted for then equations [3] and [4] of OP1 could be adjusted as follows.

**Optimization Problem 1′** (OP1′, adjusted pseudo cost-effective targeting): maximize environmental benefits with a linear adjustment of costs and crop insurance subsidies, subject to an acreage constraint. That is,

$$\begin{aligned} &\max_{\hbar\subseteq\mathscr{P}(\Omega)} \textstyle\sum_{k\in\hbar} l_k \times \left[e_k + f(r_k - s_k)\right], \\ &\text{s.t.} \quad \textstyle\sum_{k\in\hbar} l_k \le \bar{L}'. \end{aligned} \qquad [7]$$

Then the adjusted enrollment criterion is

$$\begin{cases} \text{enroll if} & e_k + f(r_k - s_k) \geq \lambda_1'; \\ \text{do not enroll if} & e_k + f(r_k - s_k) < \lambda', \end{cases} \quad [8]$$

where $\lambda_1'$ is the Lagrange multiplier representing acreage shadow value. Including $s_k$ will not change the program's acreage constraint (i.e., $\bar{L} = \bar{L}'$), but may change the CRP enrollment criterion. The budget required to pay for enrolled acres may also change because the enrollment criterion has changed. Integrating crop insurance subsidies will also change equations [5] and [6] as follows.

**Optimization Problem 2′** (OP2′, adjusted cost-effective targeting): maximize environmental benefits subject to a budget constraint, when rental cost is offset by saved crop insurance subsidies, i.e.,

$$\begin{aligned} \max_{\hbar \subseteq \mathcal{P}(\Omega)} & \sum\nolimits_{k \in \hbar} l_k e_k, \\ \text{s.t.} \quad & \sum\nolimits_{k \in \hbar} l_k (r_k - s_k) \leq \bar{M}', \end{aligned} \quad [9]$$

where $\bar{M}'$ is the government's real CRP payment which is defined to be CRP rental payment minus saved crop insurance subsidy payment due to CRP enrollment. The adjusted enrollment criterion is

$$\begin{cases} \text{enroll if} & e_k / (r_k - s_k) \geq \lambda_2'; \\ \text{do not enroll if} & e_k / (r_k - s_k) < \lambda_2'. \end{cases} \quad [10]$$

where $\lambda_2'$ is the Lagrange multiplier for the budget constraint.

All else equal, inclusion of $s_k$ in OP1′ and OP2′ will render a parcel with larger insurance subsidy per acre more competitive for CRP acceptance because its "net cost" is smaller. However, how the inclusion of $s_k$ will affect the relative competitiveness of CRP offers based on adjusted EBI depends on the function $f(\cdot)$ as well as relationships among $r_k$, $s_k$, and $e_k$. In an extreme case, if $f(r_k - s_k) - f(r_k)$ is a constant for all $k$, then inclusion of $s_k$

in OP1′ has no effect on CRP enrollment. Similarly, if $s_k$ is a constant proportion of $r_k$ for all $k$, then each parcel's relative competitiveness based on [10] will be the same as that based on [6]. In this study we empirically explore the environmental and budgetary consequences of the four alternative EBI design scenarios based upon OP1, OP1′, OP2, and OP2′.

## III. SIMULATION APPROACH AND DATA

Consistent with the four optimization problems laid out in the previous section, we simulate four different scenarios. These are: (*i*) Baseline scenario under which EBI is kept at the status quo (in line with OP1); (*ii*) Scenario 1, under which EBI in the Baseline is modified to include crop insurance subsidies (i.e., OP1′); (*iii*) Scenario 2, under which cost-effective EBI is employed without including crop insurance subsidies (i.e., OP2), and (*iv*) Scenario 3, under which cost-effective EBI is employed and crop insurance subsidies are included (i.e., OP2′). We calculate the EBI under each scenario based on each problem's enrollment criteria, specifically,

$$\begin{aligned}
&\text{Baseline (OP1)}: && \text{EBI}_0 = \text{EEBI} + a \times \left(1 - \frac{r_k}{b}\right) + c, \\
&\text{Scenario 1 (OP1}'\text{)}: && \text{EBI}_1 = \text{EEBI} + a \times \left[1 - \frac{(r_k - s_k)}{b}\right] + c, \\
&\text{Scenario 2 (OP2)}: && \text{EBI}_2 = \frac{\text{EEBI} + c}{r_k}, \\
&\text{Scenario 3 (OP2}'\text{)}: && \text{EBI}_3 = \frac{\text{EEBI} + c}{r_k - s_k},
\end{aligned} \qquad [11]$$

where $a$ and $b$ are cost parameters as in equation [2]; and $c$ represents extra bonus points.

Once we have calculated EBI points for each scenario, the offered CRP parcels can be enrolled into CRP in descending order by each parcel's EBI until the acreage or budget constraint is reached. We are interested in the environmental benefits, acreage, payments, and saved crop insurance subsidies obtained from CRP under each scenario. Specifically, when $\boldsymbol{h}^* \subseteq \mathcal{P}(\Omega)$ is the selected set of parcels under a scenario then total environmental benefits under that scenario are $\sum_{k\in\boldsymbol{h}^*} l_k e_k$ , total acres enrolled are $\sum_{k\in\boldsymbol{h}^*} l_k$ , total insurance subsidy savings are $\sum_{k\in\boldsymbol{h}^*} l_k s_k$ , total CRP nominal payments are $\sum_{k\in\boldsymbol{h}^*} l_k r_k$ , and total CRP real payments amount to $\sum_{k\in\boldsymbol{h}^*} l_k (r_k - s_k)$ .[vi] That is, we refer to real payment as the difference between total CRP nominal payments and total saved crop insurance subsidies.

In the simulation we use contract-level CRP offer data from Signups 26 and 41 across the contiguous United States, as obtained from the FSA. These two signups occurred in 2003 and 2011 with 71,073 and 38,677 offers, respectively. The signup data available to us include detailed contract-level information such as EBI for each land tract offered to CRP, rental rate requested by land owners, and whether an offer was accepted. Table 3 provides some summary statistics for the two signups, from which we can see that the average CRP rent between these two signups are around $50/acre. We also find that under each signup the average CRP rent required by farmers is only slightly lower than the average WASRR, the cap for the CRP rent payment.

Crop insurance premiums and premium subsidies are jointly determined by coverage type, coverage level, and crop price. Since the CRP offer dataset does not include crop insurance information for a CRP offer, a matching mechanism is developed to map insurance subsidies to each CRP offer. Specifically, we employ a simple polynomial curve fitting approach to map insurance subsidies to each CRP offer. To capture heterogeneous relationships between CRP rent and crop insurance subsidy across states, we fit a polynomial curve state by state. For each state in the dataset, we first regress county-level crop insurance subsidy on county-level WASRR using data available in the state. New Mexico data are pooled with Texas data while Wyoming data are pooled with Nebraska data because New Mexico and Wyoming have few counties enrolled in CRP. Here we use WASRR instead of CRP rental payment because WASRR is a better measure of land productivity and hence a better measure of the land's insurance prospects.

Suppose we estimate an $N^{th}$ degree of polynomial curve

$$\ln(S^{ij}) = \sum_{n=0}^{N} \hat{\beta}_n^j [\ln(R^{ij})]^n, \qquad [12]$$

where $S^{ij}$ and $R^{ij}$ are county-level insurance subsidy and county-level WASRR in county *i* of state *j*, respectively; and $\hat{\beta}_n^j$, $n \in \{0,...,N\}$, is the estimated coefficients for state *j*. In this study we set $N = 4$. Setting $N = 3$ or $N = 5$ only yields a negligible difference in terms of predicted insurance subsidies. In order to avoid negative insurance subsidy predictions for a CRP offer, we utilize the natural logarithm transformation of the dependent variables and independent variables in equation [12]. Upon obtaining [12], for each CRP offer we insert its WASRR into equation [12] and estimate the offer's projected insurance subsidy.[vii]

To test for the robustness of this matching approach, we also performed an alternative matching approach in which unit-level, instead of county-level, insurance subsidy information obtained from RMA are used. We show in Item A of Supporting Information (SI) that insurance subsidy predictions and simulation results from these two different approaches are close.

County-level insurance subsidies for the contiguous United States in 2003 and 2011 were obtained from Summary of Business Reports and Data of USDA's Risk Management Agency.[viii] This dataset includes information on each insured crop such as insurance type, coverage level, insured acres, total premiums, and total subsidies. We first remove crops that are ineligible for CRP enrollment and then take the weighted average (using net insured acres as weights) of total subsidies to obtain each county's average subsidy per acre. Table 3 presents the average crop insurance premiums and subsidies in years 2003 and 2011 based upon the matching approach described above. We can see that average crop insurance subsidy in 2011 was almost quadruple that in 2003 (i.e., \$31.2/acre vs. \$8.6/acre).

## IV. SIMULATION RESULTS AND ANALAYASIS

In Table 4, we present summary simulation results where Baseline and Scenario 1 are constrained by the actual enrollment acreage that occurred under the two signups (2 million acres for Signup 26 and 2.8 million acres for Signup 41), whereas Scenarios 2 and 3 are constrained by the actual level of CRP real payment (defined as CRP rental payment minus saved crop insurance subsidies by CRP enrollment) that occurred under the two signups (i.e., $95.6 million for Signup 26 and $50.2 million for Signup 41).[ix] Under Baseline (i.e., the actual CRP enrollment outcomes of the two signups), the saved crop insurance subsidy in Signup 41 is significantly higher than that in Signup 26 ($84.1 million vs. $16.9 million) although the enrolled acres are similar (2.8 million acres vs. 2 million acres). The reason for this large difference in insurance subsidy savings is that, as shown in Table 3, the average crop insurance subsidy is much higher in 2011 than that in 2003.

