Land Use Consequences of Crop Insurance Subsidies

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26, 2011

Abstract

There have long been concerns that federal crop insurance subsidies may significantly impact land use decisions. It is well known that classical insurance market information asymmetry problems can lead to a social excess of risky land entering crop production. Our conceptual model shows that the problem will arise absent any information failures. This is because the subsidy is *i*) proportional to acres planted, and *ii*) greatest for the most production risky land. Using farm-level data, we follow this observation through to establish the implications of subsidies for the extent of crop production, with particular emphasis on U.S. regions where the cropland growth is likely to have marked adverse environmental impacts. Simulation results show that when subsidy rate decreases by 5 percentage points, then about 0.60 percent of insured cropped land will be converted to non-cropped land. When crop price decreases by 5 percent, then about 1.01 percent of insured cropped land will be converted to non-cropped land.

Keywords: crop insurance, land use, crop yields, yield risk measurement.

JEL Code: Q15, Q18, Q24.

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(Preliminary Draft - Please do not Quote without Permission)

1. Introduction

The U.S. government, via subsidies and direct payment programs, contributes to the farm sector and incentivizes (directly and indirectly) land use behavior. Some of these payments are directly used for conservation and environmental protection but the majority are not. Total governmental expenditures on Conservation Reserve Program (CRP), by far the largest federal conservation program, accounts for roughly a quarter of the $12.8 billion in total government direct payments in 2008. Additionally, the federal government also paid $5.7 billion in the form of subsidies to crop insurance premiums. There have long been concerns that such payments would have significant impacts on land use decisions and changes to the agricultural landscape. Specifically in the case of crop insurance, such payments are generally not covered by World Trade Organization agreements on domestic support and so can be coupled to a change in land use.

There are definite patterns in net crop insurance payments (Glauber 2004). Over the period 2000-2007, crop growers in all of Oklahoma, Montana, Texas, Kansas, South Dakota and North Dakota received $2 or more in indemnity payouts per $1 premium paid by the grower (Babcock 2008). Typical insurance programs will pay out considerably less than $1 per $1 premium in order to cover expenses. The states in the Central Corn Belt, namely Indiana, Illinois and Iowa, are less drought-prone and the soils are generally more fertile. Yet these states all had payouts of between $0.7 and $0.9 per $1 premium paid by the grower. Intuition would suggest that subsidizing production activities on risky land will encourage more production on such land. To the extent that it has been studied, economic theory supports this

intuition (LaFrance, Shimshack, and Wu 2001).

In this article we seek to ascertain the extent to which land use patterns have been, and are likely to be, affected by crop insurance subsidies. We will seek to establish the specific policy channels, specific land use conversions, and spatial configurations of such conversions. We will also estimate the land use conversion implications of alternative policies surrounding the availability of crop insurance.

Many studies have examined the impacts of government payments on land use decisions. A few of them are specifically focused on federal crop insurance programs (Young, Vandeveer, and Schnepf 2001; Goodwin, Vandeveer, and Deal 2004; Lubowski *et al.* 2006; Stubbs 2007; GAO 2007; Carriazo, Claassen, and Cooper 2009). Goodwin, Vandeveer, and Deal (2004) represents the consensus that while crop insurance subsidies do incentivize cropping, the effect is not large. Other evidence is not so sanguine, where Chen and Miranda (2007) conclude that in the Central and Southern Plains regions corn and cotton crop abandonments are induced by crop insurance programs.

We discern large gaps in this literature. The focus has been largely at the county level of analysis. It has not focused on the region most likely to be impacted, land at the cropping fringe in the arid Western Great Plains. The measurement of extent of insurance subsidy has been very casual. Existing work has not been able to distinguish between conversion from uncultivated rangeland to cropland or between CRP and cropland. And the policy context has changed markedly since the more analytic earlier studies, culminating in Goodwin, Vandeveer, and Deal (2004) where the latter work considered data over the period 1985-'93. Biofuels policies as well as increasing global demand for food and feed has led to a dramatic increase in corn, soybean, wheat and barley prices and an expansion of land under crops during the five

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years up to 2010. Additional insurance subsidies were provided under the Agriculture Risk Protection Act of 2000, while the 2008 Farm Bill introduced further risk protection through the ACRE program. The only work we are aware of that has taken a high-resolution look at the effects of farm risk management programs on land use decisions is Carriazo, Claassen, and Cooper (2009). By constructing representative farms in the Prairie Pothole Region, they simulated the consequences of alternative policy scenarios for land use patterns. However, their data were meager and the authors acknowledge that little can be drawn from their analysis.

In this article we examine how federal policies, including agricultural risk management policies, affect land conversion decisions using field level data. Regarding the impacts of federal crop insurance subsidies on land conversion, some specific policy-relevant questions are: 1) to what extent do crop insurance subsidies affect land conversion, 2) are the impacts homogenous in all locations or are some locations particularly susceptible, and 3) can the objectives of both conservation policy and crop insurance be achieved by allowing measures of "insurance riskiness" to influence eligibility or participation in crop insurance programs and also programs that fund conservation efforts?

To address such questions, we first need to understand a typical farmer's optimal decision problem in the presence of crop insurance. We also need to understand the basic characteristics of agricultural land, including its average yield and associated risk profile. Then we can consider how current policies can be improved to mitigate the adverse impacts of federal crop insurance subsidies. In this article we first develop a model of the decision to change land use. The problem here is one of modeling and comparing returns from different land uses: crop production versus non-crop production. The return would include payments from government interventions, over the indefinite horizon, where simulations would be run over a variety of

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government program and market price scenarios. Second, we statistically estimate measures of crop insurance and related subsidies. We control for yield trends so as to correctly estimate the extent of riskiness (Just and Weninger 1999). The approach taken is similar to that in Claassen and Just (2010), who utilized USDA Risk Management Agency data at the farm level. An insurance loss index like that proposed in Hennessy (2009) is then estimated. Third, we calibrate the decision model and simulate the land use effects of crop insurance.

The article proceeds as follows. In the second section we develop a theoretical model that studies how the extent of yield risk can affect planting decisions in the presence of a crop insurance subsidy. In the third section we statistically estimate measures yield riskiness relative to crop insurance. Section 4 studies the determinants of the yield riskiness. In Section 5 we calibrate the theoretical model and simulate the land use effects of crop insurance in different scenarios. Section 6 concludes.

2. Model: Yield Risk and Distorted Planting Decisions

We consider the matter of how the extent of yield risk can affect planting decisions in the presence of a crop insurance subsidy. The analysis pertains to many land units, each with a single owner. The land units are homogeneous in that all acres in a unit are the same. But there is heterogeneity across units. To explore the effect of yield variability on planting choice, three simplifications are made to the model. The planting choice is discrete in that either all acres in a land unit are planted or none are. The utility function is of Constant absolute risk aversion (Cara) form $-e^{-\theta W}$ where $\theta > 0$ is the coefficient of absolute risk aversion. With $\mu > 0$ and $\delta \in [0, \mu]$, we also assume that yield per unit takes the following two-point discrete distribution;

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(1) $\qquad y = \begin{cases} \mu + \delta & \text{with Prob. } 0.5; \\ \mu - \delta & \text{with Prob. } 0.5. \end{cases}$

Our interest is in yield variability only, so μ is held to be a constant while δ is heterogeneous with mass distribution function $F(\delta)$ normalized such that $F(\mu) = 1$. We will assume strictly positive mass density $f(\delta)$ throughout, i.e., $dF(\delta)/d\delta \equiv f(\delta) > 0 \; \forall \delta \in [0, \mu]$.

Assumption 1: *i*) All land in a unit is planted, or none is; *ii*) Preferences follow Cara expected utility; and *iii*) Production follows yield distribution family Z where $Z = \{y:$ y follows distribution (1) and $\delta \sim F(\delta)\}$. Furthermore, $dF(\delta)/d\delta \equiv f(\delta) > 0 \; \forall \delta \in [0, \mu]$.

The alternative to cropping is to leave the land in some non-crop activities, where these could include some or all of pastoral livestock farming, hunting preserve or in a conservation program. The non-stochastic return on such activities is r per unit so that utility is $U^w = -e^{-\theta r}$ whenever the land is not planted. In short, three choices exist for the owner of a land unit with risk level δ. These are:

A) Do not crop and receive certain utility level $U^w = -e^{-\theta r}$;

B) Grow a crop but do not insure (label choice as *gni*) and face a, yet to be computed, expected utility level of $U^{gni}(\delta)$; and

C) Grow a crop and do insure (label as *gi*), where the premium is subsidized at rate $s \in [0,1]$ and the yet to be computed expected utility level is $U^{gi}(\delta; s)$.

Thus the overall problem is to identify

(2) $\qquad V(\delta; s) = \max[U^w, U^{gni}(\delta), U^{gi}(\delta; s)].$

In order to understand the decision-making process embodied in (2), it is useful to make two comparisons. These are to compare A) with B) and also compare A) with C).[1]

2.1 Comparing choices A) and B)

To establish expected utility when the land is planted we need to build up the payoffs. With output price $p > 0$ and total cost $c > 0$, expected market revenue is $\bar{\pi} = p\mu - c$. Market revenue is $\bar{\pi} + p\delta$ with Prob. 0.5 and $\bar{\pi} - p\delta$ with Prob. 0.5, so expected payout is:

(3) $\quad U^{gni}(\delta) = -0.5e^{-\theta(\bar{\pi}-p\delta)} - 0.5e^{-\theta(\bar{\pi}+p\delta)} = -0.5e^{-\theta\bar{\pi}}(e^{\theta p\delta} + e^{-\theta p\delta}).$

Let

(4) $\quad \Delta^{ni}(\delta) \equiv 2[U^{gni}(\delta) - U^{w}]e^{\theta\bar{\pi}} = 2e^{\theta(\bar{\pi}-r)} - e^{\theta p\delta} - e^{-\theta p\delta},$

where factor $2e^{\theta\bar{\pi}}$ has been included only for convenience. We seek to identify and understand the levels of $\delta \geq 0$ such that $\Delta^{ni}(\delta) = 0$. We show in Appendix A that whenever $\bar{\pi} > r$ then the only positive solution is

(5) $\quad \delta^{gni} = \dfrac{\bar{\pi} - r}{p} + \dfrac{1}{\theta p}\ln\left(1 + \sqrt{1 - e^{-2\theta(\bar{\pi}-r)}}\right).$

As $U^{gni}(\delta)$ is decreasing in δ, i.e., $dU^{gni}(\delta)/d\delta \equiv U_{\delta}^{gni}(\delta) = -0.5\theta p e^{-\theta\bar{\pi}}(e^{\theta p\delta} - e^{-\theta p\delta}) < 0$, it follows that set $\delta \in [0, \min[\mu, \delta^{gni}]]$ will be planted and so the fraction of land that would be planted is $F(\min[\mu, \delta^{gni}])$. For future reference, we formalize the rather obvious inference.

Remark 1: Absent insurance, only the least risky land is planted.

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[1] The setting we study will allow us to view choices B) and C) as just one choice because risk aversion and a subsidy will mean that choice C) is preferred over B) whenever the crop insurance contract is a meaningful choice. Therefore we need not compare B) with C).

Finally, if $\bar{\pi} = r$ then $\delta^{gni} = 0$ while $\delta^{gni} > 0$ whenever $\bar{\pi} > r$. So whenever the risk aversion parameter is strictly positive then land with strictly positive yield risk is planted if and only if the expected profit from doing so is strictly positive. Figure 1 depicts the expected utility comparison as production risk changes.

2.2 Modeling insurance

Now crop insurance is introduced. Insured yield is $\phi\mu$ where $\phi \in (0,1]$ so that the indemnity payout on each unit is $p \max[\phi\mu - y, 0]$. As expression $(\phi-1)\mu$ arises repeatedly through the analysis, we write $\vartheta = (\phi-1)\mu$ in order to reduce notation. The indemnity payout on one unit is $p \max[\vartheta - \delta, 0] = 0$ with high yield Prob. 0.5 and $p \max[\vartheta + \delta, 0]$ with low yield Prob. 0.5. The matter is only of interest whenever a payout occurs with strictly positive probability, so crop insurance will only be taken up by unit owners having yield risk that satisfies $\delta > -\vartheta$.

