The Biomass Crop Assistance Program: Critical, Notional, or Distortional Support for Cellulosic Biofuels?

Ruiqing Miao
University of Illinois at Urbana-Champaign
miaorong@illinois.edu

Madhu Khanna
University of Illinois at Urbana-Champaign
khanna1@illinois.edu

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Abstract: This study intends to quantify the impacts of the Biomass Crop Assistance Program (BCAP) on biomass production and on land use. With a focus on corn, corn stover, soybeans, miscanthus, and switchgrass, we investigate farmers' optimal land allocation among these five crops or biomass feedstock across 1,836 counties in the rain-fed area of the United States under various assumptions about farmers' time and risk preferences as well as credit constraint status. The results show that under its current budget ($125 million within five years), BCAP only has a moderate effect on incentivizing biomass production (up to 4.8 million metric tons per year). BCAP's impact on biomass production first increases then decreases in biomass price. The impact peaks when biomass price is $30 to $40 per metric ton. We also find that BCAP incentivizes biomass production on low quality land much more than production on high quality land. The geographical distribution of BCAP payments and of land use change caused by BCAP is studied as well.

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1. Introduction

When considering supplying biomass for cellulosic biofuel production, farmers have various feedstock options, such as corn stover, perennial grasses including miscanthus and switchgrass, and woody biomass. These feedstocks differ in their yield, production costs, length of establishment period and lifespan. For instance, providing biomass via using corn stover may not require much extra input when growing corn, but since the harvestable yield of corn stover is low (about 2-4 metric tons per hectare per year), the costs of harvesting and transportation to meet demand from a bio-refinery may make corn stover more costly than dedicated energy crops, such as miscanthus and switchgrass. For the choice between miscanthus and switchgrass, the trade-off is that miscanthus has high yield but high establishment cost whereas switchgrass has low yield but low establishment cost. Moreover, these feedstocks may also differ in their environmental impacts, particularly soil carbon sequestration and effects on biodiversity. Therefore, under a cellulosic biofuel mandate as in the U.S. Renewable Fuel Standard, cellulosic feedstock choices of farmers have implications for total land acreage devoted to cellulosic feedstock production, and environmental benefits to produce a given amount of biomass.

High costs of production, risky returns, and a long establishment period with upfront costs limit incentives for farmers to produce biomass from perennial energy crops such as miscanthus and switchgrass. In order to overcome these barriers to investment in energy crops, Biomass Crop Assistance Program (BCAP) was established in the Food, Conservation, and Energy Act in 2008 and reauthorized in the Agricultural Act of 2014. Key supports from BCAP are provided through three different types of payments. They are: (1) Payments to cover 50% or $500/acre (whichever the less) of energy crop establishment costs. (2) Annual payments for up to 5 years for herbaceous energy crops and up to 15 years for woody biomass to cover the foregone income from the land during the establishment period before the energy crop is harvestable and generates revenue. (3) Matching payments of $20 per ton for two years for mitigating the cost of harvesting and transporting biomass to the processing facility. Due to the heterogeneities among the energy crops in terms of yield and establishment costs, we expect that the BCAP would create different incentives for providing different feedstocks. Given its budget being set at $125 million within 5 years in the Agricultural Act of 2014, to what extent the BCAP will affect farmers' crop choices that may have implications for total land devoted to energy crops and environmental benefits? Moreover, to what extent the BCAP will affect the aggregate biomass production?

The purpose of this paper is to examine the impact of the BCAP on farmers' biomass production, with a focus on the aggregate biomass quantity increased, crop choices among various biomass crops, and the geographical configuration of biomass production in the rain-fed area of the United States. To the best of our knowledge, this study is the first one that provides a comprehensive analysis of the potential impact of BCAP.

We first present a conceptual framework under which a representative landowner optimally chooses her land allocation among conventional crops and energy crops to maximize her expected utility. By using this framework, we examine how the BCAP payments for energy crops (i.e., establishment cost subsidy, annual land-rent payment, and matching payment) will affect the landowner's optimal land allocations among these crops. We also examine the extent to which the risk and time preferences as well as credit constraint will affect a farmer's decision about the share of cropland to be allocated to energy crops and the amount of residue of conventional crops to harvest. This theoretical framework recognizes that farmers' willingness to grow an energy crop will depend not only on the returns from this energy crop production relative to alternative use of the land but also on yield riskiness, the temporal profile of the returns, and its potential to diversify the crop portfolio of farmers.

Based on the aforementioned theoretical framework, we utilize numerical simulations to quantify the effects of the BCAP on biomass production and on land-owners' optimal crop choices at a county-level in the rainfed region of the United States. We use corn and soybean as representatives for conventional crops. In addition to corn stover, we consider the options of producing biomass from two perennial energy crops: miscanthus and switchgrass. We select these two perennial energy crops because they are widely viewed as promising feedstock for cellulosic biofuels (Beach, Zhang, and McCarl 2012; Chen et al. 2014; Heaton, Dohleman, and Long 2008). Various parameter values regarding landowners' risk and time preferences, as well as the availability of loans to finance the establishment of the two perennial energy crops are considered in the analysis.

We find that the effects of BCAP on biomass production and crop choices are significantly affected by biomass price. BCAP's effect on incentivizing total biomass production reaches the highest when biomass price is \$30-\$40 per metric ton (MT). The effect decreases as biomass price deviates from \$30-\$40 per MT. Overall, we find that BCAP will only play a small role (up to 4.8 million MT per year) in increasing total biomass production. BCAP's effect reaches the highest when farmers have high discount rate and high risk aversion. We also find that BCAP will only slightly affect the crop mix of biomass production.

The mix of feedstock changes with discount rate, risk aversion, and credit constraint. When there is no credit constraint, miscanthus production will be much larger than switchgrass production. High discount rate and high risk aversion parameter are factors that discourage miscanthus production. For miscanthus and switchgrass, BCAP generally increases these two crops' production. But the incentivizing effect peaks when biomass price are about $40/MT.-$60/MT.

The rest of the paper proceeds as follows. In section 2 we outline a conceptual framework that serves as the foundation of the simulations. Data and model calibration are introduced in section 3. Section 4 summarizes simulation results and section 5 concludes.

2. Conceptual Framework

We consider a representative landowner who has two types of land to allocate between conventional annual crops and perennial energy crops. The two types of land are high quality (labeled as h) and low quality (labeled as l) land. The landowner optimally allocate land among five types of crops or biomass feedstock. These crops or biomass feedstock are: corn, corn stover, soybean, miscanthus, and switchgrass, which are labeled as c, z, s, m, and g, respectively. Here corn and soybeans are representatives for conventional crops, whereas corn stover, miscanthus, and switchgrass are representatives for biomass sources. For the Midwestern states, we assume that corn and soybeans are grown under corn-soybean rotation. Continuous corn rotation is assumed for other states. For simplicity, we assume that only one crop between miscanthus and switchgrass will be selected by the landowner if she ever allocates any land to a perennial energy crop.[1] High quality land can be allocated between conventional crops (labeled as c) and an energy crop (labeled as $e \in \{m, g\}$). We assume that low quality land is originally in a low-risk-low-return activity (e.g., enrollment in a conservation program) and can be converted the energy crop or the conventional crop. For simplicity, the return from the original use of low quality land is assumed to be a constant, π^o, and is approximated by the land rent payments for enrollment in the Conservation

[1] It is arguable that the landowner may find it optimal to adopt both miscanthus and switchgrass on her land to obtain the benefit of crop diversification. However, since miscanthus and switchgrass require different planting and management practices, mixing miscanthus and switchgrass may not be cost effective. Moreover, assuming the landowner chooses a perennial crop over the other will significantly reduce the computational burden of the simulation.

Reserve Program (CRP). The landowner's optimal decision problem has two components. The first one is to select a perennial crop between miscanthus and switchgrass. The second is to optimally determine the portion of land devoted to corn and the selected perennial crop. Let V^m (respectively, V^g) denote the landowner's maximized expected utility obtained from cropping her land when miscanthus (respectively, switchgrass) is selected. Then, the landowners' maximized expected utility from cropping her land is

$$V(\alpha,\gamma,I)=\max[V^m(\alpha,\gamma,I),V^g(\alpha,\gamma,I)], \tag{1}$$

where α measures the landowner's risk aversion, $\gamma \in [0,1]$ is utility discount rate, and *I* is a credit constraint index which equals 1 if the landowner is credit constrained and 0 if not. The credit constraint index is introduced to reflect the fact that the landowner may have a credit constraint to obtain a loan financing the establishment cost. We consider a representative farmer in each county operating under a range of assumptions about risk and time preferences, as well as credit availability.

Let x^{ij} denote the portion of total land devoted to crop type *i* on land type *j* and x^o denote the ratio of low quality land left in its original use to total land. Let L^l and L^h be the portion of low quality land and high quality land over total land, respectively. Therefore, $V^e(\alpha,\gamma,I)$, $e \in \{m,g\}$ is defined as:

$$\begin{aligned}&V^e(\alpha,\gamma,I)\equiv\\ &\max_{x^{cl},x^{el},x^o,x^{ch},x^{eh}\geq 0}\sum_{t=1}^{\bar{T}}(1+\gamma)^{-(t-1)}\mathrm{E}[u(x^{cl}\pi_t^{cl}+x^{el}\pi_t^{el}+x^o\pi^o+x^{ch}\pi_t^{ch}+x^{eh}\pi_t^{eh}\mid\alpha,\gamma,I)], \qquad (2)\\ &\text{s.t. } x^{cl}+x^{el}+x^o=L^l,\ x^{ch}+x^{eh}=L^h,\end{aligned}$$

where $\bar{T}$ is land tenure, $u(\cdot)$ is the landowner's utility function, π_t^{ij} is net returns per unit of land from crop *i* on land type *j* in year *t*.

During the first five years of planting, the landowner receives BCAP payment. We assume that a representative landowner has two tracts of land. In what follows of this section we outline the landowner's returns in the presence of BCAP payments. The BCAP enrollment mechanism under a budget constraint is illustrated at the end of the section.