To facilitate exposition, we specify four comparisons. Comparisons I through III compare Scenarios 1 through 3 with Baseline, respectively; Comparison IV compares Scenarios 2 and 3. When comparing the scenario outcomes we focus on (a) CRP enrollment acreage, program payment, and saved crop insurance subsidies, (b) environmental benefits from CRP as measured by the environmental component of EBI (i.e., physical environmental benefits, labeled as EEBI), and (c) geographic patterns in CRP enrollment changes under different designs.

**CRP Enrollment Acreage, Program Payment, and Avoided Insurance Subsidies**

Comparison II in Table 4 shows that when switching to the cost-effective targeting EBI design, enrolled acreage will increase significantly (by 42.3% and 26.6% for Signups 26 and 41, respectively) while keeping CRP real payments equal to those under Baseline. This shows the efficiency loss from using the current EBI design instead of maximizing environmental benefits per dollar spent. Notice that the percentage change in acreage enrollment under Signup 26 is larger than that under Signup 41 (see Comparisons II and III in Table 4). An explanation is that the comparison outcomes depend on acceptance rate (i.e., acreage accepted over acreage offered) under the Baseline for CRP offers. Under the Baseline the acreage acceptance rates in Signups 26 and 41 are 48% and 75%, respectively (Table 3). A smaller acceptance rate in Signup 26 indicates more competitive selection and more opportunities for increased acreage starting from the Baseline. As an extreme example, if all CRP offers are accepted under each of the four scenarios then scenario outcomes will not differ.

For Signup 41, when crop insurance subsidies are accounted for in the current EBI design (i.e., Scenario 1), the total annual CRP real payment is about 8.1% less than that under Baseline while leaving CRP enrolled acreage the same. For Signup 26, including crop insurance subsidies in the current EBI design can reduce the real CRP payment by 1%. The reduction in real CRP payment is much larger under Signup 41 than that under Signup 26 because subsidy per acre in 2011 (year of Signup 41) was almost quadruple that in 2003 (year of Signup 26) (see Table 3).

Adopting cost-effective targeting EBI and incorporating insurance subsidies into EBI design have significant impacts on saved subsidies. Under the Baseline for Signup 26 total crop insurance subsidy savings equaled about $16.9 million, amounting to about 15% of total nominal CRP payment (i.e., CRP rental rents) for enrolled acres. If cost-effective targeting is applied then the saved subsidies would increase by 41.1% when compared with Baseline (see comparison II in Table 4). When insurance subsidies are incorporated into cost-effective targeting EBI design, then the saved subsidies would increase by 47.3% for Signup 26 (see Comparison III in Table 4). Under the Baseline for Signup 41, the saved crop insurance subsidies in 2011 are $84.1 million, about 63% of nominal CRP payments ($134.3 million). The crop insurance savings are much larger under Signup 41 than those under Signup 26 because, as mentioned above, subsidy per acre was much larger in 2011. Were saved crop insurance subsidies accounted for in the current EBI design, then the saved crop insurance subsidies would increase by 3.4% for Signup 41 (Comparison I). However, were cost-effective targeting EBI used and were saved subsidies accounted for, then the saved crop insurance subsidies would increase by 28% for Signup 41 (Comparison III).

**Environmental Benefits from CRP**

Larger environmental benefits from CRP, as measured by total EEBI, can be achieved under cost-effective targeting EBI than under the current EBI.[x] For example, Comparison II in Table 4 shows that total EEBI of enrolled acres increases by 20.5% and 15.3% in Signup 26 and Signup 41, respectively. The increased total EEBI is largely from the increased enrolled acres. Since enrolled acres increase more under Signup 26 than under Signup 41 (i.e., 42.3% versus 26.6%), the total EEBI increase under Signup 26 is larger than that under Signup 41. For the same reason, the EEBI per enrolled acre decreases under Scenario 2 when compared with the Baseline scenario and the decrease is larger under Signup 26 than under Signup 41 (-15.3% versus -9%).

Table 4 also shows that incorporating crop insurance subsidies into the current EBI design will increase total EEBI of enrolled acres, average EEBI per enrolled acre, and average EEBI per dollar of CRP real payment (see Comparison I in Table 4). For Signup 26, the increases are small. For Signup 41, however, since an 8% decrease in CRP real payment occurs under Comparison I, we see a relatively large increase in EEBI per real payment dollar under Comparison I, namely 11.2%. One reason for the relatively small impacts when incorporating crop insurance subsidies into the current EBI under Signup 26 is that the cost component has significantly fewer points available than the environmental component. For both Signups 26 and 41, maximum points available for the cost component are 150 whereas maximum points available for the environmental component are 395 (see Table 2). Incorporating crop insurance subsidies by subtracting these subsidies from the rental rate only changes the cost component. When crop insurance subsidies are relatively low, as in 2003, they are only a small fraction of the rental rate and so incorporating subsidies has little impact.

**Geographic Patterns in CRP Enrollment Changes**

When compared with Baseline scenario, Scenarios 1 through 3 result in noticeable geographical patterns for the changes in CRP enrollment (see Figures 1 and 2). The Great Plains and Southeastern United States would gain CRP acreage and payments while the Midwest would see reductions. Accordingly, the Midwest would gain more commodity revenues and crop insurance subsidies under Scenarios 1 to 3 than under Baseline. These regional differences in CRP enrollment are important because of implications for welfare distribution and regional politics, and also because spatially distinct environmental and natural resources are concerned.

Table 4 also presents the amount of acres that change status under the four comparisons. That is, these acres either change from being accepted to being rejected or vice versa. Incorporating saved insurance subsidies into EBI design can result in change of status for a significant percentage of acres. In Signup 41, for instance, incorporating saved subsidies into the current EBI design would cause 10.4% of acres to change status (Comparison I in Table 4) whereas incorporating saved subsidies into the cost-effective EBI design would cause 9% of acres to change status (Comparison IV in Table 4). The largest status changes are observed under Comparison III, where 46.8% and 24.5% of total offered acres would change enrollment status in Signups 26 and 41, respectively. Figures 1 and 2 show changes in CRP acres under Comparisons I, III, and IV for Signups 26 and 41, respectively.[xi] The patterns of CRP acreage changes between these two signups are similar. CRP enrollment will increase in areas with high subsidy-to-rent ratios, such as the Great Plains and Southeastern States. As discussed in the *Introduction*, these are in the main marginal cropland regions where CRP enrollment costs are low and environmental benefits may be high. What makes these locations marginal for cropping and environmentally sensitive often also renders them poor crop insurance prospects, which indicates high insurance premiums and subsidies.

By contrast, under Scenarios 1-3 the Midwest would lose CRP acreage relative to the Baseline because cropland in this region requires higher CRP rental rates and receives lower crop insurance subsidies when compared with cropland elsewhere. For example, in Iowa the average CRP rent and insurance subsidy in 2011 are $128.1/acre and $27.3/acre, respectively, whereas in North Dakota these two numbers are $36.2/acre and $28.8/acre, respectively (Table 1). Notice that the CRP acreage change across regions is not significant in Comparison I because the total enrolled CRP acreage in Scenario 1 and Baseline are the same. However, large differences exist between cost-effective targeting EBI and current EBI as shown by Comparison III (Figures 1 and 2).

Cost effective targeting would overwhelmingly favor low rent regions whether or not crop insurance subsidies are incorporated. Our analysis suggests that the central Corn Belt would have an even lower enrollment rate were cost-effective targeting used. Furthermore, the southern Iowa and northern Missouri border region would become less competitive compared with other regions based on EEBI points and rental cost information submitted in Signups 26 and 41. Our assessment may raise concerns that CRP enrollment under the cost-effective targeting criterion would de-emphasize productive regions with erodible land, e.g., southern Iowa and northern Missouri. Our finding has bearing on the ongoing debate regarding whether it is better to spare land, a common view on the role of CRP, or to share land, as with environmental initiatives on working land (Green et al. 2005). We find that a CRP enrollment design favoring concentration of CRP on the Great Plains is a regional land sparing policy.

**Simulation Results when Constraints Vary**

In the above analysis we fixed the acreage constraint for Baseline and Scenario 1 at the actual enrolled acreage in Signups 26 and 41 and fixed the budget constraint for Scenarios 2 and 3 at the actual CRP real payment in the two signups. In this sub-section we vary these constraints to study whether similar conclusions hold regarding the efficiency of the four EBI designs under different constraint levels. Here we use Lorenz curves to depict effectiveness of the four EBI designs as the CRP budget changes, with a focus on three aspects of CRP enrollment outcomes: acreage, crop insurance subsidies saved, and total EEBI (see Figure 3).[xii] The horizontal axes in Figure 3 represent the proportion of total CRP real payment that can enroll all CRP offers in a signup. The vertical axes in the left, middle, and right columns are proportion of total acreage, proportion of total subsidies saved, and proportion of total EEBI achieved among all CRP offers in a signup, respectively.

