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Costs of Meeting the Cellulosic Biofuel Mandate with an Energy Crop with Establishment Cost and Yield Risk: Implications for Policy

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We develop a framework to examine the extent to which farmers' risk and time preferences, availability of credit to cover establishment cost, and crop insurance for conventional crops may influence farmers' decision to allocate land to a perennial energy crop and, therefore, the total costs of meeting a cellulosic biofuel mandate using this crop. We also investigate the cost-effectiveness of two supplementary policies to the mandate: an establishment cost subsidy and subsidized energy crop insurance, which may achieve the targeted level of biomass production more cost-effectively than the mandate alone. We apply this framework to examine the total costs and land requirements of providing biomass for meeting a one-billion-gallon cellulosic biofuel mandate by using miscanthus as a feedstock while accounting for temporal and spatial variability in miscanthus yields relative to those of conventional crops at a county level across the U.S. rainfed region.

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Concerns about energy security, dependence on fossil fuels, and climate change have led to policy support for biofuels in recent years. Recognition of the competition for land posed by crop-based biofuels has shifted the emphasis towards cellulosic biofuels that utilize crop or forest residues or dedicated energy crops as feedstocks. The Renewable Fuel Standard (RFS) established by the Energy Independence and Security Act (EISA) of 2007 mandates 36 billion gallons of biofuel to be consumed annually by 2022, of which at least 16 billion gallons must be cellulosic biofuels.[1] The cost of meeting this mandate will depend not only on the availability of a low cost technology for converting cellulosic biomass to ethanol but also on the availability of low cost biomass.

Studies show that energy crops, such as miscanthus (*Miscanthus* × *giganteus*) and switchgrass (*Panicum virgatum*), are promising sources of feedstock for cellulosic biofuel industry due to their relatively high yields and potential to provide a range of environmental benefits (Beach, Zhang, and McCarl 2012; Chen et al. 2014; Heaton, Dohleman, and Long 2008). These crops also have the potential to be grown on low quality land without significant loss in per acre yield and thereby mitigate the competition for land between food and fuel as compared to grain-based biofuels (Valentine et al. 2012; Dwivedi et al. 2014). Understanding the incentives and barriers to growing energy crops is critical for evaluating the potential (or specifically, the costs) of meeting the cellulosic biofuel mandate using energy crops.

Energy crops are typically perennials with a lifespan of 10 to 15 years. Their production involves a one to three-year establishment period during which a farmer would incur fixed cost of establishing these crops and forgo returns that could have been earned under alternative use of that land (such as growing conventional crops). In the absence of credit, the establishment cost has to be borne upfront instead of being annualized over the lifespan of the crop. Moreover, the production of these crops also exposes farmers to a yield risk that may differ from that of existing crops (Miao and Khanna 2014). This could create incentives for risk averse farmers to allocate a portion of their land to these crops to diversify their crop portfolio. On the other hand, risk aversion could also create disincentives for farmers to switch away from conventional crops supported by subsidized crop insurance.[2]

Studies suggest that farmers tend to be more risk averse than non-farm business owners (Roe 2013; Menapace, Colson, and Raffaelli 2013) and that their discount rates can be as high as 40% (Duquette, Higgins, and Horowitz 2012). High degree of risk aversion and high discount rate, together with a constraint on credit, can raise the price at which farmers would be willing to supply a given amount of a perennial energy crop with high upfront establishment costs. They can also affect the spatial pattern of land allocated to energy crop production; this has implications for the amount of land that will be needed to meet a given level of biofuel production using an energy crop. Thus, the risk and time preferences of farmers combined with a credit constraint and spatial variability in energy crop yields and riskiness can result in a market failure with inefficient outcomes in the form of higher cost of cellulosic biofuels and larger diversion of land to produce them. This provides a rationale for policy intervention by a risk neutral government with a relatively low discount rate.[3]

This paper develops a framework to examine the extent to which the risk and time preferences and credit constraints will affect a farmer's decision about the share of cropland to allocate to an energy crop. This framework recognizes that farmers' willingness to grow energy crops will depend not only on the returns from energy crop production relative to alternative use of the land but also on their riskiness, the temporal profile of their returns, and their potential to diversify the crop portfolio of farmers. We also analyze the effects of two policies, an establishment cost subsidy and subsidized crop insurance for energy crops, that mitigate the high upfront costs and relative riskiness of energy crop production on the incentives to allocate land to energy crop production.

We apply this framework to examine the cost of meeting a binding one-billion-gallon cellulosic biofuel mandate using an energy crop. For simplicity, we focus here on a single energy crop, miscanthus, which can be grown under a wide range of growing conditions in the rainfed region of the United States.[4] Corn and soybeans are used as representatives for conventional crops. We expand the conceptual framework to include the potential to grow these crops on high and low quality land. We then use county-specific simulated yields of miscanthus on high and low quality land and observed yields of corn and soybeans under 27 years of weather conditions to incorporate both the temporal and spatial variability in yields. Copula method is applied to model county-level joint distributions of crop yields and prices. These distributions are used to design actuarially fair crop insurance for corn, soybeans and miscanthus while accounting for correlated risks of a crop portfolio with multiple crops.

We examine the effect of risk and time preferences and credit constraint on the county-specific allocation of land to energy crops to meet the billion gallon mandate. We compare the cost-effectiveness of an establishment cost subsidy and subsidized crop insurance for miscanthus in minimizing the total cost of meeting the mandate, where the total cost is defined as the summation of the aggregate private costs of biofuel production and the government cost of supporting a policy instrument. The subsidy rates for each policy are selected to minimize the total cost. We also examine the effects of these policies on the spatial pattern of energy crop production in the rainfed US and its implications for the total land requirement to meet the mandate.

We find that a high degree of risk aversion, high discount rate, credit constraint and availability of crop insurance for corn and soybeans can increase the cost of producing enough biomass for a one-billion-gallon biofuel mandate by up to 43% and increase the land required by 16% as compared to otherwise. We also find that in most cases the cost-effective energy crop insurance subsidy rate is 0% while the cost-effective establishment cost subsidy rate is 100%. Relative to the case with no policy intervention for energy crops, the energy crop insurance reduces the total costs of meeting the 1 billion gallon mandate by 0.3% whereas establishment cost subsidy reduces these costs by 34%. However, an establishment cost subsidy increases incentives to grow miscanthus in counties where average yield is lower but its yield riskiness is negatively correlated with that of corn in order to diversify the crop portfolio. It, therefore, increases the acreage required to be converted to the miscanthus to meet the one-billion gallon mandate; this increase could be as high as 19% when the degree of risk aversion and the discount rate are high. In contrast, energy crop insurance would decrease land requirements by 2%. Our findings suggest the need to consider both the direct effects of these policies and their unintended consequences in policy design and selection.

Background and Literature Review

We now describe the mechanism by which a blend mandate in the RFS, if binding, results in biofuel producers being compensated for their marginal cost of production that is higher than the gasoline energy equivalent market value of biofuel. Our focus here is on the feedstock cost component of the marginal cost of producing biofuel. We analyze some of the factors likely to influence this cost in the case of energy crops, such as the risk and time preferences of farmers and the potential for reducing these costs by supplementing the blend mandate by policies that reduce riskiness and upfront costs of growing energy crops.

The RFS requires refineries or importers that supply gasoline for domestic use to blend biofuel proportional to the amount of gasoline they process. Compliance with the mandate is achieved by associating a Renewable Identification Number (RIN) with each unit of biofuel. When ethanol is blended with gasoline, RINs are detached from ethanol and can be traded in the RIN market and obligated parties are required to acquire enough RINs to meet their blend mandate every year. With a binding mandate the price of RINs is the gap between the marginal cost of producing biofuel and its gasoline energy equivalent value.

Therefore, this RIN price represents the cost of compliance with the mandate for blenders. A well-functioning RIN market ensures that the price of biofuel paid by blenders is equal to its marginal cost of production to biorefineries (Miao, Hennessy, and Babcock, 2012) and enables biorefineries to pay farmers the biomass price needed to induce sufficient feedstock production to meet the mandate.

Various policy incentives are currently being provided to supplement the RFS. These include the Cellulosic Biofuel Production Tax Credit (CBPTC) which provides a $1.01 per gallon tax credit for blending cellulosic biofuels with fossil fuels. With a binding mandate, it simply represents a transfer from the government to biorefineries and will not affect the total (private and public) cost of meeting the mandate. On the other hand, a policy such as the Biomass Crop Assistance Program (BCAP), established in 2008 and re-authorized in the Agricultural Act of 2014, provides an establishment cost subsidy for energy crops which lowers the upfront costs and smoothes out net returns over time.

Other programs, such as pilot crop insurance programs have been proposed for energy crops to offset the disincentives for switching from conventional crops that are usually covered by subsidized crop insurance. A survey of farmers by Fewell, Bergtold, and Williams (2011) suggests that availability of insurance programs for energy crop production will be a key factor in incentivizing farmers to grow energy crops. Designing an insurance program for energy crops has been identified as a priority area for research by the Agricultural Act of 2014, but the lack of historical data on energy crop yields has limited the development of such programs to a few energy crops (Farm Service Agency 2013).

Our study adds to the existing literature on biofuels and crop choices in several ways. Existing studies examining the efficiency of various biofuel and climate policies, such as the RFS, Low Carbon Fuel Standard, carbon tax, and various federal tax credits that promote the use of cellulosic biofuels, assume that farmers are risk neutral and have low discount rates of

2% ~ 4% (e.g., Beach, Zhang, and McCarl 2012; Chen et al. 2014; Khanna et al. 2011; and Murray et al. 2014). The findings of these studies are likely to be biased if farmers are risk-averse and use high discount rates when making decisions about converting land to energy crops. Our study examines the costs of producing a certain amount of biomass and compares the cost-effectiveness of energy crop insurance and establishment cost subsidy while accounting for the risk and time preferences of farmers. To the best of our knowledge this is the first study to do so.

A body of studies has examined the effect of crop insurance on land use and cropping decisions (e.g., Claassen, Cooper, and Carriazo 2011; Miao, Hennessy, and Feng 2012, 2014; and Woodard et al. 2012). However, all of these studies consider the discrete choice of allocating land either completely to one practice or the other. These studies do not incorporate the incentives of farmers to adopt a mix of crops (or practices) to diversify their portfolio and reduce its riskiness. Using a portfolio model, our study considers a continuous choice of allocating a portion of available land to energy crop production and incorporates the potential portfolio diversification benefits from adopting an energy crop. By examining the interaction between energy crop insurance and energy crop's diversification benefit, this study extends the existing literature on the effect of crop insurance on crop choice. We show that the outcomes depend on the combination of risk and time preferences, and presence of a credit constraint. An insurance program, even if actuarially fairly rated, may discourage the adoption of an insured crop because it reduces the diversification benefits of that crop.