The expected indemnity, and so the unsubsidized actuarially fair premium absent an administration loading factor, is $v = 0.5p \max[\vartheta + \delta, 0] + 0.5p \max[\vartheta - \delta, 0] = 0.5p \max[\vartheta + \delta, 0]$. So

(6) $$v = \begin{cases} 0.5(\vartheta + \delta)p, & \text{whenever } \delta \geq -\vartheta; \\ 0 & \text{otherwise.} \end{cases}$$

In the presence of subsidy rate $s > 0$, the actual premium is $(1 - s)v = 0.5(1 - s)p \max[\vartheta + \delta, 0]$ while the actual subsidy is $sv = 0.5s(\vartheta + \delta)p$. The following remark is key to understanding incentives in what is to follow;

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<u>Remark 2</u>: Subsidy sv is increasing in both $i)$ risk parameter δ and $ii)$ crop price p.

The subsidy is more extensive for riskier land, and also for land of a given risk level when the crop price increases. Given the subsidy, all growers with $\delta \geq -\vartheta$ will insure in light of $a)$ benefits from risk management, and $b)$ the subsidy. For $\delta < -\vartheta$ there is no benefit to insuring as the payout and premium would both equal zero so we assume that the growers do not insure.

If the land owner plants and insures (or, $\delta \geq -\vartheta$) then profits under the high (h) and low (l) yield scenarios are, respectively, $\pi^h = \bar{\pi} + p\delta - (1-s)v$ and $\pi^l = \bar{\pi} - p\delta + (\vartheta + \delta)p - (1-s)v$, or

(7)
$$\text{High}: \quad \pi^h = \bar{\pi} - 0.5p[(1-s)\vartheta - (1+s)\delta];$$
$$\text{Low}: \quad \pi^l = \bar{\pi} + 0.5p[(1+s)\vartheta - (1-s)\delta].$$

Planting time expected utility when growing an insured crop becomes

(8) $\quad U^{gi}(\delta; s) = -0.5e^{-\theta\pi^h} - 0.5e^{-\theta\pi^l} = -0.5\left(e^{(1-s)\vartheta\lambda}e^{-(1+s)\delta\lambda} + e^{-(1+s)\vartheta\lambda}e^{(1-s)\delta\lambda}\right)e^{-\theta\bar{\pi}},$

where $\lambda = 0.5\theta p$ and we note that $U_s^{gi}(\delta; s) = -(\vartheta + \delta)\lambda U^{gi}(\delta; s) \geq 0 \; \forall \delta \geq -\vartheta$. As will be shown, we cannot be sure that $U_\delta^{gi}(\delta; s) < 0$ without further qualification and so we cannot be sure that any solution to $\{\delta : U^{gi}(\delta; s) = U^w\}$ is unique.

2.3 Insurance, but no subsidy

In general, no closed-form solution is available for the δ values that solve $U^{gi}(\delta; s) = U^w$, which we label as δ^{gi}. However, a closed-form solution does exist when $s = 0$. It is shown in Appendix A that

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(9) $\quad \delta^{gi}\mid_{s=0}= \vartheta + \dfrac{2(\bar{\pi}-r)}{p} + \dfrac{1}{\lambda}\ln\left(1+\sqrt{1-e^{-2\theta(\bar{\pi}-r)}}\right)= \vartheta + 2\delta^{gni} > 0,$

upon use of (5). Therefore, $\delta^{gi}\mid_{s=0} - \delta^{gni} = \vartheta + \delta^{gni}$ and this is positive whenever $\delta^{gni} > -\vartheta$.

Now, from (8),

(10) $\quad U_{\delta}^{gi}(\delta;s)\mid_{s=0}= -0.5\lambda\left(e^{0.5\theta p(\delta-\vartheta)} - e^{-0.5\theta p(\delta-\vartheta)}\right)e^{-\theta\bar{\pi}} < 0$

as $\delta - \vartheta > 0$. So an increase in δ decreases expected utility even under unsubsidized insurance, and we can conclude:

Proposition 1: Relative to no crop insurance, the presence of unsubsidized crop insurance expands the set of land farmed from $F(\delta^{gni})$ to $F(\vartheta + 2\delta^{gni})$ whenever $\delta^{gni} > -\vartheta$. It remains the case that only the least risky land is cropped.

This unsurprising result should be viewed as a reference point because presence of an insurance subsidy may reverse the relationship between land risk type and the decision to crop.

2.4 Comparing choices A) and C)

We will inquire now into the properties of expression $\Delta^{i}(\delta;s) = 2[U^{gi}(\delta;s) - U^{w}]e^{\theta\bar{\pi}}$. If and only if $\Delta^{i}(\delta;s) \geq 0$ will it be privately optimal to crop any land unit with production risk level δ such that $\delta \geq -\vartheta$. From (8)

(11) $\quad \Delta^{i}(\delta;s) = 2e^{\theta(\bar{\pi}-r)} - e^{(1-s)\vartheta\lambda}e^{-(1+s)\lambda\delta} - e^{-(1+s)\vartheta\lambda}e^{(1-s)\lambda\delta},$

and it is critical to note that $\Delta_{\delta\delta}^{i}(\delta;s) < 0$ even in the presence of unsubsidized crop insurance. Break-even risk levels solve $\Delta^{i}(\delta;s) = 0$. From the implicit function theorem, as well as

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discussions surrounding (8) and (10), it is also readily shown that whenever the subsidy is small enough to ensure that expected utility from cropping decreases with an increase in production risk, then

(12) $\qquad \dfrac{\partial \delta^{gi}}{\partial s}\Big|_{U^{gi}(\delta^{gi};s)=U^{w}} = -\dfrac{U_s^{gi}(\delta;s)}{U_{\delta}^{gi}(\delta;s)} > 0.$

This means that an increase in subsidy rate expands the set of land units that is cropped. But of course this inference would not necessarily apply were $U_{\delta}^{gi}(\delta;s) > 0$.

Consider now the first derivative of $\Delta^{i}(\delta;s)$ with respect to yield risk which, in light of (1), reflects how more yield risk will impact optimal land allocation choice. That is, $\Delta_{\delta}^{i}(\delta;s) \geq 0$ would imply $U_{\delta}^{gi}(\delta;s) - U_{\delta}^{w} \equiv U_{\delta}^{gi}(\delta;s) \geq 0$ and riskier land would be more likely to go under the plow. The calculation is $\Delta_{\delta}^{i}(\delta;s) = [(1+s)e^{2\vartheta\lambda} - (1-s)e^{2\lambda\delta}]\lambda e^{-(1+s)(\vartheta+\delta)\lambda}$. Thus $\Delta_{\delta}^{i}(\delta;s) \geq 0$ whenever

(13) $\qquad \delta \in [0, \min[\hat{\delta}(s), \mu]]; \qquad \hat{\delta}(s) \equiv \dfrac{1}{2\lambda}\ln\left(\dfrac{1+s}{1-s}\right) + \vartheta > \delta.$

It follows that $d\hat{\delta}(s)/ds = 1/[\lambda(1-s^2)] > 0$, and so

Remark 3: The level of δ at which expected utility under insurance is maximized, or $\hat{\delta}(s)$, is increasing in the subsidy rate.

Several further comments are in order. Insurance occurs only when $\delta \geq -\vartheta$ so $\hat{\delta}(s)$ is meaningful only on that domain. Notice too that were $s = 0$ and $\vartheta < 0$ then $\hat{\delta}(s) \leq 0$ so that $\Delta_{\delta}^{i}(\delta;s) \geq 0$ for no land units. There exists a critical lower bound on $s \in [0,1]$ such that $\Delta_{\delta}^{i}(\delta;s) \geq 0$ for some land units. That lower bound is given by solving $\hat{\delta}(s) = 0$ to obtain

$s^{lb} = (e^{-2\vartheta\lambda} - 1)/(e^{-2\vartheta\lambda} + 1)$. When $\vartheta = 0$, i.e., mean yield is insured, then $s^{lb} = 0$ but s^{lb} is strictly positive under incomplete insurance.

So the possibility that expected utility under cropping increases with yield variability can only arise when a subsidy is in place. As has been stated already, taking out insurance is meaningful choice only for land with $\delta > -\vartheta$. Figure 2 depicts a possible shape for $V(\delta; s)$ in (2) as a function of δ in the presence of a crop insurance subsidy. So as to understand (2) and the figure it is important to elaborate on what happens when $\delta = -\vartheta$. As implied by the figure, the following is readily established:

Remark 4: Insured and uninsured crop production expected utilities match at $\delta = -\vartheta$, or $U^{gi}(\delta; s)|_{\delta=-\vartheta} = U^{gni}(\delta)|_{\delta=-\vartheta}$, but $U^{gi}_{\delta}(\delta; s)|_{\delta=-\vartheta} > U^{gni}_{\delta}(\delta)|_{\delta=-\vartheta}$.

The figure provides just one possible shape and so leaves much unstated. In it, the value of $-\vartheta$ is sufficiently high and the value of $\bar{\pi} - r$ sufficiently low that no land is insured in this situation. Also, the meaning of 'subcritical' in the caption has yet to be declared while we have yet to characterize how the value of s affects the shape of $V(\delta; s)$. We ask now whether $\hat{\delta}(s) > -\vartheta$. If so, then there would be an interval for δ, namely $\delta \in [-\vartheta, \hat{\delta}(s))$ such that insurance would be taken up and also $\Delta^{i}_{\delta}(\delta) \geq 0$. Both conditions apply if and only if $s > \hat{s}$ $\equiv (e^{-4\vartheta\lambda} - 1)/(e^{-4\vartheta\lambda} + 1)$. The right-hand quantity in this inequality is bounded above in value by 1. We refer to any $s < \hat{s}$ (resp., $s > \hat{s}$ as a subcritical (resp., supercritical) subsidy. If $s < \hat{s}$ then $U^{gi}_{\delta}(\delta; s) < 0$ so that a δ^{gi} that solves $U^{gi}(\delta; s) = U^{w}$ is unique.

We close this section with a summary of what we can infer from the above.

Proposition 2: (**Subcritical subsidy**) Suppose $s < \hat{s}$ and

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Ii) [See figure 2] $\delta^{gni} \leq -\vartheta$. Then no land is insured while set $\delta \in [0, \delta^{gni})$ is cropped and set

$\delta \in [\delta^{gni}, \mu]$ is not cropped;

Iii) [See figure 3] $\delta^{gni} > -\vartheta$. Then set $\delta \in [0, -\vartheta)$ is cropped but not insured, set $\delta \in$

$[-\vartheta, \min[\delta^{gi}, \mu])$ is cropped and insured, while set $\delta \in [\min[\delta^{gi}, \mu], \mu]$ is not cropped, where

δ^{gi} is the unique solution to $U^{gi}(\delta; s) = U^{w}$;

    (**Supercritical subsidy**) Suppose $s > \hat{s}$ and

IIi) [See figure 4] $\delta^{gni} > -\vartheta$. Then set $\delta \in [0, -\vartheta)$ is cropped but not insured, set $\delta \in$

$[-\vartheta, \min[\delta^{gi}, \mu])$ is cropped and insured, and set $\delta \in [\min[\delta^{gi}, \mu], \mu]$ is not cropped, where

δ^{gi} is the right-most solution to $U^{gi}(\delta; s) = U^{w}$;

IIii) [See figures 5 through 9] $\delta^{gni} \leq -\vartheta$. Then set $\delta \in [0, \delta^{gni})$ is cropped but not insured and a

convex set around $\delta = -\vartheta$ is not cropped. The set *C* of noncropped land may *a*) extend to $\delta =$

μ (figure 5), or *b*) be convex in that it does not include an interval around $\delta = \mu$ (figure 6), or

c) be nonconvex in that it includes an interval around $\delta = \mu$ while excluding an interval

around $\delta = \hat{\delta}(s)$ (figure 7). Further, *d*) when $\delta^{gni} \leq 0$ then the set of cropped land can be

riskier than the set of uncropped land (figure 8) or riskier than some cropped land and less risk

than other cropped land (figure 9).