From Figure 3 we can see that across all scenarios and signups the EBI design under Scenario 3 (i.e., cost-effective EBI design accounting for saved insurance subsidies) is the most efficient design in terms of total acreage enrolled, subsidy saved, and total EEBI associated with enrolled acreage. For Signup 26, the difference in enrollment acreage and environmental consequences between incorporating insurance subsidies into the EBI design and not doing so is insignificant because crop insurance subsidies in that signup are small. However, from the upper middle graph in Figure 3 we can see that incorporating insurance subsidies into the EBI design can increase subsidy savings, especially when enrollment is constrained at a budget less than 50% of total payment that can enroll all offers.

For Signup 41, the efficiency of EBI design can improve significantly when cost-effective EBI design is adopted and when insurance subsidies are accounted for in EBI (see the three graphs in the lower panel of Figure 3). Given the large magnitude of insurance subsidies in 2011, it is not surprising that about 35% of the total offered CRP acreage in Signup 41 can be enrolled at zero real payment under Scenario 2, as depicted by the vertical part of the Lorenz curve under Scenario 2 for Signup 41. If we further incorporate saved crop insurance subsidies into the cost-effective EBI design, then about 50% of offered CRP acreage can be enrolled at zero real payment. Similar conclusions hold for subsidies saved and total EEBI. These findings reveal the potential in efficiency improvement when cost-effective targeting EBI design is adopted and when insurance subsidies are accounted for in the design.

## V. ON MOTIVATING THE CURRENT EBI DESIGN

The CRP has 30 years of history since its inception in 1985. Like many other government programs, economic efficiency is often only one factor that influences program design and implementation. The history of the CRP and current institutional constraints all play key roles. In this section we briefly discuss the development of the CRP enrollment mechanism and try to interpret its evolution, including omission of crop insurance subsidies, from the perspectives of transactional costs and of political economy. Briefly, transactional costs, political pressures, and many other reasons, EEBI may not be an accurate measure of a CRP offer's environmental benefits. Therefore, we further analyze the performance of OP1 (i.e., the current EBI design or pseudo cost-effective targeting) and OP2 (i.e., cost-effective targeting) when EEBI doesn't accurately measure the environmental benefits of a CRP offer.

As discussed in *Conceptual Framework*, for the first nine CRP signups between 1986 and 1989, enrollment procedures were consistent with maximizing total acreage enrolled for a given budget. Specifically, any eligible CRP offer would be accepted if the offered rental payment was lower than a rent ceiling which was determined after bids were submitted. After the 1990 Farm Bill, an EBI design based upon benefit-cost ratio was created in order to improve CRP enrollment efficiency. According to Ribaudo et al. (2001, p. 15), "each [EBI] factor was divided by a term representing the estimated government cost of enrolling the bid, and standardized so that each term had the same mean and standard deviation." For general signups 10 through 13, CRP enrollment was based on this EBI design but specifics were not publicly disclosed (Osborn 1993; Jacobs, Thurman, and Marra 2014).

Commencing with the 1996 Farm Bill, EBI underwent significant changes culminating in the current 2015 EBI design as modeled in this paper. The EBI design based on benefit-cost ratio in the early 1990s was discontinued. In the current EBI design, benefit data are aggregated in a linear manner, where linear aggregates are known to have certain agreeable contract design properties (Carroll 2015). CRP rental payments requested by farmers are added to environmental components after a linear transformation. Moreover, three environmental factors (wildlife habitat, water quality, and soil erosion) are assigned the same weights. In what follows we briefly discuss drivers behind these changes.[xiii]

First and foremost, as discussed above, the EBI design prior to the 1996 Farm Bill was a "black-box" where the lack of transparency often frustrated farmers and the public (Jacobs, Thurman, and Marra 2014; p. 35 in Hamilton 2010). The FSA also realized that this lack of transparency might impede program efficiency. Moreover, according to Hamilton (2010), the FSA struggled with assigning a dollar value to a CRP offer's environmental benefits. Hamilton (2010, p. 33) notes "In earlier discussions of the EBI, there had been proposals to try and divide benefits by costs. The difficulty of quantifying the dollar value of benefits meant that eventually cost was simply incorporated as another ranking factor, with a low bid price treated as a desirable by assigning the parcel higher ranking points." However, as we have discussed in *Conceptual Framework*, adding the cost factor to EEBI implicitly assumes that EEBI and the cost factor are measured in comparable units whereas dividing EEBI by costs merely assumes that measured benefits and costs scale in proportion. Therefore, the difficulty of quantifying the CRP's dollar value of environmental benefits does not justify abandoning the benefit-over-cost approach.

The goals of reducing transaction costs and avoiding errors when measuring environmental benefits have also significantly affected EBI design. CRP enrollment decisions are centralized whereas EBI factors are measured and calculated by local FSA offices, most of which had little information technology support in the early 1990s (Hamilton 2010). Given the large number of offers within a signup period, typically a few weeks, local FSA offices have to process large amounts of information. Therefore, the current EBI design might be a good rule of thumb that uses approximations to achieve most of a "first best" solution where first-best may not take account of bounded rationality and transaction costs.[xiv] According to Ralph Heimlich, influential in EBI design during the 1990s, "a more ambitious evaluation proposal would have failed because it could not have been implemented in a timely and economic fashion, but the scheme we developed only needed readily available secondary data, data on the parcel itself, … , and could be done quickly and cheaply" (Hamilton 2010, p. 30). The advent of automation did not immediately annul the benefits of computational ease. According to Hamilton (2010, p. 36), " … a portion of the later changes in the 2002 iteration of the EBI came from the need to simplify and automate the process. Categories not easily automated at the time were sometimes dropped. … they removed the points based on distance to water and wetlands because it was the source of much human error. Some people measured distance from the center of a lake and others started from the closest shore."

Political pressures are another factor that shapes the current EBI design. When FSA designed the EBI, conservation and wildlife organizations as well as other interest groups were brought into the discussions (Hamilton 2010, p.31). The fact that wildlife habitat, water quality, and soil erosion factors receive a common weights in EBI design may indicate that it is an equilibrium outcome under these political pressures, where equal division is a common equilibrium in non-market bargaining situations (Andreoni and Bernheim 2009). Intense pressure from agricultural, environmental and other interest groups was mediated through the political process with intent to have the U.S. Department of Agriculture adjust EBI specifications (Hamilton 2010, p.30). Jacobs (2010) has found a positive correlation between a state's political representation on congressional committees that influence CRP and the state's CRP acreage and payments.

In the 2014 Farm Bill crop insurance subsidies are linked with conservation compliance programs such as the highly erodible land conservation provision (Sodbuster), the wetland conservation (Swampbuster), and the grassland conservation (Sodsaver) (Orden and Zulauf 2015). However crop insurance program participation has never been included in CRP enrollment mechanisms. Several practical reasons may explain this omission. First, premium subsidy is a portion of the premium which depends directly on crop price levels and so may vary across years. Since CRP contracts typically have 10-15 years duration, it is difficult to quantify premium subsidy savings for a CRP offer. Second, some land eligible for CRP may not have a crop insurance record. According to Shields (2015), about 83% of total crop acreage was covered under crop insurance in 2011. But land might be enrolled into future subsidized federal crop insurance programs even if the tract has no historical record of enrollment, so quantifying premium subsidy savings from CRP enrollment is problematic.

A further complication is that crop insurance premium subsidies have not been presented as a pure transfer to farmers, but rather as a safety net in the event of a contingency outside the course of normal events (Coble and Barnett 2013). Transfers are readily seen as a government redistribution endeavor rather than as the provision of a public good or redress of market failure. Premium subsidies have been seen as support to farmers in order to make crop insurance affordable (Coble and Knight 2002). In addition to the added cost to growers that use subsidized insurance, the crop insurance industry and agribusiness in general may dislike any codification of a transfer view of premium subsidies such as their inclusion as a cost in EBI design.

In sum, lobbying pressure and intent to reducing transaction costs have significantly affected the EBI's design. As we have discussed above, difficulty in assigning a dollar value to environmental benefits should not be a valid reason to abandon a benefit over cost approach to EBI design. Perhaps, due to methodology issues, use of a dollar value for environmental benefits is unrealistic so that some form of EEBI will always be an approximation for the environmental benefits a CRP offer provides. Innovations in information technology suggest that the technology difficulties that rationalized EBI design a generation ago no longer exist. Indeed, although insurance premium quotes for specific land parcels are all unique and the underlying rate-setting methodology is involved, growers can now obtain close estimates online at the U.S. Dept. of Agriculture Risk Management Agency website.

There are many other reasons that the current EEBI score system may not represent the true environmental benefits even in the absence of political pressure and transaction costs. Perhaps the greatest difficulty lies in assessing the exact environmental benefits of a CRP offer. The assessment would have to first identify and quantify all physical benefits associated with a CRP offer, which in itself is not a trivial task. This is evidenced by the fact that signups may differ on identified benefits. For instance, carbon sequestration was not included in the EEBI for early signups. Signup 41 accounted for benefits from "Pollinator Habitat" whereas Signup 26 did not. Quantification might further involve the demand for environmental services. In general a benefit should receive a larger weight when more people can enjoy it. Yet most factors in the current EEBI are not weighted by population.

Given that the EEBI in use will perhaps never precisely measure the environmental benefits of a CRP offer, one may ask if there is an EBI design choice that is less prone to measurement errors. Therefore, in the following subsection we examine the robustness of the EBI designs under OP1 and OP2 with respect to potential EEBI measurement errors.

