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How willing are landowners to supply land for bioenergy crops in the Northern Great Lakes Region?

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Abstract

Land to produce biomass is essential if the United States is to expand bioenergy supply. Use of agriculturally marginal land avoids the food vs. fuel problems of food price rises and carbon debt that are associated with crop and forestland. Recent remote sensing studies have identified large areas of US marginal land deemed suitable for bioenergy crops. Yet the sustainability benefits of growing bioenergy crops on marginal land only pertain if land is economically available. Scant attention has been paid to the willingness of landowners to supply land for bioenergy crops. Focusing on the northern tier of the Great Lakes, where grassland transitions to forest and land prices are low, this contingent valuation study reports on the willingness of a representative sample of 1124 private, noncorporate landowners to rent land for three bioenergy crops: corn, switchgrass, and poplar. Of the 11% of land that was agriculturally marginal, they were willing to make available no more than 21% for any bioenergy crop (switchgrass preferred on marginal land) at double the prevailing land rental rate in the region. At the same generous rental rate, of the 28% that is cropland, they would rent up to 23% for bioenergy crops (corn preferred), while of the 55% that is forestland, they would rent up to 15% for bioenergy crops (poplar preferred). Regression results identified deterrents to land rental for bioenergy purposes included appreciation of environmental amenities and concern about rental disamenities. In sum, like landowners in the southern Great Lakes region, landowners in the Northern Tier are reluctant to supply marginal land for bioenergy crops. If rental markets existed, they would rent more crop and forestland for bioenergy crops than they would marginal land, which would generate carbon debt and opportunity costs in wood product and food markets.

Keywords: bioenergy crops, bioenergy supply, contingent valuation, corn, food vs. fuel, land availability, marginal land, poplar, sustainability, switchgrass, Willingness to supply land

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Introduction

Research into biofuel and bioelectricity development has been a major focus of scientists, land grant universities, and government agencies in the United States following the passage of the Energy Independence and Security Act of 2007. One guiding assumption of this effort to foster second-generation bioenergy markets has been the notion that significant tracts of marginal agricultural and forestlands could provision biomass without necessarily displacing feed, forage, and timber cultivation. Seminal studies, such as the US Department of Energy (2011) Billion Ton report and the Gelfand *et al.* (2013) article on 'Marginal Lands in the US Midwest', document the stock of rural lands with biophysical conditions that suggest they could be primed to generate large quantities of biomass, in the form of permanent grasses and dedicated fast-growth forests, supplemented by crop residues.

In stark contrast, a growing number of studies probe the critical social and economic questions of whether, and under what market conditions, private landowners of 'marginal lands' would be willing to supply land for biomass production (Jensen *et al.*, 2007; Paulrud & Laitila, 2010; Qualls *et al.*, 2012; Bergtold *et al.*, 2014). Most of these studies survey a representative, random sample of private landowners on willingness to supply a specific type of biomass, such as permanent grasses (Jensen *et al.*, 2007; Bocqueho & Jacquet, 2010; Qualls *et al.*, 2012;), residues from crops (Tyndall *et al.*, 2011; Altman & Sanders, 2012; Altman *et al.*, 2015), or woody biomass

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(Joshi & Mehmood, 2011; Aguilar *et al*., 2014). Some studies (Paulrud & Laitila, 2010; Mooney *et al*., 2015; Skevas *et al*., 2016) examine multiple biomass sources and attempt to identify the land types that landowners would dedicate to energy biomass production. The advantage of identifying land types is that this information reveals the degree to which 'marginal lands' are likely to play a small or large role in the provisioning of biomass. These findings can then be used to evaluate potential economic and environmental impacts of bioenergy on the landscape.

This study examines land use decisions governing cellulosic biomass on specific land types in the Northern Tier of Michigan and Wisconsin. The region is of interest for several reasons. First, it represents an important 'extensive margin' for biomass provisioning across the north of the United States, one where forests predominate in a cool weather environment, but they are accompanied by both cropland and farmable noncropland that are not a primary source of food from US agriculture. Although all three land types fit an economic definition of 'marginal land' in the sense that rural land prices and rental rates are low (implying low expected profitability of commercial use), only the farmable noncroplands are marginal in the sense that changing their use would affect neither food nor wood markets. The conversion of cropland to bioenergy crops potentially can affect food and feed prices, while the conversion of forestland to bioenergy crops can affect timber markets (NRC, 2011). These conversions also create a 'carbon debt' whereby many years of bioenergy cropping are required to compensate for the carbon released from forest clearing (Fargione *et al*., 2008).