    The contrast between figures 2 and 3 is in how the presence of insurance, subsidized or not,

flattens out expected utility through state-conditioned transfers. This ensures that $\delta^{gi} \geq \delta^{gni}$,

with $\delta^{gi} > \delta^{gni}$ whenever $\delta^{gni} < -\vartheta$. In figure 4 the subsidy is large enough that more risk

increases expected utility, and so expands the set of land to be planted. In figure 5 the return to

noncrop uses is large enough that insurance is not relevant, even under a low but supercritical

subsidy rate. Figure 6, however, has this return to the noncrop option low enough and subsidy high enough that the set of cropped land is nonconvex. The riskiest and least risky land units are cropped, but intermediate lands are not. The cropping of the riskiest land is driven by a subsidy so enticing as to overcome the risk exposure and associated high premium cost.

Figures 7-9 provide what are perhaps the most curious outcomes. In figure 7 neither the set of cropped land nor the set of noncropped land is convex. Near $\delta = \mu$, the premium subsidies may be high but the risk incurred is still too high to support cropping. Figure 8, which is a special case of *IIii*) *b*) and figure 6, provides another interesting possibility. Here, $\bar{\pi} < r$ so that low risk land units will not be cropped. But the subsidy is such that cropping occurs at high risk. Figure 9 is the extension of *IIii*) *c*) and figure 7 to when $\bar{\pi} < r$ so that only an interior interval in $\delta \in [0, \mu]$ is cropped.

From the perspective of policy, figures 3 and 8 capture some widely held concerns about the land use implications of crop insurance in some parts of the United States. Bear in mind that our analysis is not about adverse selection or moral hazard market failures as a result of asymmetric information. Information asymmetry is not necessary in order for only the riskiest land to be cropped. While information asymmetries and/or mispriced contracts may indeed be part of the story, the simplest and most direct story is one of a subsidy that is most valuable on the riskiest land. Figure 3 shows that the subsidy brings riskier land into production even if, as in our model, higher risk is not generally associated with less risky land. As pointed out in Remark 2, the effective subsidy is largest for the land with highest production risk. Figure 8 shows that the subsidy can be so strong as to reverse the intuitive ordering on how land should enter production, i.e., where demand is highest for the least risky land as a factor in production. This brings us to the matter of working through circumstances under which cases *IIii*) *b*) and *c*) will occur.

2.5 Nonconvex choice sets

When $\bar{\pi} > r$, $s > \hat{s}$ and $\delta^{gni} \leq -\vartheta$ then which among figures 5 through 9 apply depends upon the values of $U^{gi}(\delta;s)$ when *i*) evaluated at $\hat{\delta}(s) = \arg\max_\delta U^{gi}(\delta;s)$ and when *ii*) evaluated at μ. We will first consider *i*) when $\hat{\delta}(s) < \mu$, i.e., an interior maximum. If $U^{gi}(\delta;s)|_{\delta=\hat{\delta}(s)} <$

U^w then figure 5 applies, i.e., insurance is never taken out. If $U^{gi}(\delta;s)|_{\delta=\mu} \geq U^w$ then figure 6 applies so that the most risky and the least risky units are cropped but intermediate risk units are not. If $\hat{\delta}(s) < \mu$, $U^{gi}(\delta;s)|_{\delta=\hat{\delta}(s)} \geq U^w$ and $U^{gi}(\delta;s)|_{\delta=\mu} < U^w$ then figure 7 applies, i.e., the set of non-cropped land is nonconvex with some in the locality of $\delta = -\vartheta$ and some in the locality of $\delta = \mu$ while the set of cropped land is also nonconvex. So the evaluation

$U^{gi}(\delta)|_{\delta=\hat{\delta}(s)} - U^w$ determines the applicable case.

Insert $\hat{\delta}(s)$ into (11) to obtain the maximum value of $\Delta^i(\delta)$ given subsidy rate s, i.e.,[2]

(14)
$$\Delta^i(\delta)|_{\delta=\hat{\delta}(s)} = 2e^{\theta(\bar{\pi}-r)} - e^{-2s\vartheta\lambda + H[0.5(1-s),0.5(1+s)]};$$
$$H[x_1,x_2] = -x_1 \ln(x_1) - x_2 \ln(x_2);$$

where $H[x_1,x_2]$ is the entropy function. So $\Delta^i(\delta)|_{\delta=\hat{\delta}(s)} > 0$ whenever

(15) $\quad \bar{\pi} - r > \dfrac{\Gamma(s) - \ln(2)}{\theta};\quad \Gamma(s) = -2s\vartheta\lambda + H[0.5(1-s),0.5(1+s)].$

Here if the difference in expected profits, or $\bar{\pi} - r$, exceeds $[\Gamma(s) - \ln(2)]/\theta$ then there exists a risk type that will take out the subsidized insurance.

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[2] Details are provided in Appendix A.

We proceed at this point to investigate $\Gamma(s)$, which has properties

$$\Gamma(s)\,|_{s=0} - \ln(2) = 0; \qquad \lim_{s\to 1}\Gamma(s) - \ln(2) = -2\vartheta\lambda - \ln(2) \mathbin{\text{¡}} 0;$$

(16)
$$\Gamma_s(s) = -2\vartheta\lambda + \frac{1}{2}\ln\left(\frac{1-s}{1+s}\right) = \left(-\vartheta - \hat{\delta}(s)\right)\lambda < 0$$

$$\text{(as } \hat{\delta}(s) > -\vartheta \text{ for the problem to be meaningful);}$$

$$\Gamma_{ss}(s) = -\frac{1}{1-s^2} \le 0 \ \forall s \in [0,1).$$

Figure 10 depicts expression $[\Gamma(s) - \ln(2)]/\theta$ as a function of s over the relevant range, i.e., when $s > \hat{s}$. It is concerned with whether a supercritical subsidy is such as to bring land into production. There are two cases where the first and most straightforward is that depicted in panel *a*), where $\lim_{s\to 1}\Gamma(s) - \ln(2) = -2\vartheta\lambda - \ln(2) > 0$, or $e^{-2\vartheta\lambda} \equiv e^{-\vartheta\theta p} > 2$. On the horizontal axis is subsidy rate while on the vertical axis is the expected profit gap $\bar{\pi} - r$ absent subsidy effects. If cropping is quite profitable then one does not need a subsidy rate much larger than the critical rate to ensure that cropping occurs under subsidized insurance. So the interval of subsidy rates such that some land types are cropped and insured is large. Panel *b*) provides the more interesting case, corresponding to figure 8, in which $e^{-\vartheta\theta p} < 2$ so that $\lim_{s\to 1}\Gamma(s) - \ln(2)$ <0. Then it is possible for a subsidy rate above the supercritical subsidy rate to induce cropping under insurance even when $\bar{\pi} < r$. As $\Gamma_\vartheta(s) = -2s\lambda < 0$, an increase in the value of ϑ toward zero (or subsidized, risk-free insurance) pushes curve $[\Gamma(s) - \ln(2)]/\theta$ everywhere and so makes this outcome more likely. With a less negative value of ϑ, the situation where risky land will be cropped while risk-free land will not will arise at a lower subsidy rate.

If instead we consider *ii*) where $\hat{\delta}(s) \ge \mu$, i.e., a boundary maximum, then the question is whether $\Delta^i(\delta;s)\,|_{\delta=\mu} > 0$. This resolves to whether

$$
(17) \quad s > \frac{\ln\left(\dfrac{e^{-(\mu-\vartheta)\lambda}+e^{(\mu-\vartheta)\lambda}}{2}\right)-\theta(\bar{\pi}-r)}{(\mu+\vartheta)\lambda} \equiv \frac{\ln\left(\cosh[(\mu-\vartheta)\lambda]\right)-\theta(\bar{\pi}-r)}{(\mu+\vartheta)\lambda} \equiv s^{*}.
$$

We make two notes at this point. First, and as one would expect, $ds^{*}/d(\bar{\pi}-r)<0$ or the critical subsidy such that the riskiest land is cropped becomes smaller as the incentive to crop the least risk land increases. Second, $ds^{*}/d\vartheta<0$ so that, as with *i*) when $\hat{\delta}(s)<\mu$, under *ii*) and a less negative value of ϑ a smaller subsidy value will lead to the situation where risky land is cropped while risk-free land is not.

The theoretical model predicts that subsidized crop insurance expand the set of land farmed. It also shows that there exists a critical subsidy rate such that if the subsidy rate higher than this critical rate then the expected utility from cropping increases with yield risk. Our empirical investigation in what follows will cast light on the extent to which the set of land that is cropped expands in response to insurance subsidies, and also on whether there are parts of the United States where only the most risky land will be cropped. In the next section we first study yield risk that is relevant to crop insurance, i.e., yield risk in the lower tail of a yield distribution.

3. Yield Risk Relevant to Crop Insurance

In this section we measure an insurance loss index that is proposed in Hennessy (2009). We need to control for yield trends so as to correctly estimate the extent of riskiness (Just and Weninger 1999). The detrending approach taken here is the same as the approach in Claassen and Just (2010). We first describe the data we utilize in this section and then introduce the method to obtain the yield risk relevant to crop insurance.

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3.1 Data

The data set utilized in this section covers corn and wheat yields in 12 Midwest states (IA, IL, IN, KS, MI, MN, MO, ND, NE, OH, SD, and WI) and two states (OK and TX) on the Southern Great Plains. The field-level yield data are obtained from the Risk Management Agency (RMA) of the U.S. Department of Agriculture (USDA). The RMA yield data contain yield history on each insured unit under the federal crop insurance program. An insured unit can be a single field or several fields of a farm. The yield history has up to 10 years yield record for each insured unit. To avoid very small samples for some insured units, we restrict the RMA yield data such that each record contains 10 years of actual yield.

County-level yield data of corn and wheat over 1960-2009 in these 14 states are obtained from National Agricultural Statistics Service (NASS) of USDA. The county-level NASS yield data are used to detrend RMA field-level data as the former are available over a longer time frame. Not every county has yield data for each year in the time range 1960-2009. To have time series spans sufficient for trend estimation, we require that every county selected for our data set have 45 or more years of yield data in the time range 1960-2009. In our selected data set, the missing values of the county-level yield are filled by using multiple imputation method. Then the county-level yield trend is estimated by locally weighted regression to capture the   non-linearity of yield trend (Claassen and Just 2010).

3.2 Measuring Yield Risk

Let y_{ijkt} be the yield of unit *i* of farm *j* in county *k* and year *t*. Here the unit means the crop insurance unit, which can be a single field of a farm or the entire farm. Then y_{ijkt} can be written as

(18)
$$y_{ijkt} = \hat{y}_{ijkt} + \epsilon_{ijkt},$$

where $\hat{y}_{ijkt}$ is the unit level trend yield, and ϵ_{ijkt} is an error term with mean zero.

Unit level yield trend, $\hat{y}_{ijkt}$, is constructed as

(19)
$$\hat{y}_{ijkt} = \hat{y}_{kt}^c + \psi_{ijk},$$

where $\hat{y}_{kt}^c$ is the county-level yield trend, and

(20)
$$\psi_{ijk} = E_{t|ijk}(y_{ijkt}) - E_{t|ijk}(\hat{y}_{kt}^c).$$

The acreage-weighted average operator, $E_{t|ijk}(x_{ijkt})$, is defined as

(21)
$$E_{t|ijk}(x_{ijkt}) \equiv \frac{\sum_t a_{ijkt} x_{ijkt}}{\sum_t a_{ijkt}},$$

where a_{ijkt} is acreage related with x_{ijkt}. For units, a_{ijkt} is acres of the unit. For counties, a_{kt} is acreage "Harvested" of county k in year t.