2.1. Returns under BCAP

Let y_t^{ij} denote the stochastic yield of crop $i \in \{c, z, s, m, g\}$ on land type $j \in \{h, l\}$ in year *t*. Yield of the energy crop depends on the age of the crop within its lifespan of T^e years where $e \in \{m, s\}$. We define the first $\tau^e < T^e$ years in each lifespan as the establishment period and years $\tau^e + 1$ to T^e is the mature period. Price of crop *i* in year *t* is represented by p_t^i. In the case of biomass feedstocks (corn stover, miscanthus, and switchgrass), production is assumed to occur under a long term contractual arrangement between farmers and a biorefinery to ensure certainty of supply of biomass for the refinery at a price p_t^b, which is fixed over its lifespan. Here we assume that price is the same across corn stover, miscanthus, and switchgrass. The price of the conventional crop is a stochastic variable, whose distribution is known to the farmer. The fixed and variable costs of producing crop *i* on land type *j* in year *t* are represented by f_t^{ij} per unit of land and v_t^{ij} per unit of biomass produced, respectively. We denote the establishment cost of the energy crop per unit of land by w^e. When the landowner is not credit constrained, then she has access to a loan at interest rate *r*.

We consider the case of revenue insurance for corn (and soybeans if under corn-soybean rotation) which is widely adopted for conventional crops by U.S. farmers (Shields 2013). For corn, the indemnity payment per unit of land in year *t* and on land type $j \in \{h, l\}$ is specified as

$$\iota_t^{cj} = \max\left[\phi^c \mathrm{E}(y_t^{cj}) \max[p_t^{\text{proj}}, p_t^{\text{harv}}] - p_t^{\text{harv}} y_t^{cj}, 0\right], \tag{3}$$

where ϕ^c is insurance coverage level; p_t^{proj} and p_t^{harv} are projected price and harvest price established by Risk Management Agency (RMA) (2011), respectively.

Let Γ, Λ, and Ψ denote the matching payment, establishment payment, and annual payment of the BCAP, respectively. According to the regulations of BCAP, producers can obtain up to two years of matching payment and up to five years of annual payment for herbaceous energy crops. The establishment payment is 50% of establishment cost with a cap at \$500 per acre. For corn stover, since it is a by-product of corn, only matching payment applies. If harvested, corn stover will generate net returns per unit of land at

$$\pi_t^{zj} = \begin{cases} (p_t^z - v_t^{zj} + \Gamma_t^{zj}) y_t^{zj} - f_t^{zj} & \text{if } t \le 2, \\ (p_t^z - v_t^{zj}) y_t^{zj} - f_t^{zj} & \text{if } t > 2. \end{cases} \tag{4}$$

The landowner will harvest corn stover only if the expected net returns of doing so are positive. That is, landowner will provide corn stover if $\sum_{t=1}^{30} (1+r)^{-(t-1)} \pi_t^{zj} > 0$. This is because that the landowner may be in a long-term contract of supplying corn stover to a biorefinery and does not have the option of not harvesting corn stover in a specific year even if the returns in that year is negative.

The profit per unit of land for the conventional crop in year *t* on land type *j* can be written as

$$\pi_t^{cj} = (p_t^c - v_t^{cj}) y_t^{cj} - f_t^{cj} + \iota_t^{cj} - (1-\theta)\mathrm{E}[\iota_t^{cj}] + \pi_t^{zj}, \tag{5}$$

where θ is insurance premium subsidy rate for the conventional crop.

For energy crops, we assume that the annual payment starts in year 1 and that the matching payment starts when the crop reaches mature period. We further assume that matching payment lasts for two years whereas annual payment lasts for τ^{Ψ} years. Under BCAP, the annual payment is affected by whether the landowner is receiving revenue from selling biomass and by the type of use of biomass. We refer readers to McMinimy (2015) for further details about the reasons that annual payment can be reduced.

With a fixed price contract, the profits from energy crop production can be written as

$$\pi_t^{ej} = \begin{cases} -[w_t^{ej} - \Lambda_t^{ej}]I + \Psi_t^j, & t \in \{1,...,\tau^e\} \\ (p_t^e - v_t^{ej})y_t^{ej} - f_t^{ej} - (1-I)A(\mathbf{w}^{ej}, \Lambda^{ej}, r) + \Psi_t^j + \Gamma_t^{ej}(y_t^{ej}, p_t^e), & t \in \{\tau^e + 1,...,\tau^e + 2\} \\ (p_t^e - v_t^{ej})y_t^{ej} - f_t^{ej} - (1-I)A(\mathbf{w}^{ej}, \Lambda^{ej}, r) + \Psi_t^j, & t \in \{\tau^e + 3,...,\tau^\Psi\} \\ (p_t^e - v_t^{ej})y_t^{ej} - f_t^{ej} - (1-I)A(\mathbf{w}^{ej}, \Lambda^{ej}, r), & t \in \{\tau^\Psi + 1,...,T^e\}, \end{cases} \quad (6)$$

where $A(\mathbf{w}^{ej}, \Lambda^{ej}, r)$ is the annuity the farmer needs to pay back due to the loan for establishment cost. The annuity is determined by the establishment cost ($\mathbf{w}^{ej} \equiv \{w_1^{ej},..., w_{\tau^e}^{ej}\}$), BCAP establishment payment ($\Lambda^{ej} \equiv \{\Lambda_1^{ej},...,\Lambda_{\tau^e}^{ej}\}$), and the interest rate (r). Equation (6) indicates that the farmer finances the portion of the establishment cost that is not offset by BCAP establishment payment in the establishment period and will pay back the loan over the mature period.

2.2. Land Enrollment Mechanism under BCAP

As of May 2015, the BCAP has not included a settled rule that screens enrollment requests when the BCAP budget is not large enough to accept all the requests. In this study, we assume that the BCAP assigns a higher priority to land that has a larger biomass production increase per BCAP payment dollar. Land will be enrolled according to a descending order in biomass production increase per BCAP dollar until the BCAP budget limit is reached. This assumption implies that the BCAP will bring the largest biomass production increase possible.

3. Data and Model Calibration

Our numerical simulation analyzes the county-specific allocation of land between miscanthus, switchgrass, and conventional crops (corn and soybeans) for 1,836 counties in 30 states. The counties included in the dataset are those east of the 100th Meridian that have historical corn yield data from National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA) and simulated miscanthus yields on at least one type of land. Summary statistics of the data used in the simulation are provided in Table 1.

3.1. Crop Yields

Large scale commercial production of miscanthus and switchgrass is yet to commence in the United States. Therefore, we use the crop-growth model DayCent to obtain simulated yields of these two perennial crops. DayCent is the daily time-step version of the CENTURY biogeochemical model that is widely used to simulate plant growth based on information of precipitation, temperature, soil nutrient availability, and land-use practice (Del Grosso et al. 2011, 2012; Davis et al. 2012). Data from field experiments with miscanthus across the rainfed United States are used to calibrate the productivity parameters in the model that relate soil attributes and weather with yields (Hudiburg *et al.* 2014).[2] The model was used to simulate annual yield of miscanthus in the mature years on both low quality land and high quality land for each of the 1,836 counties in the rainfed region of the US under 27 years of county-specific historical weather information for the 1980-2003 period assuming 24-year cycling of weather conditions.[3] From Table 1 we can see that the average yield of miscanthus (across time and counties) on high and low quality land is very close to each other (27.2 vs. 26.8 MT/ha. at 15% moisture). For switchgrass, the same yield pattern holds whereas the yields are much lower (14.1MT/ha. on high quality land and 12.7MT/ha. on low quality land).

County-specific corn and soybean yields are obtained from NASS for the matching years with miscanthus and switchgrass yields. Since data on corn and soybean yield on low

[2] Several studies have used various crop growth models to simulate energy crop yield based on data obtained from experimental fields. ALMANAC is a crop growth model which has been used in several site-specific studies to simulate yield of switchgrass (Kiniry et al. 1996, 2005; McLaughlin et al. 2006). Originally developed for Ireland to predict miscanthus yield, MISCANMOD has been used to simulate the yield of miscanthus across Europe (Clifton-Brown, Stampfl, and Jones 2004) and for Illinois (Khanna, Dhungana and Clifton-Brown 2008) and the midwest (Jain et al. 2010). Most recently, Miguez et al. (2012) developed a semi-mechanistic dynamic crop growth and production model, BioCro, to simulate the yield of miscanthus in the US. However, unlike DayCent model, these models have not been calibrated to provide energy crop yield on low and high quality land.

[3] The quality of agricultural land was defined using the land capability class in the Soil Survey Geographic (SSURGO) database (NRCS, link: http://www.nrcs.usda.gov/wps/portal/nrcs/main soils/survey/). High quality soils had land capability classifications of 1 or 2. Poor quality soils were defined as those land types whose land capability classification was greater than 5.

quality land are not available, we assume that they are 2/3 of yields on high quality land following Hertel et al. (2010). In the eight central Midwest states (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin) we assume that corn and soybean are growing in rotation. For other states in the rain-fed area, we assume that corn is grown continuously. Following Khanna et al. (2011), harvested corn stover yield is calculated by assuming a 1:1 grain-to-residue weight ratio and a 30% stover removal rate. For example, if corn yield on a tract of land is 1 MT per acre, then the corn stover yield on this tract of land is 0.3 MT per acre.

Since county-level crop yields have lower variance than farm-level crop yield, we use an inflated county-level yield variance in simulation to mimic farm-level yield variance following Claassen, Cooper, and Carriazo (2011). For corn and soybeans in each county, we inflate the yield variance to a level such that the revenue insurance premium calculated from the inflated yield distribution is equal to the premium of Crop Revenue Coverage at 75% coverage level reported in RMA's Summary of Business Reports and Data (http://www.rma.usda.gov/data/sob.html). Because energy crop insurance programs do not exist yet, we inflate the variance of miscanthus and switchgrass yields by the same magnitude as we inflate the variance of corn yield.

3.2. Crop Prices

Three types of prices of corn and soybeans are used in the simulation: received prices, projected futures prices, and harvest futures prices. We use State level received prices from NASS to calculate realized profit of corn and soybean. Projected futures price and harvest futures price are used to calculate crop insurance indemnity following. These futures prices are determined by following RMA (2011) rules. Specifically, projected futures price and harvest futures price for corn are the average daily settlement price in February and October, respectively, for the Chicago Board of Trade (CBOT) December corn futures contract. For soybean, the projected price and harvest price are the average daily settlement prices in February and October, respectively, for the CBOT November soybean futures contract. The CBOT futures prices of corn and soybeans over 1980-2010 are obtained from Barchart.com. We convert all prices to 2010 dollars using the Gross Domestic Product implicit deflator obtained from Federal Reserve Economic Data.

