Adopting Bio-Energy Crops: Does Farmers' Attitude toward Loss Matter?

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Abstract

This paper analyzes farmers' willingness to grow a perennial energy crop (namely, miscanthus) while accounting for their attitude toward loss based on prospect theory. The analysis includes 1,877 U.S. counties east of the 100th Meridian that have data for corn yield and for miscanthus. We first estimate distributions of profits for miscanthus and conventional crops. The average probability of having a loss from growing miscanthus on high and low quality land for each county is calculated. We then study farmers' optimal land allocation between miscanthus and conventional crops under prospect theory, and separately, under expected utility theory. Results show that all else equal, miscanthus production is lower when farmers' loss aversion is considered than when loss aversion is ignored. Moreover, geographical configuration of miscanthus adoption predicted by prospect theory significantly differs from that predicted by expected utility theory.

Keywords: Adoption, Bioenergy Crops, Expected Utility Theory, Prospect Theory, Miscanthus

JEL codes: D81, Q15, Q16

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Introduction

The emerging cellulosic biofuel and bioproduct industry requires the development of biomass markets. In these markets, however, technological and demand uncertainty is high and moreover, economic and policy challenges need to be overcome for farmers to successfully engage as viable suppliers of biomass. Large scale biomass production, as envisioned by the Billion-ton study (USDOE 2005, 2011, and 2016), is anticipated to significantly rely on high yielding dedicated energy crops in order to avoid competition with food crop production. While perennial energy crops such as miscanthus (Miscanthus × giganteus) and switchgrass (Panicum virgatum) are promising and can provide a range of environmental benefits (Hudiburg et al. 2016), the commercial scale production of these perennial energy crops has not commenced yet due to, in part, farmers' lack of information about these crops' profit profiles, particularly in risk dimension.

Simply comparing average profit from a perennial energy crop with that of a conventional crop cannot assist farmers in making decisive crop choice decisions because a large literature has shown that most people are not only risk averse but also loss averse. For example, a survey conducted by Smith et al. (2011) show that the fear of establishment failure or biorefinery shutdown that will cause extreme losses in returns is a significant barrier to adopting dedicated energy crops, which is consistent with numerous economic and physiological findings that people tend to be more sensitive to a loss than to a same-magnitude gain (see Barberis 2013 for a review). Therefore, risk of profit (especially in the loss domain) and farmers' attitude toward risk and loss are two important factors that will influence farmers' decision to grow these perennial energy crops.

Previous studies either only examine the breakeven prices as a measure of average profitability (e.g., Miao and Khanna 2014), study profit distributions of energy crops in specific regions (e.g., Dolginow et al. 2014; Skevas et al. 2015), or investigate impacts of policy instruments such as insurance for energy crops, establishment cost subsidies, and the Biomass Crop Assistant Program (Miao and Khanna, 2017 and *forthcoming*). These studies are based on expected utility theory whenever farmers' risk preferences are considered. None of them have investigated how farmers' loss aversion will affect farmers' willingness to grow a perennial energy crops.

This study aims to fill in this gap. Expected utility theory does not consider the point one starts from and how will deviation from the starting point (i.e., reference point) affects people's valuation to a risky prospect. Unlike expected utility theory, prospect theory differentiates gains from losses relative to a reference point in regard to decision making. It predicts that farmers who are loss averse will put more emphasis on the profit profile in the loss domain of an enterprise. Numerous studies have shown that prospect theory provides better predictions of people's decision making under risk and uncertainty than does the expected utility.[1] Therefore, in this paper we first conduct a comprehensive analysis of profits associated with converting land from conventional crops to producing miscanthus at the county-level across the rainfed area of the United States. We then analyze farmers' willingness to grow miscanthus in each county based on expected utility theory (or, separately, prospect theory). The analysis is of practical importance because it provides a) potential farmers of the perennial crops with a reference regarding the profile of energy crops' profits in order to facilitate their adoption decisions; and b) potential cellulosic biorefinery investors with geographical configuration of areas where the

[1] We refer readers to Barberis (2013) for a comprehensive review.

perennial energy crop production is most viable in order to facilitate their plant location decisions. The analysis will further shed light on how accounting for farmers' loss aversion may affect farmers' adoption behavior.

We first develop a conceptual framework that models a presentative landowner's optimal land allocation problem by using prospect theory. We then conduct numerical simulation for 1,877 U.S. counties east of the 100th Meridian that have yield data for both corn and miscanthus. Our results show that all else equal, miscanthus production is lower when farmers' loss aversion is considered than when loss aversion is ignored. Moreover, geographical configuration of miscanthus adoption predicted by prospect theory significantly differs from that predicted by expected utility theory. The analysis show that the risk of crop failure significantly hinders farmers' adoption for miscanthus, indicating that policy supports that absorb such a risk may encourage farmers' adoption of energy crops.

The rest of the paper proceeds as follows. The next section outlines a conceptual framework that serves as the foundations of our simulations, followed by a section that provides a description of the simulation framework and data. The last two sections summarize simulation results and conclude.

Conceptual framework

In this section we develop a conceptual framework under which a representative farmer optimally allocates a tract of land between a conventional use and a bioenergy crop (i.e., miscanthus) to maximize her decision-weighted utility under prospect theory. We assume that the farmer has one unit of land in total. This unit of land consists of two types of quality: high quality land at portion s^h and low quality land at portion s^l. Clear, $s^h + s^l = 1$. For high quality land, the farmer will decide the optimal land division between two uses: growing a conventional crop (labeled as *c*) and growing an energy crop (labeled as *e*). For low quality land, the farmer will decide the optimal land division among three uses: staying idle (labeled as *o*), growing a conventional crop, and growing an energy crop. Let x^o denote the amount of low quality land kept idle; and let x^{ij} denote the portion of total land devoted to crop type $i \in \{c, e\}$ on land type $j \in \{h, l\}$. Clearly, we have $x^{ch} + x^{eh} = s^h$ and $x^o + x^{cl} + x^{el} = s^l$. Furthermore, let π^o be the non-stochastic profit per unit of land when the land is kept idle. Let π^{ij} be the random profit per unit of land from growing crop *i* on land type *j*. Therefore, for a given land-use allocation, i.e. $\{x^{ch}, x^{eh}, x^o, x^{cl}, x^{el}\}$, the farmer's random profit is:

$$\pi = x^{ch}\pi^{ch} + x^{eh}\pi^{eh} + x^o\pi^o + x^{cl}\pi^{cl} + x^{el}\pi^{el}. \quad (1)$$