From equations (18) to (20), we have the detrended yield as

(22)
$$\begin{aligned} \epsilon_{ijkt} &= y_{ijkt} - \hat{y}_{ijkt} = y_{ijkt} - \hat{y}_{kt}^c - \psi_{ijk} \\ &= y_{ijkt} - \hat{y}_{kt}^c - E_{t|ijk}(y_{ijkt}) + E_{t|ijk}(\hat{y}_{kt}^c). \end{aligned}$$

Clearly we have $E_{t|ijk}(\epsilon_{ijkt}) = E_{t|ijk}\left(y_{ijkt} - \hat{y}_{kt}^c - E_{t|ijk}(y_{ijkt}) + E_{t|ijk}(\hat{y}_{kt}^c) \right) = 0.$

Now let us construct a risk (or insurance loss) measure. Since the insurable yield is calculated using the average of 10-year historical actual yields, then a risk measure same as the Insurance Loss Index in Hennessy (2009) is

(23)
$$r_{ijkt} = \frac{\max[\phi E_{t|ijk}(y_{ijkt}) - (E_{t|ijk}(y_{ijkt}) + \epsilon_{ijkt}), 0]}{E_{t|ijk}(y_{ijkt})} = \frac{\max[(\phi - 1)E_{t|ijk}(y_{ijkt}) - \epsilon_{ijkt}, 0]}{E_{t|ijk}(y_{ijkt})},$$

where $\phi \in [0,1]$ is coverage level. Once we obtain r_{ijkt}, we can calculate weighted average county-level yield risk of one policy year. Please recall that we use RMA data of four policy

years: 1994, 1999, 2004, and 2009. Each RMA data set of one policy year contains 10 years of yield history of one unit. Let a_{ijkt}^p be the acreage of unit u_{ijk}^p in year t in the data set of policy year p. Then in the data set of policy year p, the total acreage over all units and all 10 years in county k are

$$(24) \qquad A_k^p \equiv \sum_{ijt}(\alpha_{ijkt}^p) = \sum_t\left(\sum_j\left(\sum_i(\alpha_{ijkt}^p)\right)\right).$$

Then the weight of r_{ijkt}^p in data set of policy year p is

$$(25) \qquad w_{ijkt}^p = \frac{a_{ijkt}^p}{A_k^p}.$$

Therefore, the weighted average county-level yield risk of policy year p is

$$(26) \qquad r_k^p = \sum_{ijt}\left(w_{ijkt}^p r_{ijkt}^p\right).$$

Let

$$(27) \qquad A_k \equiv \sum_p A_k^p,$$

that is, A_k is the total unit acreage of county k over all units, all 10 years, and all policy year data sets. Then the weighted average county-level yield risk over policy years can be written as

$$(28) \qquad r_k = \sum_p\left(\frac{A_k^p r_k^p}{A_k}\right).$$

Figures 11 and 12 present the geographical distributions of county-level risks in equation (28) of corn and wheat, respectively. The risk values in these two maps are calculated by assuming coverage level, ϕ in equation (23), as 75%. For Figure 11, the missing counties in North Dakota (ND) and South Dakota (SD) are majorly because we excluded counties that have more than five missing values on county-level yield observations.

From Figures 11 and 12 we can see that, at least for ND and SD, the risk distributions of corn

and wheat have similar pattern. For example, the south-eastern part and the north-western part

are low risk area for wheat production in ND. This is true as well for corn production in ND.

An econometrical explanation of yield risks is provided in next section.

4. Explaining Riskiness

In this section we regress county-level yield risks in equation (28) on county level growing

degree days, precipitation, Land Capability Class configurations (explained below), and

farming practice. We obtained reasonable values of goodness-of-fit (around 0.4) from

regressions. The coefficients of almost all variables are consistent with intuition. In what

follows we first explain the constructions of the independent variables and then report the

regression results.

4.1 constructing independent variables

Growing degree days

For growing degree days, we use the same data as Schlenker and Roberts (2009) did. A

detailed data description can be found by the link

http://www.columbia.edu/~ws2162/dailyData/dataDescription.pdf . Following Schlenker *et al.*

(2006), we set the upper and lower thresholds of growing degree days as 8 degree Celsius and

32 degree Celsius, respectively. We also assume the threshold temperature is 34 degree Celsius

when calculating the over-heat degree days. That is, temperature over 34 degree Celsius is

thought harmful to crop's growth.

The data set of Schlenker and Roberts (2009) contains county-level monthly average degree days of the United States over period 1950-2005. The time period we select is from 1975 to 2005. We selected growing season as April to September, following Following Schlenker *et al.* (2006) and Deschênes and Greenstone (2007). Then we sum up monthly degree days in the growing season for each county in a year to calculate the total degree days of one county in one year's growing season. Then we calculate the county-level simple average of growing season degree days between 8 °C and 32 °C, as well as degree days beyond 34 °C over 1975-2005. The results are named as *dday8_32* and *dday34*, respectively. We also calculate the standard deviations of growing season degree days between 8 °C and 32 °C, as well as degree days beyond 34 °C over 1975-2005. The results are denoted as *dday_8_32_std* and *dday_34_std*, respectively. Summary statistics of the four variables (i.e., *dday8_32*, *dday34*, *dday_8_32_std*, and *dday34_std*) are listed in Table 1.

Precipitation

The precipitation data are also from Schlenker and Roberts. The simple average of growing season precipitation of each county over 1975-2005 (*prec* from hereon) are calculated by using the same ways of calculating growing degree day variables discussed above. So is the standard deviation of precipitation (*prec_std* from hereon). The summary statistics of variables *prec* and *prec_std* are provided in Table 1.

Land Capability Classes (LCC)

The LCC data are obtained from National Resource Inventory (NRI) data set. Instead of calculating a weighted average of LCC for each county as we did in DU Report No. 2, this time we are interested in the effect of sub-classes of LCC on county-level yield risks. Since

LCC higher than 4 are not suitable for crops, we only focus on LCC from 1 to 4. In this range of LCC, there are 13 sub-classes. They are: 1, 2C, 2E, 2S, 2W, 3C, 3E, 3S, 3W, 4C, 4E, 4S, and 4W (see Table 2). Here C means climate; E means erosion; S means shallow, drought or stony; and M means water. For each county in our sample, we calculate the percentage of acreage under each of these 13 sub-classes over the total acreages under LCC 1-4. The acreages are from "Expansion Factors" column in the table "point" of NRI data set. Therefore, we obtain 13 variables, namely *LCC1*, *LCC2C*, *LCC2E*, *LCC2S*, *LCC2W*, *LCC3C*, *LCC3E*, *LCC3S*, *LCC3W*, *LCC4C*, *LCC4E*, *LCC4S*, and *LCC4W*. The percentage of acreage under LCC 2, 3, and 4 can be calculated by using

$$
\begin{aligned}
LCC2 &= LCC2C + LCC2E + LCC2S + LCC2W, \\
LCC3 &= LCC3C + LCC3E + LCC3S + LCC3W, \text{ and} \\
LCC4 &= LCC4C + LCC4E + LCC4S + LCC4W,
\end{aligned}
\tag{29}
$$

respectively. The summary statistics of these variables are presented in Table 1.

Practice Types

For corn, there are two practice types in our RMA data sample. They are irrigated (coded as 2) and non-irrigated (coded as 3). For wheat, the practice types are irrigated (coded as 2), non-irrigated (coded as 3), continuous cropping (coded as 4), and summer fallow (coded as 5). As we did for LCC, for each county we calculate the percentage of unit acreages under each practice types. Hence for corn, we obtain variables *prac2* and *prac3*, which stand for the percentage of unit acreages under practice types 2 and 3, respectively. For wheat, we obtain variables *prac2*, *prac3*, *prac4*, and *prac5*. The summary statistics are in Table 1.

Explanations for Table 1

In Table 1 variables "*cty_risk_mul*" and "*cty_risk_add*" mean the county-level yield risk calculated by using the multiplicative method and additive method, respectively.(?????explain these two methods) Variable "*dday34_sqrt*" is the square root of variable "*dday34.*" We are interested in "*dday34_sqrt*" because Schlenker *et al.* (2006) documented that "the square root gives the best fit" (footnote 13 of Schlenker *et al.* 2006). The summary statistics of LCC 4C (i.e., variable lcc4c) are all zeros because in our sample no acreage is under this sub-class. Please note that Table 1 shows that the number of observation points in the NRI data of the 14 states (1,385 counties) is only 25. However, the total number of observation points is 212,368. The counties with LCC 4C land are not included in our sample.

4.2 regressions and results

We tried multiple regressions for corn yield risk and for wheat yield risk (Table 3 and Table 4). The dependent variable is "*cty_risk_mul*". Results show that about 40% of the variation of the county-level yield risks can be explained by variables we discussed in section 2.1. Extra explanatory variables could include more land-quality information (such as land slope) and information about farmers in one county (such as average age and education), *etc*.

Corn yield risk

From Table 3 we can see that, higher land quality has larger effect on mitigating corn yield risks. For example, in regression (1) of Table 3, the coefficient of variables *LCC2E* and *LCC3E* are -0.000189 and -0.000031, respectively. This means that everything else equal, increasing acreage of LCC2E land will decrease yield risk by 0.000189, which is about 0.4% of the mean risk in our sample. However, increasing acreage of LCC3E land will only decrease yield risk

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by 0.000031, which is about 0.08% of the mean risk in the sample. Regression (3) show that increasing the percentage of LCC 4 land will increase the yield risk.

Regression results also show that for degree days between 8 °C and 32 °C, both coefficients of *dday8_32* and *dday8_32_squa* are significantly affect yield risks. However, the standard deviations of degree days between 8 °C and 32 °C do not significantly affect yield risks.

Variable *dday34*, the measure of over-heat, has positive coefficient no matter in a linear or square root specification, which means over-heat increases yield risks. Variable *dday34_std* has significant negative coefficients in regressions (1) and (3). One possible interpretation could be that evenly happened over-heats cross years are worse than a dramatic over-hear in one year but no over-heat in other years, which may be because "when crops are sufficiently adversely affected by the heat, the incremental damage from further increases is sharply reduced" (Schlenker *et al*. 2006) . Taking an extreme example, we assume that crop will be completely destroyed when *dday34* is higher than or equal to 1. We then consider a 30-year period. If during this period *dday34* is equal to 1 in each year (here the standard deviation is 0), then crops in every year will be completely destroyed. However, if during this period there is only one year with *dday34* equal to 30 and no over-heat in the other 29 years, then crop in this period will only be destroy once.

The effect of precipitation on yield risks is ambiguous, since the squared term of precipitation shows different signs. To determine the effect of precipitation one needs to know the specific precipitation levels because the coefficient of *prec_squa* is significant. We also can see that irrigation reduces yield risks.

Wheat yield risk

For wheat yield risk, most variables show the same effect pattern as variables in corn yield risk regressions discussed above. What is different from corn yield risk analysis is that the percentage of LCC1 land does not significantly affect wheat yield risk. I do not have a confident explanation for this. By studying that whether LCC1 land is devoted to grow wheat may provide an explanation to this or provide hints for further exploration. Specifically, if LCC1 land is largely used to grow corn, then naturally LCC1 acreage does not affect wheat yield risk.

5. Simulations on the Land Use Effect of Crop Insurance Subsidy Rate and Crop Prices

In this section we simulate the expected utility to be derived from putting land of a given production capability and climate profile into production under a given cropping system as coverage level ϕ, subsidy rate s, and returns to non-cropping r change. We will then ask such questions as i) which RMA counties are most likely to be influenced to enter cropping as the subsidy rate changes, and ii) how commodity prices affect incentives to convert production risky land. In what follows we first describe the model calibration and then discuss the simulation results.

5.1 Model Calibration

In order to calculate the expected utility a farmer obtains from non-cropping, *gni*, or *gi,* we need to know coefficient of absolute risk aversion (ARA), output prices, production costs, return to non-cropping, yield distribution, and coverage level as well as the subsidy rate corresponding to each coverage level. Due to the limitation of data, in our simulation we focus

on corn. Since we do not have corn prices in TX, the simulation does not cover TX. We now discuss the values of these variables applied in our simulation.

Coefficient of ARA

Babcock *et al*. (1993) suggested a method that utilized risk premium and probability premium to determine appropriate range of ARA coefficients. They showed that the reasonable range of ARA coefficients is determined by the variation of the possible payment of a lottery. Their calculation showed that when the gamble size is between $100 and $10,000 and when the probability premium is in [0.005, 0.49], then the ARA coefficient range is [0.0002, 0.000462]. Since the average acreage of a unit is 98 acres and the average unit-level yield standard deviation is 31 in our data set, ARA coefficient range at [0.0002, 0.000462] can be a reasonable range for our study. Therefore in our simulation we set ARA coefficient equal to a value from set $\{0.0002, 0.0003, 0.0004\}$.

Output Prices

For output prices of corn, we utilize the county-level annual average cash price in 2009 market year. Corn cash prices are obtained from CashGrainBids.com. In the original cash price data obtained from CashGrainBids.com there may be multiple markets in one county. We average the prices across these markets in the county to generate the output prices.