**Implications when EEBI Scores Do Not Measure Actual Environmental Benefits**

The actual environmental benefits of a CRP offer are unknown and so are the true measurement errors. Consequently we need to make assumptions about the properties of measurement errors before we analyze the performance of EBI designs derived from OP1 and OP2 to compare their robustness to measurement errors. Actual measurement error may have a complicated format because, as we have discussed above, the current EEBI score system may deviate from the true environmental benefits in many aspects. For simplicity, however, we consider two types of measurement errors: additive error (denoted by $\epsilon$) and multiplicative error (denoted by $\xi$). We admit that this approach is quite ad hoc and is used only for illustrative purposes.

Let $\text{EEBI}^{\text{corr}}$ stand for the EEBI after measurement error is corrected. That is, $\text{EEBI}^{\text{corr}}$ is the actual environmental benefit of a CRP offer. Therefore with: *i*) additive error, $\text{EEBI}^{\text{corr}}$ is defined as $\text{EEBI}^{\text{corr}} \equiv \text{EEBI} + \epsilon,$ and *ii*) multiplicative error $\text{EEBI}^{\text{corr}}$ is defined as $\text{EEBI}^{\text{corr}} \equiv \text{EEBI} \cdot \xi.$ The additive correction for EEBI posits a missing environmental benefit that adds to total environmental benefit, following the current EBI design which implicitly assumes that various benefit components are additive. The multiplicative format posits missing variation in a factor that multiplies other environmental benefits. For example, if a social planner puts an equal weight on each person's valuation for CRP benefits, then the population that have access to a tract of CRP land could be one of such multipliers. In what follows we utilize the county-level population to construct $\epsilon$ and $\xi$. In Item B of the SI, we present a more general simulation approach where $\epsilon$ and $\xi$ are randomly drawn from certain probability distributions. We find that the basic conclusions regarding the robustness of OP1 and OP2 still hold under this more general approach.

County-level population data are obtained from the U.S. Census Bureau. We use 2003 and 2011 population data for Signups 26 and 41, respectively. Since we do not have specific location information on offered CRP land within a county or the geographical distribution of a county's population, we assign the same value to $\epsilon$ and, separately, to $\xi$ for CRP offers within the same county. That is, for any CRP offers *i* and *j* that are in the same county, we assume $\epsilon_i = \epsilon_j$ and $\xi_i = \xi_j$. Suppose a county's population is at the $n^{\text{th}}$ percentile among all U.S. counties. Then for any CRP offer *i* in this county, we let $\epsilon_i = n$, following the spirit of current EEBI design (i.e., each factor of wildlife, water quality, and soil erosion accounts for 0-100 points).[xv] For the multiplicative correction, we let $\xi_i = n/50$, indicating the EEBI of CRP offers in the county with median population is not affected by the multiplicative correction.

In this section we consider optimization problems OP1 (equation [3]) and OP2 (equation [5]). Because here we only focus on environmental benefit measurement errors, we do not consider subtracting the saved crop insurance premium subsidies from the rent of a CRP offer as described in optimization problems OP1′ and OP2′. Let $\text{OP1}^{\text{corr}}$ and $\text{OP2}^{\text{corr}}$ denote OP1 and OP2 when optimizing on corrected EEBI, $\text{EEBI}^{\text{corr}}$. That is, $\text{OP1}^{\text{corr}}$ and $\text{OP2}^{\text{corr}}$ are the same as OP1 and OP2, respectively, except that in $\text{OP1}^{\text{corr}}$ and $\text{OP2}^{\text{corr}}$ environmental benefit $e_k = \text{EEBI}_k^{\text{corr}}$ for CRP offer *k*. Recall that in OP1 and OP2, however, $e_k = \text{EEBI}_k$. We are interested in a) the total actual environmental benefits measured by $\text{EEBI}^{\text{corr}}$ under each optimization problem OP1, $\text{OP1}^{\text{corr}}$, OP2, and $\text{OP2}^{\text{corr}}$, b) the robustness of OP1 and OP2 to environmental benefit measurement errors, and c) county-level enrollment changes after environmental benefit measurement has been corrected.

Table 5 summarizes simulation results based on the enrollment mechanisms derived from the four optimization problems (i.e., OP1, $\text{OP1}^{\text{corr}}$, OP2, and $\text{OP2}^{\text{corr}}$). Recall that OP1 has an acreage constraint whereas OP2 has a budget constraint that is equal to the CRP real payment under OP1. From Table 5 we can see that for the same CRP outlay, total $\text{EEBI}^{\text{corr}}$ under OP2 is always greater than that under OP1 across the two signups and the two environmental benefit measurement corrections. Under a given signup and a given measurement correction, total $EEBI^{corr}$ under OP1 (respectively, OP2) is smaller than that under $OP1^{corr}$ (respectively, $OP2^{corr}$) because OP1 and OP2 optimize total EEBI instead of total $EEBI^{corr}$. Total $EEBI^{corr}$ achieved by $OP1^{corr}$ is not directly comparable with that achieved by $OP2^{corr}$ because CRP acreage and payment differ under the two optimization problems.

Regarding robustness with respect to measurement errors, we find that OP2 outperforms OP1 across the two signups and the two types of measurement correction. Under the additive correction, for both Signups total $EEBI^{corr}$ achieved by OP1 is about 96% of that achieved by $OP1^{corr}$. However, total $EEBI^{corr}$ achieved by OP2 is above 99% of that achieved by $OP2^{corr}$. OP2 also shows greater robustness than OP1 under multiplicative measurement errors. For example, in Signup 41, OP2 reaches 98.2% of total $EEBI^{corr}$ achieved by $OP2^{corr}$ whereas OP1 only reaches 87.1% of total $EEBI^{corr}$ achieved by $OP1^{corr}$.

A possible explanation for this result is as follows. Notice that an error term affects the CRP enrollment outcomes through affecting CRP offer ranking. One way to measure how including an error term will affect CRP offer ranking is to calculate the correlation coefficient between the EBI values before and after including the error term. Intuitively, the higher the correlation coefficient, the smaller the effect will be. Table S1 in the SI presents such correlation coefficients for Signups 26 and 41 under both additive and multiplicative corrections. For each signup and under each type of measurement errors, the correlation coefficient for OP2 is larger than that for OP1, indicating that including the error term will have smaller impacts on CRP offer ranking under OP2 than under OP1. However, one should note that since the robustness is determined by the distributions of error terms and of measured EEBI, as well as the construction of EBI under an optimization problem, we cannot conclude that OP2 is always more robust than OP1 with respect to measurement errors. Here we have only considered two measurement error specifications. Under some other measurement error specifications, OP1 may be more robust than OP2. We leave investigations in this direction for future research.

Figure 4 includes maps depicting changes in county-level CRP acreage under Signups 26 and 41 upon correcting for our posited additive measurement error. Across the four maps in Figure 4, we find that CRP acreage in the Great Plains counties would decrease whereas CRP acreage in the Eastern U.S. counties would increase under both OP1 and OP2 were the additive correction to be applied to EEBI. This is intuitive because counties in the Eastern United States are generally more populous than those in the Great Plains (see Figure S1 in the SI). The same result holds under the multiplicative correction for the measurement errors (Figure 5). In Figure 4, the acreage changes shown on the two maps on the right side have smaller magnitude than those on the two maps on the left, which indicates that OP2 is more robust to additive measurement errors than OP1. A similar finding holds under multiplicative correction (see Figure 5).

Figure S2 in the SI presents four maps of the county-level CRP acreage change when comparing enrollment under $OP2^{corr}$ with that under OP1 (i.e., the baseline scenario). We find that under the additive correction (see the two maps on the left side of Figure S2), the CRP acreage changes are quite similar to those under Comparison III in Figures 1 and 2. That is, when compared with the baseline scenario (i.e., enrollment under OP1), enrollment under $OP2^{corr}$ would reduce CRP acreage in the Midwest. This indicates that the effect of the additive correction on enrollment acreage is dominated by that of switching from OP1 to OP2. However, the effect of multiplicative correction dominates that of switching from OP1 to OP2. As a result, many counties on the Great Plains would lose some CRP acreage (see the two maps on the right side of Figure S2).

## VI. CONCLUDING REMARKS

Strong demand for food and biofuels in recent years has increased the pressure to draw more land into agricultural production. On the other hand, both CRP and FCIP are receiving intense scrutiny as legislators seek to tighten federal budget outlays. The purpose of this article is to promote a better understanding of how EBI design affects the cost-effectiveness of CRP as well as interactions between CRP and FCIP with a focus on the budgetary and environmental impacts. Given that the Agricultural Act of 2014 will gradually reduce total acreage enrolled in the CRP, it is likely that competition to enroll in the program will strengthen so long as CRP rental payments are not too low when compared with cash rental rates. Consequently, choice of enrollment design will likely play a more important role in future signups. Accounting for savings on crop insurance subsidies, perhaps through a soil attribute proxy for yield variability, can assist in managing total program tax dollar costs while also better screening land into its most efficient use.

Based on CRP enrollment data from Signups 26 and 41, as well as crop insurance subsidy data in corresponding years, we simulate the impacts of including saved crop insurance subsidies into EBI calculations under different EBI designs. We show that there is significant potential to improve upon the CRP's enrollment design and that large regional redistributions of enrolled CRP acres would result.