As mentioned above, prospect theory accounts for people's attitude toward loss and hence perform better than expected utility theory in predicting people's choices under risk and uncertainty (Bougherara and Piet, 2014; Bocquého et al., 2014). Thus, we use the prospect theory to examine how farmers' preferences in risk and loss change their decision regarding adoption of bio crops. The prospect theory consists of three major components. First is the reference point through which one can decide whether a gain or loss occur. The second component is the value function that reflects how a fixed profit is valued by the farmer. The third is probability weighting function that describes how the farmer derives decision weight based on profit probability. In what follows of this section, we describe the three components in detail.

Since the farmer's problem is to decide how much land should be allocated to the energy crop, a natural reference point is the expected profit from original land use when energy crop is absent. That is, the reference point profit equals profits from devoting all high quality land to conventional crop and keeping all low quality land idle. Specifically, let $\overline{\pi}$ denote the reference point profit. Then, we have

$$\bar{\pi} = m^h \mathrm{E}(\pi^{ch}) + m^l \pi^o, \tag{2}$$

where $\mathrm{E}(\cdot)$ is the expectation operator.

Suppose that there are $m+n$ possible realizations for the random profit π, namely, π_k, $k \in \Omega \equiv \{-m, 1-m, ..., -1, 1, ..., n\}$. The probability that π_k occurs is q_k. Following Tversky and Kahnemen (1992), the value function for a profit realization π_k is specified as

$$v(\pi_k) = \begin{cases} (\pi_k - \bar{\pi})^\alpha & \text{if } \pi_k \geq \bar{\pi} \\ -\lambda[-(\pi_k - \bar{\pi})]^\alpha & \text{if } \pi_k < \bar{\pi}, \end{cases} \tag{3}$$

where λ is the loss aversion parameter and α is the risk aversion parameter. When $\lambda > 1$ then the farmer is loss averse and when $\lambda < 1$ then the farmer is loss loving. When $\lambda = 1$ then the farmer is loss neutral. Similarly, when $\alpha > 1$ then the farmer is risk loving and when $\alpha < 1$ then the farmer is risk averse. When $\alpha = 1$ the farmer is risk neutral. In equation (3), if $\pi \geq \bar{\pi}$ then a gain occurs whereas if $\pi < \bar{\pi}$ then a loss occurs. This value function is concave for gains, and convex for losses, which is equivalent to risk aversion in gains and risk loving in losses.

Following Tversky and Kahnemen (1992), the probability weighting functions over the gain domain and the loss domain can be specified as:

$$\begin{aligned} w^+(\phi_k) &= \frac{\phi_k^\gamma}{(\phi_k^\gamma + (1-\phi_k)^\gamma)^{1/\gamma}}, \quad \text{for gains} \\ w^-(\phi_k) &= \frac{\phi_k^\delta}{(\phi_k^\delta + (1-\phi_k)^\delta)^{1/\delta}}, \quad \text{for losses,} \end{aligned} \tag{4}$$

where $w^+(\cdot)$ and $w^-(\cdot)$ are strictly increasing functions with both domain of definition and range as [0,1], such that $w^+(0) = w^-(0) = 0$ and $w^+(1) = w^-(1) = 1$. Moreover, γ and δ are fixed parameters; ϕ_k is the accumulative probability of profit realization, π_k. If $\pi_k \geq \bar{\pi}$ then $\phi_k = \Pr\{\pi \geq \pi_k\}$. If $\pi_k < \bar{\pi}$ then $\phi_k = \Pr\{\pi \leq \pi_k\}$. Unlike sum of probabilities being equal to 1, sum of decision weights is not necessarily equal to 1. Assuming that $\pi_k > \pi_{k'}$ if and only if $k > k'$, the decision weight for profit realization π_k is then specified as:

$$d_k = \begin{cases} w^+(\phi_n) & \text{if } k = n, \\ w^+(\phi_{k+1}) - w^+(\phi_k) & \text{if } 1 \le k < n, \\ w^-(\phi_k) - w^-(\phi_{k-1}) & \text{if } -m < k \le -1, \\ w^-(\phi_{-m}) & \text{if } k = -m. \end{cases} \quad (5)$$

Kahneman and Tversky (1979) had the observation that people underweight high probability events and overweight low probability events. Note the prospect theory does not assume that people over or under estimate the probabilities. It states that people are just subjectively over or under weighting them when making their decisions. The farmer's decision problem is to select a land allocation plan, $\{x^{ch}, x^{eh}, x^o, x^{cl}, x^{el}\}$, maximizing

$$\sum_{k \in \Omega} d_k v(\pi_k). \quad (6)$$

In the next section we describe the simulation framework and data utilized in the simulation.

Simulation Framework and Data

Our simulation includes 1,877 counties in the rainfed region of the United States. Each county is assumed to be managed by a representative farmer who allocates land between miscanthus and corn for high quality land as well as among miscanthus, corn, and idling for low quality land. Following previous literature (e.g., Jain et al., 2008; Chen et al., 2014), we assume that the lifespan of miscanthus is 15 years. We consider a 30-year temporal framework under which miscanthus can finish two lifecycles. 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 to the energy crop or the conventional crop. In the simulation π^o is approximated by land rent payments of the Conservation Reserve Program (CRP).