Our simulated data on energy crop yields allows us to develop county specific distributions of yields and to quantify yield riskiness. We extend previous analysis of the effects of risk and uncertainty on the incentive to convert land to an energy crop that considers a representative farmer (Song, Zhao and Swinton 2011) or a single state (Dolginow et al. 2014) by incorporating the heterogeneity in riskiness and returns to energy crop production across the rainfed United States. Additionally, unlike Dolginow et al. (2014) where biomass price is exogenously fixed based on its energy content, we endogenously determine the price of biomass needed to achieve a targeted level of production.

There is also a large literature examining the impact of risk aversion on crop choice between two risky annual crops, following the seminal work of Just and Zilberman (1983) (see review in Chavas, Chambers, and Pope 2010). Our analysis contributes to this literature by showing that risk aversion creates a preference for certainty of returns not only within a period but also across periods. As a result, risk aversion has a more adverse effect on the incentives to convert land from an annual crop to a perennial crop with a large upfront cost, in a manner similar to that of a high discount rate. Bocquého and Jacquet (2010) illustrate the importance of credit constraint and risk aversion on farmers' adoption of energy crops but do not compare the effectiveness of alternative policy interventions to induce their production.

Conceptual Framework

We develop a conceptual model of a farmer's decision problem of allocating a tract of land between a conventional crop and an energy crop to maximize expected utility while taking crop prices and policy incentives as given. We examine how the optimal land allocation between the two crops is affected by the farmer's risk and time preferences, the presence of insurance for energy and conventional crops, an establishment cost subsidy and credit availability to finance the establishment of the energy crop. We then use this framework to specify the total costs of providing a given amount of biomass from energy crops under various preference and policy parameters.

Suppose a farmer has one unit of homogenous land that can be devoted to a conventional crop (denoted as c) and an energy crop (denoted as e). For simplicity, we represent the perennial nature of the energy crop by considering two periods in its lifespan: an establishment period and a mature period. In the establishment period the farmer incurs costs of establishing the energy crop and does not obtain any harvest from this crop. In the mature period the farmer incurs fixed and variable costs and gains revenue from the energy crop. Let $w > 0$ be the establishment cost per unit of land under energy crop and $\theta \in [0,1]$ be the establishment cost subsidy rate. Moreover, the farmer may face a credit constraint with no access to a loan that finances the establishment cost of the energy crop. We denote the credit constraint indicator by I which equals 0 if there is no credit constraint and 1 if there is credit constraint. Therefore, the profit per unit of land from growing energy crop in the establishment period is $-(1-\theta)wI.$ In the mature period, we denote the stochastic profit per unit of land from growing energy crop as $\pi^e = \mu^e + \epsilon^e$ where μ^e is the mean of energy crop profit and ϵ^e is a stochastic term with $\mathrm{E}(\epsilon^e) = 0$ and $\mathrm{Var}(\epsilon^e) = \sigma^e.$

We assume that the conventional crop is an annual crop which completes one lifecycle within each period and the profits of the conventional crop in the two periods have independent and identical distributions. Therefore, the profit per unit of land in a period from growing the conventional crop is $\pi^c = \mu^c + \epsilon^c$ where μ^c is the mean of conventional crop profit and ϵ^c is a stochastic term with $\mathrm{E}(\epsilon^c) = 0$ and $\mathrm{Var}(\epsilon^c) = \sigma^c.$ We represent the correlation between the profits of the conventional crop and the energy crop by $\mathrm{cov}(\epsilon^c, \epsilon^e) \equiv \sigma^{ce}.$

The farmer chooses a portion of land $x \in [0,1]$ to be devoted to the energy crop at the beginning of the establishment period. Assuming full utilization of land, the land devoted to the conventional crop is $1-x.$ Let $\pi_0(x)$ and $\pi_1(x)$ be the farmer's profit from the entire tract of land in the establishment period and mature period, respectively. We have

$$\begin{aligned} \pi_0(x) &= (1-x)(\mu^c + \epsilon^c) - x(1-\theta)wI, \\ \pi_1(x) &= (1-x)(\mu^c + \epsilon^c) + x(\mu^e + \epsilon^e). \end{aligned} \tag{1}$$

The farmer's problem is to choose *x* to maximize the present value of expected utility over the two periods. That is,

$$\max_{x\in[0,1]} \mathrm{E}[\mathrm{u}(\pi_0(x))+\beta u(\pi_1(x))], \tag{2}$$

where $u(\cdot)$ is utility function with $u'(\cdot)>0>u''(\cdot)$; and $\beta\in[0,1]$ is discount factor reflecting the farmer's time preference. Assuming an interior solution, the first order condition of the maximization problem in (2) can be written as,

$$H(x)\equiv \mathrm{E}[\mathrm{u}'(\pi_0(x))\frac{\partial\pi_0(x)}{\partial x}]+\beta\mathrm{E}[u'(\pi_1(x))\frac{\partial\pi_1(x)}{\partial x}]=0. \tag{3}$$

Applying the implicit function theorem, we have $\partial x^*/\partial\eta=-\partial H/\partial\eta\big/\partial H/\partial x^*$, where x^* is the solution of equation (3) and η is an arbitrary exogenous parameter. It is readily checked that $\partial H/\partial x^*<0$ because $u''(\cdot)<0$. Therefore, sign($\partial x^*/\partial\eta$) = sign($\partial H/\partial\eta$). Following Just and Zilberman (1983), we utilize the first-order Taylor series approximation of $u'(\cdot)$ to approximate $H(x)$ in equation (3). Specifically, $u'(\pi_t)=u'(\bar{\pi}_t)+u''(\bar{\pi}_t)[\pi_t-\bar{\pi}_t]$, where $\bar{\pi}_t=\mathrm{E}(\pi_t)$ and $t\in\{0,1\}$.

For analytical tractability, we assume a constant absolute risk aversion (CARA) utility function with form $u(\pi)=-e^{-\lambda\pi}$, where λ is the absolute risk aversion parameter. CARA utility functions are widely used in the literature due to their simplicity and irrelevance of initial wealth (Hennessy, Babcock, and Hayes 1997; Bocquého and Jacquet 2010). After some algebra that is presented in Item A of Supporting Information (SI), equation (3) can be re-written as,

$$H(x)=\underbrace{u'(\bar{\pi}_0)[\lambda(1-x)\sigma^c-(\mu^c+(1-\theta)wI)]}_{\text{Term I}}+\underbrace{\beta u'(\bar{\pi}_1)[(\mu^e-\mu^c)-\lambda\Omega]}_{\text{Term II}}=0, \tag{4}$$

where $\Omega\equiv x\sigma^e-(1-x)\sigma^c+(1-2x)\sigma^{ce}$. One can check that Ω is the marginal effect of *x* on the variance of mature period profit, $\pi_1(x)$. Terms I and II in equation (4) are the marginal utility of *x* in the establishment period and mature period, respectively. They can be interpreted as follows: in the establishment period, the disutility from an increase in the share of land under the energy crop, *x*, is the reduction in utility caused by the forgone mean profit from the conventional crop and the incurred establishment cost for the energy crop, which is expressed by $u'(\bar{\pi}_0)[\mu^c + (1-\theta)wI]$. However, an increase in *x* will reduce the variance of profit in the establishment period, which will increase expected utility by $u'(\bar{\pi}_0)[\lambda(1-x)\sigma^c]$. Based on the assumption that land is fully utilized, one can show that Term I is negative (see Item B of SI). Rearrange this negative Term I we obtain

$$\lambda < \frac{\mu^c + (1-\theta)w}{(1-x)\sigma^c}, \tag{5}$$

which excludes an extreme case in which the farmer is so risk averse that an increase in energy crop share, *x*, may increase her utility in the establishment period by reducing the variance of her returns in that period.

Term II in equation (4) describes the benefit and cost in the mature period from an increase in energy crop share, *x*. The term $\beta u'(\bar{\pi}_1)(\mu^e - \mu^c)$ represents the discounted utility change caused by a change in mean profit per unit land when *x* increases. Since Ω is the change in variance of profit per unit land in the mature period due to a marginal increase in *x*, the term $-\beta u'(\bar{\pi}_1)\lambda\Omega$ measures the discounted utility change caused by an increase in *x* through its effect on the variance of profit. If $\Omega < 0$ then $-\beta u'(\bar{\pi}_1)\lambda\Omega > 0$. This indicates that if an increase in *x* decreases the variance of profit in the mature period, then it will increase farmer's expected utility by $-\beta u'(\bar{\pi}_1)\lambda\Omega$.

Effect of Crop Insurance on Incentives for Energy Crop Production

We now examine the effect of the presence of actuarially fair insurance for energy crops and for conventional crops on optimal land allocation. Actuarially fair insurance if un-subsidized will not affect the mean of energy crop profit. However, the variance of profit will be reduced because the left-tail profit risk is covered. From equation (4) we see that when $\sigma^{ce} = 0,$ then $\partial H \,/\, \partial \sigma^{e} = -\beta \lambda x u'(\overline{\pi}_1) < 0$ and $\partial H \,/\, \partial \sigma^{c} = \lambda (1-x)[u'(\overline{\pi}_0) + \beta u'(\overline{\pi}_1)] > 0.$ This indicates that if the profits of conventional crops and energy crops are uncorrelated, then the presence of unsubsidized insurance for energy crops (respectively, conventional crops) will increase (respectively, decrease) the optimal land portion devoted to the energy crop.

If, however, the profits of the conventional crop and energy crop are correlated, then the presence of unsubsidized energy crop insurance may not always encourage energy crop production. This is because the presence of energy crop insurance will not only affect the variance of energy crop profit, but also affect the correlation between energy crop profit and conventional crop profit, σ^{ce}. Intuitively, if profits from the two crops are negatively correlated then the diversification benefit, which results from reducing overall profit variance, of growing an energy crop is high. When insurance for energy crop becomes available the negative correlation of the profits between the two crops is weakened and so is the diversification benefit of the energy crop. If the reduced diversification benefit dominates the benefits of energy crop insurance in reducing profit risk, then the optimal quantity of land devoted to energy crop will be reduced by the presence of energy crop insurance. The presence of conventional crop insurance will also reduce the need for diversification by growing an energy crop and increase the relative riskiness of growing the energy crop, thereby reducing the incentives to grow the energy crop. This result provides theoretical support for empirical findings that the availability of crop insurance encourages crop specialization (O’Donoghue, Roberts, and Key 2009).