Production Costs

Production costs (i.e., parameter c in the model) in the simulation are obtained from state-level crop budgets, which are publicly available on websites of extensions at the major land-grant

university in each state.[3] For states SD and OK, we could not find the crop budgets in 2009. So we utilize the crop budgets in 2011 of the two states times discount factors to approximate production cost in 2009. For fixed cost, the discount factor is 0.96; and for the variable cost, the discount factor is 0.93. The way we obtained the two discount factors is dividing the average fixed cost (or variable cost) in 2009 in ND by the same kind of cost in 2011 in ND. The state-level production costs used in our simulation are presented in Table 5. The production costs include cash rent of land but do not include crop insurance premium because we have an individual term for the premium, v.

Yield Distribution

We assume that the unit-level yield has beta distribution. We then utilize the maximum likelihood method to estimate each unit's distribution based on the detrended yield observations of each unit. We draw 1,000 draws from the estimated distributions. These draws are used as yield realizations to calculate expected utilities from cropping.

Returns to Non-cropping

We employ average county-level rental payments of Conservation Reserve Program (CRP) in 2009 as the return to non-cropping. The CRP rental payments are obtained from the website of Farm Service Agency (FSA) (web link: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=rns-css). In our simulation we assume that crop insurance subsidy has a complete pass-through into CRP rental payment. That is, the CRP rental payments fully reflect the change of crop insurance subsidies.

Coverage Levels and Corresponding Subsidy Rates

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[3] Website links of the crop budgets are provided in Appendix B.

The coverage levels and corresponding subsidy rates as of May 2011 are presented in Table 6. Farmers can choose any coverage level in Table 6 and then the government subsidizes at a rate corresponding to the coverage level chosen. The subsidy rate ranges from 38% to 80% and decreases as the coverage level increases. In the simulation a typical farmer chooses a coverage level that maximizes her expected utility.

5.2 Simulation Results

In the simulation we are interested in the land-use effect when the crop insurance subsidy rate or crop price varies, *ceteris paribus*. Our preliminary results show that when subsidy rate is decreased by 5 percentage point at each coverage level, then averagely 0.60% of cropped land in our data set will be converted into non-cropped land. The state-level land use effect of this subsidy rate decrease is presented in Table 7. In addition, when crop price is decreased by 5%, then averagely 1.01% of cropped land in our data set will be converted into non-cropped land. The state-level land use effect of crop price decrease is presented in Table 7 as well.

The county-level land use effects when subsidy rate (crop price) decreases by 5 percentage points (5 percent) are visually presented in Figure 13 (Figure 14). From the maps in Figure 13 and Figure 14 we can see that the southeastern part of ND and the middle part of KS are areas that mostly affected by decreases of subsidy rate or crop price. However, Iowa, southern Minnesota, middle Illinois, eastern South Dakota, and eastern Nebraska are least affected by such decreases. The reason for this land-use effect pattern is that marginal land are more sensitive to the changes of subsidy rate or crop prices than high productive land are. By comparing Figure 11 and Figure 13 (or Figure 14) we can see that the risky area is basically the same as the most affected area by subsidy or price decreases.

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6. Conclusions

In order to understand how federal crop insurance subsidies influence land-use decisions, in this study we develop a conceptual mode about optimal land allocation in the presence of crop insurance subsidies. Our conceptual model shows that the social excess of risky land entering crop production will arise solely due to the subsidy. This is because the subsidy is *i*) proportional to acres planted, and *ii*) greatest for the most production risky land which usually includes newly converted grassland.

Using farm-level data, we follow the conceptual results through to establish the implications of subsidies for the extent of land use. We first complement USDA Risk Management Agency (RMA) insurance unit yield data with USDA NASS county-level yield data to develop a risk measure that reflects expected payout. Then we explain riskiness by regressing the risk measure on county average values for land quality and whether data. The regressions can show what sorts of land are most risky for production and the magnitude of subsidies the land receives. Finally, we simulate the expected utility to be derived from putting land of a given production capability and climate profile into production as subsidy rate and returns to non-cropping change. Our empirical estimation and simulation show that risky land is more sensitive to the changes of crop insurance subsidy rates and crop prices. The geographic configurations of the land use change effects of crop insurance subsidies and crop prices are provided.

Appendix A

Demonstration of eqn. (5): Write $x = e^{\theta p \delta}$. Then the breakeven δ such that $\Delta^{ni}(\delta) = 0$, or $\delta = \delta^{gni}$, satisfies

(A1) $\quad e^{-\theta(\bar{\pi}-r)}x^2 - 2x + e^{-\theta(\bar{\pi}-r)} = 0.$

Apply the quadratic formula to solve:

(A2) $\quad x = e^{\theta(\bar{\pi}-r)} \pm e^{\theta(\bar{\pi}-r)}\sqrt{1 - e^{-2\theta(\bar{\pi}-r)}}.$

Note that were $x < 1$ then $\delta < 0$, which we have ruled out without loss of generality. Write $\tau = e^{\theta(\bar{\pi}-r)}$ and consider whether the smaller root has value no larger than 1, i.e., whether $\tau - \tau(1-\tau^{-2})^{0.5} < 1$. Re-arrange to obtain condition $\tau - 1 < \tau(1-\tau^{-2})^{0.5}$ where quantities on both sides are positive in value whenever $\bar{\pi} > r$ so that squaring will not change the ordering. So we ask whether $1 < \tau$. This is true, so $x < 1$, the negative root can be precluded and we consider only the larger root.

Demonstration of eqn. (9): Then $U^{gi}(\delta;s) = U^w$ becomes $0 = 2e^{\theta(\bar{\pi}-r)} - e^{\vartheta\lambda}e^{-\lambda\delta} - e^{-\vartheta\lambda}e^{\lambda\delta}$ from (8). Label $y = e^{-(\vartheta-\delta)\lambda}$ where of course $y > 1$. We seek to solve

(A3) $\quad e^{-\theta(\bar{\pi}-r)}y^2 - 2y + e^{-\theta(\bar{\pi}-r)} = 0.$

This has the same form as (A1), so that

(A4) $\quad y \equiv e^{-(\vartheta-\delta)\lambda} = e^{\theta(\bar{\pi}-r)} + e^{\theta(\bar{\pi}-r)}\sqrt{1 - e^{-2\theta(\bar{\pi}-r)}},$

and the first equation in (9) follows. Use (5) to obtain the second equation in (9).

Demonstration of Remark 4: From (8) and (3),

(A5) $\quad U^{gi}(\delta;s)\mid_{\delta=-\vartheta}=-0.5\left(e^{\theta p\vartheta}+e^{-\theta p\vartheta}\right)e^{-\theta\bar{\pi}}=U^{gni}(\delta)\mid_{\delta=-\vartheta}$.

Also,

$$U_{\delta}^{gi}(\delta;s)\mid_{\delta=-\vartheta}=0.25\theta p\left((1+s)e^{0.5\theta p(1-s)\vartheta}e^{0.5\theta p(1+s)\vartheta}-(1-s)e^{-0.5\theta p(1+s)\vartheta}e^{-0.5\theta p(1-s)\vartheta}\right)e^{-\theta\bar{\pi}}$$

(A6) $\quad =0.25\theta p\left((1+s)e^{\theta p\vartheta}-(1-s)e^{-\theta p\vartheta}\right)e^{-\theta\bar{\pi}}$;

$$U_{\delta}^{gni}(\delta)\mid_{\delta=-\vartheta}=0.5\theta pe^{-\theta\bar{\pi}}\left(e^{\theta p\vartheta}-e^{-\theta p\vartheta}\right);$$

so that

$$U_{\delta}^{gi}(\delta;s)\mid_{\delta=-\vartheta}-U_{\delta}^{gni}(\delta)\mid_{\delta=-\vartheta}$$

(A7) $\quad =0.25\theta p\left((1+s)e^{\theta p\vartheta}-(1-s)e^{-\theta p\vartheta}\right)e^{-\theta\bar{\pi}}-0.5\theta pe^{-\theta\bar{\pi}}\left(e^{\theta p\vartheta}-e^{-\theta p\vartheta}\right)$

$\quad \overset{\text{sign}}{=}(1+s)e^{\theta p\vartheta}-(1-s)e^{-\theta p\vartheta}-2e^{\theta p\vartheta}+2e^{-\theta p\vartheta}=se^{\theta p\vartheta}+se^{-\theta p\vartheta}-e^{\theta p\vartheta}+e^{-\theta p\vartheta}>0.$

Demonstration of Eqn. (14): Write eqn. (11) as

$$\Delta^{i}(\delta)\big|_{\delta=\hat{\delta}(s)} -2e^{\theta(\bar{\pi}-r)} = -e^{(1-s)\vartheta\lambda}e^{-(1+s)\lambda\left[\frac{1}{2\lambda}\ln\left(\frac{1+s}{1-s}\right)+\vartheta\right]} - e^{-(1+s)\vartheta\lambda}e^{(1-s)\lambda\left[\frac{1}{2\lambda}\ln\left(\frac{1+s}{1-s}\right)+\vartheta\right]}$$

$$= -e^{(1-s)\vartheta\lambda}e^{-0.5(1+s)\left[\ln\left(\frac{1+s}{1-s}\right)+2\lambda\vartheta\right]} - e^{-(1+s)\vartheta\lambda}e^{0.5(1-s)\left[\ln\left(\frac{1+s}{1-s}\right)+2\lambda\vartheta\right]}$$

$$= -e^{(1-s)\vartheta\lambda-0.5(1+s)\ln\left(\frac{1+s}{1-s}\right)-(1+s)\lambda\vartheta} - e^{-(1+s)\vartheta\lambda+0.5(1-s)\ln\left(\frac{1+s}{1-s}\right)+(1-s)\lambda\vartheta}$$

$$= -e^{-2s\vartheta\lambda-0.5(1+s)\ln\left(\frac{1+s}{1-s}\right)} - e^{-2s\vartheta\lambda+0.5(1-s)\ln\left(\frac{1+s}{1-s}\right)}$$

$$= -\left\{e^{-0.5(1+s)\ln\left(\frac{1+s}{1-s}\right)} + e^{0.5(1-s)\ln\left(\frac{1+s}{1-s}\right)}\right\}e^{-2s\vartheta\lambda} = -\left\{\left(\frac{1+s}{1-s}\right)^{-0.5(1+s)} + \left(\frac{1+s}{1-s}\right)^{0.5(1-s)}\right\}e^{-2s\vartheta\lambda}$$

$$= -\left\{1+\left(\frac{1+s}{1-s}\right)\right\}\left(\frac{1+s}{1-s}\right)^{-0.5(1+s)}e^{-2s\vartheta\lambda} = -\frac{2}{(1-s)}\left(\frac{1-s}{1+s}\right)^{0.5(1+s)}e^{-2s\vartheta\lambda}$$

$$= -\frac{2}{(1-s)^{0.5(1-s)}(1+s)^{0.5(1+s)}}e^{-2s\vartheta\lambda} = -\frac{1}{\left(\frac{1-s}{2}\right)^{(1-s)/2}\left(\frac{1+s}{2}\right)^{(1+s)/2}}e^{-2s\vartheta\lambda}$$

(A8)
$$= -\frac{1}{e^{\frac{(1-s)}{2}\ln\left(\frac{1-s}{2}\right)+\frac{(1+s)}{2}\ln\left(\frac{1+s}{2}\right)}}e^{-2s\vartheta\lambda} = -e^{-2s\vartheta\lambda-\frac{(1-s)}{2}\ln\left(\frac{1-s}{2}\right)-\frac{(1+s)}{2}\ln\left(\frac{1+s}{2}\right)}$$

$$= -e^{-2s\vartheta\lambda+H[0.5(1-s),0.5(1+s)]}.$$

Appendix B

The website links of crop budgets utilized in this article. The links were accessed between April 12th, 2011 and April 20th, 2011.