The stochastic yield of crop $i \in \{c, e\}$ in year *t* on land type $j \in \{h, l\}$ is denoted by y_t^{ij}. Price of crop *i* in year *t* is represented by p_t^i. In the case of the energy crop, 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^e, which is fixed over its lifespan. 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* in year *t* are represented by f_t^{ij} per unit of land and v_t^{ij} per unit of biomass produced, respectively. Because more than 80% of major crops' acreage is covered under federal crop insurance in the United States (Shields, 2013), in the simulation we include indemnity payments provided by crop insurance in farmer's profits from conventional crops. The indemnity payment per unit land in year *t* and on land type $j \in \{h, l\}$ for a conventional crop is specified as

$$\iota_t^{cj} = \max\left[\theta^c \mathrm{E}(y_t^{cj}) \max[p_t^{\mathrm{proj}}, p_t^{\mathrm{harv}}] - p_t^{\mathrm{harv}} y_t^{cj}, 0\right], \tag{7}$$

where θ^c is insurance coverage level for the conventional crop; p_t^{proj} and p_t^{harv} are projected price and harvest price established by Risk Management Agency (RMA) (2011), respectively. The profit per unit of land for the conventional crop in year *t* on land type *j* can be written as

$$\pi_t^{cj} = (p_t^c - v_t^{cj}) y_t^{cj} - f_t^{cj} + \iota_t^{cj} - (1-\tau)\mathrm{E}[\iota_t^{cj}], \tag{8}$$

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

Yield of the energy crop depends on the age of the crop within its lifespan of *T* years. We define the first $T^e < T$ years in the lifespan as the establishment period and years $T^e + 1$ to *T* is the mature period. Therefore, the energy crop's profit can be specified as

$$\begin{cases} \pi_t^{ej} = -f_t^{ej} I, & t \in \{1, \ldots, T^e\} \\ \pi_t^{ej} = (p_t^e - v_t^{ej}) y_t^{ej} - f_t^{ej} - (1-I) A(f_1^{ej}, \ldots, f_{T^e}^{ej}, r), & t \in \{T^e + 1, \ldots, T\}, \end{cases} \tag{9}$$

where *I* is a credit constraint indictor which equals 0 if there is no credit constraint and 1 if there is credit constraint; *r* is interest rate; and $A(w_1^j,...,w_{T^e}^j,r)$ is the annuity the farmer needs to pay back due to the loan for establishment cost. By inserting equations (8) and (9) into equation (1) we have the total profit the farmer obtains from her land. Based upon the prospect theory we have described in the Conceptual Framework section, the farmer's optimization problem can be specified as:

$$\max_{x^{ch},x^{eh},x^{o},x^{cl},x^{el}\geq 0} \sum_{t=1}^{30} \beta^{t-1}[\sum_{k\in\Omega^{Nt}} d_{kt} v(\pi_{kt})] \quad \text{s.t.} \quad x^{ch}+x^{eh}=s^h, \text{ and } x^o+x^{cl}+x^{el}=s^l, \tag{10}$$

where Ω^{Nt} is the set Ω under N draws (N = 1,000 in this study) and in year *t*. Set Ω^{Nt} is determined in the following way. First, for a given set of land allocation, $\{x^{ch},x^{eh},x^{o},x^{cl},x^{el}\}$, obtain the profit from the land under each draw. Second, take difference between the profit under each draw and the reference point profit, $\bar{\pi}$. Third, sort these differences and identify the number of losses and gains (i.e., negative differences are losses and positive differences are gains). Fourth, *m* and *n* in set Ω equal the number of losses and gains, respectively.

To prevent extreme changes in land use based on expected utility maximization and to allow for the possibility of other behavioral factors that may influence land use such as amenity values of the land (Skevas, Swinton, and Hayden 2014), for each county we limit the amount of land that can be converted to energy crop to 25% of the sum of low and high quality land in that county by following Chen et al. (2014). The average acreage of high and low quality land per county is 28,841 hectares and 4,507 hectares, respectively, prior to any land availability restriction for perennial energy crops (table 1). In what follows of this section we describe the data and parameters used in the simulation.

Crop yields

Due to the lack of large scale commercial production, we obtain county-level yield data, both on low quality land and high quality land, for miscanthus over the same temporal and geographical range by using DayCent model. 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). In Table 1 we can see that on high and low quality land, the average yield of miscanthus is 27.2 and 26.8 metric tons (MT)/ha. at 15% moisture. We also utilize DayCent to obtain simulated yields for corn grain, corn stover, and soybean grain on both high and low quality land even though historical data on these crops is available from National Agricultural Statistics Service (NASS).[2] This ensures consistency in methods underlying yield estimates across the various crops considered here. Additionally, use of DayCent-simulated corn and soybean yields implies that we do not need to rely on arbitrary assumptions that are used in previous studies to obtain corn and soybean yields on low quality land, or to obtain corn stover yield.

In DayCent model, the high quality land is approximated by land under crop production whereas the low quality land is approximated by land under pasture. Together with land management practice and observed daily weather information, properties of dominant soil type

[2] Yields of miscanthus on experiment sites are used to calibrate and validate the crop productivity parameters in the model that relate soil attributes and weather with crop yields. These sites are in Nebraska, Illinois, Kentucky, New Jersey, South Dakota, Louisiana, Michigan, Mississippi, Oklahoma, and Georgia (Hudiburg et al. 2016). The observed yield data on these sites were obtained from the national scale BETYdb database (EBI 2013). Data from NASS on row crop yields were used to calibrate the productivity parameters for row crops. The model is validated by examining the goodness of fit of a regression between observed and simulated yields for each crop from the national database. We refer readers to Hudiburg et al. (2016) and Dwivedi et al. (2015) for details about DayCent calibration and validation.

of cropland and pasture land in each county are used in input files to simulate crop yields on high quality land and low quality land, respectively. These properties of dominant soil type include percentage sand, percentage silt, percentage clay, pH, and soil depth. Overall, when compared with high quality land, low quality land has lower pH value (6.12 vs. 6.24) and has smaller soil depth (173.5cm vs. 177cm). Due to the lack of knowledge of how technology advances or learning in crop management will improve energy crop yields, we do not include an upward yield trend for miscanthus in the simulations. Introducing a yield trend parameter will add another layer of uncertainty to the results. Accordingly, to assure consistency we do not assume a yield trend for conventional crops either.