Several simplifying assumptions in our analysis may result in biased estimates of budgetary and environmental impacts upon incorporating crop insurance into EBI design. We do not consider administration and operating (A&O) costs associated with crop insurance. The government also subsidizes crop insurance by paying A&O costs which amounted to $1.4 billion in 2014, compared to $6.3 billion in premium subsidies (Shields 2015). If enrolling land in CRP reduces some of these A&O costs, our results would underestimate the budgetary impacts of incorporating crop insurance subsidies into the CRP enrollment formula. In addition, although CRP payment per acre is fixed during a contract's life, once an offer is accepted into CRP the saved insurance subsidy may vary across years because of fluctuating crop prices or changes in crop insurance policy. For simplicity our analysis has assumed away this variation in insurance subsidies. We expect that the insights arrived at would not be affected were we to relax this assumption. A further caveat is that some land offered to CRP may not have crop insurance coverage and hence does not receive crop insurance subsidies. This fact will render an overestimation of the budgetary impacts of incorporating crop insurance subsidies into EBI design. Moreover, in our analysis we do not consider how farmers' bidding behaviors may respond to a change in EBI design and hence affect the efficiency of CRP (Jacobs, Thurman, and Marra 2014; Vukina et al. 2008). Relaxing these simplifying assumptions may be of interest for future research.

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**Table 1. Average crop insurance premium, premium subsidy, CRP rental rate, and cropland cash rental rate in North Dakota and Iowa** (unit: $/acre)

| | North Dakota | | | | Iowa | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Premium | Premium Subsidy | CRP Rent | Cash Rent | Premium | Premium Subsidy | CRP Rent | Cash Rent |
| 2002 | 10.9 | 6.3 | 33.1 | 36.5 | 11.7 | 6.2 | 100.8 | 120 |
| 2003 | 14.0 | 8.0 | 33.1 | 36.5 | 13.0 | 6.9 | 101.9 | 122 |
| 2004 | 16.5 | 9.5 | 33.0 | 37.5 | 18.0 | 9.7 | 103.4 | 126 |
| 2005 | 15.1 | 8.8 | 33.1 | 39.0 | 15.6 | 8.4 | 104.3 | 131 |
| 2006 | 18.9 | 11.0 | 33.1 | 39.0 | 18.2 | 9.7 | 105.3 | 133 |
| 2007 | 24.6 | 14.3 | 33.2 | 41.0 | 29.6 | 15.9 | 106.2 | 150 |
| 2008 | 47.6 | 27.8 | 33.7 | 42.5 | 44.4 | 23.8 | 110.9 | 170 |
| 2009 | 29.3 | 18.1 | 34.0 | 45.5 | 35.3 | 20.1 | 115.8 | 175 |
| 2010 | 28.1 | 17.6 | 34.9 | 46.5 | 28.0 | 16.1 | 120.1 | 176 |
| 2011 | 45.3 | 28.8 | 36.2 | 51.5 | 48.0 | 27.3 | 128.1 | 196 |
| 2012 | 41.8 | 27.0 | 37.6 | 58.0 | 41.6 | 24.0 | 131.6 | 235 |
| 2013 | 46.8 | 30.4 | 41.2 | 65.0 | 42.7 | 22.9 | 140.6 | 255 |
| 2014 | 39.0 | 25.5 | 43.0 | 68.0 | 33.2 | 17.3 | 151.9 | 260 |

Data source: All data are obtained from public datasets of USDA agencies. Premium and subsidy data are from RMA, CRP rent from FSA, and cash rent from NASS.

**Table 2. Points for Components of CRP Environmental Benefits Index (EBI) in General Signups over 1997-2011**

| Signup number | 15 | 16 | 18 | 20 | 26 | 29 | 33 | 39 | 41 |
|---|---|---|---|---|---|---|---|---|---|
| Signup year | 1997 | 1997 | 1998 | 1999 | 2003 | 2004 | 2006 | 2010 | 2011 |
| Cost component parameter: *a* | 190 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 |
| Cost component parameter: *b* | 165 | 165 | 165 | 165 | 185 | 185 | 204 | 220 | 220 |
| Maximum of cost components | 200 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| Maximum of EEBI | 400 | 410 | 410 | 410 | 395 | 395 | 395 | 395 | 395 |
| Maximum of EBI | 600 | 560 | 560 | 560 | 545 | 545 | 545 | 545 | 545 |
| Cut-off EBI for acceptance | 259 | 247 | 245 | 246 | 269 | 248 | 242 | 200 | 221 |

Notes: Cost component = $a\times(1-(\text{rental rate}/b))$ + extra bonus points. Specifically, these extra bonus points are "N6b" and "N6c" in CRP signups. In Signup 26, N6b equaled 0 if a CRP offer required cost share and equaled 10 if not. N6c was the lower of 15 and the difference between rental rate and maximum payment rate. In Signup 41, N6c was eliminated while N6b measures how much the offered CRP rent was lower than the maximum payment rate. See links www.fsa.usda.gov/Internet/FSA_File/crpebi03.pdf and www.fsa.usda.gov /Internet/FSA_File/crp_41_ebi.pdf for details. EEBI is the sum of the scores for environmental factors, and EBI = EEBI + cost components.

**Table 3. Summary Statistics for CRP Offer Data of Signups 26 and 41 as well as Crop Insurance Data in 2003 and 2011**

| | Signup 26 (Year 2003) | | Signup 41 (Year 2011) | |
|---|---|---|---|---|
| | Offered | Accepted | Offered | Accepted |
| Total number of offers | 71,073 | 38,619 | 38,677 | 29,861 |
| Total acres (million acres) | 4.15 | 2.00 | 3.75 | 2.82 |
| Average CRP rental payment ($/acre) | 48 | 52 | 47 | 48 |
| Average WASRR ($/acre)* | 50 | 54 | 50 | 51 |
| Average EBI | 271 | 302 | 270 | 286 |
| Average EEBI | 177 | 210 | 161 | 179 |
| Average crop insurance premium ($/acre)† | 14.7 | | 50.1 | |
| Average crop insurance subsidy ($/acre)† | 8.6 | | 31.2 | |

Notes: * WASRR stands for weighted average soil rental rate. † Crop Insurance premiums and subsidies for insured acres growing crops that are not eligible for CRP enrollment are excluded from calculations. Insurance premiums and subsidies have been imputed by regression matching.

**Table 4. Pairwise Comparisons between the Scenarios Regarding Budgetary and Environmental Outcomes of CRP**

| | | Comp. I | Comp. II | Comp. III | Comp. IV | |
|---|---|---|---|---|---|---|
| | | Percentage change from Baseline | | | | |
| | Baseline Absolute values | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 2 Absolute values | Scenario 3: percentage change from Scenario 2 |
| **Signup 26** | | | | | | |
| Total acres enrolled (million acres) | 2.0 | - | 42.3% | 45.4% | 2.8 | 2.2% |
| Total annual CRP real payment (million $)* | 95.6 | -1.0% | - | - | 95.6 | - |
| Total annual CRP nominal payment (million $) | 112.5 | -0.5% | 6.2% | 7.1% | 119.5 | 0.9% |
| Crop insurance subsidy saved per year (million $) | 16.9 | 1.8% | 41.1% | 47.3% | 23.9 | 4.5% |
| Total EEBI of enrolled acres (million) | 417.0 | 0.5% | 20.5% | 20.9% | 502.5 | 0.4% |
| Average EEBI per enrolled acre | 210.1 | 0.5% | -15.3% | -16.8% | 177.9 | -1.8% |
| Average EEBI per dollar of CRP real payment | 4.4 | 1.4% | 20.5% | 21.0% | 5.3 | 0.4% |
| Acres that change status (million acres)† | - | 4.7% | 43.0% | 46.8% | 1.8 | 8.7% |
| **Signup 41** | | | | | | |
| Total acres enrolled (million acres) | 2.78 | - | 26.6% | 28.6% | 3.52 | 1.5% |
| Total annual CRP real payment (million $)* | 50.2 | -8.1% | - | - | 50.2 | - |
| Total annual CRP nominal payment (million $) | 134.3 | -0.9% | 16.3% | 17.5% | 156.1 | 1.1% |
| Crop insurance subsidy saved per year (million $) | 84.1 | 3.4% | 26.0% | 28.0% | 105.9 | 1.6% |
| Total EEBI of enrolled acres (million) | 498.0 | 2.2% | 15.3% | 15.5% | 574.0 | 0.2% |
| Average EEBI per enrolled acre | 179.1 | 2.2% | -9.0% | -10.2% | 163.0 | -1.3% |
| Average EEBI per dollar of CRP real payment | 9.9 | 11.2% | 15.3% | 15.5% | 11.4 | 0.2% |
| Acres that change status (million acres)† | - | 10.4% | 22.5% | 24.5% | 0.8 | 9.0% |

Notes: * Calculated by using total annual CRP nominal payment minus crop insurance subsidy saved per year. † Under Comparisons I to III, the percentage change from Baseline is calculated by using acres that change status when compared with Baseline divided by total acres *offered* in a signup. Under Comparison IV, percentage change from Scenario 2 is calculated by *i*) obtaining the difference between "acres that change status when compared with Baseline" under Scenarios 3 and 2; and *ii*) divide the difference by "acres that change status when compared with Baseline" under Scenario 2.