Second, recent surveys of private landowners in the agricultural areas of southern Michigan and Wisconsin (Mooney *et al*., 2015; Skevas *et al*., 2016) reveal that relatively little marginal land would be made available for biomass production even at high rental rates. These findings are explained by: (a) high opportunity costs associated with current land uses, especially the feed and forage demands of integrated livestock operations; (b) uncertainty and sunk investment associated with some land use changes (Song *et al*., 2011); (c) amenity values associated with current land uses; and (d) other landowner characteristics and preferences.

A third reason for focusing on the Northern Tier of these two states is *prima facie* evidence of lower opportunity costs for biomass provisioning. Land rental rates for cropland and grasslands are considerably lower than in the southern regions of these states. Crop enterprise budget analyses of yields, revenues, and costs associated with cellulosic biomass cultivation in the northern Great Lakes region (Kells & Swinton, 2014) demonstrate that the Northern Tier has a comparative advantage in terms of biomass cultivation (with relatively higher yields of biomass compared to crop and forage production). These comparative advantage conditions are likely to be evident in other Great Lakes states with significant forest cover (e.g., Minnesota and New York). Previous studies of Northern Tier biomass prospects have focused almost exclusively on woody biomass (Joshi & Mehmood, 2011; Aguilar *et al*., 2014), rather than on the wider range of biomass options afforded by the marginal land types of the region. By contrast, this study probes the full array of land types that landowners could dedicate to biomass production, specifically the choice of using cropland, noncrop marginal land, and forestlands, for any of the three main types of biomass (annual grasses, perennial grasses, and wood). The survey design captures the potential to change current land allocation toward or away from crops, forests, and other uses to biomass provisioning.

The empirical analysis exploits a hurdle model estimation strategy (Cragg, 1971; Ma *et al*., 2012) that allows us to treat the landowners' problem in two stages: a first-stage probit model of the willingness to participate in each biomass market and a second-stage truncated regression that explores the amount of land dedicated to the activity contingent on participation. This estimation strategy allows a careful examination of the factors shaping the participation and the land quantity decisions. It thus allows for the possibility that factors can shape either, both, or neither of the decisions. The results help to sort out in what ways land use choices are sensitive to land rental rates and to other nonincome-related factors.

The data collection on landowner willingness to rent out land for bioenergy crops relies on contingent valuation methodology (Cameron & James, 1987; Carson & Hanemann, 2005; Mooney *et al*., 2015; Skevas *et al*., 2016) to explore the responsiveness of landowners to different rental prices for the biomass types. This type of survey research design randomizes the starting price treatment seen by respondents to probe a wide range of possible rental rates. The rental rate scenarios are preceded by survey questions about current land uses and then succeeded by ones that detail explanatory factors related to landowner wealth and income, preferences for amenities, environmental attitudes, and concerns about rental arrangements. The nonincome factors may be especially relevant to Northern Tier landowners for whom these properties and their use are frequently not significant sources of income but may instead provide major recreational or other nonpecuniary values.

The empirical analysis addresses two main questions related to the supply of biomass in the Northern Tier. First, how much land is available for energy biomass in the Northern Tier of Michigan and Wisconsin?

In particular, how does that availability vary by land type – with specific attention to noncrop marginal land where expansion of bioenergy crops would have minimal effect on food and wood markets and on the level of carbon debt. In order to elicit willingness to supply land for production of bioenergy crops, (a) without requiring the respondent to have the equipment and/or capital to produce their own energy biomass, and (b) without incurring the costs of land clearing, the land supply questions inquire about landowner willingness to rent out land for biomass production, rather than asking whether the landowner would produce energy biomass himself or herself. Second, what factors affect supply of land for renting for bioenergy crops in this region? Specifically, (a) What is the relative importance for landowners in this region of profitability (e.g., rental rate) as compared to amenities (e.g., environmental quality and rental process issues)? (b) How does the relative importance of these attributes compare with findings from agricultural zones, such as the southern parts of these same states? (c) How do the determinants of willingness to supply land for bioenergy crops vary between the decision on *whether* to supply any land at all and *how much* land to offer to rent?

The article is structured as follows: The next section presents our conceptual model of the landowner decisions about land use. The third section develops the empirical methods in three parts: the sample frame, the survey design, and the estimation strategy. Section four presents the main empirical findings. The final section discusses the implications of the findings for bioenergy policy and for future research related to land use decisions by private landowners and other types of landowners.