Corn is either grown in rotation with soybeans or in continuous corn. For counties that do not produce soybean (as evident by the lack of data on soybean yield in the dataset), we assume that corn is grown continuously. Table 1 presents summary statistics of data simulated by DayCent. Yields for corn grain harvested on high and low quality land are 139.1 bu/acre and 127.2 bu/acre respectively, that means on average corn grain yield on low quality land is about 9% lower than that on high quality land. For soybeans, however, the yield difference between low quality land and high quality land is about only 3%. Yields for corn stover harvested on high and low quality land are 2.6MT/ha and 2.4MT/ha, respectively. We assume that farmers harvest a fixed portion (i.e. 30%) of produced stover, as there is no consensus on how much corn stover should be left in the field to maintain soil organic carbon and to manage erosion.

Since we assume that miscanthus has a 15-year lifespan, we consider a 30-year period land tenure in which miscanthus completes two lifecycles. Miscanthus is assumed to have no harvestable yield in the first year, 50% of mature yield in the second year, and full mature yield in the third year and onward within a lifecycle. For miscanthus, we assume that there is a 10%

probability of complete crop failure. In the case of complete crop failure, the grower will have to re-establish in the second year, and therefore she will have no harvest in the second year but will have 50% of mature yield in the third year. In the case of complete crop failure, full mature yield is achieved in the fourth year. For simplicity we assume that re-establishment will be successful for sure. It's important to note that there will be establishment cost again in the second year in case of complete crop failure.

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 the state-level received prices from NASS to calculate realized profit of corn and soybean. Projected futures prices and harvest futures prices are used to calculate crop insurance indemnity for corn and soybeans. These futures prices are determined by following RMA (2011) rules based on Chicago Board of Trade (CBOT) futures prices. 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. Biomass price is assumed to be constant over the farmer's planning period. For simplicity we consider farm-gate biomass prices which do not include transportation cost from farms to bio refineries. We also assume that prices in each year are draws from the same price-yield joint distribution and do not consider the autocorrelation of prices across years. We expect that relaxing this assumption will not affect qualitative insights but will make analysis more complicated and less transparent.

Riskiness of Crop Production

To reflect stochastic crop yields, stochastic prices of corn and soybeans, and the correlations among these yields and prices, a joint yield-price distribution is estimated for each county for up to eight yields (i.e., corn grain, corn stover, soybean grain, and miscanthus on both high and low quality land) and two prices (i.e., corn and soybean grain prices). Since biomass price has been assumed to be a constant which will be varied to obtain supply curves of biomass, biomass price is not included in the joint yield-price distribution. We utilize the copula approach to model joint distributions due to its flexibility (Yan 2007; Du and Hennessy 2012; Zhu, Ghosh, and Goodwin 2008). For simplicity, we assume that the distribution of conventional crop prices does not change as land is converted to energy crop production; this is not an unreasonable assumption given the relatively small amount of land (and at least a portion of which is of low quality and used for pasture) being used for energy crop production.

Production Costs

The county-specific production costs of the crops considered in this study are the same as those in Chen et al. (2014). The method and assumptions underlying the calculation of county-specific production costs of miscanthus, 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). 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 production costs include expenses on fertilizer, labor, fuel and machinery for harvesting, baling, transportation, and storage.[3] We construct county-specific fixed and variable costs of production as in Chen et al. (2014). For corn stover, the average

[3] Wide ranges of estimates for miscanthus' establishment costs exist in the literature. For example: Lewandowski et al. (2003) document that the range is $348/ha. to $5,958/ha., whereas James, Swinton, and Thelen (2010) assume that low and high extremes of the costs are $562/ha. or 20,232/ha., respectively. Our establishment cost is about in the middle of these ranges and has been used by Jain et al. (2010), Chen et al. (2014), Miao and Khanna (2014), Dwivedi et al. (2015), and Hudiburg et al. (2016).

variable cost ($17.5/MT) is close to that of miscanthus whereas the average fixed cost ($48.5/ha.) is much lower than that of the miscanthus. Regarding conventional crops, the production costs that include fertilizer, chemicals, seeds, harvesting, drying, and storage 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 and the variable costs for a crop are assumed to be the same on low and high quality land within a county.

Risk and Loss Aversion Parameters

These parameters are directly obtained from the literature. Tversky and Kahneman (1992) took value of risk aversion parameter at α = 0.88 and value of loss aversion parameter at λ = 2.25. For the two parameters (i.e., γ and δ), this study has taken values of γ = 0.61 and δ = 0.69 directly from Tversky and Kahnemen (1992) as well, which they calculate using the experimental data. In the simulation we vary the parameters to study the impacts of loss aversion, risk aversion, and probability weighting.

Simulation Results

Summary statistics for crop profitability and riskiness when biomass price is assumed to be $50/MT and $100/MT are presented in Table 2. With biomass price at $50/MT, conventional crops (i.e., corn rotated with soybeans) on high quality land has the highest average profits i.e. $6263.55/ha. in 30 year Net Present Value (NPV) (NPV discount rate is taken at 10%). However, conventional crops on high quality land presents a high standard deviation as compare to others. Miscanthus on low quality land has the lowest average profits ($1303.8/ha.), as measured by NPV; it also has the lowest standard deviation as compare to others. When biomass price is at $50/MT, miscanthus has the average profits of $1,417.04/ha. and $1,303.8/ha., as measured by NPV, on high quality land and low quality land respectively. When biomass price is at $100/MT, the two numbers are $12,890/ha. and $12,635/ha., respectively, however, then miscanthus stands out as having the highest average profits on both types of land. To understand the geographical configuration of miscanthus profits, we have created four maps showing county level profitability. Figure 1 depicts 30 year mean net present value ($/ha.) for miscanthus under two biomass prices ($50/MT, and $100/MT) on two types of land (high quality and low quality land). We find that when biomass price increases from $50/MT to $100/MT, the number of counties having negative 30 year NPV for miscanthus decreases. We also find that NPV values increases, as when biomass price is at $50/MT, miscanthus has the average 30-year of NPV of profits at $1,417.04/ha. and at $1,303.8/ha., on high quality land and low quality land respectively. When biomass price is at $100/MT, the two numbers are $12,890/ha. and $12,635/ha., respectively. We also find that NPV goes down a little when we move from high quality land to low quality land. Figure 1 depicts that the lowest 30 year mean net present value for miscanthus is in northeast region and north-west part of mid-west region, and highest is in south part of mid-west region and north part of southern region.