To analyze the effect of an insurance premium subsidy on land portion devoted to the energy crop, we note that subsidizing crop insurance premium is equivalent to increasing the mean profit of the associated crop because the insurance premium is simply a constant subtracted from crop revenue. A premium subsidy offsets a part of premium and increases the mean profit. We can analyze the effect of a premium subsidy on land allocation by analyzing the effect of an increase in the mean profit from equation (4) (seeItem C in SI):

$$\frac{\partial H}{\partial \mu^e} = \beta u'(\overline{\pi}_1)[1 - \lambda x(\mu^e - \mu^c - \lambda \Omega)]. \tag{6}$$

From (4) and (5) we know that $\lambda x(\mu^e - \mu^c - \lambda\Omega) > 0$. Therefore, the sign of $\partial H / \partial \mu^e$ is undetermined without further information regarding the risk aversion parameter, λ, the difference between energy crop profit and conventional crop profit, $\mu^e - \mu^c$, and the marginal effect of *x* on the variance of mature period profit, Ω. *Ceteris paribus*, an increase in the mean of energy crop profit, μ^e, will affect the marginal utility of land devoted to the energy crop (i.e., *x*) in two opposite ways. First, an increase in μ^e will increase marginal utility of *x* because now one unit of energy crop land provides more returns relative to the conventional crop. This effect is captured by $\beta u'(\overline{\pi}_1)$ in equation (6). Second, an increase in μ^e will increase the overall profit of the farmer and hence decrease the marginal utility of a given *x* as shown by $-\lambda\beta u'(\overline{\pi}_1)x[(\mu^e - \mu^c) - \lambda\Omega] = \beta u''(\overline{\pi}_1)x[(\mu^e - \mu^c) - \lambda\Omega] < 0$ in equation (6). When a farmer is very risk averse (with a large λ), then the second effect may dominate the first one. In this case, if the mean profit of energy crop increases and if reducing energy crop land can reduce the overall variance of the portfolio, then it may be optimal to do so.

Effects of Establishment Cost, Establishment Cost Subsidy, and Credit Constraint

Based on expressions (4) and (5) and derivations shown in Item D of SI, we show that whenever the farmer is credit constrained (i.e., $I = 1$) then $\partial H / \partial \theta > 0$ and $\partial H / \partial w < 0$. This result indicates that when the farmer is credit constrained then an increase in establishment cost, *w*, will decrease the share of land devoted to energy crops whereas an increase in establishment cost subsidy rate, θ, will increase the share of land devoted to energy crops.

When the farmer is not credit-constrained ($I = 0$), then the utility in the establishment period will not be affected by a change in a decrease in establishment cost, *w* or in establishment cost subsidy rate, θ. This is because the farmer can finance the portion of establishment cost that is not covered by establishment cost subsidy. However, an increase in establishment cost subsidy or a decrease in establishment cost will reduce the payment for the loan (and hence increase the returns) in the mature period, which has the same effect as increasing the mean of energy crop profits as we have discussed based on equation (6). To see this, by equation (4), we have

$$\begin{aligned} \left.\frac{\partial H}{\partial \theta}\right|_{I=0} &= \beta w(1+r)u'(\bar{\pi}_1)[1-\lambda x(\mu^e-\mu^c-\lambda\Omega)] = w(1+r)\frac{\partial H}{\partial \mu^e}, \\ \left.\frac{\partial H}{\partial w}\right|_{I=0} &= -\beta(1-\theta)(1+r)u'(\bar{\pi}_1)[1-\lambda x(\mu^e-\mu^c-\lambda\Omega)] = -(1-\theta)(1+r)\frac{\partial H}{\partial \mu^e}, \end{aligned} \tag{7}$$

which show that the effects of θ and *w* are simply the effect of μ^e times some constants. Item E in SI presents the algebra to obtain these two equations.

Effects of Time and Risk Preference

Based on expressions (4) and (5) it is readily checked that $\partial H / \partial \beta > 0$, which indicates that an increase in discount factor will increase the optimal quantity of land devoted to the energy crop. This is quite intuitive since the energy crop returns only occur in the mature period. However, the effect of risk aversion on the optimal land allocation is not straightforward. From equation (4) we can derive the following result as shown in Item F in the SI:

$$\frac{\partial H}{\partial \lambda} = \underbrace{u'(\bar{\pi}_0)(1-x)\sigma^c - \beta u'(\bar{\pi}_1)\Omega}_{\text{Term I}} + \underbrace{(\bar{\pi}_1-\bar{\pi}_0)u'(\bar{\pi}_0)[\lambda(1-x)\sigma^c-(\mu^c+(1-\theta)wI)]}_{\text{Term II}}. \tag{8}$$

On the one hand, an increase in risk aversion makes risky returns within a period less preferable. Term I in equation (8) captures this effect. Specifically, the expression $u'(\bar{\pi}_0)(1-x)\sigma^c$ in Term I reflects the effect of λ on the marginal utility of *x*, through the variance of total profits in the establishment period, $\pi_0(x)$. This term is positive because as

λ becomes larger, an increase in *x* will be more preferable in the establishment period since an increase in *x* will make the returns in that period less risky. Similarly, $-\beta u'(\bar{\pi}_1)\Omega$ in Term I measures the effect of λ on the marginal utility of *x* through the variance of aggregate profits in the mature period, $\pi_1(x)$. Its sign is determined by the sign of Ω which is ambiguous without further assumptions regarding the relationships between the variance of and covariance between conventional crop profit and energy crop profit. If Ω is negative, indicating that an increase in *x* will decrease the variance of $\pi_1(x)$, then $-\beta u'(\bar{\pi}_1)\Omega$ is positive, stating that an increase in λ will make the energy crop more attractive.

On the other hand, in a two-period model an increase in risk aversion has an inter-temporal effect. It implies that variance in returns across periods will bring disutility to the farmer as compared to smooth returns over the two periods. Term II in equation (8) is a linear approximation of such an inter-temporal effect of λ on *x*'s marginal utility. Based on equation (1) and the inequality (5) we know this term is negative, which indicates that, from the perspective of smoothing inter-temporal returns, an increase in risk aversion will decrease the marginal utility of *x* because an increase in *x* will make the returns across the two periods less smooth. It is readily checked that when $\bar{\pi}_0 = \bar{\pi}_1$, then Term II in equation (8) is 0. This indicates that if the mean profits in the two period are perfectly smooth then the inter-temporal effect of λ on the marginal utility of *x* diminishes to 0. However, the inter-temporal effect of λ is stronger when the difference between $\bar{\pi}_0$ and $\bar{\pi}_1$ is larger.

Total costs of Producing Biomass from the Energy Crop

By solving the farmer's optimization problem described in equation (2) we can identify the optimal land allocation to energy crops, $x^*(\mu^e \mid \Gamma)$, where Γ is a set of exogenous parameters specified in the model. If we further specify that μ^e, the mean of energy crop profit, as a function of biomass price, p^e, and energy crop yield, y^e, then the expected supply function of energy biomass from one unit of land can be written as $\bar{q}^e = \bar{Q}(p^e) = x^*(\mu^e(p^e, y^e) \mid \Gamma)\mathrm{E}[y^e]$. Once we obtain this supply function, then for any given biomass production target, we can endogenously determine the biomass price needed and the total private costs of inducing the production. Specifically, if the expected biomass production target is $\bar{q}^M$ then the biomass price required will be $\bar{Q}^{-1}(\bar{q}^M)$, and the aggregate private costs of producing $\bar{q}^M$ amount of biomass will be the area underneath the supply curve represented by $\int_0^{\bar{q}^M} \bar{Q}^{-1}(\bar{q}^e)d\bar{q}^e$, which includes not only the production costs of energy crop but also the forgone profit from growing the conventional crop. The factors discussed above that affect farmers' willingness to allocate land to an energy crop will affect the biomass price needed to meet the target.

We also seek to examine the cost-effectiveness of energy crop insurance and establishment cost subsidy in inducing a given level of biomass production. For a given policy instrument, we identify the establishment cost subsidy rate (i.e., $\theta \in [0,1]$) and energy crop insurance premium subsidy rate (i.e., $s^e \in [0,1]$) to minimize the aggregate production cost of a given biomass production:

$$V_\kappa = \min_{\kappa \in [0,1]} \{ \int_0^{\bar{q}^M} \bar{Q}^{-1}(\bar{q}^e \mid \kappa, \Gamma) d\bar{q}^e + H(\kappa \mid \bar{q}^M, \Gamma) \}, \tag{9}$$

where κ is either θ or s^e. The first term in the above equation, is total private costs incurred by farmers to produce $\bar{q}^M$ amount of energy crop biomass; and the second term, $H(\kappa \mid \bar{q}^M, \Gamma)$, is cost of the policy instrument for the government. In this term we also account for savings in conventional crop insurance subsidy for the government when cropland is converted to growing miscanthus. We consider the establishment cost subsidy to be more cost-effective than a crop insurance subsidy if $V_\theta < V_{s^e}$.[5]

Simulation Framework

We extend the framework developed above in several ways to simulate the allocation of land to an energy crop using county-level data for the rain-fed region (east of 100th meridian) of the United States. We consider two types of land qualities: high and low, that are labeled as *h* and *l*, respectively. High quality land can be allocated to either the conventional crop (*c*) or an energy crop (*e*). 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 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}. Additionally, 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. 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* 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 and the interest rate for a loan to cover these costs by *r*. Policy support in the form of an establishment cost subsidy for the energy crop is denoted by the subsidy rate $\theta \in [0,1]$.

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

$$\iota_t^{cj} = \max\left[\phi^c \mathrm{E}(y_t^{cj}) \max[p_t^{\text{proj}}, p_t^{\text{harv}}] - p_t^{\text{harv}} y_t^{cj}, 0\right], \tag{10}$$

where ϕ^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

$$\pi_t^{cj} = (p_t^c - v_t^{cj}) y_t^{cj} - f_t^{cj} + \iota_t^{cj} - (1 - s^c)\mathrm{E}[\iota_t^{cj}], \tag{11}$$

where s^c is insurance premium subsidy rate for the conventional crop.

For energy crops, with a fixed price contract, revenue insurance is equivalent to yield insurance. Therefore, insurance indemnity for the energy crop is

$$\iota_t^{ej} = p^e \max[\phi^e \mathrm{E}(y_t^{ej}) - y_t^{ej}, 0], \tag{12}$$

where ϕ^e is insurance coverage level for the energy crop. The profits from energy crop production can be written as

$$\begin{cases} \pi_t^{ej} = -(1-\theta) w_t^j I, & t \in \{1, \dots, T^e\} \\ \pi_t^{ej} = (p_t^e - v_t^{ej}) y_t^{ej} - f_t^{ej} + \iota_t^{ej} - (1 - s^e)\mathrm{E}[\iota_t^{ej}] - (1 - I) A(w_1^j, \dots, w_{T^e}^j, \theta, r), & t \in \{T^e + 1, \dots, T\}, \end{cases} \tag{13}$$

where $A(w_1^j, \dots, w_{T^e}^j, \theta, r)$ is the annuity the farmer needs to pay back due to the loan for establishment cost, and s^e is insurance premium subsidy rate for the energy crop. Equation (13) indicates that the farmer finances the portion of the establishment cost that is not offset by subsidy in the establishment period and will pay back the loan over the mature period.