**Table 5. Simulation Results Based on Additive Error and Multiplicative Error**

| | Additive Correction | | | | Multiplicative Correction | | | |
|---|---|---|---|---|---|---|---|---|
| | OP1 | OP1$^{corr}$ | OP2 | OP2$^{corr}$ | OP1 | OP1$^{corr}$ | OP2 | OP2$^{corr}$ |
| **Signup 26** | | | | | | | | |
| Total acres enrolled (million acres) | 2.0 | 2.0 | 2.8 | 2.8 | 2.0 | 2.0 | 2.8 | 2.1 |
| Total annual CRP real payment (million $) | 95.6 | 99.3 | 95.6 | 95.6 | 95.6 | 100.7 | 95.6 | 95.6 |
| Total annual CRP nominal payment (million $) | 112.5 | 116.7 | 119.5 | 119.3 | 112.5 | 118.4 | 119.5 | 114.3 |
| Crop insurance subsidy saved per year (million $) | 16.9 | 17.5 | 23.9 | 23.8 | 16.9 | 17.8 | 23.9 | 18.7 |
| Total EEBI$^{corr}$ of enrolled acres (million) | 501.3 | 517.9 | 600.1 | 605.3 | 357.4 | 465.4 | 363.5 | 464.2 |
| Average EEBI$^{corr}$ per enrolled acre | 252.5 | 261.0 | 212.5 | 216.9 | 180.1 | 234.5 | 128.7 | 220.6 |
| Average EEBI$^{corr}$ per CRP real payment dollar | 5.2 | 5.2 | 6.3 | 6.3 | 3.7 | 4.6 | 3.8 | 4.9 |
| Acres that change status when compared with Baseline (million acres) | - | 0.8 | 1.8 | 1.8 | - | 1.5 | 1.8 | 1.6 |
| **Signup 41** | | | | | | | | |
| Total acres enrolled (million acres) | 2.8 | 2.8 | 3.5 | 3.5 | 2.8 | 2.8 | 3.5 | 3.1 |
| Total annual CRP real payment (million $) | 50.2 | 49.3 | 50.2 | 50.2 | 50.2 | 44.9 | 50.2 | 50.2 |
| Total annual CRP nominal payment (million $) | 134.3 | 135.6 | 156.1 | 156.4 | 134.3 | 130.9 | 156.1 | 144.0 |
| Crop insurance subsidy saved per year (million $) | 84.1 | 86.3 | 105.9 | 106.2 | 84.1 | 86.1 | 105.9 | 93.8 |
| Total EEBI$^{corr}$ of enrolled acres (million) | 577.7 | 599.7 | 672.9 | 674.2 | 296.5 | 340.4 | 340.3 | 346.5 |
| Average EEBI$^{corr}$ per enrolled acre | 207.8 | 215.8 | 191.2 | 191.0 | 106.6 | 122.5 | 96.7 | 113.5 |
| Average EEBI$^{corr}$ per CRP real payment dollar | 11.5 | 12.2 | 13.4 | 13.4 | 5.9 | 7.6 | 6.8 | 6.9 |
| Acres that change status when compared with OP1 (million acres) | - | 0.6 | 0.8 | 0.9 | - | 1.2 | 0.8 | 1.1 |

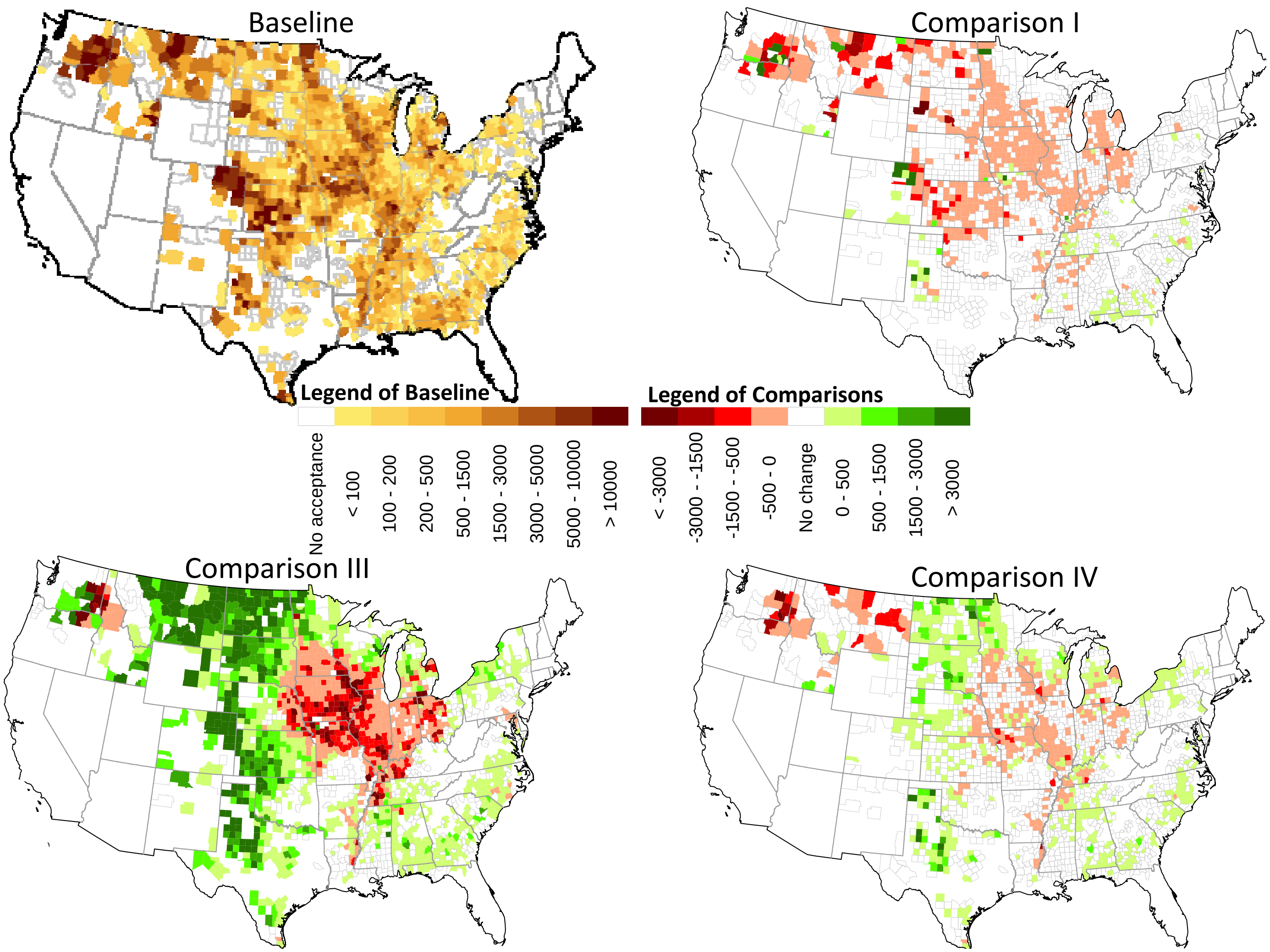


**Figure 1. Acres Enrolled into CRP in Baseline and CRP Acreage Changes under Comparisons I, III, and IV (Signup 26).** Notes: in the Baseline map, counties with gray border but without color had CRP offers but none were accepted. Counties with neither border nor color had no CRP offers. In the three Comparison maps, counties with gray border but without color had no enrollment changes.