For the crop riskiness, first we have employed coefficient of variation (CV) as a measure of profit risk, and we find that with biomass price at $100/MT, on average miscanthus (with CV of 0.34 on both types of land) is much less risky than conventional crops (with CV of 0.39 and 0.42 on high and low quality land respectively). However, if biomass price is set at $50/MT, then miscanthus (with CV around 2) is riskier than conventional crops (with CV around 0.45). To understand the geographical configuration about crop riskiness, the study has also calculated the average probability of having a loss from growing miscanthus on high and low quality land for each county under both $50/Mt and $100/Mt prices. Our results show that under a biomass price at $50/MT (a price close to the average breakeven price of biomass grown on marginal land as calculated by Miao and Khanna (2014)), the average probability of having a loss from growing miscanthus on cropland across the 1,836 counties is about 28.4%. On marginal land, the probability is about 29.8%. If biomass price is at $100/MT (a price close to the average breakeven price of biomass grown on cropland in Miao and Khanna (2014)), then the probability of having a loss for miscanthus on cropland is 2.4%. On marginal land the probability is 2.8%. Figure 2 depicts probability of loss on growing miscanthus under two biomass prices ($50/MT, and $100/MT) on two types of land (high quality and low quality land). We find that when biomass price increases from $50/MT to $100/MT, probability of loss on growing miscanthus decreases. There is not much difference in the probability of loss if we compare two types of land. Figure 2 depicts that the highest probability of loss on growing miscanthus is in northeast region and north-west part of mid-west region because miscanthus yields are very low in this area, and lowest is in south part of mid-west region and north part of southern region.

As discussed earlier, in this study, we have developed a conceptual framework under which a representative farmer optimally allocates a tract of land between a conventional use and a bioenergy crop (i.e., miscanthus) to maximize her decision-weighted utility under prospect theory. On the basis of these optimal land shares, we have calculated the total production for miscanthus and corn stover. Results presented in table 3 show that all else equal, miscanthus production is much lower when farmers are loss averse than when they are loss neutral. This indicates that farmers' loss preference plays a critical role in determining miscanthus production. When value of loss aversion parameter is larger than 1, then the farmer is loss averse and when it is equal to 1, then the farmer is loss neutral. In the results, when value of loss aversion parameter changes from 1.00 to 2.25, total miscanthus production decreases from 0.07 MMg. to 0.02 MMg.

under the $50/MT price and decreases from 236.41 MMg. to 140.66 MMg. under the 100/MT price. We find that, on cropland, when value of loss aversion parameter changes from 1.00 to 2.25, total miscanthus production decreases from 233.19 MMg. to 138.35 MMg. under the $100/MT price, which is a 41% decrease, whereas in case of pasture the same decrease is only 28%. Thus, loss aversion has a more negative effect on adoption on high quality land as compare to low quality land. This results further supports the previous literature on the risk analysis applied to perennial energy crops, which states that resistance of perennial species makes them less risky and more profitable on low quality land as compare to conventional crops. On the contrary, perennial energy crops are less profitable on high quality land as compare to conventional crops. This is also one of the main reasons that, this study is using land with two types of quality to compare the profitability and riskiness of perennial energy crops with different land uses.

In support of this analysis, figure 3 depicts county level total Miscanthus production under two biomass prices ($50/MT, and $100/MT) and two scenarios (loss neutral and loss averse). We find that when biomass price increases from $50/MT to $100/MT, expansion in miscanthus production occurs at the extensive margin (i.e., new counties join in miscanthus production) as more counties start producing miscanthus. However, when farmers' attitude toward loss changes from loss averse to loss neutral, then expansion in miscanthus production mainly occurs at the intensive margin (i.e., in counties already producing some miscanthus) as low and high quality lands in these counties are converted to miscanthus crop production. These results show that when farmers are facing a decision of adopting bioenergy crops, then their attitude toward loss matter. The more loss averse the farmer, the less likely is miscanthus production. The results also show that the effects of biomass prices and loss preferences on miscanthus production differ: an increase in biomass encourages miscanthus production at the extensive margin whereas an increase in loss tolerance encourages miscanthus production at the intensive margin. Figure 3 also depicts that the highest miscanthus production is in the Midwestern region excluding the north-west part of mid-west region, and then we can also see some distribution of miscanthus production in northeast and southern region.

For the corn stover production, there is a negligible decrease in production figures, when value of loss aversion parameter changes from 1 to 2.25 under the $50/MT price and a small increase in production figures, when value of loss aversion parameter changes from 1 to 2.25 under the $100/MT price. This represents a different behavior of farmer as compare to the case of miscanthus. Here prospect theory plays an important role in explaining this different behavior. Prospect theory deals with the scenario when farmers value gains and losses differently in order to take decisions. It also states that losses are treated in the opposite manner as gains. Results in table 2 support this explanation, as under a biomass price at $50/MT the average probability of having a loss from growing miscanthus across the 1,836 counties is about 29% on both types of land, whereas the average probability of having a loss from growing row crops is only less than 1% on both types of land. So, a farmer will treat these two crops differently while taking any decisions.