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 m^l and m^h be the share of low quality land and high quality land in total land, respectively. Therefore, $m^l + m^h = 1.$ A risk averse farmer is assumed to choose the amount of each land type to allocate to crops *c* and *e* by maximizing the following objective function:

$$\max_{x^{cl},x^{el},x^{o},x^{ch},x^{eh}\geq 0} \sum_{t=1}^{T} \beta^{t-1} \mathrm{E}[u(x^{cl}\pi_t^{cl} + x^{el}\pi_t^{el} + x^{o}\pi^{o} + x^{ch}\pi_t^{ch} + x^{eh}\pi_t^{eh})] \quad (14)$$
$$\text{s.t. } x^{cl} + x^{el} + x^{o} = m^{l},\ x^{ch} + x^{eh} = m^{h},$$

where β is the discount factor equal to $1/(1+\gamma)$ with $\gamma \in [0,1]$ being the discount rate. We consider a representative farmer in each county operating under a range of assumptions about risk and time preferences, credit availability and policies.

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 G of SI. Once the distribution is identified, we calculate revenue, insurance premiums, and premium subsidies for both conventional crops and energy crops by using Monte Carlo approach. We obtain an aggregate supply curve by numerically solving problem (14) for heterogeneous counties in the rainfed United States 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®.

Data

Our numerical simulation analyzes the county-specific allocation of land between the energy crop (miscanthus), and conventional crops (corn and soybeans) for 1,795 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.

Crop Yields

Large scale commercial production of miscanthus is yet to commence in the United States. The crop-growth model DayCent is used to obtain simulated yields of miscanthus. 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).[6] 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 1,795 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.[7] 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 (9.6 vs. 9.5 dry tons per acre).

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

Since county-level crop yields have lower variance than farm-level crop yield, it is typical to use an inflated county-level yield variance in simulation to mimic farm-level yield variance (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 yield by the same magnitude as we inflate the variance of corn yield. Item I in SI provides a detailed description of the inflation procedure.

We use the yield data described above to quantify yield riskiness of the energy crop relative to conventional crops. Table 2 provides further statistical information of corn and miscanthus yield in various geographical regions. Using the coefficient of variation (CV) of crop yields as a measure of yield risk, we find that on average miscanthus yield (with CV of 0.25) is much less risky than corn yields (with CV of 0.4). On average the correlation coefficient between miscanthus and corn yield within a county is -0.11; this indicates the potential for benefits from diversification by growing miscanthus. We also find that crop yield risks differ across geographical regions. Typically, for both corn and miscanthus, regions with lower mean yield have higher yield CV. Corn and miscanthus yield risks are high in Great Plains and Southeast. Across the Midwestern and Southeastern counties, mean corn yield and mean miscanthus yield are positively correlated; whereas in the Great Plains and Northeastern areas, they are negatively correlated.

Crop Prices

Three types of prices of corn and soybeans are used in the simulation: received prices, projected prices, and harvest prices. We use State level received prices from NASS to calculate realized profit of corn and soybean. Projected price and harvest price are used to calculate crop insurance indemnity following RMA (2011) rules (see equation (10)). Specifically, projected price and harvest 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.

Production Costs

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). 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. The cost of miscanthus in the first year of establishment includes expenses on rhizomes, planting machinery, fertilizer and land preparation, which is about $1,258 per acre on average. For the second year and onward these costs include expenses on fertilizer, labor, fuel and machinery for harvesting, baling, transportation, and storage.[8] 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 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 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.

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 while land under cropland pasture/idle land (as defined by NASS) is low quality land. County-specific acreage in each of these categories are 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). Therefore, to be conservative we assume that only 5% of low quality land is available for growing miscanthus.[9] 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 the implied 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. Based on this approach and following 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.

Simulation Results

We construct 16 scenarios through combinations of the following four terms: discount rates (low value is 2% and high is 10%), risk aversion parameter (low value is 0.00001 and high is

0.00005), whether insurance for corn and soybeans is available, and whether farmers are credit constrained. The baseline scenario is one where a) risk aversion parameter and discount rate are low, b) farmers are not credit constrained, and c) corn (and soybeans if under a corn-soybean rotation) is insured with subsidized insurance. In the simulations we assume that the cellulosic biofuel mandate is one billion gallons which requires 15 million dry short tons (MT) of biomass (with 15% moisture), assuming a biomass-to-ethanol conversion rate of 67.4 gallons per dry short ton of biomass (Jain *et al.* 2010).

For each of these scenarios, we simulate the biomass supply at various exogenously specified biomass price and obtain supply curves. We then determine the biomass price required to induce production of 15 MT of biomass and examine the effect of introducing either energy crop insurance or establishment cost subsidy on the supply curve and the biomass price needed to meet the 15 MT requirement. We also estimate the government expenditure needed to support each of these policy instruments. In the simulation, the coverage level of insurance for corn and soybeans is set to be 75% and the corresponding premium subsidy rate is 55%.[10] To facilitate comparison, the coverage level of miscanthus insurance is set to 75% as well. However, the premium subsidy rate and establishment cost subsidy rate are chosen to minimize aggregate (private and public) biomass production cost.

Supply of Biomass in the Absence of Policy Intervention

Figure 1 depicts the supply curves under the 16 scenarios in the absence of any policy interventions for energy crops. We find that biomass prices are lower when there is no credit constraint (comparing the right panels with the left panels in Figure 1) or when insurance for conventional crops is absent (comparing the upper panels with lower panels in Figure 1). A credit constraint leads to a significant leftward shift in the supply curve due to the significant amount of establishment cost leading to much larger variability in returns across time periods than the conventional crop. We also find that, as predicted in the conceptual framework, a high discount rate leads to a higher biomass price; an increase in discount rate from 2% to 10% increases biomass price by 17.2% (see Scenario 4 in Table 3).

Table 3 shows that the biomass price required for producing the 15 MT of biomass in the baseline scenario is $53/ton. In the other 15 scenarios, this price ranges from 28% lower to 45% higher than that in the baseline scenario. When farmers are not credit-constrained the increase in risk aversion decreases biomass price and shifts the supply curve to the right. For example, everything else equal, a higher degree of risk aversion with a low discount rate lowers the biomass price needed for inducing production of 15 MT by 6.2% (scenario 8 in Table 3). Although miscanthus has lower yield risk than the conventional crop and provides diversification benefits *within* a harvest year, the high establishment cost makes the returns of miscanthus very risky *across* periods. When the farmers can use a loan to smooth their returns then the variability in returns across periods caused by the establishment cost is mitigated and the diversification benefit *within* a harvest year induces production at lower biomass price. However, the imposition of a credit constraint, all else unchanged, increases biomass price by 6.9% relative to the baseline (scenario 2 in Table 3).

This effect of credit constraint on biomass price is larger when risk aversion is higher as shown in Figure 1. For instance, with low risk aversion and high discount rate, the imposition of a credit constraint increases the biomass price by over 10% (see scenarios 4 and 5 in Table 3). With the same discount rate but with high risk aversion, imposing credit constraint increases the biomass price by over 33% relative to that without a credit constraint (see scenarios 12 and 13). As shown by our conceptual framework, this is because higher risk aversion indicates a greater preference for smoothing returns over the lifespan of miscanthus. If farmers are credit constrained and more risk averse, then they will require a much higher price as a compensation for forgoing returns in the establishment period.

The effect of insurance for corn and soybeans on biomass price is also large. In the absence of subsidized crop insurance for corn and soybeans, biomass price is lower by 7% ~ 23%, depending on farmers' time and risk preferences as well as credit availability. This price decrease is larger when farmers are more risk averse. This is partly because insurance for conventional crops may weaken the diversification benefit from growing energy crops. The higher the risk aversion, the larger the diversification benefit from growing energy crops and the greater the decrease in biomass price by removing insurance for conventional crops.

Table 3 also presents the acreage devoted to miscanthus under the 16 scenarios. In the baseline the production of 15 MT of biomass requires about 1.28 million acres of land. An increase in risk aversion increases the land requirements to meet the mandate by 11.4% in the absence of a credit constraint (scenario 8) because it shifts miscanthus production to land in counties with riskier corn production in order to diversify the crop portfolio; however, these counties have lower miscanthus yield. Table 2 shows that the average within county yield correlation coefficient between corn and miscanthus is -0.11, which indicates that diversification benefit from growing miscanthus can be large. In miscanthus-producing counties under scenarios 8 and 9 corn yield risk (CV) is negatively correlated with miscanthus yield mean (with correlation coefficient at -0.15). As a result, higher risk aversion leads to an increase in the total land required to produce 15 MT of biomass. Maps (a) and (b) in Figure 2 show the acreage of miscanthus under the baseline scenario and scenario 8, respectively. An increase in risk aversion increases miscanthus production in the Northern Great Plains, where corn yield risk is high and miscanthus yield are relatively low (Map (b) in Figure 2). Further, notice that in the Northern Great Plains, corn yield CV and miscanthus yield CV are negatively correlated (the last row in Table 2), indicating that for counties with high corn yield risk the diversification benefit from growing miscanthus can be large.

We also find that the addition of a credit constraint together with higher risk aversion shifts miscanthus production to the Midwestern area and increases total miscanthus acreage significantly (scenario 9) as shown in Map (c) in Figure 2. When farmers are credit constrained and more risk averse, the high establishment cost of miscanthus leads to higher disutility in the establishment period relative to the baseline case. The lower profits from corn in the southeastern region reduces incentives to grow miscanthus when there is a credit constraint while the higher corn profit in the Midwest enables farmers to bear the lower utility during the establishment period for miscanthus in return for the higher returns during the mature phase, particularly at the relatively high biomass price. Additionally, we find that the availability of conventional crop insurance, together with a high degree of risk aversion and discount rate, and presence of credit constraint lead to a 16.2% increase in total land requirement to produce the 15 MT of biomass (scenario 13 in Table 3; Map (a) in Figure 3).