3.3. Production Costs

The method and assumptions underlying the calculation of county-specific production costs of miscanthus, switchgrass, corn, and soybeans in the rain-fed region are described in Khanna, Dhungana, and Clifton-Brown (2008), Jain *et al*. (2010) and Chen *et al*. (2014). Miscanthus is assumed to have a 15-year lifespan with no harvestable yield in the first year and 50% of mature yield in the second year. Switchgrass is assumed to have a 10-year lifespan and its mature yield is reached starting from the first year. The cost of miscanthus in the first year of establishment includes expenses on rhizomes, planting machinery, fertilizer and land preparation, which is about $3,108/ha. on average. For the second year and onward these costs include expenses on fertilizer, labor, fuel and machinery for harvesting, baling, transportation, and storage.[4] The cost of switchgrass in the first year of establishment is much smaller than that of miscanthus, which is about $249.4/ha. We construct county-specific fixed and variable costs of production as in Chen et al. (2014); summary statistics on these are reported in Table 1. For corn stover, the variable cost ($17.5/MT) is close to that of miscanthus and switchgrass whereas the fixed cost ($48.5/ha.) is much lower than that of the two perennial crops. For conventional crops, the production costs including fertilizer, chemicals, seeds, harvesting, storage and drying are collected from crop budgets compiled by state extension services (see Chen et al. 2014). On average, the annual fixed and variable costs for corn are $136.5 per acre and $1.3 per bushel, respectively. The fixed cost per acre

[4] The second year is also assumed to involve some additional costs of establishment due to a need for replanting a portion of the field due to non-survival of the first year crop (see Jain et al., 2010).

and the variable cost per unit yield for a crop are assumed to be the same on low and high quality land within a county.

3.4. Land Availability, Farm Size, and Risk Aversion Parameter

We assume that land planted under corn and soybeans in the eight Midwestern states and under corn in the remaining states is high quality land whereas land under cropland pasture/idle land (as defined by NASS) is low quality land. County-specific acreage in each of these categories is the observed 5-year averages over 2008-2012 obtained from NASS. We exclude land enrolled in CRP from available idle cropland due to restrictions on harvesting biomass from acres enrolled in CRP. The availability of low quality land for energy crop production is also likely to be limited by farmers' willingness to convert land with other amenity values to energy crops (Skevas, Swinton, and Hayden 2014). Table 1 shows that the average acreage of high and low quality land per county is 69,678 acres and 10,509 acres, respectively.

Farm size is one of the factors that determine the variance of annual net returns for a farmer. To estimate this variance, we obtain data on county-level average farm size from the category "area operated per farm operation" in the 2007 Census of Agriculture. The average farm size in our dataset is 329 acres. The share of acreage of low quality land on a farm is assumed to be the same as that in the county.

The values of absolute risk aversion (ARA) parameter, λ, for the CARA utility function differs across studies and ranges from 0.000000921 (Collender and Zilberman 1985) to 0.538 (Love and Buccola 1991). Babcock, Choi, and Feinerman (1993) argue that large ARA values may indicate unrealistically high risk aversion and show that an ARA of 0.538 may imply that farmers are willing to pay 97% of the standard deviation of net returns to eliminate return risk (see Table 1 in Babcock, Choi, and Feinerman (1993)). They suggest selecting ARA parameter values based on risk premium, defined as the percentage of the standard deviation of net returns that the decision maker is willing to pay to eliminate the risk of net returns. Following this approach and Hennessy, Babcock, and Hayes (1997) we utilize 0.00001 (implying an underlying risk premium of 10%) and 0.00005 (implying an underlying risk premium of 50%) to be the ARA parameter values in the low risk aversion and high risk aversion scenarios, respectively.

We assume that miscanthus has a 15-year lifecycle whereas switchgrass has a 10-year one. Therefore, we consider a 30-year period land tenure (i.e., $\bar{T} = 30$) in which miscanthus finishes two lifecycles and switchgrass finishes three. For miscanthus and switchgrass, BCAP payments only occur in the first five years of the first lifecycle. For corn stover, BCAP payment only occurs in the first two years over the 30-year period.

A joint yield-price distribution is estimated to reflect the stochastic crop yields of corn, soybeans, and miscanthus and stochastic prices of corn and soybeans as well as the correlations among them. We utilize the copula approach to model joint distributions due to its flexibility (Yan 2007; Du and Hennessy 2012; Zhu, Ghosh, and Goodwin 2008). Details about the copula approach are presented in Item 1 of the supporting information (SI) of this paper. Once the distribution is identified, we calculate revenue, insurance premiums, and premium subsidies for conventional crops by using Monte Carlo approach. We obtain an aggregate supply curve by numerically solving the optimization problems in equations (1) and (2) for heterogeneous counties in the rainfed US for a range of exogenously specified biomass price levels and a given set of parameter values (see Item H of SI for a detailed procedure of simulating the supply curve). The model is solved by using grid search approach performed with MATLAB®.

4. Simulation Results

4.1 Effects of BCAP on Biomass Supply

By numerical simulation we investigate BCAP's effects on biomass supply under eight scenarios. These eight scenarios are combinations of high and low discount, high and low risk aversion, as well as with and without credit constraint. Figure 1 presents supply curves of each feedstock among corn stover, miscanthus, and switchgrass under the eight scenarios without considering BCAP payments. We find that high discount, high risk aversion, and credit constraint significantly discourage miscanthus production. For example, under the high discount, high risk aversion, and credit constraint (HHC hereafter) scenario, the annual production of miscanthus in a mature year under $100/MT. price is about 14 million MT (MMT) (see the first graph on the upper panel of Figure 1). However, under the low discount, low risk aversion, and no credit constraint (LLNC hereafter) scenario, the annual miscanthus production in a mature year under the same price is about 141 MMT (see the last graph on the lower panel of Figure 1). Everything else equal, relax the credit constraint will always increase miscanthus production (compare graphs in the upper panel with those in the lower panel in Figure 1). When landowners are credit constrained, reducing risk aversion or discount rate will significantly increase miscanthus production. When landowners are not credit constrained, however, reducing risk aversion or discount rate will only increase miscanthus production at a much smaller scale.

Unlike miscanthus production, switchgrass production will be reduced by relaxing credit constraint. This is because when landowners are not credit constrained then miscanthus is more preferable than switchgrass due to the high yield of miscanthus. Across all eight scenarios presented in Figure 1, the supply curves of corn stover are stable. This is intuitive because, unlike perennial crops, no establishment costs are endured for providing corn stover and returns from harvesting corn stover are realized annually.

Figure 2 presents the same sets of supply curves when BCAP payments are accounted for. By comparing Figures 1 and 2 we find that the supply curves in these two figures are almost identical, which indicates that the BCAP payments do not significantly affect the supply of biomass feedstocks. Figure 3 presents a higher resolution of BCAP's effects on biomass supply. We can see that under the eight scenarios and $20/MT to $100/MT biomass price range, the largest amount of total biomass increase caused by BCAP is about 4.8 MMT per mature year which occurs under the scenario with high discount, high risk aversion, and no credit constraint (see the first graph in the lower panel of Figure 3). Assuming biomass to ethanol conversion rate at 63.2 gallons per MT of biomass with 15% moisture (Jain *et al.* 2010), this 4.8 MMT of biomass is equivalent to about 303 million gallons of cellulosic biofuel per mature year. Given the BCAP's limited budget ($125 million within 5 years), it is not surprising that the BCAP only moderately incentivizing biomass production. When comparing the supply curves for miscanthus in the upper panel of Figure 1 with those in the lower panel in Figure 1, we find that the availability of loans financing establishment cost of energy crops has larger effects in incentivizing miscanthus production than BCAP alone.

From Figure 3 we find an inverse U-shaped relationship between biomass price and biomass increased by BCAP. The BCAP's effect on biomass production reaches the highest when biomass prices are $30/MT to $40/MT. The magnitude of the effect decreases when biomass price is either higher or lower than $30/MT to $40/MT. When biomass price is very low (e.g., $20/MT), farmers are not interested in biomass production even if there is support from BCAP. On the other hand, when biomass price is very high, farmers are keen in producing biomass even if there is no BCAP. This explains why we have an inverse U-shaped curve for BCAP's effect.

We also find that BCAP plays different roles in incentivizing the three types of biomass feedstock considered in this study. Across all the 8 scenarios, when biomass price is below $60/Mg., then BCAP incentivizes the production of corn stover; however, when biomass price is higher than $60/Mg., then BCAP dis-incentivizes corn stover production.

The reason is that when biomass price is as high as $60, the production of miscanthus and switchgrass may reach the margin to be profitable. Under this situation, the presence of BCAP payments strengthens the profitability of miscanthus and switchgrass and hence landowners switch some of their land from corn to miscanthus or switchgrass. For miscanthus, BCAP generally increases its production. Similar to BCAP's effect on total biomass production, BCAP's effect on miscanthus also has an inverse U-shaped relationship with biomass price. This incentivizing effect peaks when biomass price are about $50/Mg.-$60/Mg. In some cases the presence of BCAP may decrease production of switchgrass (e.g. see the first graph in the upper panel of Figure 3). Similar reason for why BCAP decreases corn stover production applies here.

4.2 Distribution of BCAP payments

Figure 4 presents BCAP payments by crop under the eight scenarios. Across all scenarios, BCAP budget is not binding until biomass price reaches $40/MT. The reason is that when biomass price is low, landowners has little interest in providing biomass and hence the demand for BCAP payments is low. When biomass price is as low as $20-$30/MT, the majority of BCAP payments are received by corn stover providers because under this price range growing perennial crops is rarely profitable. As biomass price increases, the amount of BCAP payment that goes to perennial energy crops increases whereas that goes to corn stover decreases. In most cases of the eight scenarios, especially when landowners are not credit constrained, miscanthus receives the largest portion of BCAP payments because a) miscanthus has high yield and is likely to be enrolled into BCAP according to the enrollment mechanism described in section 2.2; and b) once miscanthus is enrolled into BCAP, it will receive large payment to compensate its high establishment cost.