Conclusions

This study examines how farmers' preferences in risk and loss affect their decision regarding perennial energy crop adoption. It is a first study that takes into account farmers' loss aversion preference when modeling farmers' adoption of perennial energy crops in the rainfed area of the United States, thus extending the previous studies based on expected utility theory to study perennial energy crop production. Risk and loss preferences were analyzed by using a behavioral decision model, namely prospect theory. Our results points out that when farmers are faced with the decision of adoption of energy crops, then their attitude toward loss matter. As compare to a loss neutral farmer, a loss averse farmer is less likely to adopt miscanthus. Our results also demonstrate that loss aversion has a larger negative impact on adoption on high quality land as compare to low quality land, which aligns with the previous literature that perennials energy crops are generally less profitable than conventional crops on high quality land, and more profitable than conventional crops on low quality land.

In this study, geographical configuration of risk of returns is analyzed as well. This study provides the first comprehensive economic analysis about the risk profile of profits from growing miscanthus and from harvesting corn stover across the rainfed United States. Our results show that expected utility theory and prospect theory predict different geographical configuration of miscanthus adoption, indicating the importance of the decision rule that farmers use in making crop choices in determining their incentives to grow miscanthus.

Our results suggest that policymakers should target those areas where share of low quality land is more in farmland, as adoption on marginal land is more probable. The maps shown in figure 1, 2, and 3 provides important reference to potential farmers of the perennial energy crops regarding the profit and loss profile of energy crops, and also facilitate potential cellulosic biorefinery investors with geographical configuration of areas where the perennial energy crop production is most viable in order to facilitate their plant location decisions. As the analysis show that the risk of crop failure significantly hinders farmers’ adoption for miscanthus, we recommend policymakers to target policies that absorb such a risk, in order to encourage farmers for adoption of energy crops, such as the establishment cost subsidy and annual payment in the Biomass Crop Assistance Program (BCAP). The conclusions of this paper reveals the importance of accounting for producers' loss preferences when studying their bioenergy crop adoption decisions.

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

			Mean	Std. Dev.	Min.	Max.
Yields[b]	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
	corn stover harvested on high quality land (MT/ha.)		2.6	0.6	0.01	6.9
	corn stover harvested on low quality land (MT/ha.)		2.4	0.54	0.02	6.5
	corn grain on high quality land (bu./acre)		139.1	39.2	0.7	304.5
	corn grain on low quality land (bu./acre)		127.2	34	0.5	297.3
	soybean grain on low quality land (bu./acre)		42.9	20	1	112.3
	soybean grain on low quality land (bu./acre)		41.5	19.5	0.1	109.2
Costs[c]	miscanthus (year 1)	establishment cost $/ha	3108	46.2	3033	3247.9
	miscanthus (years 2-15)	variable cost ($/MT)	17.2	2	14.2	19.6
		fixed cost ($/ha.)	166	29	113.1	258.7
	corn stover	variable cost ($/MT)	17.5	2.1	12.6	21.7
		fixed cost ($/ha.)	48.5	10.9	20.3	75
	corn	variable cost ($/bu.)	1.3	0.4	0.8	2.7
		fixed cost ($/acre)	136.5	28.6	91.4	221.8
	soybean	variable cost ($/bu.)	1.5	0.3	0.8	1.8
		fixed cost ($/acre)	107.4	45.4	59.4	195.9
Price ($/bu)	corn	projected price	4.1	1.2	2.6	7.8
		harvest price	3.8	1.3	2.2	8.1
		received price[d]	4	1.3	1.9	9.1
	soybeans	projected price	9.5	2.9	5.4	17.2
		harvest price	9.3	3	5.4	19.3
		received price[d]	9.2	2.6	5.3	17.3
Acreage (ha. per county)		high quality land	28,841	38,228	202	252,448
		low quality land[e]	4,507	4,680	0	42,154

Note: [a] Costs and prices are in 2010 dollars; MT refers to metric tons of biomass with 15% moisture content. [b] Corn grain and stover yields are under corn-soybean (CS) rotation. Under corn-corn rotation, yields are assumed to be 12% lower than that under CS rotation. [c] The first year costs of miscanthus only consist of establishment cost. [d] The received price is state-level annual average price while the projected price and harvest price are futures prices calculated following RMA (2011). [e] Land characterised as cropland pasture and idle (net of CRP acres) reported by NASS in 2007.

Table 2. Profitability and Riskiness of Row Crops and Miscanthus (30 Year NPV)

When biomass price is $50/Metric ton

	Mean	Std. Dev.	Min.	Max.	CV
Profitability ($/ha.):					
Row crops profits' NPV on high quality land	6263.55	2699.77	-4110.58	36748.24	0.44
Row crops profits' NPV on low quality land	5579.86	2584.44	-3390.09	37479.85	0.47
Miscanthus profits' NPV on high quality land	1417.04	2062.66	-9941.88	12860.58	1.74
Miscanthus profits' NPV on low quality land	1303.8	2041.65	-9564.81	11792.11	2.07
Probability of having a Loss (in percentage):					
For row crops on high quality land	0.89	4.88	0	71.5	5.49
For row crops on low quality land	0.9	4.84	0	68.3	5.4
For miscanthus on high quality land	28.38	23.91	2.3	100	0.84
For miscanthus on low quality land	29.88	25.17	0	100	0.84

When biomass price is $100/Metric ton

	Mean	Std. Dev.	Min.	Max.	CV
Profitability ($/ha.):					
Row crops profits' NPV on high quality land	7162.11	2755.96	-3004.88	38666.98	0.39
Row crops profits' NPV on low quality land	6398.33	2655.51	-2793.94	38715.82	0.42
Miscanthus profits' NPV on high quality land	12890.3	4356.35	-9517.3	40815.8	0.34
Miscanthus profits' NPV on low quality land	12635	4309.48	-9443.76	38955.06	0.34
Probability of having a Loss (in percentage):					
For row crops on high quality land	0.34	2.8	0	60.2	8.1
For row crops on low quality land	0.32	2.7	0	54.5	8.49
For miscanthus on high quality land	2.41	7.62	0	83.5	3.16
For miscanthus on low quality land	2.84	8.47	0	87.2	2.98

Table 3. Total Production for Miscanthus & Cornstover (Million Mg.)