IA: http://www2.econ.iastate.edu/faculty/duffy/extensionnew.html

IL: http://www.farmdoc.illinois.edu/manage/2009_crop_budgets.pdf

IN: http://www.agecon.purdue.edu/extension/pubs/index.asp

KS: http://www.agrisk.umn.edu/Budgets/Display.aspx?RecID=9&Pg=1

MI:

https://www.msu.edu/~steind/1%20%20Crop%20Budget%20MID%20Mich_2010%20Winter%20MASTER%201_28_10.pdf

MN: http://faculty.apec.umn.edu/wlazarus/documents/cropbud.pdf

MO: http://www.fapri.missouri.edu/farmers_corner/mktng_newsletter/Mar09DM.pdf

ND: http://www.ag.ndsu.edu/farmmanagement/crop-budget-archive

NE: http://www.agrisk.umn.edu/Budgets/Display.aspx?RecID=4831&Pg=2

OH: http://aede.osu.edu/programs/farmmanagement/budgets/

OK: http://www.agecon.okstate.edu/budgets/sample%20files/Corn2.1ctc.pdf

SD: http://www.sdstate.edu/sdces/districts/north/3/farmmanagement.cfm

WI: http://cdp.wisc.edu/crop%20enterprise.htm

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	Corn (obs: 937)				Wheat (obs: 727)			
Table 1. Summary Statistics of Variables								
Variable	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
cty_risk_mul	0.038	0.030	0	0.249	0.057	0.033	0	0.219
cty_risk_add	0.041	0.046	0	0.732	0.061	0.095	0	2.431
lcc1	6.3	9.2	0.0	58.7	5.6	8.8	0.0	58.7
lcc2c	2.5	7.9	0.0	70.9	3.9	9.3	0.0	70.9
lcc2e	23.2	13.8	0.0	77.4	23.1	13.6	0.0	77.4
lcc2s	2.5	5.2	0.0	44.0	2.6	5.7	0.0	44.0
lcc2w	20.9	18.1	0.0	89.9	19.3	18.9	0.0	89.9
lcc3c	0.6	4.9	0.0	61.4	0.9	5.7	0.0	61.4
lcc3e	20.4	15.5	0.0	78.5	20.8	15.5	0.0	78.5
lcc3s	2.1	4.3	0.0	34.4	2.4	4.7	0.0	34.4
lcc3w	6.4	9.1	0.0	74.5	6.7	9.9	0.0	74.5
lcc4c	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lcc4e	10.6	12.2	0.0	96.8	11.0	11.9	0.0	64.1
lcc4s	2.7	7.3	0.0	75.1	2.0	4.8	0.0	41.0
lcc4w	1.8	4.6	0.0	62.7	1.7	4.8	0.0	72.1
dday8_32	1997.7	293.5	1331.8	2855.1	2074.3	365.2	1297.7	2908.7
dday34	3.7	5.4	0.0	28.3	6.3	8.4	0.0	46.4
prec	54.5	8.7	27.9	69.5	51.9	10.1	27.9	69.5
dday8_32_std	127.6	9.0	99.8	158.2	126.5	9.8	99.8	156.0
dday34_std	4.1	4.1	0.1	22.3	5.9	5.8	0.1	28.9
prec_std	12.0	2.5	6.1	18.1	11.6	2.8	6.1	18.1
prac2	15.5	30.8	0.0	100.0	1.1	4.9	0.0	55.7
prac3	84.5	30.8	0.0	100.0	80.1	39.4	0.0	100.0
prac4	-	-	-	-	6.6	20.0	0.0	99.4
prac5	-	-	-	-	12.2	28.6	0.0	100.0
lcc2	49.0	21.8	0.0	98.4	48.9	21.5	0.0	98.4
lcc3	29.6	16.6	0.0	93.5	30.8	16.6	0.0	93.5
lcc4	15.1	15.0	0.0	96.8	14.7	13.2	0.0	81.9
dday8_32_squa	4076789	1189565	1773689	8151551	4435807	1531226	1684039	8460452
prec_squa	3042.8	881.8	776.9	4825.7	2796.0	993.9	776.9	4825.7
dday34_sqrt	1.6	1.1	0.2	5.3	2.0	1.5	0.2	6.8
dday34_squa	42.5	111.8	0.0	801.2	110.3	259.5	0.0	2156.8

Table 2. Number of Observation Points under Each LCC in the 14 States

LCC	1	2C	2E	2S	2W	3C	3E
No. of Obs. Points	15,179	8,978	6,6383	8,139	45,493	1,926	66,270
Percentage (%)	7.1	4.2	31.3	3.8	21.4	0.9	31.2
LCC	3S	3W	4C	4E	4S	4W	Total
No. of Obs. Points	7,540	15,689	25	31,515	8,467	4,525	212,368
Percentage (%)	3.6	7.4	0.0	14.8	4.0	2.1	100.0

Table 3. Regressions on Corn Yield Risk

Variable	(1) Coef.	(1) t-value	(2) Coef.	(2) t-value	(3) Coef.	(3) t-value
lcc1	-0.000526	-5.41	-0.000577	-5.78	-0.000336	-3.48
lcc2e	-0.000189	-2.87	-0.000231	-3.43	-	-
lcc2w	-0.000263	-3.96	-0.000325	-4.84	-	-
lcc3e	-0.000031	-0.37	-0.000064	-0.75	-	-
lcc3w	-0.000171	-1.64	-0.000196	-1.83	-	-
lcc2	-	-	-	-	-0.000044	-0.82
lcc3	-	-	-	-	-	-
lcc4	-	-	-	-	0.000378	4.99
dday8_32	-0.000386	-9.50	-0.000246	-7.17	-0.000377	-9.62
dday34	0.010444	7.90	-	-	0.011266	8.83
prec	-0.004386	-4.04	-0.005827	-5.46	-0.005429	-5.19
dday8_32_std	0.000119	1.09	-0.000015	-0.14	0.000172	1.59
dday34_std	-0.005266	-5.00	-	-	-0.005378	-5.22
prec_std	0.002388	3.78	0.001662	2.60	0.002538	4.28
prac2	-0.000447	-10.46	-0.000408	-9.38	-	-
prac3	-	-	-	-	0.000480	11.36
dday8_32_squa	0.000000	9.02	0.000000	6.63	0.000000	9.06
dday34_squa	0.000031	2.93	-	-	-0.000286	-8.81
prec_squa	-0.000273	-8.11	0.000044	4.15	0.000041	4.00
dday34_sqrt	-	-	0.007098	3.46	-	-
constant	0.541414	11.79	0.472135	10.48	0.488611	10.95
R-squared	0.410		0.374		0.429	
F-value	42.61		42.36		53.31	

Note: Since we record results to 6 decimal places, coefficient with value "0.000000" in the table is not necessarily equal to 0.

Table 4. Regressions on Wheat Yield Risk

Variable	(1) Coef.	(1) t-value	(2) Coef.	(2) t-value	(3) Coef.	(3) t-value
lcc1	0.000179	1.27	0.000164	1.17	-0.000057	-0.39
lcc2e	-0.000358	-3.91	-0.000303	-3.31	-	-
lcc2w	-0.000196	-2.14	-0.000103	-1.12	-	-
lcc3e	-0.000112	-0.96	-0.000120	-1.04	-	-
lcc3w	-0.000219	-1.63	-0.000195	-1.45	-	-
lcc2	-	-	-	-	-0.000514	-6.31
lcc3	-	-	-	-	-0.000441	-4.13
lcc4	-	-	-	-	-	-
dday8_32	-0.000093	-2.10	-0.000161	-3.35	-0.000053	-1.22
dday34	0.003473	3.36	-	-	0.003569	3.59
prec	-0.006792	-4.57	-0.005334	-3.76	-0.007310	-5.18
dday8_32_std	0.000156	1.04	0.000036	0.26	0.000230	1.57
dday34_std	-0.003598	-3.29	-0.004443	-3.89	-0.003625	-3.39
prec_std	0.002065	2.49	0.001367	1.68	0.001997	2.58
prac2	-0.000420	-1.75	-0.000305	-1.30	-0.000275	-1.16
prac3	0.000048	0.76	0.000065	1.04	0.000040	0.65
prac4	-	-	-	-		
prac5	0.000084	0.98	0.000068	0.80	0.000043	0.51
dday8_32_squa	0.000000	2.91	0.000000	3.82	0.000000	2.03
dday34_squa	-0.000033	-2.06			-0.000030	-1.95
prec_squa	0.000057	3.86	0.000047	3.44	0.000061	4.42
dday34_sqrt	-	-	0.022010	4.30	-	-
constant	0.271820	5.11	0.308769	5.75	0.262331	5.02
R-squared	0.368		0.372		0.388	
F-value	24.29		26.33		30.05	

Note: Since we record results up to 6 decimal places, coefficient with value "0.000000" in the table is not necessarily equal to 0.

Table 5. State Level Average Production Cost of Corn in 2009
($/acre)

State:	IA	IL	IN	KS	MI	MN	MO	ND	NE	OH	OK	SD	TX	WI
Cost:	696	670	694	358	557	599	516	306	402	693	263	439	573	544

Note: The cost includes cash rent of land but does not include crop insurance premium

Table 6. Crop Insurance Premium Subsidies on Yield- and Revenue-Based Coverage
(government-paid portion of premium as a percent of total premium, 2009 crops)

Yield coverage level (%)	CAT	50	55	60	65	70	75	80	85
Premium subsidy (%)	100	67	64	64	59	59	55	48	38

Source: Table 1. of Shields (2010).

Table 7. Land Use Effects when Subsidy Rate Decreases by 5 Percentage
Point or when Price Decreases by 5 Percent
(%)

State	Decrease Subsidy Rate	Decrease Price
IL	0.15	0.32
IN	0.44	0.89
IA	0.05	0.10
KS	1.50	4.25
MI	0.30	0.37
MN	0.12	0.24
MO	2.38	2.65
NE	0.12	0.20
ND	1.12	1.21
OH	0.77	0.89
OK	0.08	0.77
SD	0.10	0.15
WI	0.70	1.01
Average	0.60	1.01

Expected
utility

Thick black line is

$U^{gni}(\delta)$ $\max[U^{gni}(\delta;s),U^{w}]$

U^{w}

δ^{gni}

U^{w}

$\delta = 0$ $\delta = \mu$

Cropped land   Uncropped land
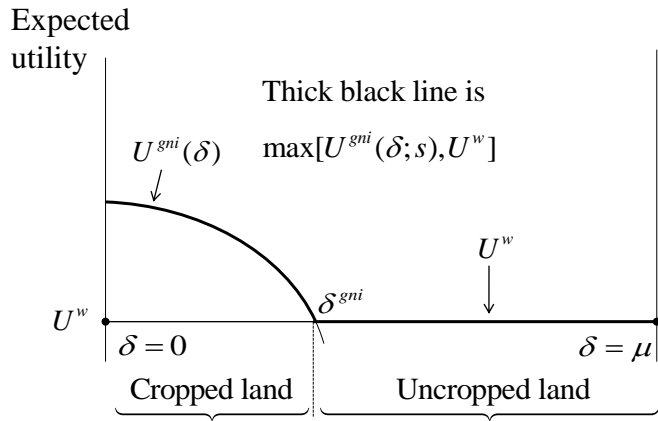
Figure 1. Maximum of uninsured expected utility
and noncropping expected utility as risk changes

Expected
utility

Thick black line is $V(\delta;s)$

$U^{gni}(\delta)$

δ^{gni}

$-\vartheta$ U^{w}

U^{w}

$\delta = 0$ $\delta = \mu$

$U^{gi}(\delta;s)$

Cropped land

Uncropped land
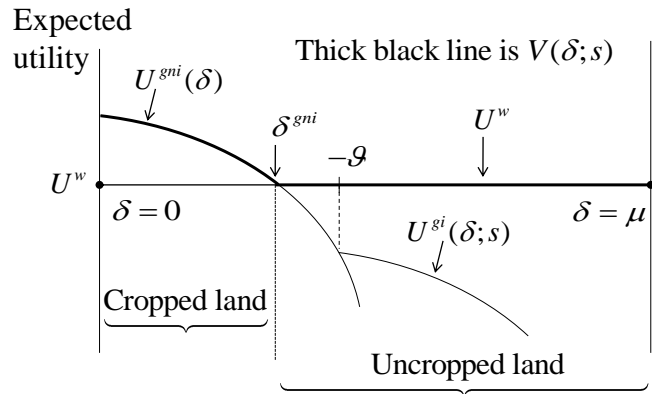
Figure 2. Subcritical subsidy rate and high return
on noncrop option