The four maps in Figure 5 depict the geographical distribution of county-level total BCAP payment. These maps show that BCAP payment is mainly distributed in regions outside of the Corn Belt. Although the Corn Belt is the region where most corn stover is produced under any scenario (see the two maps in the upper panel in Figure 6), this region may not be competitive in BCAP enrollment according to the land screening mechanism described in section 2.2. In other words, since BCAP payments are unlikely to change landowners' decision on whether to provide corn stover, land in the Corn Belt is unlikely to be enrolled into BCAP when facing competition from other regions. The geographical pattern of BCAP payment varies when biomass price increases. When biomass price is \$50/MT, the Northeastern region receives a large portion of BCAP payment (see the two maps on the left panel of Figure 5). However, an increase in biomass price from \$50/MT to \$100/MT shifts BCAP payments from the Northeastern region to the Great Plains. The reason is that the yields of corn stover and of the perennial crops are lower in the Great Plains that those in the Northeastern region (see Table 1 in Miao and Khanna). When biomass price increases from \$50/MT to \$100/MT, then providing biomass becomes close to the margin to be profitable in the Great Plains whereas providing biomass in the Northeastern region has surpassed that margin. Therefore, under the price at \$100/MT, land in the Great Plains is more likely to be enrolled into BCAP than that in the Northeastern region.

Moreover, the geographical distribution of BCAP payments is also affected by landowners' discount rate, risk aversion, and credit constraint. For instance, under the \$100/MT biomass price, when landowners have high discount, high risk aversion, and credit constraint then BCAP payments are mainly distributed in the southern area in the rainfed region. When landowners have low discount, low risk aversion, and no credit constraint, however, BCAP payments are mainly received by the Northern Great Plains. One possible explanation is as follows. When landowners have high discount, high risk aversion, and credit constraint, then given the low yield of energy crops and corn stover in the Northern Great Plains (see Figure 1 in Miao and Khanna), the landowners have little incentive to grow miscanthus and switchgrass. However, when the landowners have low risk aversion and no credit constrained, then growing miscanthus and switchgrass may become a viable choice in the Northern Great Plains and BCAP payment may have larger incentive for biomass production in this region than other regions.

4.3 Effects of BCAP on Land Use

In addition to BCAP's effect on total biomass production and BCAP payments' geographical distribution, we are interested in how BCAP will affect the land use for perennial energy crops and their geographical distribution. Table 2 summarizes the land use for miscanthus and switchgrass under two biomass prices and two scenarios of landowners' discount, risk aversion, and credit constraint status. From Table 1 we can see that when biomass price is $50/MT then about 90% of the land used for the two perennial energy crops is low quality land. When biomass price increases to $100/MT, then the land used for these two perennial crops increases on both of low and high quality land but high quality land increases in a larger amount. Under this biomass price, about 50% of land used for these two perennial crops is low quality land. When landowners have high discount, high risk aversion, and credit constraint, then the acreage for switchgrass is about 10 times as large as that for miscanthus. When landowners have low discount, low risk aversion, and no credit constraint, however, then the opposite is true.

BCAP generally increase land used for miscanthus and switchgrass in most cases. One exception is that when biomass price is $100/MT and when landowners have high discount, high risk aversion and credit constrained, the BCAP decreases the acreage for switchgrass. The reason is that under these conditions landowners change land use from growing switchgrass to miscanthus or conventional crops. We find that BCAP increases the use of low quality land for the two perennial crops at a much larger scale than it increases the use of high quality land. This difference is much larger when biomass price is \$50/MT than when biomass price is \$100/MT.

Maps in Figures 6 to 8 depict county-level land use and land use change for corn stover, miscanthus, and switchgrass when biomass price is \$50/MT. As we have mentioned above, corn stover production mainly occurs on the Corn Belt. This pattern is not affected by landowners' time and risk preferences as well as credit constraint status. However, the presence of BCAP will slightly shift some corn stover acreage from the southern rainfed region to the Northeastern region (see Figure 6). When landowners have high discount, high risk aversion, and credit constraint, then miscanthus production mainly occurs in the Southern region. However, when landowners have low discount, low risk aversion, and no credit constraint, then miscanthus production can occur in the fringe of Corn Belt and the Southeastern states. The presence of BCAP will increase miscanthus acreage in the Northeastern region. When landowners have high discount, high risk aversion, and credit constraint, switchgrass production widely occurs in the southern part of the rainfed region (see the upper left map in Figure 8). However, when landowners have low discount, low risk aversion, and no credit constraint, then the majority acreage of switchgrass will be replaced by miscanthus acreage (compare the upper right maps in Figures 7 and 8). BCAP will increase switchgrass acreage at a moderate scale.

5. Conclusions

BCAP was re-authorized in the Agricultural Act of 2014 in order to support the production of energy crops and lower the price needed to induce farmers to convert land to these crops. This study is aimed to quantify BCAP's impacts on energy crop production, crop choices, and geographical configuration of land allocation. We find that given its current budget at \$125 million in a five-year period, BCAP only incentivize biomass production at a moderate magnitude. Moreover, BCAP's impacts on biomass production vary with biomass price, landowners' discount rate, risk aversion, and credit constraint status. The geographical distribution of BCAP payments is also significantly affected by landowners' time and risk preference as well as credit constraint status. While BCAP has a moderate land-use effect for the two perennial energy crops (miscanthus and switchgrass), it increases production of these two crops on low quality land at a much larger magnitude than it increases production on high quality land.

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Table 1. Summary Statistics of Data Utilized in the Simulation[a]

			Mean	Std. Dev.	Min.	Max.
Yields	miscanthus on high quality land (MT/ha.)		27.2	2.9	3.5	48.3
	miscanthus on low quality land (MT/ha.)		26.8	2.8	2.8	47.4
	switchgrass on high quality land (MT/ha.)		14.1	2.8	0.4	32.1
	switchgrass on low quality land (MT/ha.)		12.7	3.3	0.4	31.1
	corn (bu./acre)		127.7	35.0	0.7	228.3
	soybean (bu./acre)		44.0	8.1	8.5	65.9
Costs[b]	miscanthus (year 1)	establishment cost ($/ha.)	3108.0	46.2	3033.6	3247.9
	miscanthus (year 2)	variable cost ($/MT)	17.2	2.0	14.2	19.6
		fixed cost (($/ha.)	602.5	28.8	547.9	692.8
		establishment cost ($/ha.)	510.3	24.0	474.5	593.9
	miscanthus (years 3-15)	variable cost ($/MT)	17.2	2.0	14.2	19.6
		fixed cost ($/ha.)	166.0	29.0	113.1	258.7
	switchgrass (year 1)	variable cost ($/ton)	17.2	2.0	14.2	19.6
		fixed cost (($/acre)	332.7	22.8	294.0	392.9
		establishment cost ($/acre)	249.4	20.0	223.0	319.0
	switchgrass (year 2)	variable cost ($/ton)	17.2	2.0	14.2	19.6
		fixed cost (($/acre)	254.9	53.9	143.5	368.3
	switchgrass (year 3-10)	variable cost ($/ton)	17.2	2.0	14.2	19.6
		fixed cost (($/acre)	251.6	40.6	169.1	354.1
	corn	variable cost ($/bu.)	1.3	0.4	0.8	2.7
		fixed cost ($/acre)	136.5	28.6	91.4	221.8
	corn stover	variable cost ($/MT)	17.5	2.1	12.6	21.7
		fixed cost ($/ha.)	48.5	10.9	20.3	75.0
	soybean	variable cost ($/bu.)	1.5	0.3	0.8	1.8
		fixed cost ($/acre)	107.4	45.4	59.4	195.9
Prices ($/bu.)	corn	projected price	4.1	1.2	2.6	7.8
		harvest price	3.8	1.3	2.2	8.1
		received price[c]	4.0	1.3	1.9	9.1
	soybeans	projected price	9.5	2.9	5.4	17.2
		harvest price	9.3	3.0	5.4	19.3
		received price[c]	9.2	2.6	5.3	17.3
Acreage (ha. per county)		low quality land[d]	4253	4015	0	31656
		high quality land	28198	38039	0	252448
CRP rental rates ($/hectare)			161	84	35	983
Farm size (hectares)			133	128	16	1573

Note: [a] Costs, prices, and CRP rental rates are in 2010 dollars. [b] For miscanthus, the first year costs only consist of establishment cost. The second year costs consist of variable cost and fixed cost. A large part of the fixed cost in the second year is establishment cost that cover replanting, chemical and machinery expenses, etc. [c] The received price is annual average price received in a marketing year (downloaded from NASS of USDA) while the projected price and harvest price are futures prices calculated following RMA (2011). [d] This is the land characterised as cropland pasture and idle (net of CRP acres) reported by NASS in 2007.