Effect of Policy Interventions for Energy Crop Production

Energy Crop Insurance

Table 4 presents simulation results when actuarially fair energy crop insurance with 75% coverage level is available to farmers, at a premium subsidy rate chosen to minimize total costs for producing the 15 MT of biomass. We find that the most cost-effective premium subsidy rate is either 0% or very close to 0%, which is much lower than subsidy rate available to conventional crops of 55% in our simulation. This result can be explained in part by the findings in Miao, Hennessy, and Feng (2012) where the authors theoretically show that insurance premium subsidy may attract riskier land (i.e., land with low mean yield but high yield risk) to enter production because the subsidy is in proportion to the premium which is higher on riskier land. In our dataset, the correlation coefficient between miscanthus yield mean and CV across the counties in the dataset is -0.3 on high quality land and -0.35 on low quality land, which indicates that the lower the mean yield, the higher the yield risk. Therefore, riskier land may gain larger premium subsidy than less risky land and hence will more likely enter production when insurance is subsidized than unsubsidized. As a result, subsidizing insurance premium may increase total cost for producing a given amount of biomass. To have a better contrast, we simulate land allocation when energy crop insurance premium subsidy rate is 100% (Table S2 in SI). Results show that when energy crop insurance premium subsidy rate increases to 100% from the cost-effective subsidy rate and when corn is insured, then acreage of low quality land devoted to miscanthus will always increase. When corn is not insured, however, the acreage effect of the 100% subsidized energy crop insurance is ambiguous.

The presence of energy crop insurance with cost-effective premium subsidy rate leads to a very small reduction in the biomass price and total costs. With low risk aversion and discount rate it may even lead to a marginal increase in biomass price (first row in Panel A of Table 4) because it may decrease the diversification value of miscanthus. The reasons for this small effect are twofold. First, the low yield risk and fixed biomass price result in low insurance premium for miscanthus (about $14 per acre per year in the baseline case when biomass price is $53 per ton). In contrast, the average premium for corn insurance is about $45 per acre per year. Second, since there is no yield of miscanthus in the first year, energy crop insurance does not play a role until the second year. Discounting of future utility lowers the benefits of energy crop insurance.

Imposing energy crop insurance has a small effect on miscanthus acreage and its geographical distribution. In most cases energy crop insurance will decrease the total miscanthus acreage by around 2%. This is because it provides incentives to produce miscanthus in Southeastern region where both yield mean and risk are higher while reducing it in the Midwestern counties in scenario 13 (see Map (b) in Figure 3). Additionally, the reduction in biomass price reduces the profitability of growing miscanthus in the Midwestern states with a high opportunity cost of land.

Effect of Establishment Cost Subsidy

Our simulation results show that the cost-effective establishment cost subsidy rates are generally 100% with exceptions in a few cases (see Table 4). When farmers' discount rate is high, this is not surprising given the assumed low discount rate of government (2% in this study). However, even when farmer's discount rate is as low as the government's, the cost-effective establishment cost subsidy rate can be as high as 95% or 100% with a credit constraint (see the second rows in Panels A and C in Table 4) because the large establishment cost significantly decreases utility in the establishment period and increases the utility variation across periods. By alleviating the credit constraint, an establishment cost subsidy will significantly increase farmers' utility in the establishment period and smooth the utility across periods so that the higher biomass price can be largely lowered by establishment cost subsidy, particularly when the discount rate is high. For the same reason, when the farmers are not credit-constrained and more patient, then the cost-effective establishment cost subsidy rate can be as low as 0% (see the first row in Panel A of Table 4).

Furthermore, we find that when both risk aversion and discount are high then a 100% establishment cost subsidy can reduce biomass price by 35% to 50%, depending on whether or not the farmers are credit constrained (see Panel D of Table 4). However, an establishment cost subsidy will impose significant costs on the government. Panel D of Table 4 shows that the annualized cost can be as high as $213 million per mature year in the lifecycle of miscanthus to support one billion gallon of cellulosic biofuel. In terms of government outlay, this is equivalent to subsidizing miscanthus-based cellulosic biofuel at $0.21 per gallon. While large, this is considerably smaller than the tax credit of $1.01 per gallon currently offered to cellulosic biofuel production as of 2014.

In contrast to energy crop insurance, the establishment cost subsidy tends to increase total acreage of miscanthus for producing the 15 MT of biomass. In the presence of high establishment cost, production of miscanthus is more likely to be viable in high yielding counties. A 100% establishment cost subsidy increases the incentives to produce miscanthus in regions where its diversification benefits are high even though average yield of miscanthus is low. This is particularly the case when the degree of risk aversion is high. Map (c) in Figure 3 depicts the change in miscanthus acreage when a 100% establishment cost subsidy rate is provided under scenario 13 (high risk aversion and discount rate, and with insurance for corn and soybeans). The biomass price falls by 35% relative to the no-policy case; this reduces incentives to grow it in the Midwest (a higher opportunity cost region for miscanthus) and shifts acreage to the Great Plains and Southeast. Since miscanthus yield in Great Plains is much lower, we observe that the total acreage of miscanthus increases by 9-20% to produce the 15 MT of biomass with an establishment cost subsidy.

Policy Instrument Comparison

Our analysis generates several policy relevant insights. First, we find that an establishment cost subsidy reduces the total private and public costs of inducing production of 15 MT of biomass by a much larger percentage than energy crop insurance. This follows from the combination of risk averse farmers, large upfront costs but relatively low yield risk of miscanthus. Risk aversion creates a preference for smoothing income both across time periods and within a time period operates in a manner similar to a discount rate in discouraging switching to a perennial crop that involves high upfront costs from a conventional crop that provides annual returns. In contrast to the large upfront costs of energy crop production relative to annual crops, the relatively low and negatively correlated (with conventional crop) risks of energy crop yields together with the fixed biomass price results in low variability in returns and high diversification benefits from energy crop production. Energy crop insurance (with or without a premium subsidy) therefore has a small impact on aggregate costs of inducing biomass production to meet the mandate.

Second, we find that the cost minimizing levels of establishment cost subsidy rate and energy crop insurance subsidy rate vary with the risk and time preferences of farmers and the presence of a credit constraint. The cost-effective establishment cost subsidy rate ranges from 0% to 100% and is low when risk aversion is low and when there is no credit constraint. Provision of credit at low market rates of interest could reduce the need for an establishment cost share subsidy. Third, our analysis shows that the government costs of supporting the cost minimizing level of establishment cost subsidy can be significantly higher than those of supporting a subsidized energy crop insurance program, particularly if there is high risk aversion, large discount rates and a credit constraint.

Finally, we find that an establishment cost share subsidy could substantially increase the energy crop acreage needed while energy crop insurance could marginally reduce the acreage needed to achieve the mandated level of biomass production. This is because the reduction in fixed costs of energy crop production reduces the incentives to grow it in high yielding areas and increases the incentives to grow it in regions with risky corn yields and lower miscanthus yield (due to the negative correlation between the two) while energy crop insurance encourages production in areas with riskier miscanthus yields but higher average yield, such as the Southeast in the United States.

Conclusions

We develop a conceptual framework to show the effect of risk aversion, high discount rates and a credit constraint on the supply of energy crops and on the costs of producing a given amount of biomass to meet a cellulosic biofuel mandate. We then analyze the cost-effectiveness of supplementary policies (i.e., energy crop insurance and establishment cost subsidy) to the mandate that may achieve the mandated level of biofuel production at lower total cost than the mandate alone. We find that high degree of risk aversion, large discount rate, credit constraint and availability of crop insurance for conventional crops can significantly increase the total cost and total land to provide biomass meeting the one-billion-gallon cellulosic biofuel mandate (by 43% and 16%, respectively). We also find that establishment cost subsidy is more cost-effective than energy crop insurance under a wide range of assumptions about risk and time preferences of farmers. The cost-effective establishment cost subsidy rate is 100% in most cases whereas the cost-effective energy crop insurance subsidy rate is either 0% or close to 0% (except when farmers are unconstrained by credit, more patient, and less risk averse). However, when compared with scenarios under which there is no policy interventions for energy crops, establishment cost subsidy tends to increase total acreage required to meet the one-billion gallon cellulosic biofuel whereas energy crop insurance tends to decrease this acreage. It also requires higher government expenditures than an energy crop insurance subsidy. Policy choice, therefore, needs to be based on consideration of these potential trade-offs between these policy outcomes.

We make a number of simplifying assumptions in our analysis to keep it tractable. We consider the two policies—establishment cost subsidy and energy crop insurance—individually; depending on farmer risk and time preferences, providing energy crop insurance and establishment cost subsidy simultaneously may be more cost effective than either policy by itself. Moreover, we consider miscanthus as the only source of cellulosic feedstock and do not account for the potential of corn stover to be used as a cellulosic feedstock. Including corn stover in the opportunity cost of miscanthus production will only obscure, but not obviate, the insights we seek to provide on farmers' land allocation decisions. Additionally, the analysis was conducted based on objective risks of miscanthus production which might differ from the subjective risk perceptions since large scale production of miscanthus is yet to be undertaken. We leave these issues to be addressed by future research but expect the qualitative insights provided by our analysis to hold.

References

Babcock, B.A. 2012. "The Politics and Economics of the U.S. Crop Insurance Program." in J.S. Graff Zivin and J.M. Perloff eds. The Intended and Unintended Effects of U.S. Agricultural and Biotechnology Policies. University of Chicago Press.

Babcock, B.A., K.E. Choi, and E. Feinerman. 1993. "Risk and Probability Premiums for CARA Utility Functions." Journal of Agricultural and Resource Economics 18(1): 17-24.

Beach, R.H., Y.W. Zhang, and B.A. McCarl. 2012. Modeling Bioenergy, Land Use, and GHG Emissions with FASOMGHG: Model Overview and Analysis of Storage Cost Implications. Climate Change Economics 3(3), 34 pages.

Bocquého, G. and F. Jacquet. The adoption of switchgrass and miscanthus by farmers: impact of liquidity constraints and risk preferences. Energy Policy 38(5): 2598-2607.

Chavas, J.P., R.G. Chambers, and R.D. Pope. 2010. "Production Economics and Farm Management: A Century of Contributions." American Journal of Agricultural Economics 92(2): 356-375.

Chen, X, H. Huang, M. Khanna and H. Onal. 2014. "Alternative Fuel Standards: Welfare Effects and Climate Benefits." Journal of Environmental Economics and Management 67(3): 241–257.

Claassen, R., J.C. Cooper, and F. Carriazo. 2011. "Crop Insurance, Disaster Payments, and Land Use Change: The Effect of Sodsaver on Incentives for Grassland Conversion." Journal of Agricultural and Applied Economics, 43(2):195-211.

Clifton-Brown, J.C., P. Stampfl, M.B. Jones. 2004. "Miscanthus biomass production for energy in Europe and its potential contribution to decreasing fossil fuel carbon emissions." Global Change Biology. 10: 509–18.