44

Expected utility

Thick black line is $V(\delta;s)$

$U^{gni}(\delta)$

$U^{gi}(\delta;s)$

U^w

U^w

$\delta = 0$ $-\mathcal{G}$ δ^{gni} δ^{gi} $\delta = \mu$

Cropped land   Uncropped land
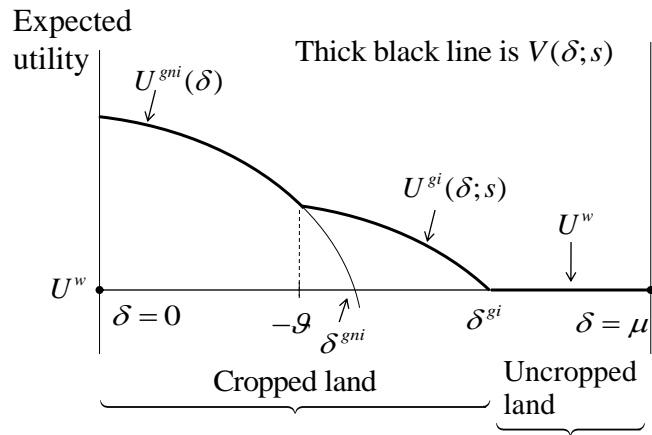
Figure 3. Subcritical subsidy rate and low return on noncrop option

Expected utility

Thick black line is $V(\delta;s)$

$U^{gni}(\delta)$

$U^{gi}(\delta;s)$

δ^{gni}

U^w

U^w

$\delta = 0$ $-\mathcal{G}$ $\hat{\delta}(s)$ δ^{gi} $\delta = \mu$

Cropped land   Uncro-pped
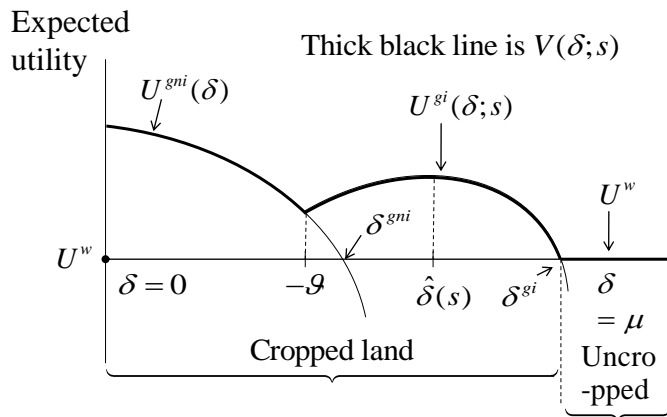
Figure 4. Supercritical subsidy rate and low return on noncrop option

45
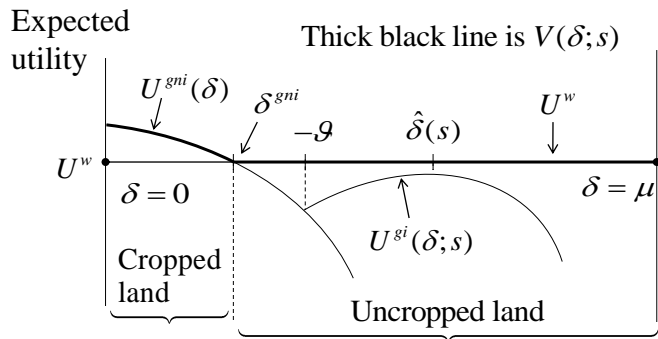
Figure 5. Supercritical subsidy rate that does not create nonconvex set of uncropped land units
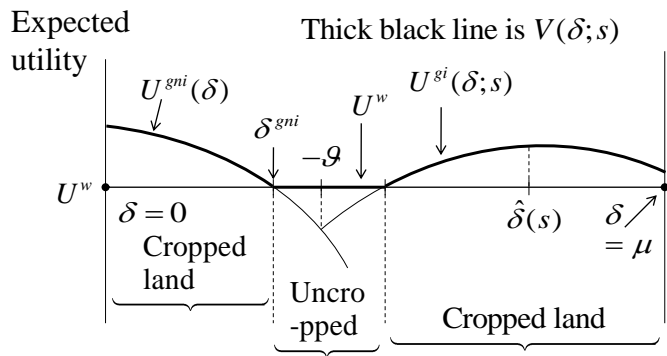
Figure 6. Supercritical subsidy rate that creates interior convex set of uncropped land units
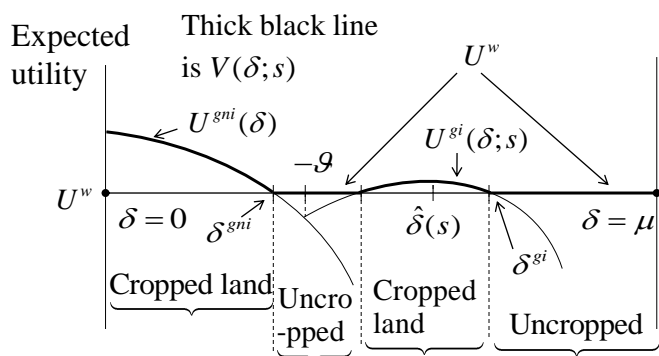
Figure 7. Supercritical subsidy rate that creates nonconvex set of uncropped land units
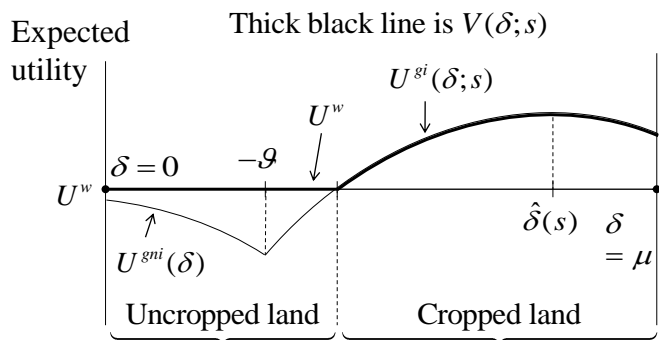

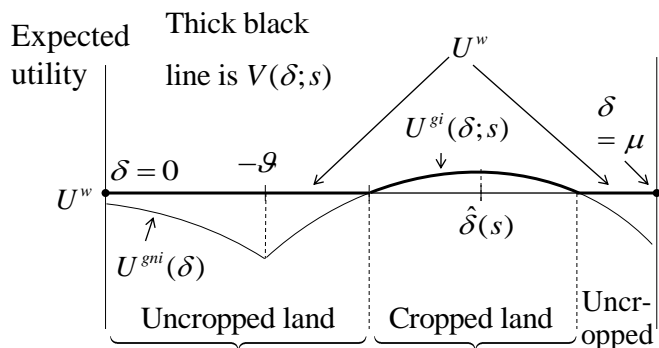Figure 8. Supercritical subsidy rate where only the riskiest land is cropped

Expected utility

Thick black line is $V(\delta;s)$

U^w

$U^{gi}(\delta;s)$

$\delta = \mu$

$\delta = 0$

$-\vartheta$

U^w

$\hat{\delta}(s)$

$U^{gni}(\delta)$

Uncropped land

Cropped land

Uncr-opped

Figure 9. Supercritical subsidy rate where only the least and most risky lands are uncropped

$[\Gamma(s) - \ln(2)]/\theta$

$\bar{\pi} - r$

$s = 0,$
$\bar{\pi} - r = 0$

$s = \hat{s}$

$s = 1$

$(0,0)$

$[\Gamma(s) - \ln(2)]/\theta$

$s = \hat{s}$

$s = 1$

$\bar{\pi} - r$

s such that some land types are cropped & insured

s such that some land types are cropped & insured given $\bar{\pi} - r < 0$

Panel $a)$

Panel $b)$
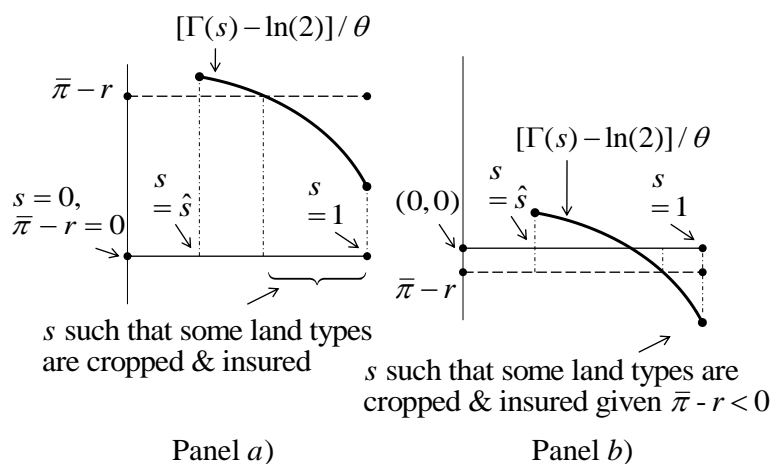
Figure 10. When supercritical subsidy brings most risky land only into production
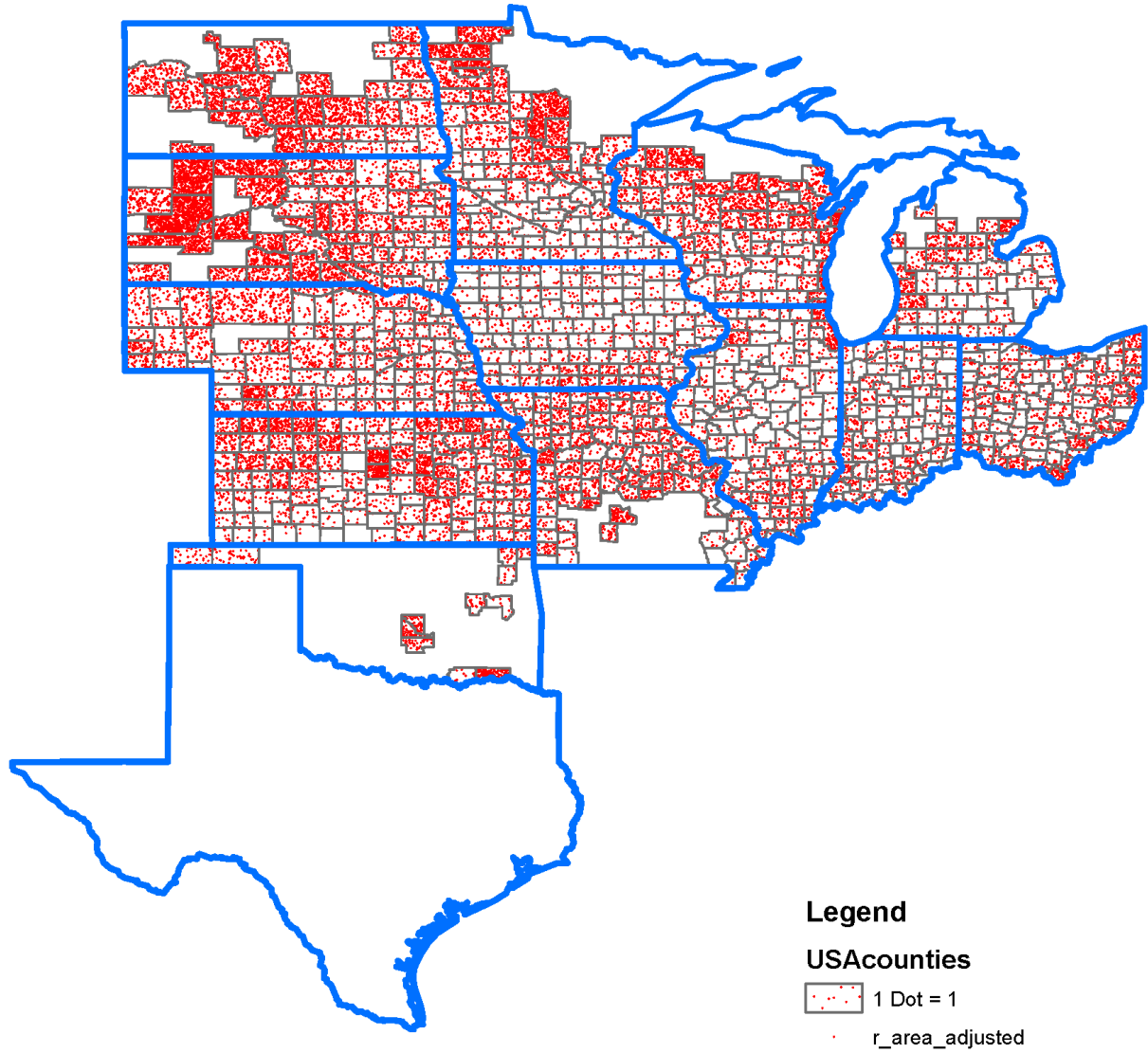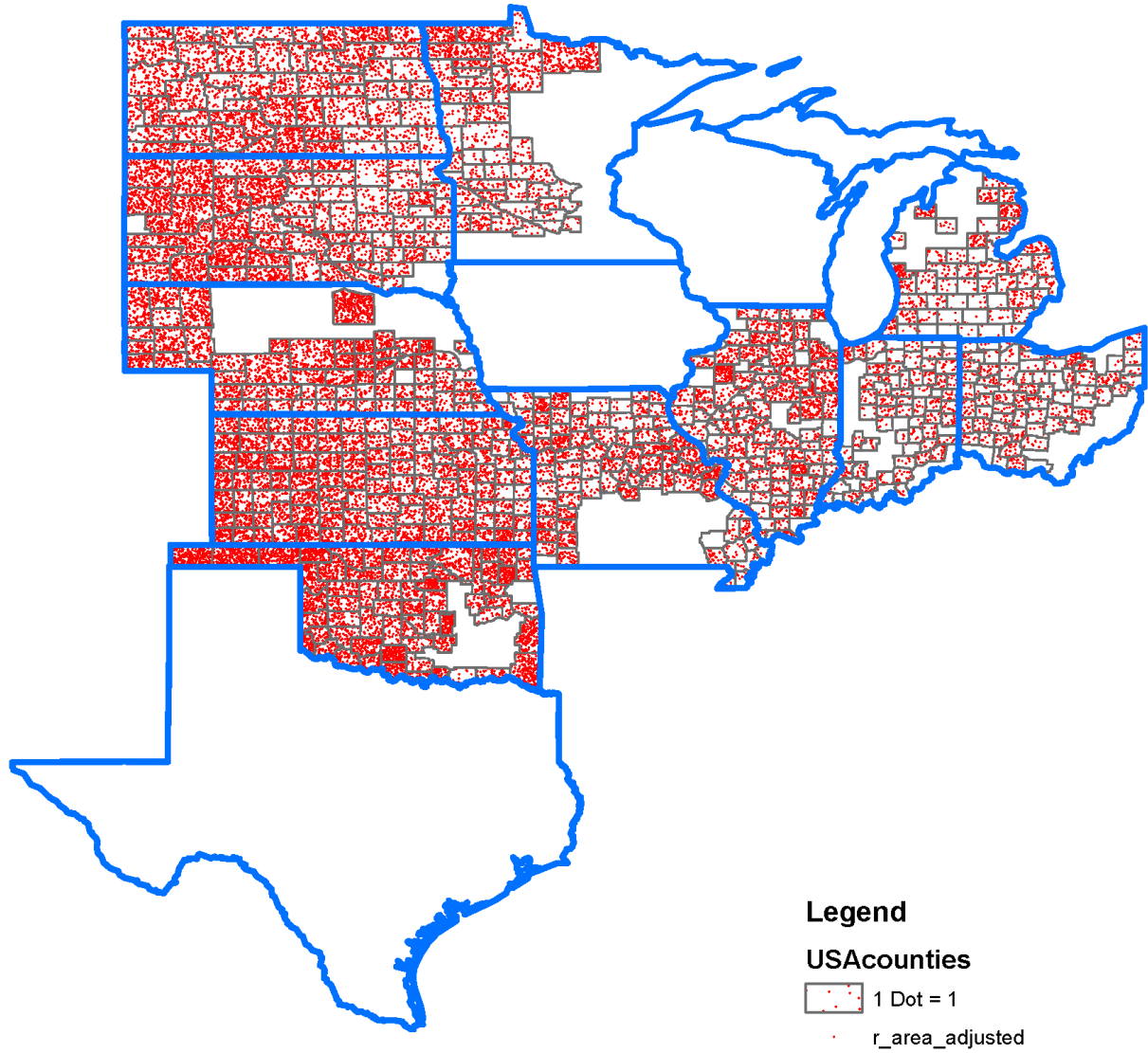
Figure 11. Corn: County-level Yield Risks