Table 2. Land for Miscanthus and Switchgrass under Various Scenarios (in mil. hectares)

		Land for biomass when there is no BCAP				**Land use changed when there is BCAP**			
		High discount, high risk aversion, credit constrained, and biomass price ($/MT) at:		Low discount, low risk aversion, not credit constrained, and biomass price ($/MT) at:		High discount, high risk aversion, credit constrained, and biomass price ($/MT) at:		Low discount, low risk aversion, not credit constrained, and biomass price ($/MT) at:	
Biomass	**Land Type**	**50**	**100**	**50**	**100**	**50**	**100**	**50**	**100**
Miscanthus	High	0.00	0.05	0.18	2.92	0.001	0.000	0.002	0.008
	Low	0.05	0.44	1.51	2.37	0.013	0.041	0.034	0.016
	Total	0.05	0.49	1.69	5.29	0.015	0.041	0.037	0.024
Switchgrass	High	0.08	2.31	0.01	0.06	0.004	-0.001	0.000	0.000
	Low	0.67	2.00	0.10	0.27	0.090	-0.033	0.008	0.039
	Total	0.75	4.31	0.11	0.33	0.093	-0.034	0.009	0.039
Total	High	0.08	2.36	0.19	2.98	0.005	-0.001	0.002	0.008
	Low	0.72	2.44	1.61	2.64	0.103	0.008	0.042	0.055
	Grand Total	0.80	4.80	1.80	5.62	0.108	0.007	0.044	0.063

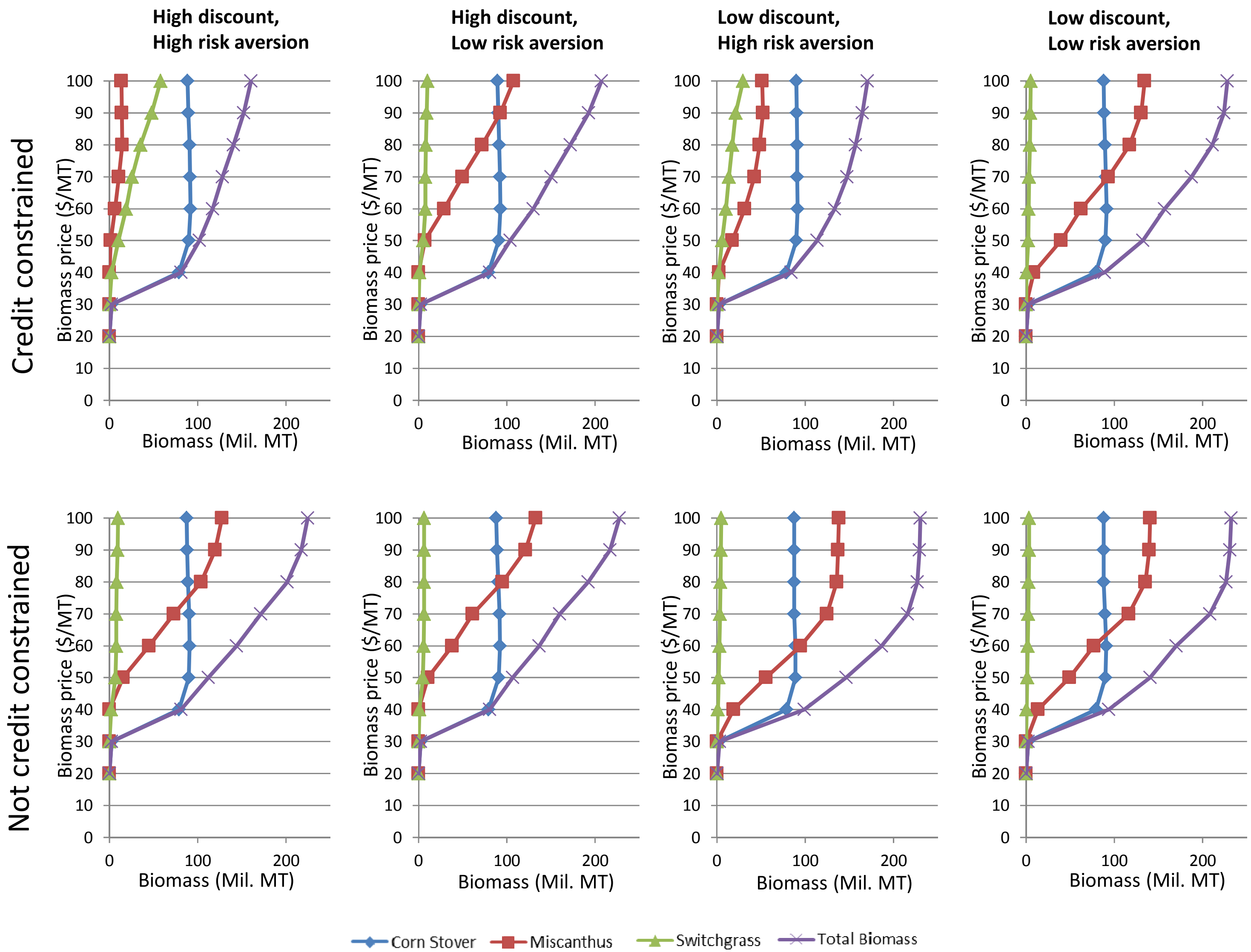

Figure 1. Biomass Supply Curves without BCAP (in million metric tons, 15% moisture)

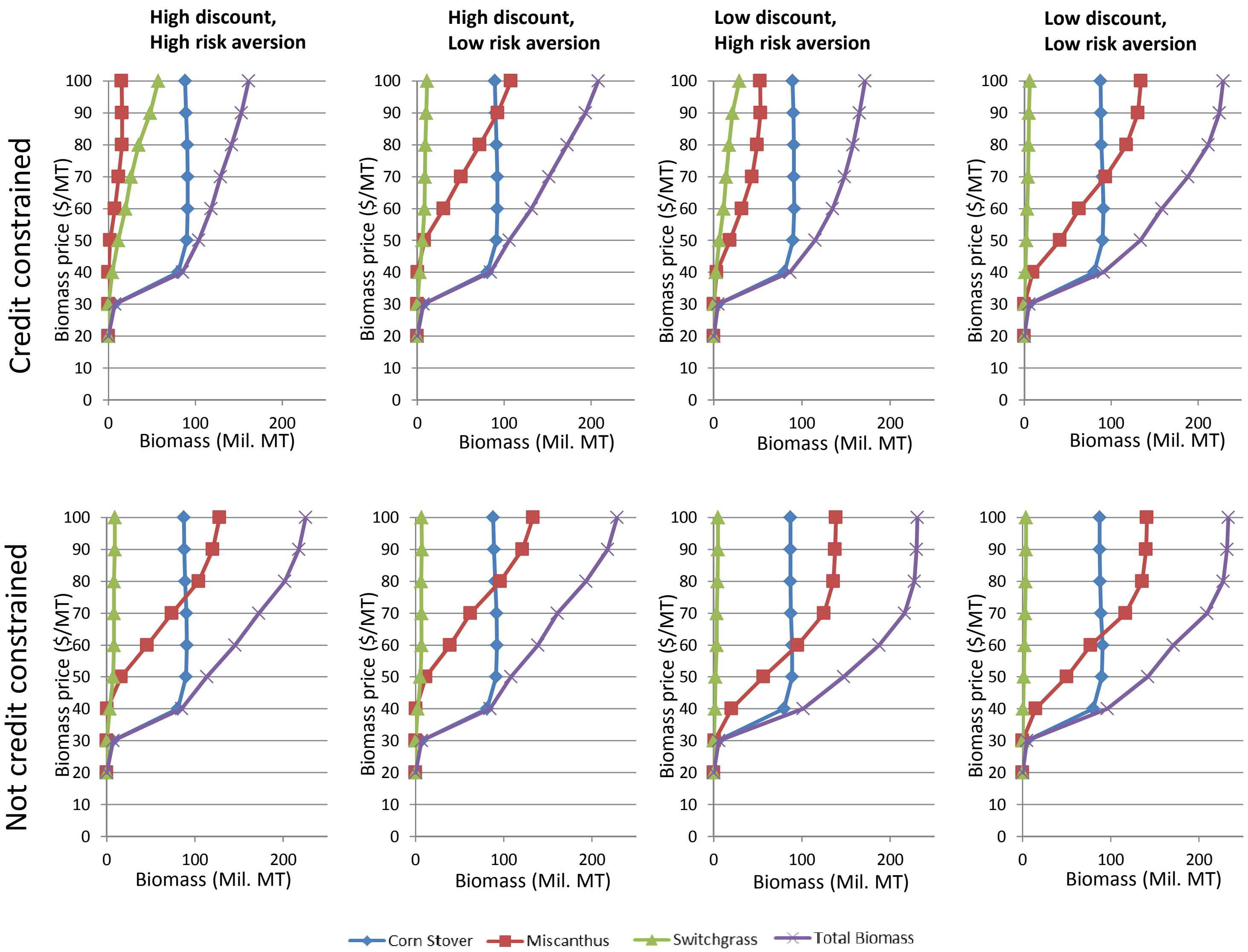

Figure 2. Biomass Supply Curves with BCAP (in million metric tons, 15% moisture)