Biomass Price (per MT.)	$50	$50	$100	$100
Loss Aversion Parameter	1.00	2.25	1.00	2.25
Total Production for Miscanthus	0.07	0.02	236.41	140.66
On cropland	0.07	0.02	233.19	138.35
On pasture	0.00	0.00	3.22	2.31
Total Production for Corn stover	99.73	99.71	81.84	88.59
On cropland	88.84	88.84	74.65	80.74
On pasture	10.90	10.87	7.19	7.85

Note: When value of loss aversion parameter is larger than 1, then the farmer is loss averse and when it is equal to 1, then the farmer is loss neutral.

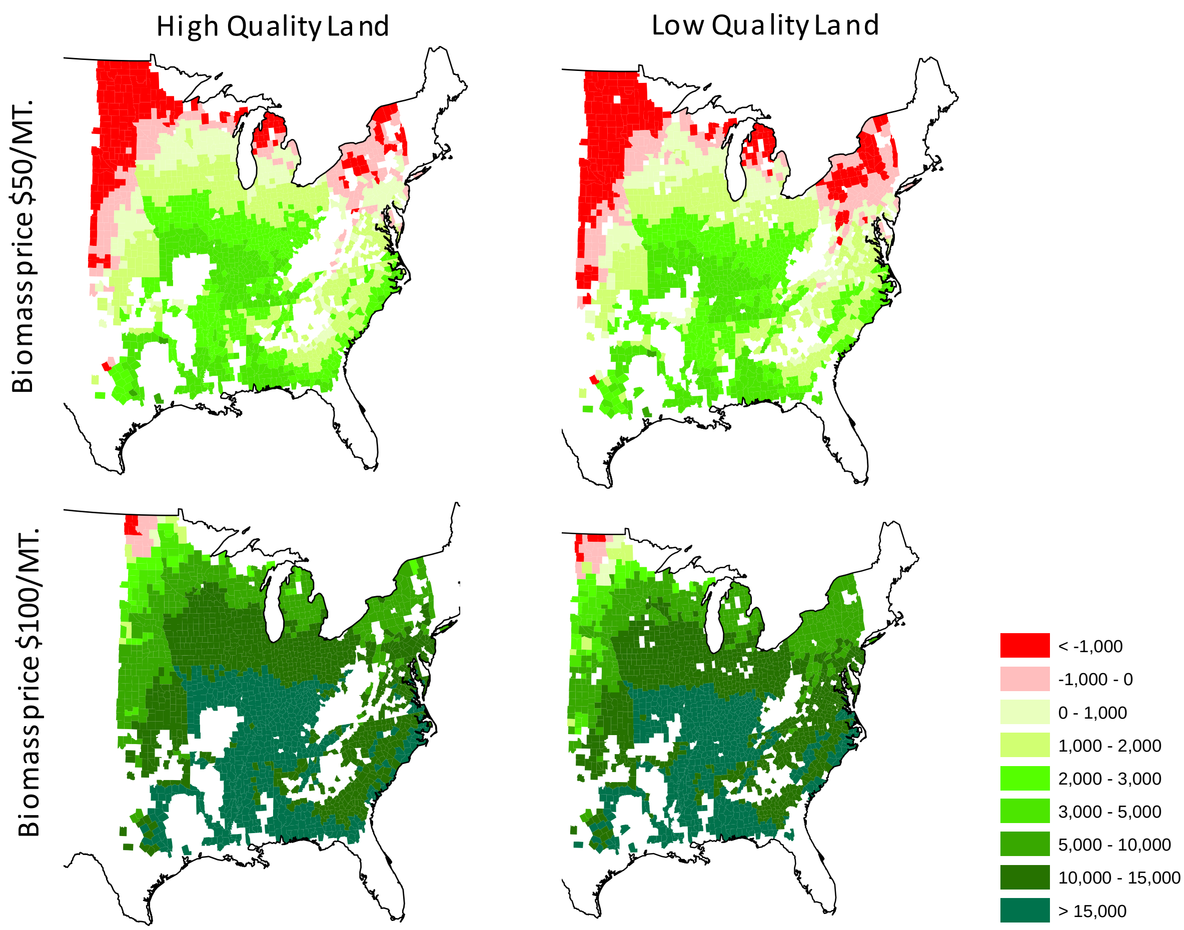

Figure 1. 30 year Mean Net Present Value ($/ha.) for Miscanthus under two different biomass prices.

Note: NPV discount rate is taken as 10%.