Collender, R. N., and D. Zilberman. 1985. "Land Allocation Decisions Under Alternative Return Distributions." American Journal of Agricultural Economics. 67(4):727-731.

Davis, S.C., W.J. Parton, S.J. Del Grosso, C. Keough, E. Marx, P. Adler, E.H. DeLucia. 2012. "Impacts of second-generation biofuel agriculture on greenhouse gas emissions in the corn-growing regions of the US." Frontiers in Ecology and the Environment 10: 69-74.

Del Grosso, S.J., W.J. Parton, C.A. Keough, and M. Reyes-Fox. 2011. "Special Features of the DayCent Modeling Package and Additional Procedures for Parameterization, Calibration, Validation, and Applications", in L.R. Ahuja and Liwang Ma eds. *Methods of Introducing System Models into Agricultural Research*, p. 155-176, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. USA.

Del Grosso, S. J., W.J. Parton, P.R. Adler, S.C. Davis, C. Keough, and E. Marx. 2012. "DayCent Model Simulations for Estimating Soil Carbon Dynamics and Greenhouse Gas Fluxes from Agricultural Production Systems." in M. Liebig, A.J. Franzluebbere, and R. Follett eds. *Managing Agricultural Greenhouse Gases: Coordinated Agricultural Research through Gracenet to Address Our Changing Climate*: 241-250, Academic Press, Elsevier.

Du, X. and D.A. Hennessy. "The Planting Real Option in Cash Rent Valuation." *Applied Economics*. 44(2012):265-276.

Duquette, E., N. Higgins, and J. Horowitz. 2012. "Farmer discount rates: experimental evidence." American Journal of Agricultural Economics 94(2):451-456.

Dwivedi, P, W. Wang, T. Hudiburg, D. Jaiswal, W. Parton, S. Long, E, DeLucia, and M. Khanna. 2014. "Cost of Abating Greenhouse Gas Emissions with Cellulosic Ethanol," Working paper, Energy Biosciences Institute, University of Illinois. Urbana-Champaign.

Dolginow, J., R.E. Massey, N.R. Kitchen, D.B. Myers, and K.A. Sudduth. 2014. "A

Stochastic Approach for Predicting the Profitability of Bioenergy Grasses." Agronomy Journal 106(6): 2137-2145.

Farm Service Agency of U.S. Department of Agriculture. 2013. "BCAP: Biomass Crop Assistance Program — Energy Feedstocks from Farmers and Foresters." February. Available at http://www.fsa.usda.gov/Internet/FSA_File/bcap_documentation.pdf (accessed on June 17, 2014).

Fewell, J., J. Bergtold, and J. Williams. 2011. "Farmers' Willingness to Grow switchgrass as a Cellulosic Bioenergy Crop: A Stated Choice Approach." Paper presented at the 2011 Joint Annual Meeting of the Canadian Agricultural Economics Society & Western Agricultural Economics Association, Banff, Alberta, Canada.

Heaton, E., F. Dohleman, and S. Long. 2008. "Meeting US biofuel goals with less land: The potential of miscanthus." *Global Change Biology*. 14:2000-2014.

Hennessy, D.A., B.A. Babcock, and D.J. Hayes. 1997. "Budgetary and Producer Welfare Effects of Revenue Insurance." American Journal of Agricultural Economics. 79(3): 1024-34.

Hertel, T., A. Golub, A. Jones, M. O'Hare, R. Plevin and D. Kammen. 2010. "Global Land Use and Greenhouse Gas Emissions Impacts of US Maize Ethanol: Estimating Market-Mediated Responses." BioScience 60(3): 223-231.

Hudiburg, T.W., S.C. Davis, W. Parton, and E.H. DêLucia. 2014. "Bioenergy Crop Greenhouse Gas Mitigation Potential under a Range of Management Practices." Global Change Biology Bioenergy. doi: 10.1111/gcbb.12152.

Jain, A. K., M. Khanna, M. Erickson, and H. Huang. 2010. "An Integrated Biogeochemical and Economic Analysis of Bioenergy Crops in the Midwestern United States." Global Change Biology Bioenergy. 2: 217-234.

Just, R.E. and D. Zilberman. 1983. "Stochastic Structure, Farm Size and Technology Adoption in Developing Agriculture." Oxford Economic Papers 35(2): 307-328.

Khanna, M., X. Chen, H. Huang and H. Önal. 2011. "Supply of Cellulosic Biofuel Feedstocks and Regional Production Pattern". American Journal of Agricultural Economics. 93(2): 473-480.

Khanna, M., B. Dhungana, and J. Clifton-Brown. 2008. "Costs of Producing miscanthus and switchgrass for Bioenergy in Illinois." Biomass and Bioenergy. 32:482-93.

Kiniry, J.R., K.A. Cassida, M.A. Hussey, J.P. Muir, W.R. Ocumpaugh, J.C. Read, R.L. Reed, M.A. Sanderson, B.C. Venuto, J.R. Williams. 2005. "Switchgrass simulation by the ALMANAC model at diverse sites in the southern U.S." Biomass and Bioenergy, 29, 419–25.

Kiniry, J.R., M.A. Sanderson, J.R. Williams. 1996. "Simulating Alamo switchgrass with the ALMANAC model." Agronomy Journal. 88: 602–06.

Love, H. A., and S. T. Buccola. 1991. "Joint Risk Preference-Technology Estimation with a Primal System." American Journal of Agricultural Economics 73(3):765-774.

McLaughlin, S.B., J.R. Kiniry, C. Taliaferro, D. Ugarte. 2006. "Projecting yield and utilization potential of switchgrass as an energy crop." Advances in Agronomy. 90: 267–97.

Menapace, L., G. Colson, and R. Raffaelli. 2013. "Risk aversion, subjective beliefs, and farmer risk management strategies." American Journal of Agricultural Economics 95(2): 384-389.

Miao, R., D.A. Hennessy, and B.A. Babcock. 2012. "Investment in Cellulosic Biofuel Refineries: Do Waivable Biofuel Mandates Matter?" American Journal of Agricultural Economics 94(3): 750-762.

Miao, Ruiqing, D.A. Hennessy, and H. Feng. 2012. "The Effect of Crop Insurance Subsidies and Sodsaver on Land Use Change." Center for Agricultural and Rural Development, Iowa State University. Working Paper 12-WP 530.

Miao, Ruiqing, D.A. Hennessy, and H. Feng. 2014. "Native Grassland Conversion: The Roles of Risk Intervention and Switching Costs." *Land Economics* (in press).

Miao, R. and M. Khanna. 2014. "Are Bioenergy Crops Riskier than Corn? Implications for Biomass Price Contracts," *Choices* 29 (1), 1st Quarter.

Miguez, F.E., M. Maughan, G.A. Bollero, and S.P. Long. 2012. "Modeling spatial and dynamic variation in growth, yield, and yield stability of the bioenergy crops miscanthus × giganteus and Panicum virgatum across the conterminous United States." Global Change Biology: Bioenergy. 4(4):509-520.

Murray, B.C., M.L. Cropper, F.C. de la Chesnaye, and J.M. Reilly. 2014. "How Effective are US Renewable Energy Subsidies in Cutting Greenhouse Gases?" American Economic Review: Papers and Proceedings, 104(4): 569-574.

O'Donoghue, E.J., M.J. Roberts, and N. Key. 2009. "Did the Federal Crop Insurance Reform Act Alter Farm Enterprise Diversification?" Journal of Agricultural Economics 60(1): 80-104.

Peplow, M. 2014. "Cellulosic Ethanol Fights for Life." *Nature* 507(7491). Nature Publishing Group, March 11. Available at http://www.nature.com/news/cellulosic-ethanol-fights-for-life-1.14856 (accessed on June 25, 2014).

Roe, B.E. 2013. "How Well Do Farmers Tolerate Risk? Comparisons with Nonfarm Business Owners and the General Population." Choices 28(4), 4th Quarter.

Risk Management Agency (RMA). 2011. Commodity Exchange Price Provisions (CEPP). Available at: http://www.rma.usda.gov/policies/cepp.html (accessed on September 8th, 2014).

Shields, D.A. 2013. Federal Crop Insurance: Background. Congressional Research Service Report. Available at http://fas.org/sgp/crs/misc/R40532.pdf (accessed on September 8th, 2014).

Skevas, T., S. M. Swinton and N. J. Hayden. 2014. "What Type of Landowner Would Supply Marginal Land for Energy Crops?" Biomass & Bioenergy 67: 252-259.

Song, F., J. Zhao, and S.M. Swinton. 2011. "Switching to Perennial Energy Crops under Uncertainty and Costly Reversibility." American Journal of Agricultural Economics 93(3): 768-783.

Valentine, J., J. Clifton-Brown, A. Hastings, P. Robson, G. Allison, and P. Smith. 2012. "Food vs. Fuel: the Use of Land for Lignocellulosic 'Next Generation' Energy Crops that Minimize Competition with Primary Food Production." Global Change Biology Bioenergy 4:1-19.

Woodard, J.D., A.D. Pavlista, G.D. Schnitkey, P.A. Burgener, and K.A. Ward. 2012. "Government Insurance Program Design, Incentive Effects, and Technology Adoption: The Case of Skip-Row Crop Insurance." American Journal of Agricultural Economics. 94(4): 823-37.

Yan, J. 2007. "Enjoy the Joy of Copulas: with a Package copula." Journal of Statistical Software. 21(4):1-21.

Zhu, Y., S.K. Ghosh, and B.K. Goodwin. 2008. "Modeling Dependence in the Design of Whole Farm Insurance Contract --- A Copula-Based Model Approach." Paper presented at The Agricultural and Applied Economics Association (AAEA) Annual Meeting, 27-29 July, Orlando, FL.