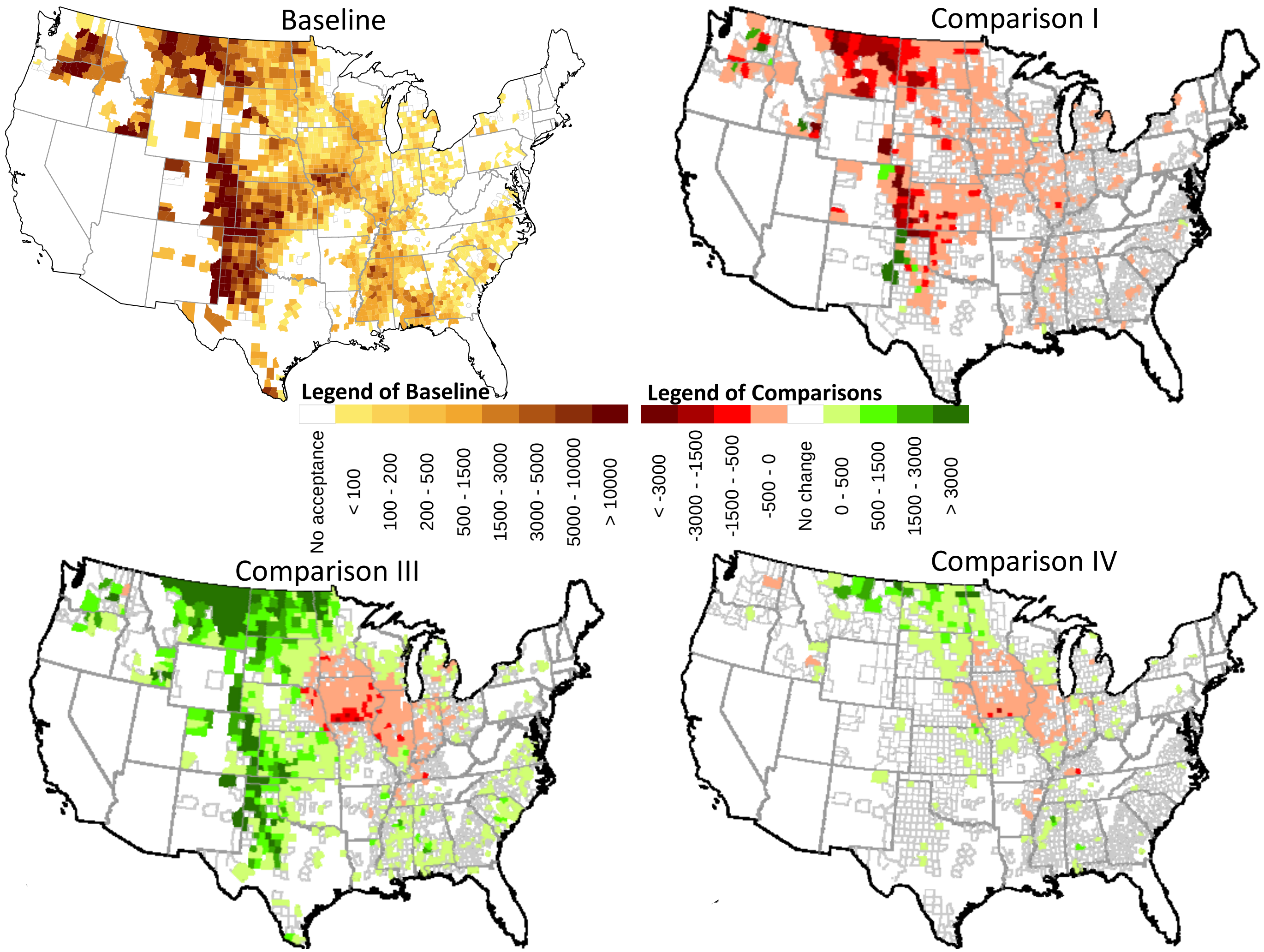


**Figure 2. Acres Enrolled into CRP in Baseline and CRP Acreage Changes under Comparisons I, III, and IV (Signup 41).** Notes: in the Baseline map, counties with gray border but without color had CRP offers but none were accepted. Counties with neither border nor color had no CRP offers. In the three Comparison maps, counties with gray border but without color had no enrollment changes.

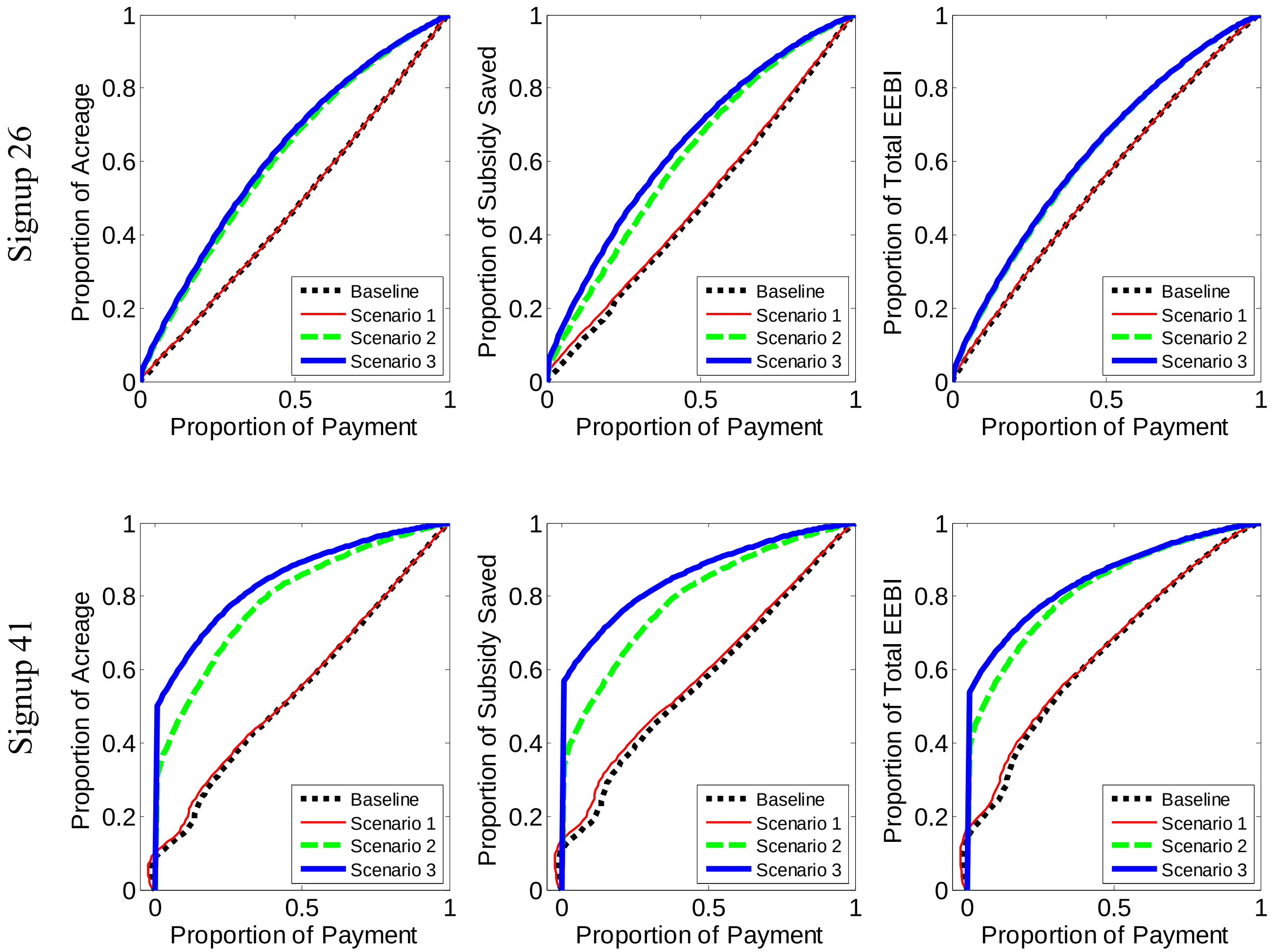


**Figure 3. Proportion of Acreage, Subsidy Saved, and EEBI when CRP Real Payment Varies**

Notes: Recall that CRP real payment is defined as CRP nominal payment minus saved crop insurance subsidies. The large magnitude of insurance subsidy in 2011 made it possible for about half of the CRP acreage to be enrolled at zero real payment. Since Baseline and Scenario 1 are constrained by acreage and for some regions insurance subsidies are larger than CRP rent, the real payment can be negative when acreage constraints are small.

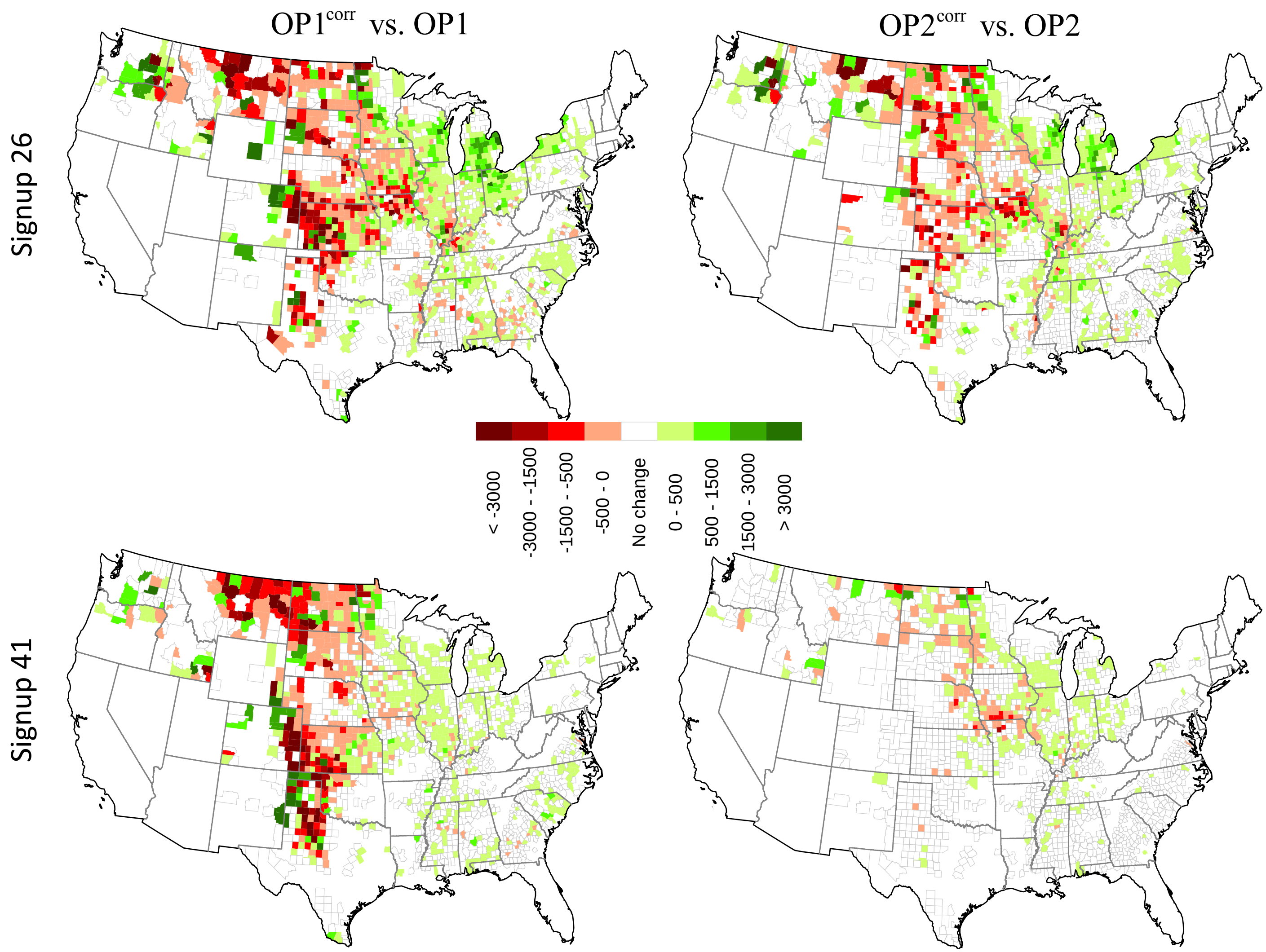


**Figure 4. Changes of Acres Enrolled into CRP after Measurement Errors are Corrected Assuming Additive Correction.** Notes: in the maps, positive numbers indicate an increase in CRP acres after accounting for the measurement errors. Counties with gray border but without color had no enrollment acreage changes whereas counties with neither border nor color had no CRP offers.