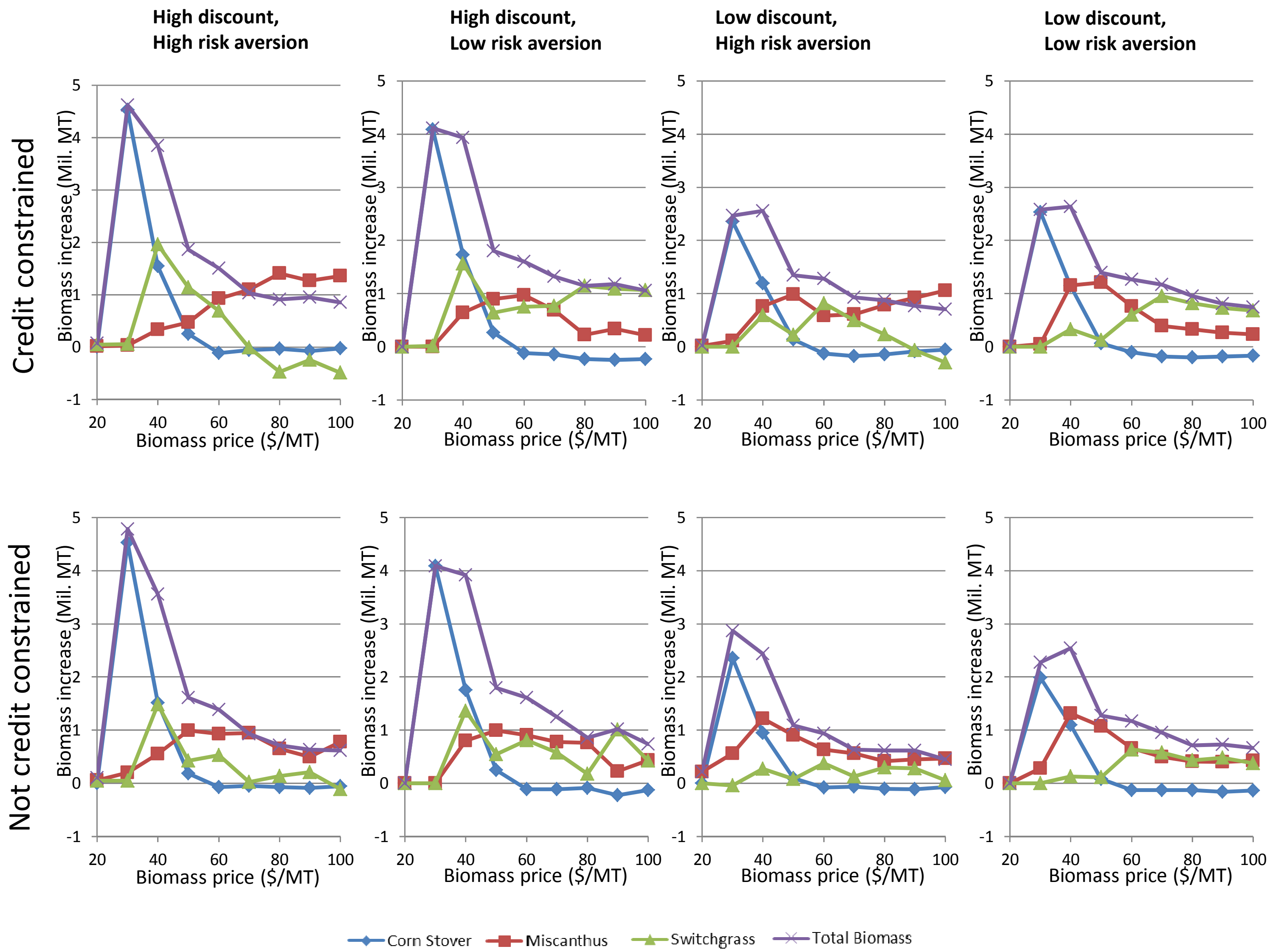

Figure 3. Biomass Increase Caused by BCAP when Biomass Price Varies

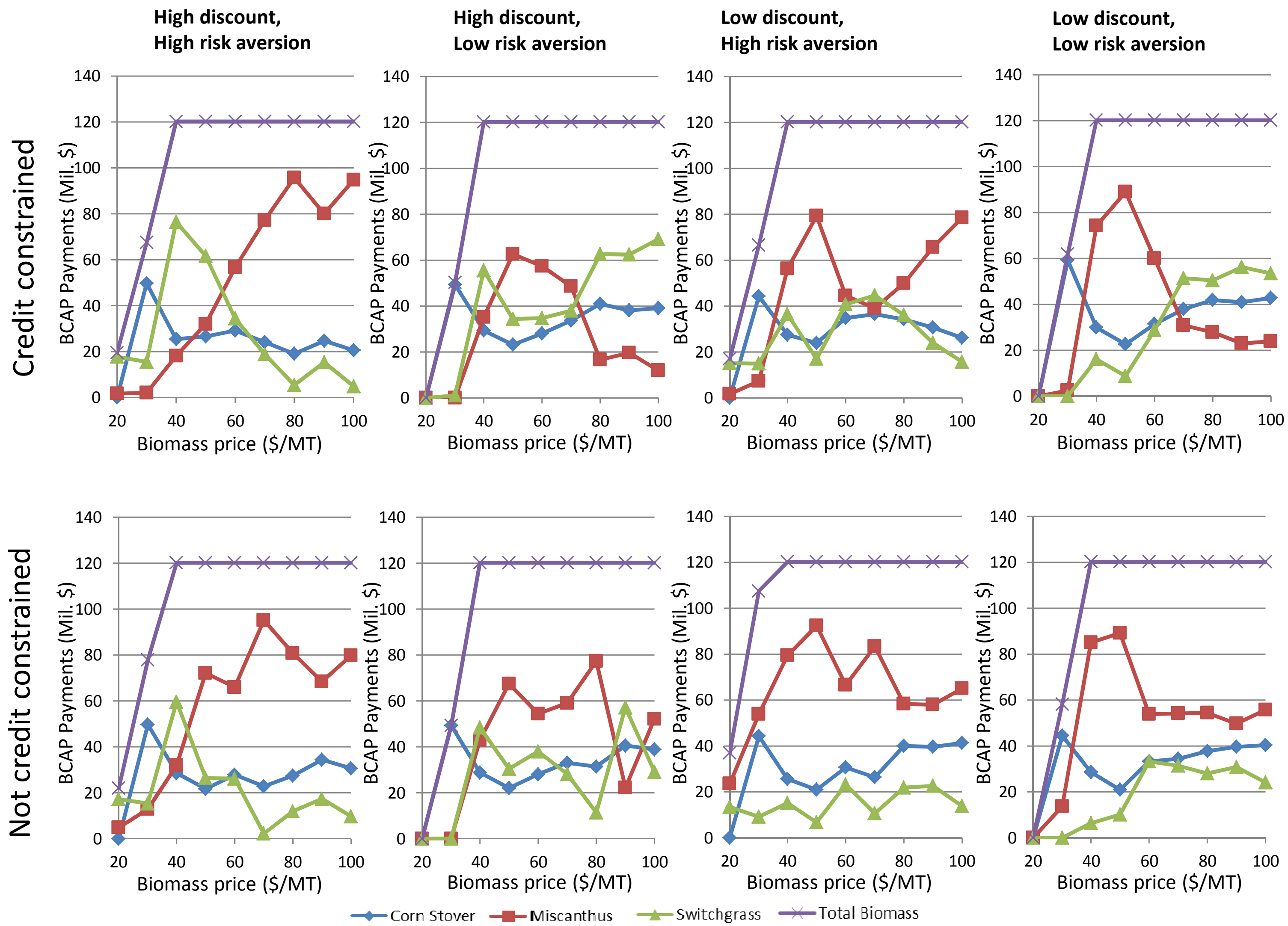

Figure 4. BCAP Payments by Crop when Biomass Price Varies (net present values in mil. dollars)

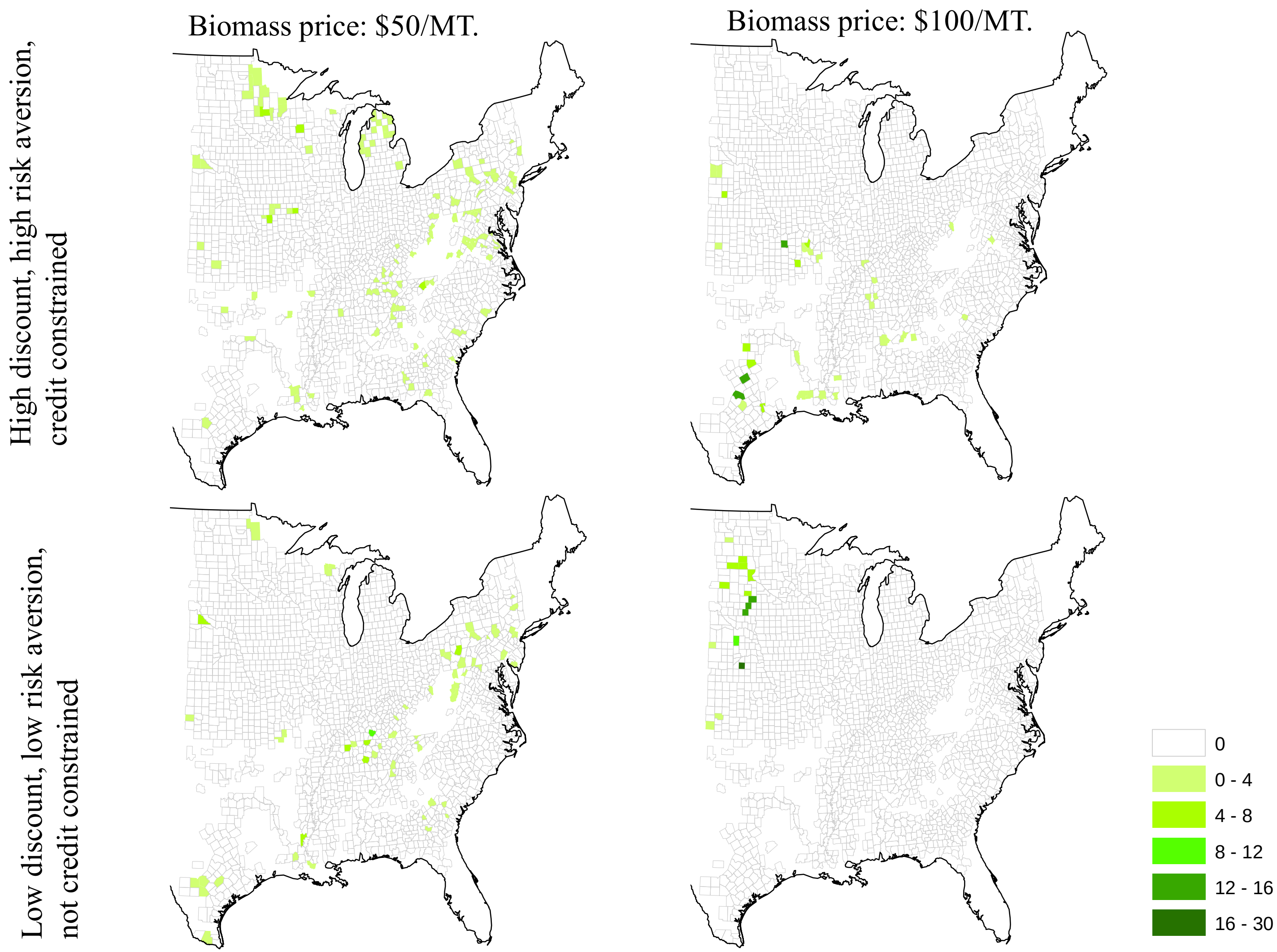

Figure 5. Regional Distribution of BCAP Payments (5-year net present value, in million dollars)