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

			Mean	Standard deviation	Min.	Max.
Yields	Miscanthus on high quality land (ton/acre)		9.6	1.0	1.3	17.2
	Miscanthus on low quality land (ton/acre)		9.5	1.0	1.0	16.9
	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 ($/acre)	1258	19	1228	1314
	Miscanthus (year 2)	variable cost ($/ton)	15.4	2.0	12.4	17.8
		fixed cost (($/acre)	249	13	224	283
		establishment cost ($/acre)	220	10	204	256
	Miscanthus (years 3-15)	variable cost ($/ton)	15.4	2.0	12.4	17.8
		fixed cost ($/acre)	72	13	48	108
	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
Prices ($/bu.)	corn	projected price	4.1	1.2	2.6	7.8
		harvest price	3.8	1.3	2.2	8.1
		received price[c]	4.0	1.3	1.9	9.1
	soybeans	projected price	9.5	2.9	5.4	17.2
		harvest price	9.3	3.0	5.4	19.3
		received price[c]	9.2	2.6	5.3	17.3
Acreage (acres per county)		low quality land[d]	10509	9921	0	78222
		high quality land	69678	93994	0	623800
CRP rental rates ($/acre)			65	34	14	398
Farm size (acres)			329	317	39	3888

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. The acreage is before applying the 5% land availability assumption

Table 2. Yield and Riskiness of Corn and Miscanthus Across Regions[a]

	Great Plains	Midwest	Southeast	Northeast	Overall
Summary Statistics for Corn Yield and Risk					
Mean of corn yield	120.2	144.6	115.6	115.6	127.7
CV of corn yield[b]	0.41	0.35	0.44	0.41	0.40
Correlation coefficient between corn yield mean and CV across counties	-0.79	-0.76	-0.51	-0.40	-0.73
Summary Statistics for Miscanthus Yield and Risk on High Quality Land					
Mean of miscanthus yield on high quality land	7.3	9.3	11.2	8.4	9.6
CV of miscanthus yield on high quality land[b]	0.32	0.21	0.27	0.20	0.25
Correlation coefficient between miscanthus yield mean and CV	-0.28	-0.46	-0.51	-0.69	-0.30
Summary Statistics for Miscanthus Yield and Risk on Low Quality Land					
Mean of miscanthus yield on low quality land	7.1	9.1	11.1	8.1	9.5
CV of miscanthus yield on low quality land[b]	0.32	0.22	0.27	0.21	0.25
Correlation coefficient between miscanthus yield mean and CV	-0.44	-0.49	-0.48	-0.65	-0.35
Correlations Between Miscanthus and Corn Yield and Risk on High Quality Land					
Average correlation coefficient of within-county corn and miscanthus yield[c]	-0.05	-0.08	-0.16	-0.18	-0.11
Correlation coefficient of corn and miscanthus yield mean[d]	-0.38	0.25	0.21	-0.13	-0.07
Correlation coefficient between corn yield CV and miscanthus yield CV	-0.02	0.43	0.30	0.10	0.35

Note: [a] In our analysis rainfed United States includes counties on the east of 100th Meridian. Great Plains area includes North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas; Midwest includes Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, Ohio, and Missouri; Southeast includes Arkansas, Louisiana, Kentucky, Tennessee, Mississippi, Alabama, West Virginia, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida; Northeast includes the remaining states in the rainfed United States. The calculations for this table are based on crop yields after variance inflation (see Data section in the text for details). [b] We first calculate the CV for each county, then take average across the CVs of the counties included. [c] We first calculate the correlation coefficient of corn and miscanthus yields for each county and then take average of calculated correlation coefficients across counties. [d] We first calculate the mean of corn and miscanthus yields for each county, then we calculate the correlation coefficient across counties.

Table 3. Effects of Risk and Time Preferences on Costs and Acreage to Meet the 15 MT of Biomass Production Target

	Scenario No.	Corn insurance	Credit constraint	Biomass price ($/ton)	Total cost (mil. $)	Miscanthus acreage (mil. acres)
Baseline[a]	0	yes	no	53.02	676.4	1.28
				Changes from baseline (%)		
Panel A: Low risk aversion, low discount	1	yes	yes	6.9	6.6	4.8
	2	no	no	-9.2	-6.7	6.6
	3	no	yes	-2.3	0.7	5.2
Panel B: Low risk aversion, high discount	4	yes	no	17.2	18.6	3.8
	5	yes	yes	27.9	28.8	3.4
	6	no	no	7.3	11.3	3.3
	7	no	yes	18.4	22.4	3.7
Panel C: High risk aversion, low discount	8	yes	no	-6.2	-8.5	11.4
	9	yes	yes	16.7	15.0	12.8
	10	no	no	-28.0	-28.4	9.1
	11	no	yes	-2.5	-3.5	13.9
Panel D: High risk aversion, high discount	12	yes	no	11.5	11.6	6.4
	13	yes	yes	44.9	43.1	16.2
	14	no	no	-12.3	-10.9	6.2
	15	no	yes	24.5	23.0	13.2

Note: [a] There is no policy intervention for energy crops under these 16 scenarios. In the baseline scenario the farmer is assumed to have low risk aversion and low discount rate. The high and low values for the absolute risk aversion parameters are 0.00005 and 0.00001, respectively. The high and low discount rates are 10% and 2%, respectively. The total cost is the annual cost of supplying 15 MT of biomass.

Table 4. Cost-Effectiveness and Acreage Implications of Energy Crop Insurance Premium Subsidy and Establishment Cost Subsidy

	No policy intervention				Under energy crop insurance					Under establishment cost subsidy				
	Credit constraint	Biomass price ($/ton)	Total cost (mil. $)	Miscanthus acreage (mil. acres)	Cost-effective subsidy rate	Govt. cost (mil. $)	Biomass price	Total cost	Miscanthus acreage	Cost-effective subsidy rate	Govt. cost (mil. $)	Biomass price	Total cost	Miscanthus acreage
	Absolute values				Absolute values		Change from no policy intervention scenarios (%)			Absolute values		Change from no policy intervention scenarios (%)		
Panel A: Low risk aversion, low discount	no	53.0	676	1.28	0%	0	0.15	-0.03	2.34	0%	0	0	0	0.00
	yes	56.7	721	1.34	0%	0	-0.28	-0.28	-2.24	95%	176	-25.87	-4.72	2.99
Panel B: Low risk aversion, high discount	no	62.2	802	1.33	0%	0	-0.58	-0.12	-3.76	100%	186	-31.31	-12.72	4.51
	yes	67.8	871	1.32	5%	1	-0.15	-0.11	0.76	100%	186	-37.02	-19.63	5.30
Panel C: High risk aversion, low discount	no	49.8	619	1.42	0%	0	-0.70	-0.97	-1.41	15%	29	-3.72	-1.29	1.41
	yes	61.9	778	1.44	20%	3	-0.58	-0.51	0.69	100%	213	-40.03	-19.02	6.94
Panel D: High risk aversion, high discount	no	59.1	755	1.36	0%	0	-0.68	-1.32	-1.47	100%	213	-35.03	-15.50	19.12
	yes	76.9	968	1.48	5%	1	-0.59	-0.31	-2.03	100%	213	-50.03	-34.09	9.46

Note: Insurance for conventional crops is available under all scenarios considered in this table. The high risk aversion and low risk aversion are absolute risk aversion parameters at 0.00005 and 0.00001, respectively. The high discount and low discount stand for 10% and 2% discount rate, respectively. The total cost is the annual cost of supplying 15 MT of biomass. To save space we only present scenarios under which corn is insured in this table. See Table S1 in SI for results under scenarios where corn insurance is eliminated.

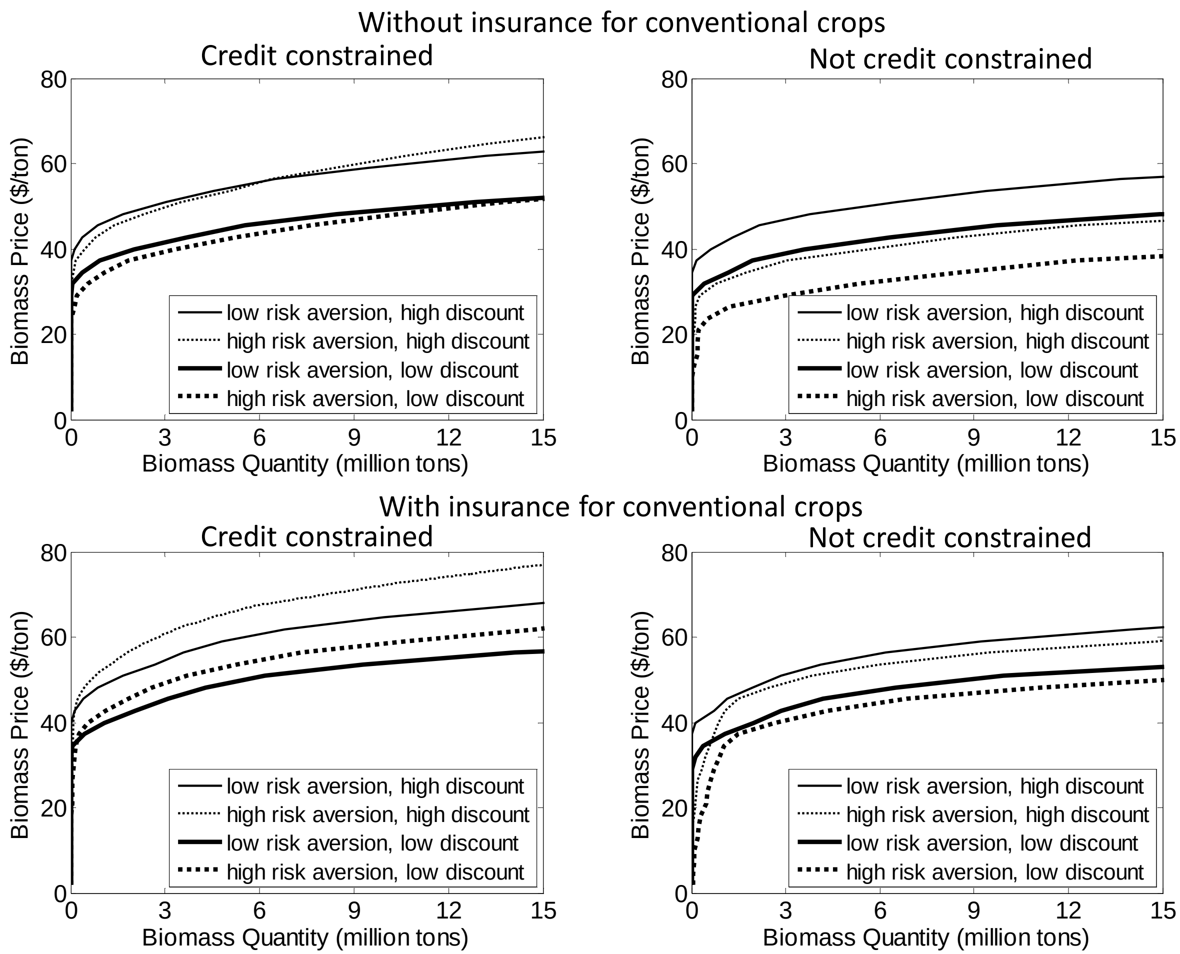

Figure 1. Biomass Supply Curves under Various Scenarios

Note: The absolute risk aversion parameter for high and low risk aversion are 0.00005 and 0.00001, respectively. The high and low discount rates are 10% and 2%, respectively.