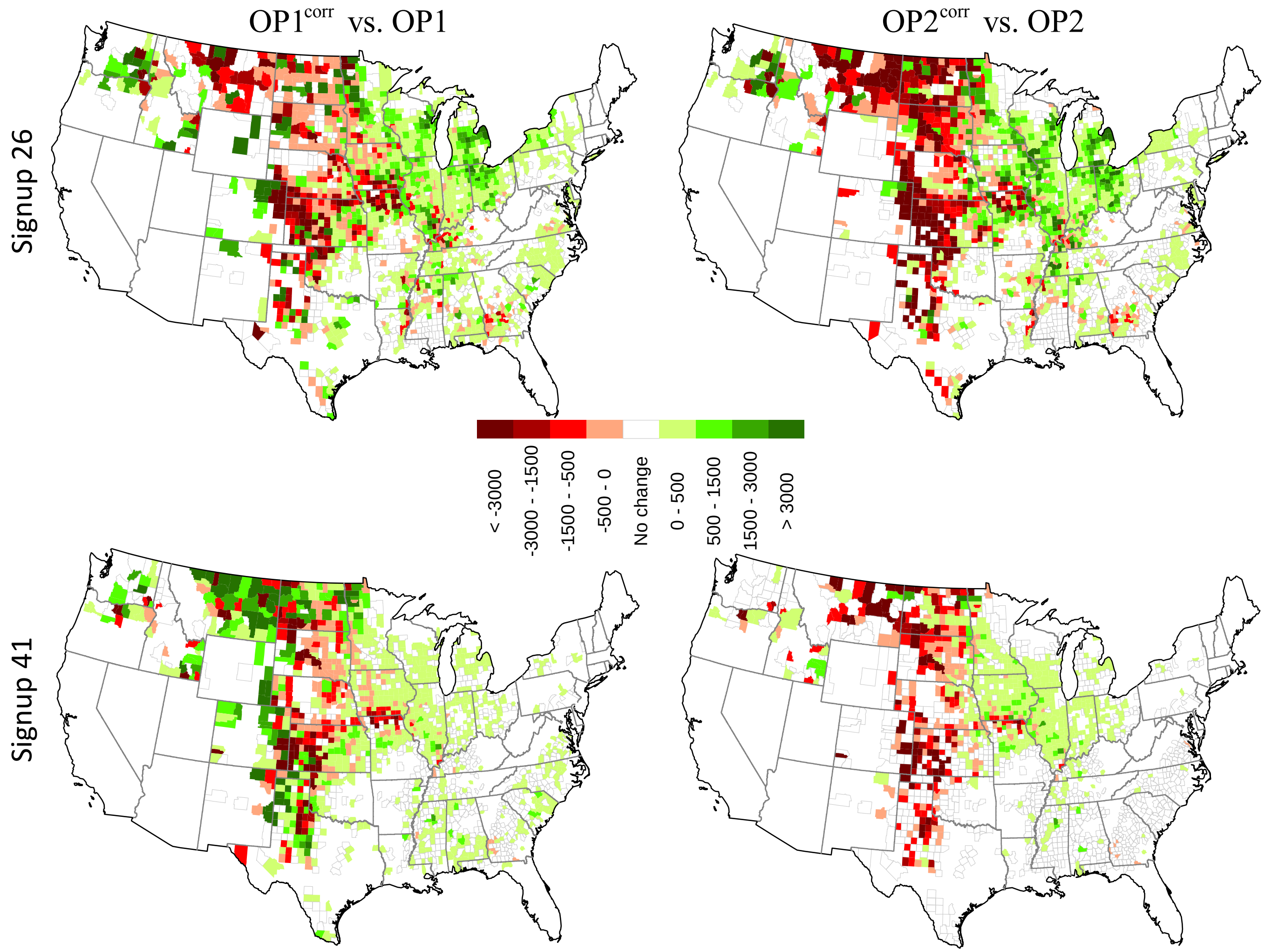


**Figure 5. Changes of Acres Enrolled into CRP after Measurement Errors are Corrected Assuming Multiplicative Correction.** Notes: in the maps, positive numbers indicate an increase in CRP acres after accounting for the measurement errors. Counties with gray border but without color had no enrollment acreage changes whereas counties with neither border nor color had no CRP offers.

[i] Land enrollment criterion design for CRP has evolved significantly since the establishment of CRP in 1985. We refer readers to Jacobs, Thurman, and Marra (2014) for a detailed discussion on this matter.

[ii] In addition to crop insurance subsidies, the U.S. government also provides farmers with other forms of subsidy payments such as Counter Cyclical Payment and Agriculture Risk Coverage Payment. Here we only focus on crop insurance subsidies for two reasons: simplicity and the nature of crop insurance subsidies. Table 1 indicates that crop insurance subsidies were relatively high in risky production regions compared to CRP and cash rents in those regions. Zulauf (2014) show that other payments (e.g., direct payments before the 2014 Farm Bill) were more positively correlated with field crop production as determined by the market. Therefore, incorporating crop insurance subsidies is more likely to alter the ranking of CRP offers than incorporating other payments.

[iii] Most CRP land is enrolled through a competitive bidding process during general signup periods, designated periods of a few weeks in a year during which farmers are invited to submit applications to enroll their cropland.

[iv] EEBI is not completely exogenous because, for example, a farmer can choose a land cover practice that is more beneficial to wildlife in order to obtain a higher EEBI point. Since a) our focus is on how the costs of enrolling CRP offers (i.e., CRP rental rent and saved crop insurance premium subsidies) should be included in the EBI design and b) the EEBI points that can be affected by farmers' choices are less than one third of maximum EEBI, for simplicity we take the EEBI values as exogenously determined.

[v] Regardless, we recognize that the EEBI may not accurately measure environmental benefits. We discuss this issue in a separate section below.

[vi] It is possible that an accepted CRP offer is not covered by crop insurance, which will cause our simulation results of premium savings to be overestimated. However, given the fact that a) crop insurance covers about 83% of total crop acreage (Shields 2015) and b) CRP offers are typically less fertile and more risky, we do not expect the overestimation to be large. As a result we do not account for this possibility in our simulation for simplicity.

[vii] This matching approach is similar to that used by Schlenker and Roberts (2009) to obtain daily weather data from monthly weather information.

[viii] Link: http://www.rma.usda.gov/data/sob.html (accessed on January 5, 2015).

[ix] In the simulation, we do not constrain CRP enrollment in a county to be no more than 25% of cropland, a constraint that is imposed by FSA. This constraint is omitted from our simulation because a) we only focus on two signups and CRP offers in these signups are only a small fraction of CRP acreage stock; b) were the constraint for CRP acreage in a county to be accounted for, then data for CRP acreage stock before a signup as well as data for expiring CRP contracts would be necessary and these data are currently unavailable to us; c) the CRP acreage cap is not firm in that a county may have CRP acreage larger than 25% of cropland if "the Secretary [of Agriculture] determines that such action would not adversely affect the local economy of such county." (Food Security Act of 1985, page 1509)

[x] We have discussed rationales for using EEBI as a measure of environmental benefits and limitations of such use in the Conceptual Framework section.

[xi] Changes in CRP acres under Comparison II are similar to those under Comparison III and are therefore not presented.

[xii] Since Baseline and Scenario 1 are constrained by acreage, we vary their acreage constraints from zero to the sum of all offered acreage and then obtain subsidy saved, total EEBI, and real payment under each acreage constraint level. We then generate the Lorenz curves reflecting the relationships between real payment and enrolled acreage, subsidy saved, and total EEBI for Baseline and Scenario 1. Because insurance subsidies are larger than CRP rent in some regions, the real payment under Baseline and Scenario 1 can be negative when acreage constraints are small.

[xiii] For a detailed documentation including original interviews about these changes with regulators and EBI developers, we refer readers to Hamilton (2010, Chapter 2).

[xiv] See Conlisk (1996) for a review of bounded rationality and Bogetoft and Olesen (2002) for examples of rules of thumb in agricultural contract design.

[xv] We are aware that the population impacted by a CRP offer is accounted for in the current EEBI design when scoring the offer's groundwater quality, surface water quality, and wind erosion impact factors. Here we include an individual population factor trying to reflect the society's evaluation of other benefits of a CRP offer, such as wildlife, erosion reduction, and recreational values.