Figure 12. Wheat: County-level Yield Risks

Legend

USAcounties
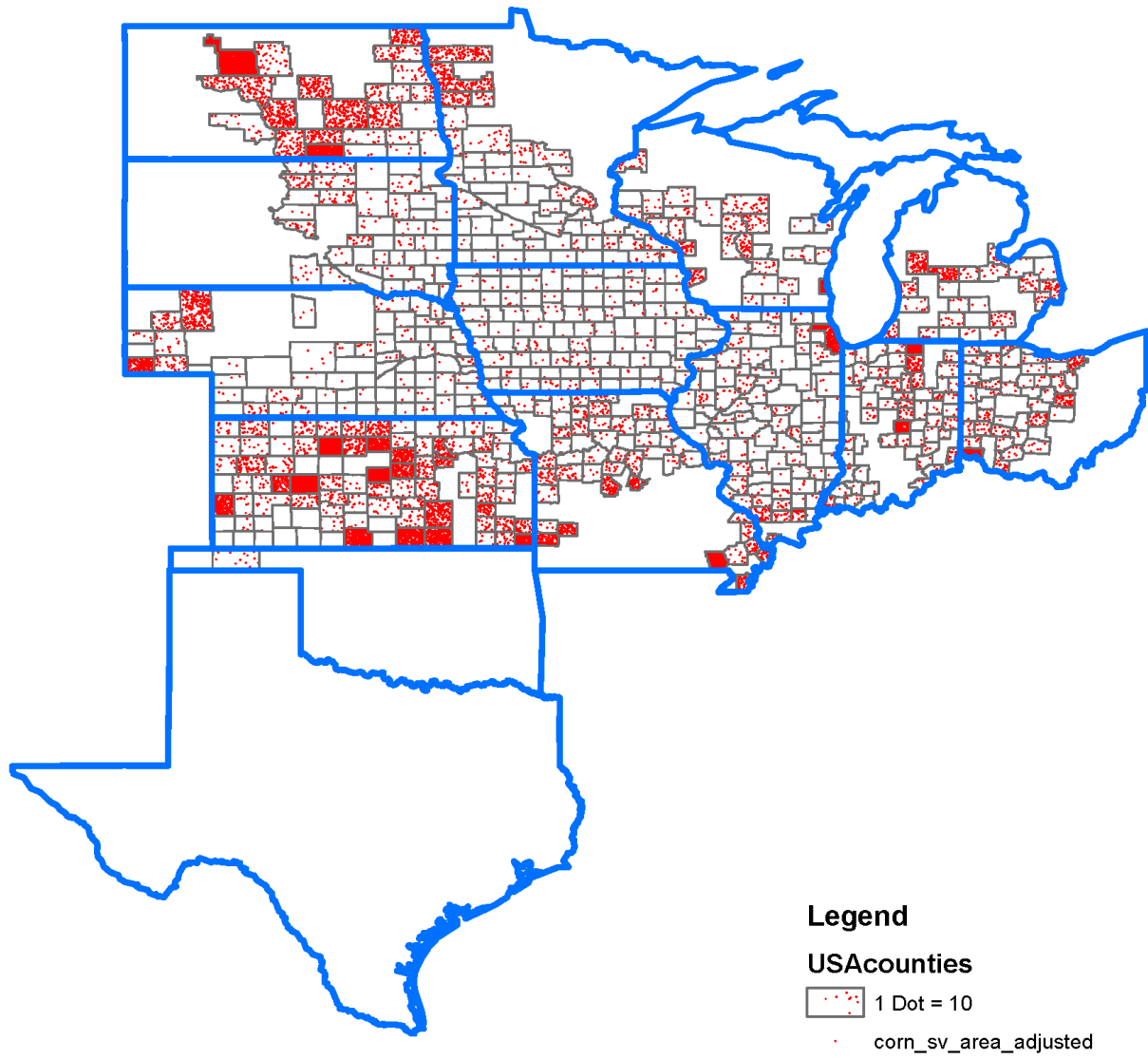
1 Dot = 10

· corn_sv_area_adjusted

Figure 13. Effects on Land Use When Crop
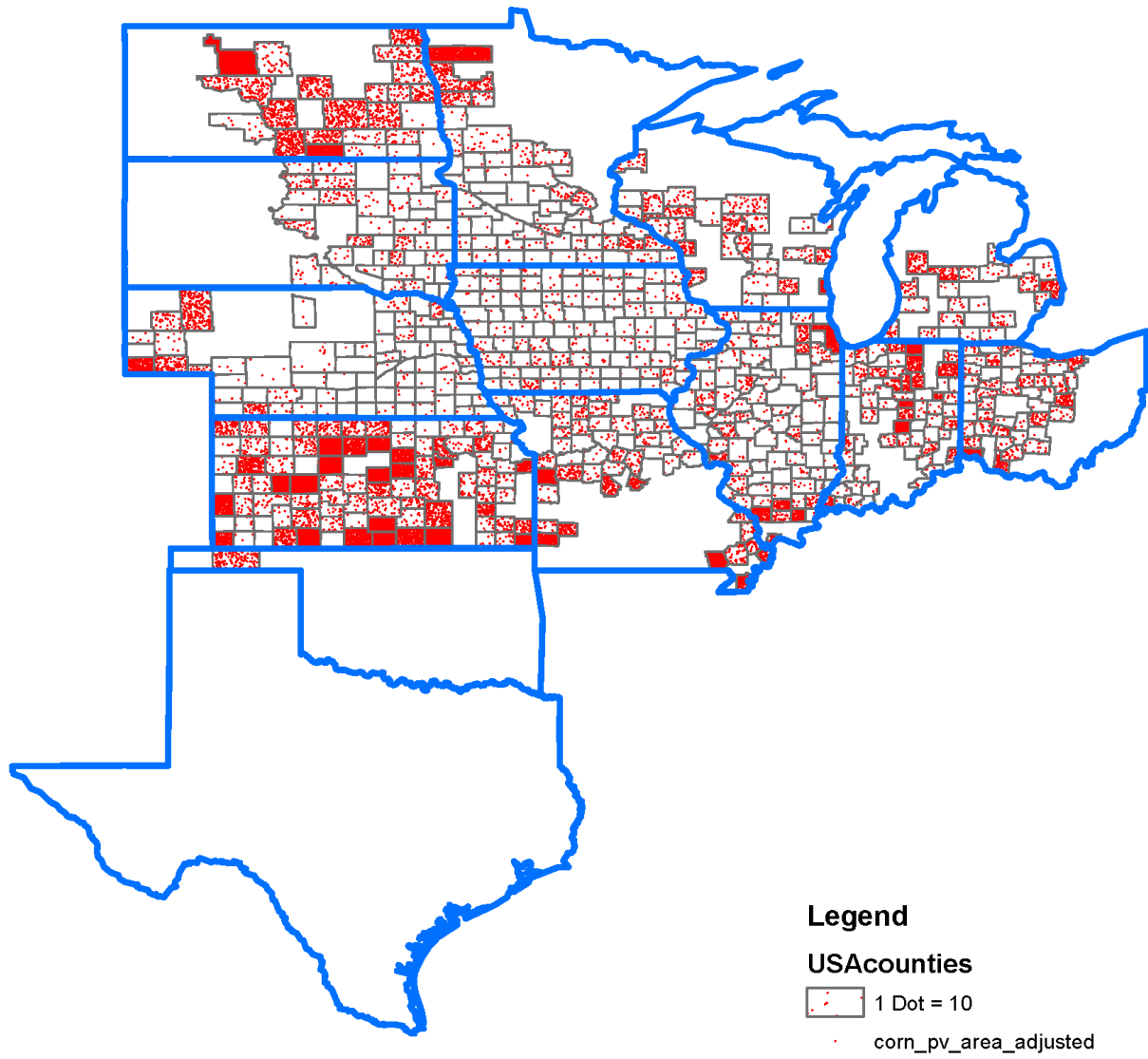Insurance Subsidy Rate Decreases by 5 Percentage Points

Figure 14. Effects on Land Use When Crop
Price Decreases by 5 Percent