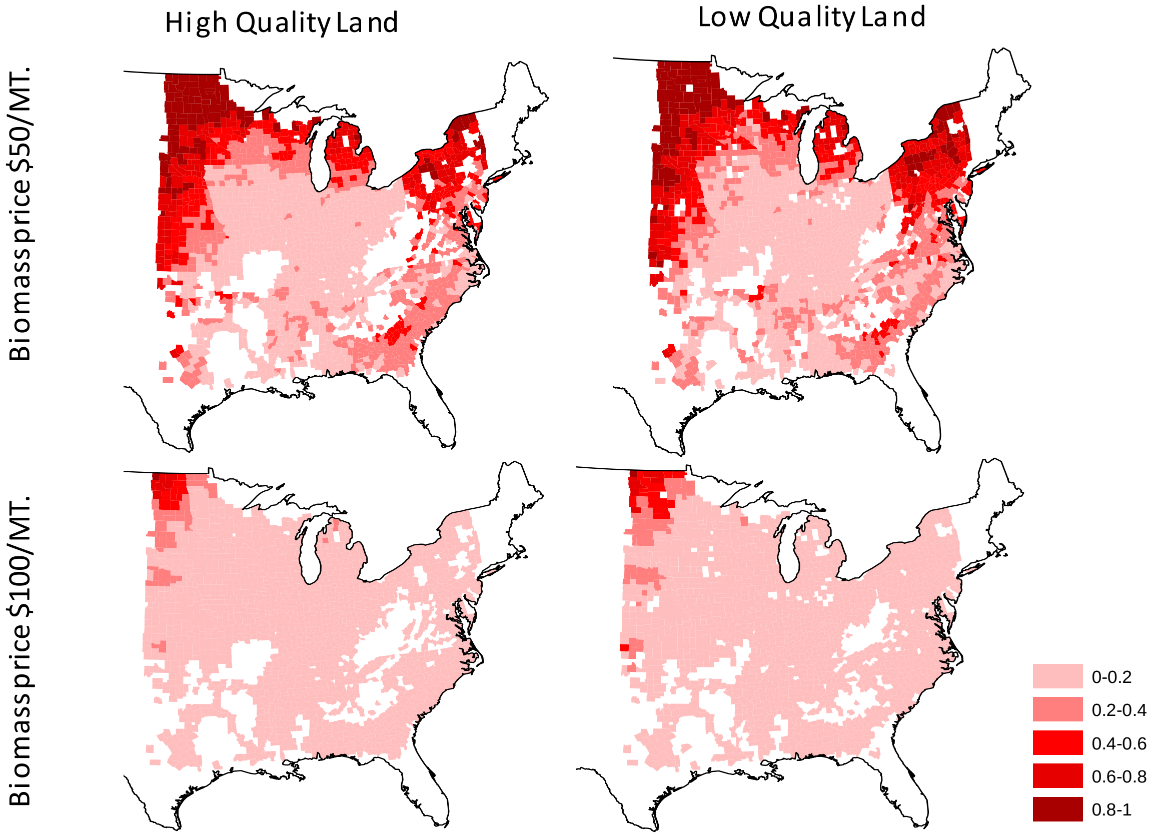

Figure 2. Probability of Loss for growing Miscanthus on high quality land and low quality land under two different biomass prices.

Note. In DayCent model, the high quality land is approximated by land under crop production whereas the low quality land is approximated by land under pasture.

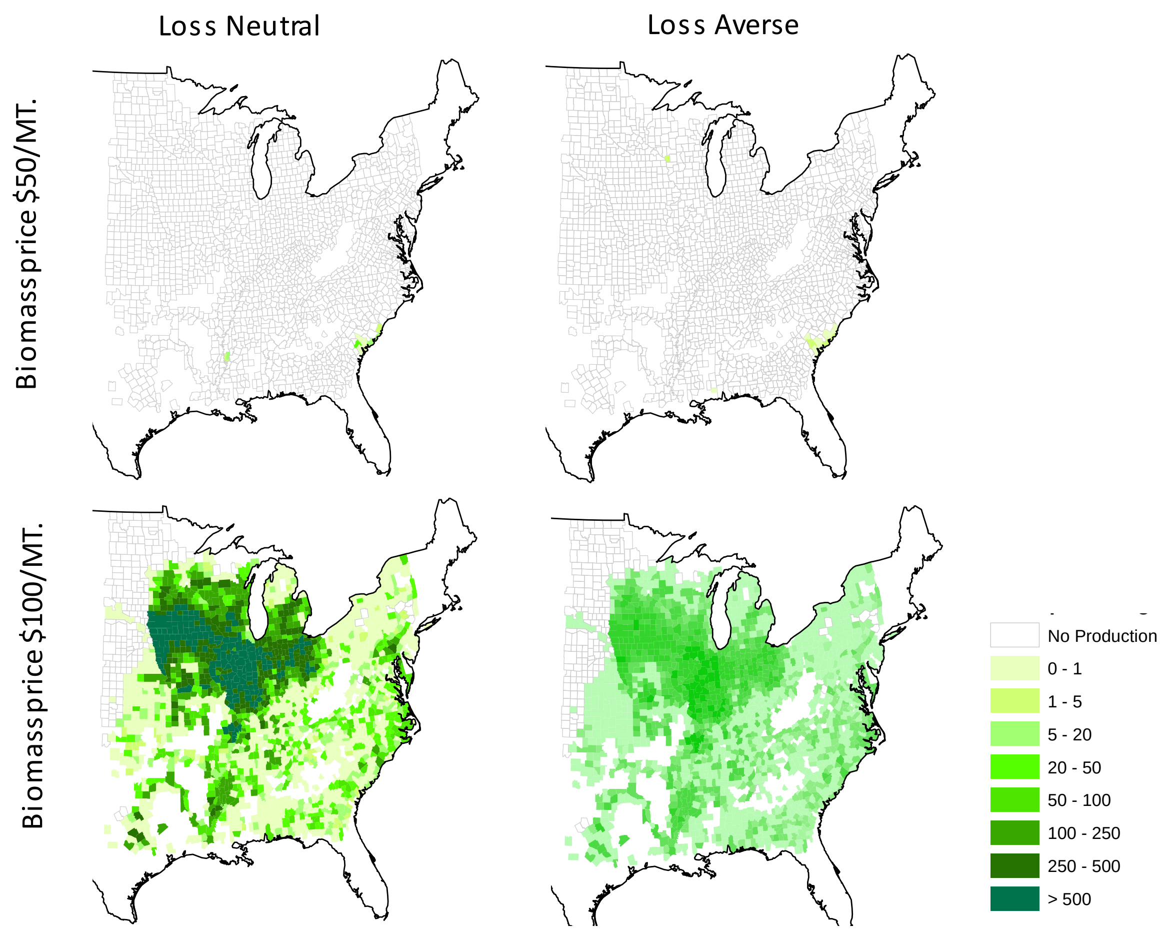

Figure 3. Average County-level Miscanthus production (1,000 metric tons) under two different biomass prices for loss neutral and loss averse scenarios