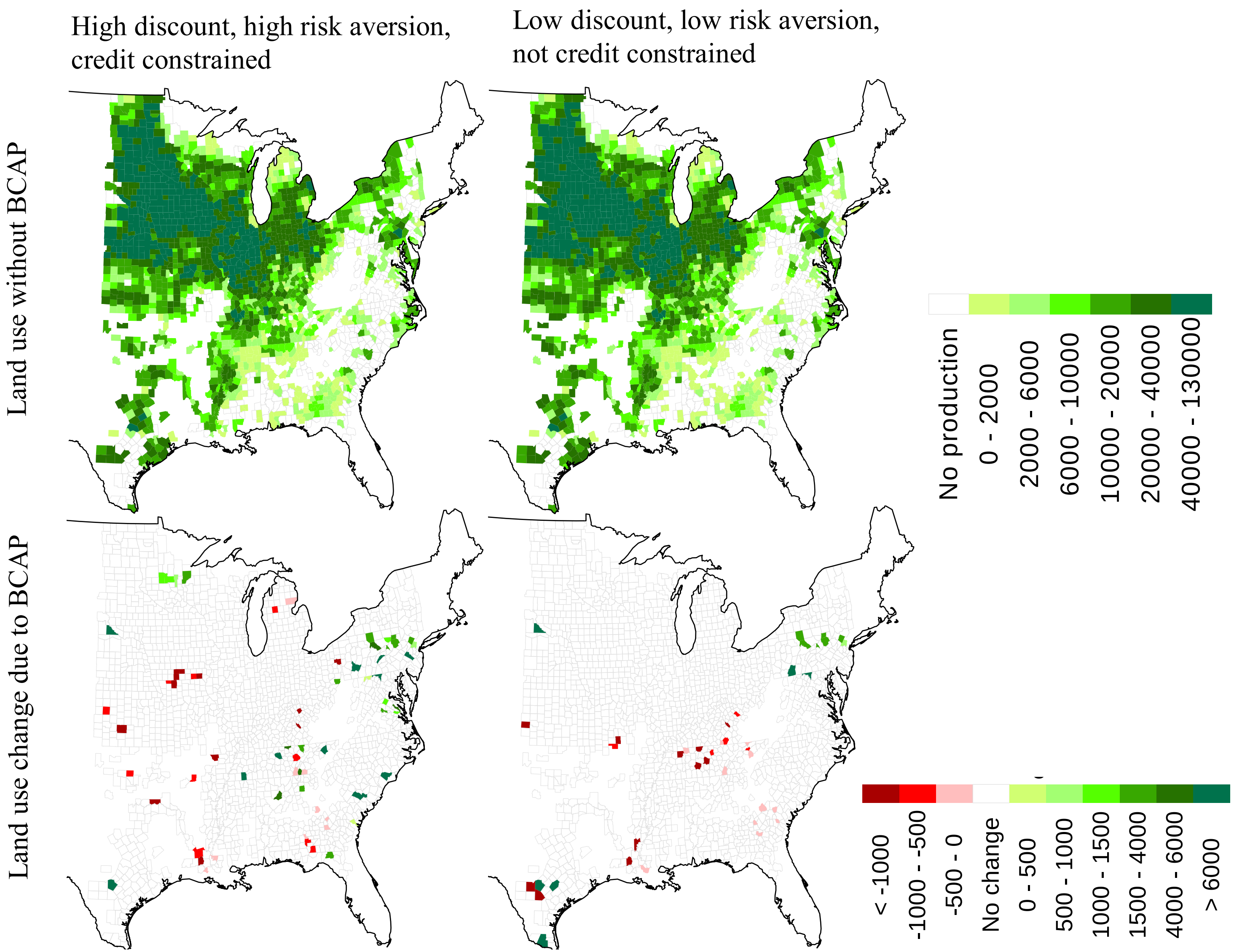

Figure 6. Land Use and Land Use Change for Corn Stover when Biomass Price is $50/MT (unit: hectares)

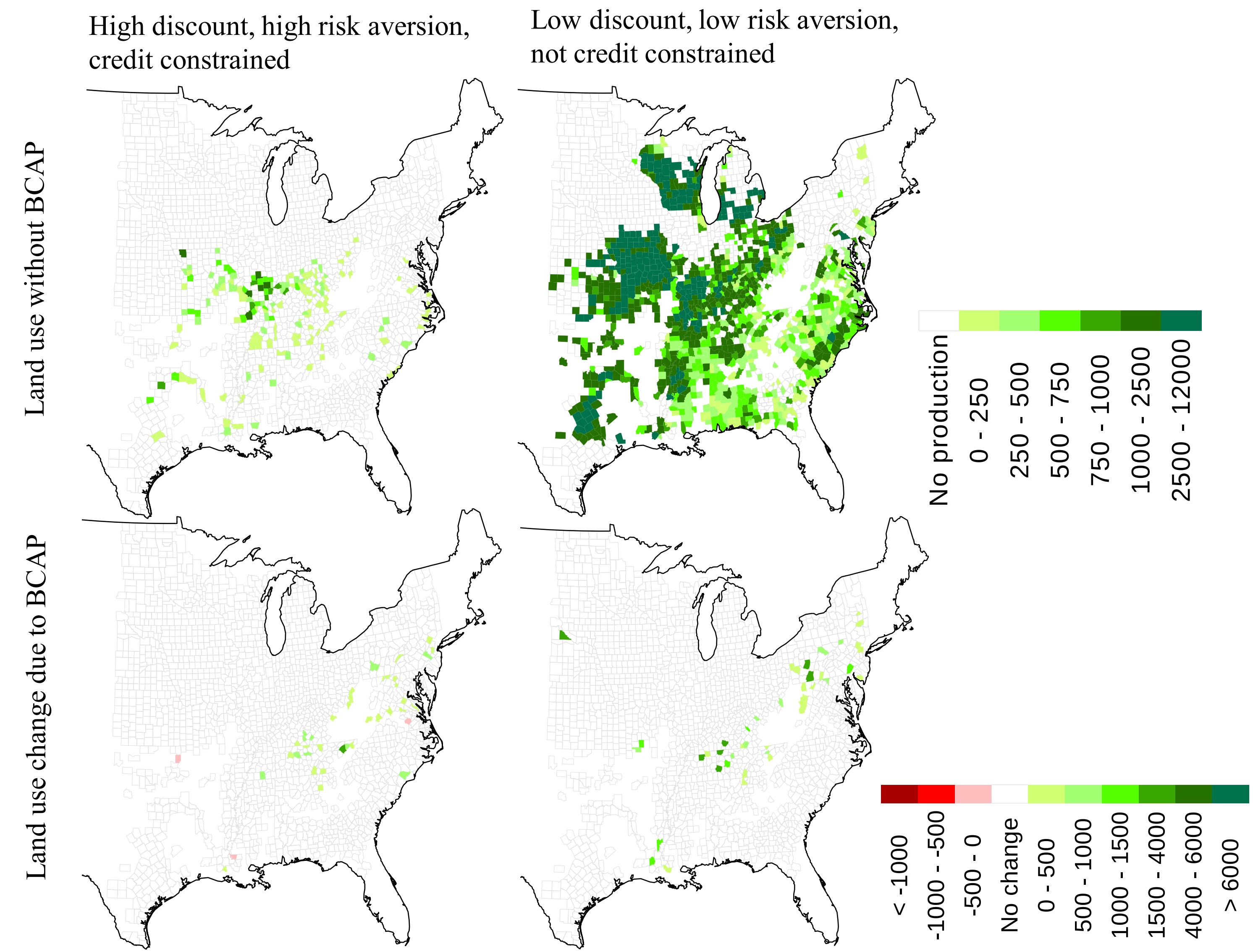

Figure 7. Land Use and Land Use Change for Miscanthus when Biomass Price is $50/MT (unit: hectares)

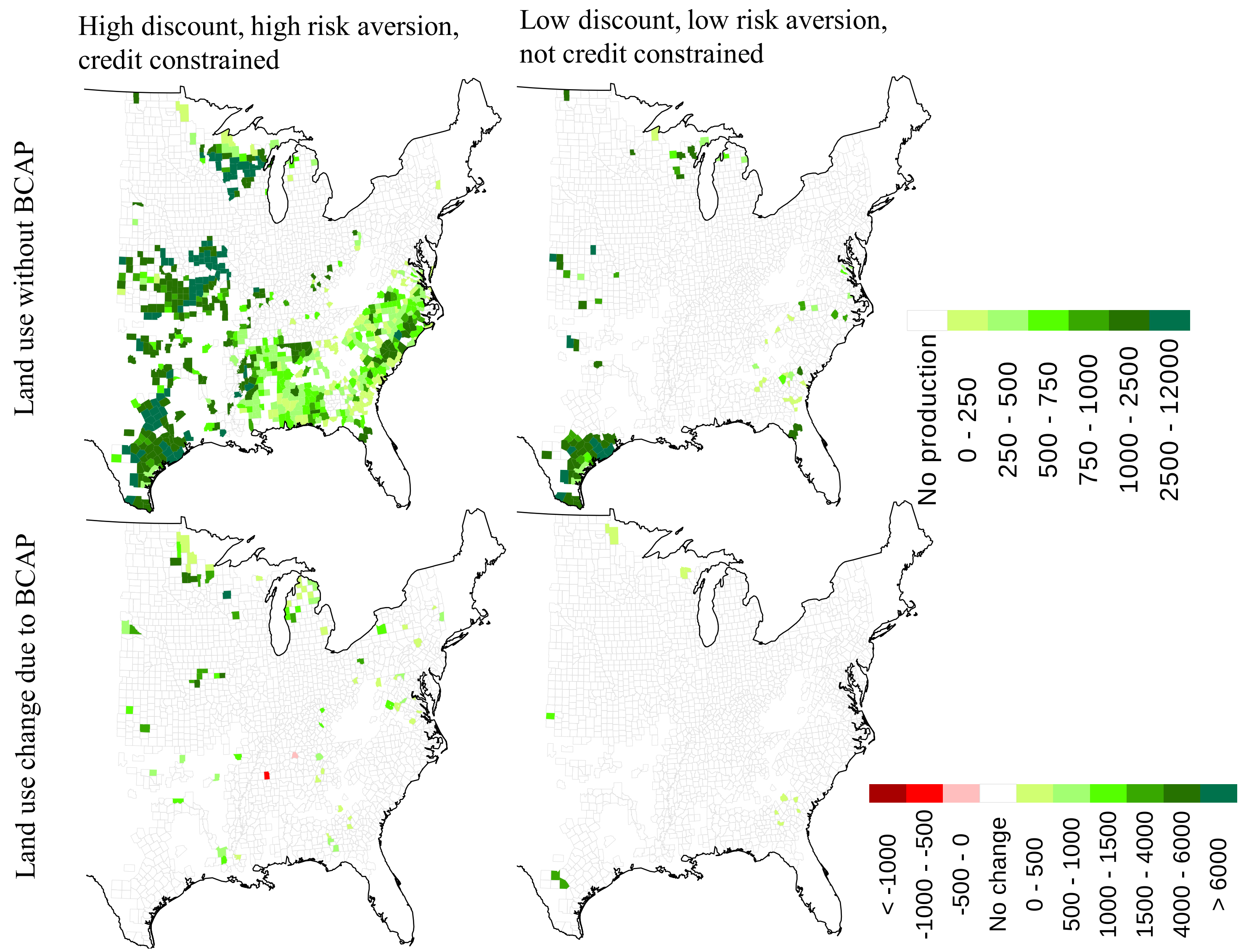

Figure 8. Land Use and Land Use Change for Switchgrass when Biomass Price is $50/MT (unit: hectares)

Supporting Information for "The Biomass Crop Assistance Program: Critical, Notional, or Distortional Support for Cellulosic Biofuels?"