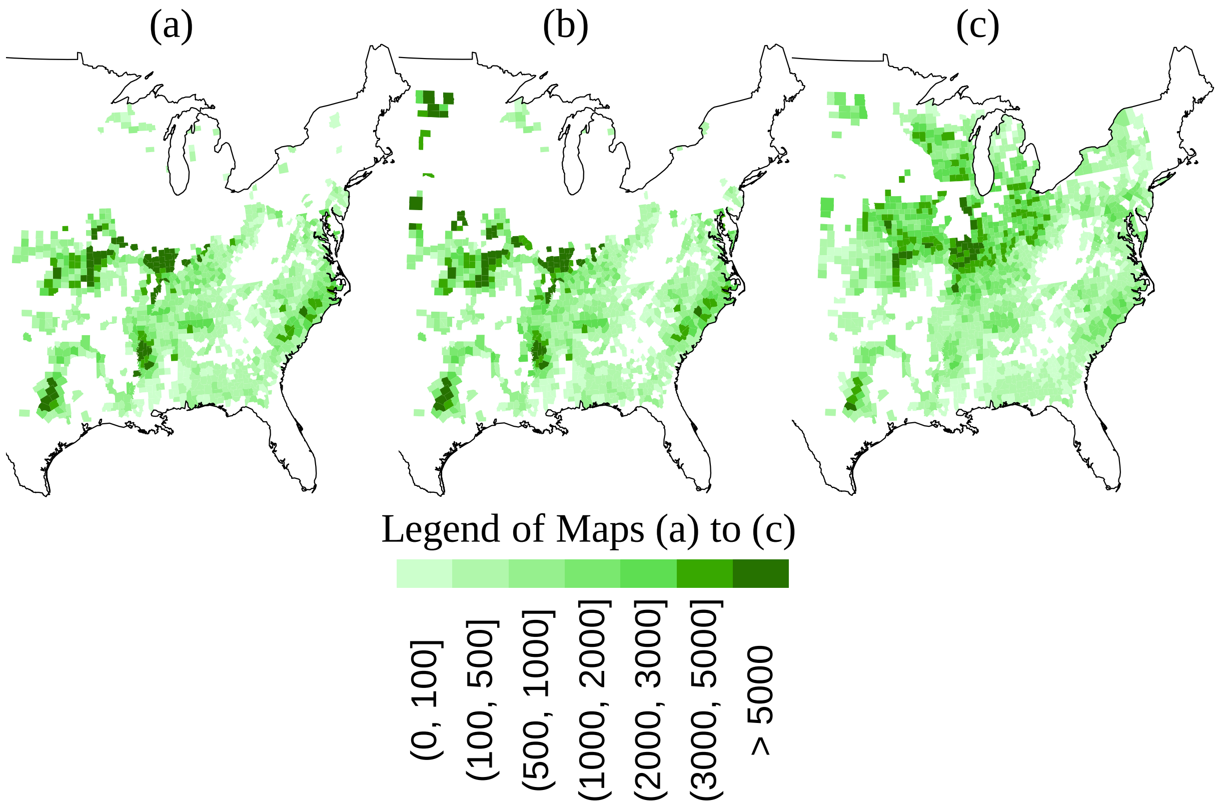

Figure 2. Miscanthus Acreage under Various Scenarios without Policy Intervention (unit: acres)
Note: Map (a) is under the baseline scenario (low risk aversion, low discount rate, insured corn and soybeans, and no credit constraint). Map (b) is under scenario 8 (high risk aversion, low discount, insured corn and soybeans, and no credit constraint). Map (c) is under scenario 9 (high risk aversion, low discount, insured corn and soybeans, and credit constraint).

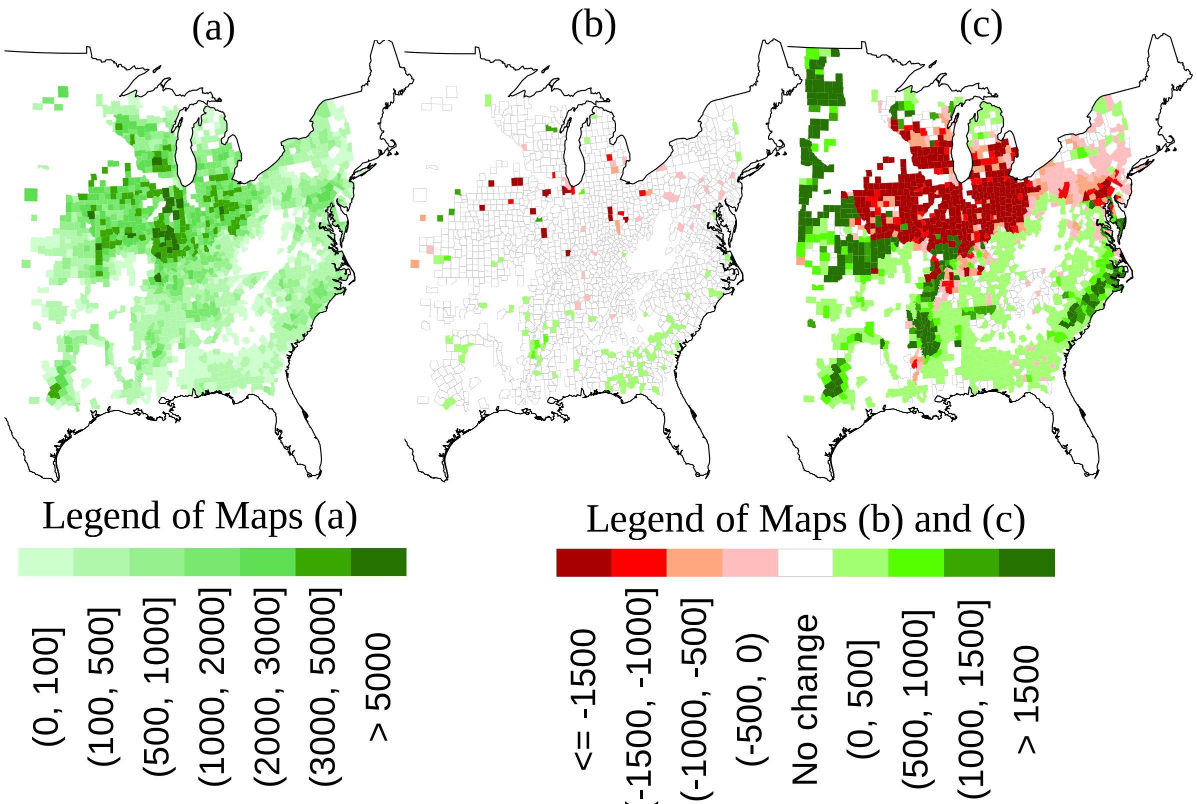

Figure 3. Effects of Alternative Policies on Miscanthus Acreage (unit: acres)

Note: Map (a) is under scenario 13 described in Table 3 (i.e., high risk aversion, high discount, insured corn and soybeans, credit constraint, and no policy interventions for energy crops). Map (b) describes acreage changes when energy crop insurance with 5% premium subsidy rate is imposed under scenario 13 in Table 3. Map (c) describes acreage changes when a 100% establishment cost subsidy is imposed under scenario 13 in Table 3. Red colors in maps (b) and (c) indicate areas where acreage decreases with policy interventions for energy crops whereas green colors indicate areas where it increases.

[1] Large scale production of cellulosic biofuels is at the take-off stage (Peplow 2014). The first commercial-scale cellulosic biorefinery (Crescentino biorefinery) commenced operation in Italy in 2013 and several cellulosic biorefineries in the United States and Brazil have scheduled start-up dates in 2014 (link: http://www.biofuelsdigest.com/bdigest/2014/04/17/brazil-biofuels-digests-10-top-trends-for-2014/ (accessed on July 18, 2014). The first of these, POET-DSM Advanced Biofuels opened a commercial-scale cellulosic ethanol plant in the United States in September 2014 (link: http://poetdsm.com/pr/first-commercial-scale-cellulosic-plant).

[2] Crop insurance coverage is currently available to more than 350 commodities in all 50 states and more than 80% of eligible acres are enrolled in various insurance programs with federally subsidized premiums. Crop insurance can provide coverage that replaces up to about 85% of the projected revenue of a crop. The U.S. federal government subsidizes crop insurance by providing about 60% of the cost of the insurance premium (Babcock 2012).

[3] Other justifications for government intervention to support energy crop production include the environmental benefits (such as greenhouse gas mitigation) they provide that are not priced. The policy to address those could be a Pigouvian tax (such as a carbon tax) targeted at the externality. Chen et al. (2014) show that an unrealistically high carbon tax would be needed to induce production of cellulosic biofuels given their current costs, even if the effects of risk and time preferences of farmers are ignored.

[4] Miscanthus is a particularly productive energy crop whose yields are twice as high as that of other energy crops such as switchgrass. Studies show that it is likely to be more profitable to produce than switchgrass under a wide range of growing conditions in the rainfed US (Jain et al. 2010; Chen et al. 2014; Beach, Zhang, and McCarl 2012; Miao and Khanna 2014).

[5] Note that with a binding biofuel mandate, minimizing total cost as defined here is equivalent to maximizing social welfare (defined as the surplus of biomass producers net of government cost and compliance cost of blenders) without considering the environmental benefits of displacing gasoline with biofuels. Here we implicitly assume constant returns to scale in the industrial cost of conversion of feedstock to biofuel. Compliance cost of blenders is the product of the quantity of ethanol mandated and the difference between the energy equivalent price of ethanol and the marginal cost of production. For simplicity we assume that the cellulosic biofuel production is small enough to not affect conventional crop prices and fuel prices for consumers and therefore consumer surplus is unchanged. We also ignore the environmental benefits of cellulosic biofuels such as their lower carbon intensity relative to fossil fuels, which would provide additional justification for government intervention. We refer readers to Chen et al. (2014) for analysis of the cost effectiveness of alternative policies in mitigating greenhouse gas emissions.

[6] 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 United States. However, unlike DayCent model, these models have not been calibrated to provide energy crop yield on low and high quality land.

[7] 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.

[8] 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).

[9] We find that no more than one third of the 5% low quality land is selected for miscanthus production in our simulation. Varying the available share of low quality land is unlikely to affect the qualitative direction of our results.

[10] According to RMA's Summary of Business Reports and Data, for Crop Revenue Coverage (CRC) plan of corn and soybeans, insurance policies with 75% coverage level are the most popular plans among farmers in terms of acres covered. For instance, in 2010, CRC policies with 75% coverage level insured about 33% of total acres covered by CRC. The corresponding premium subsidy rate for policies with 75% coverage level is 55% (Shields 2013).