Ruiqing Miao and Madhu Khanna

Item 1

We present in this item a brief introduction to copula approach and procedures of how to estimate the copula and to obtain draws from the estimated copula.

Sklar (1959) showed that any continuous *l*-dimensional joint distribution, $F(z_1,...,z_l)$, can be uniquely expressed by two components. The first comprises of the *l* marginal distributions. The second is an *l*-dimensional copula, which is an *l*-dimensional joint distribution with standard uniform marginal distributions. Mathematically, we have

$$F(z_1,...,z_l) = C(F_1(z_1),...,F_l(z_l)), \tag{S1}$$

where $C(\cdot)$ is the copula function; and $F_i(z_i)$ is the marginal distribution of random variable z_i, $i \in \{1,...,l\}$. Define $\eta_i \equiv F_i\left(z_i\right)$, then the copula function in equation (S1) can be written as

$$C(\eta_1,...,\eta_l) = F(F_1^{-1}(\eta_1),...,F_l^{-1}(\eta_l)), \tag{S2}$$

where $F_i^{-1}(\cdot)$, $i \in \{1,...,l\}$ is the inverse marginal distribution function of random variable z_l. In our simulation we utilize the Multivariate Gaussian Copula (MGC) because it is one of the most commonly used copulas in risk management (Zhu, Ghosh, and Goodwin 2008).[1] The MGC can be expressed as

$$C(\eta_1,...,\eta_l;\rho) = \Phi_l(\Phi^{-1}(\eta_1), ... ,\Phi^{-1}(\eta_l);\rho), \tag{S3}$$

where ρ is a dependence matrix that captures dependence between the marginal distributions; $\Phi_l(\cdot)$ is the *l*-dimensional multivariate standard normal distribution with mean zero and

[1] For farm revenue modeling, Zhu, Ghosh, and Goodwin (2008) find that simulation outcomes are robust to replacing MGC with related distributions such as the Multivariate Student's *t* Copula (MTC).

correlation matrix as ρ, and $\Phi^{-1}(\cdot)$ is the inverse distribution function of the standard one-dimensional normal distribution.

Based on the MGC, once we identify the marginal distributions, $F_i(z_i)$, $i \in \{1,\ldots,l\}$, and the dependence matrix, ρ, then we can obtain the joint distribution, $F(\cdot)$, by equations (S1) and (S3). A common method used to estimate the marginals and the correlation matrix is the Inference Function for Margins (IFM) method proposed by Joe (2005). The basic idea of the IFM method can be expressed in a two-step procedure. The first step fits parameters of the marginal distributions using maximum likelihood estimation (MLE). In the second step, the dependence parameters in matrix ρ are estimated using MLE by taking the marginal distributions' parameters estimated in the first step as given.

In what follows of this item we introduce procedures of how to estimate the copula and to obtain draws from the estimated copula. Here we use a central Midwestern county that has corn and soybeans, as well as low quality land and high quality land as an example to illustrate. For such a county we need to estimate a six-dimension copula. These six dimensions are: corn yield on high quality land, soybean yield on high quality land, Miscanthus yield on high quality land, Miscanthus yield on low quality land, corn price, and soybean price. Futures prices are used when estimating the joint price-yield distributions. Because yields of corn and soybeans on low quality land are not available, we simply assume that they are 2/3 of yields on normal cropland by following Hertel et al. (2010). The same procedure follows for other counties.

Estimating Copula

Following Du and Hennessy (2012), we assume that crop yields have beta distributions and crop prices have log-normal distributions. Once we have estimated the price-yield joint distributions, we can obtain draws from the estimated joint distributions and conduct Monte Carlo simulations. County-level yields of corn and soybeans over 1979-2010 are obtained from National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture

(USDA). Counties with yield observation numbers less than 16 within the 32-year period are removed from the data set. We then apply a simple linear detrending approach to remove the systematic components of yield variation for each county and transfer the de-trended yield to the 2010 yield by adding back the county-level trend yield of 2010. Let y_t^i denote the county-level yield crop $i \in$ {corn on high quality land (or *ch*), soybeans on high quality land (or *sh*), Miscanthus on high quality land (or *mh*), Miscanthus on low quality land (or *ml*)} in year $t \in \{1979,...,2010\}$ for a county. For corn and soybeans the yields used here are yields after detrending and adding yield trend of 2010 onto the residuals. For Miscanthus, since there is not an explicit yield trend incorporated in the DayCent model, Miscanthus yields are not detrended. The procedure to obtain county-level yield marginals is as follows.

Step 1): Let $\overline{y}^i$ and $\underline{y}^i$ denote the upper bound and lower bound of y_t^i, respectively. We assume that $\overline{y}^i = \max[y_{1979}^i,...,y_{2010}^i]$ and $\underline{y}^i = \min[y_{1979}^i,...,y_{2010}^i]$.

Step 2): Yield y_t^i is transformed to a standard beta random variable ξ_t^i by letting $\xi_t^i = (y_t^i - \underline{y}^i)/(\overline{y}^i - \underline{y}^i)$. We then estimate the beta distribution parameters by using the maximum likelihood estimation (MLE), which is performed by using command "fitdist" in MATLAB®.

When estimating the county-level crop price marginals, we follow Zhu, Ghosh, and Goodwin (2008) by assuming that the difference between the logarithms of harvest price and projected price is normally distributed. That is, for corn and soybeans, $\tilde{p}_t^c = \log p_t^{c,\text{harv}} - \log p_t^{c,\text{proj}}$ and $\tilde{p}_t^s = \log p_t^{s,\text{harv}} - \log p_t^{s,\text{proj}}$ have normal distributions. The parameters for this normal distribution are estimated by using MLE as well. Then we obtain the marginal distribution for corn prices and soybean prices.

Once we obtain the yield and price marginals, then the MGC dependence matrix, ρ, can be estimated by a procedure as follows. The density function of the copula function in equation (S3) can be written as

$$c(\eta_1,...,\eta_6;\rho)=\frac{\partial^m C(\eta_1,...,\eta_6;\rho)}{\partial\eta_1\cdots\partial\eta_6}.$$

Recall that $\eta_l \equiv F_l(z_l)$ is the marginal distributions of the copula. Let $\hat{F}^{ch}(y^{ch})$, $\hat{F}^{sh}(y^{sh})$, $\hat{F}^{mh}(y^{mh})$, $\hat{F}^{ml}(y^{ml})$, $\hat{F}^{c}(\tilde{p}^{c})$, and $\hat{F}^{s}(\tilde{y}^{s})$ denote the estimated marginal distributions of corn yield on high quality land (*ch*), soybean yield on high quality land (*sh*), Miscanthus yield on high quality land (*mh*), Miscanthus yield on low quality land (*ml*), corn price (*c*), and soybean price (*s*), respectively. Then the dependence matrix, ρ, can be estimated by

$$\hat{\rho}=\arg\max_{\rho}\sum_{t=1}^{T}\log c(\hat{F}^{ch}(y_t^{ch}),\hat{F}^{sh}(y_t^{sh}),\hat{F}^{mh}(y_t^{mh}),\hat{F}^{ml}(y_t^{ml}),\hat{F}^{c}(\tilde{p}_t^{c}),\hat{F}^{s}(\tilde{p}_t^{s});\rho),$$

where *T* is the number of observations. In the simulation the estimation is performed by using command “copulafit” of MATLAB®.

Obtaining Draws from the Estimated Copula

In this subsection we demonstrate the procedure to generate random variates from an estimated copula described above. The procedure follows the method in Cherubini, Luciano and Vecchiato (2004, p.181). It can be described as follows.

Step 1). Find the Cholesky decomposition, *A*, of the estimated dependence matrix $\hat{\rho}$.

Step 2). Draw six independent random variates $n=(n_1,...,n_6)'$ from the standard normal distribution $N(0,1)$.

Step 3). Let $u = An$.

Step 4). Let $v_i=\Phi(u_i)$, $i\in\{1,...,6\}$ where $\Phi(\cdot)$ is the univariate standard normal distribution function and u_i is the *i*th element of *u*.

Step 5). Let $(z_1,...,z_6)' = (F_1^{-1}(v_1),...,F_6^{-1}(v_6))$, where $F_l^{-1}(v_l)$ denote the *l*th inverse marginal distribution function. Then $(z_1,...,z_6)'$ is one random draw from the six-dimensional Gaussian copula.

Step 6). Repeat Steps 1) to 5) *N* times (*N*=1000 in this study) to obtain *N* draws from the estimated copula. Notice that because the yield marginals of the copula are beta distributions with support [0,1], after obtaining draws from the copula one needs to transform the yield draws to crop yield to be used in Monte Carlo simulation by using $y^i = \xi^i(\overline{y}^i - \underline{y}^i) + \underline{y}^i$. Similarly, for crop price a transformation is also needed to convert the difference of logarithm prices to harvest price. The formula is $p^{i,\text{harv}} = \exp(\tilde{p}^i + \log p^{i,\text{proj}})$, where $\tilde{p}^i$ is part of the random draws from the estimated copula, and $p^{i,\text{proj}}$ is the historical projected price in year 2010 for crop *i*. For each draw of harvest futures price, we add on price basis to obtain a draw of received price, where price basis reflects costs of transportation, storage, and interest, etc. Price basis for corn (soybeans) is calculated by using 30-year average over 1981-2010 of the difference between corn (soybeans) futures price and state-level corn (soybeans) received prices. The received prices are downloaded from NASS of USDA.

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