Conceptual model

Prior research suggests that landowners who own more than one type of land think of land types distinctly (Skevas *et al*., 2016). They are more inclined to devote land to a closely related use (e.g., change to a different grass crop on cropland) than to undertake a major land use change (e.g., replace an annual grass crop with a perennial tree crop). Hence, we disaggregate the land use decision among three land types: cropland, farmable noncropland, and forestland. We assume that landowners maximize utility from each type of land type (i) by choosing the area devoted to a given crop (j). We assume that landowner utility comes in part from consumption of marketed goods purchased with money income. That income may be generated as net returns from land-based activities (e.g., crop production, timber harvest) or from nonland income sources. We further assume that landowners derive utility from environmental amenities. Finally, because we elicit willingness to supply land to grow bioenergy crops by hypothesizing a rental market, we assume that the utility function may include disamenities associated with renting land (such as noise and loss of privacy).

Let $\pi^i = \sum p_j^i A_j^i$ denote land revenue generated by renting land type i with A_j^i acres in crop j at rental rate p_j^i up to the total area available of land type i, $\bar{A}^i$. Landowners gain utility from consuming goods and services purchased with income that is the sum of land revenue (π) and nonland income (NLI); consumption is denoted $c(\pi^i + \text{NLI})$.

Then, the utility maximization problem on land type i is defined as:

$$\max_{A_j^i} \; u(\, c(\pi^i + \text{NLI}),\, \text{env}^i,\, \text{rent}^i) \quad s.t. \; \sum_j A_j^i \le \bar{A}^i \tag{1}$$

Utility is a function of consumption (c), environmental amenities (env), and rental disamenities (rent) from renting land for bioenergy crops $j = 1,\ldots,J$. Landowners maximize their utility by choosing the area of land to devote to each crop, recognizing that their choice may affect the level of amenities received from the land. The optimal solution to the maximization problem is given by the bioenergy land supply equation:

$$A_j^{i*} = A(p_j^i,\, \text{env}^i,\, \text{rent}^i | \bar{A}^i, \text{NLI}) \tag{2}$$

For convenience in stating hypotheses, we assume the function $A(.)$ to be differentiable in each of its arguments.

The arguments in the bioenergy land supply equation represent theoretical expectations that can be subjected to empirical hypothesis tests that would lead to rejection of the null hypotheses listed below for the reasons indicated:

- H1: Rental rate (p) has no effect on willingness to rent land or amount of land supplied. But if landowners are market oriented, we expect land area to increase in response to higher rental rate offers ($A'(p) > 0$).
- H2: Environmental amenities (env) have no effect on willingness to rent land or amount of land supplied. But if landowners enjoy land-based environmental amenities that might be curtailed by shifting land to bioenergy uses, we expect enjoyment of environmental amenities to reduce land area offered for bioenergy uses ($A'(\text{env}) < 0$).
- H3: Rental disamenities (rent) have no effect on willingness to rent land or amount of land supplied. But if landowners dislike dealing with renters, then we

expect rental disamenities to reduce the land area offered for bioenergy crops ($A'(\text{rent}) < 0$).

- H4: Land available $\bar{A}$ has no effect on willingness to rent land or amount of land supplied. But if owners of larger tracts of land are either more prone to choose to rent out land, or else once they choose to rent they tend to rent out more land, then we expect larger scale landowners to supply more land for bioenergy crops ($A'(\bar{A}) > 0$).

Data and empirical methods

Landowner sampling and survey methods

To study land supply for bioenergy crops at the extensive margin where the cold and short growing season limits agricultural land use, we selected the Northern Tier of Wisconsin and Michigan. This region is primarily composed of forest but includes significant percentages of cropland and other nonforestland, some of it farmable. The region was chosen for its relatively lower agricultural productivity and the associated lower opportunity cost of conversion to bioenergy crops as compared to more agriculturally productive lands to the south (Kells & Swinton, 2014). Figure 1 illustrates the geographical extent of the Northern Tier region in these two states. It is comprised of a 76 county area with boundaries corresponding to the Northern Lake States Forest and Forage Region as defined by the USDA Major Land Resource Area land classification taxonomy (USDA-NRCS, 2006).

The data for our study come from a mail survey of Northern Tier landowners gathered during October 2014 to April 2015. The survey was conducted following Dillman *et al.*'s (2008) total design method. Four mailings were sent out during 2014 as follows: (1) presurvey postcard to alert recipients (October 10), (2) first questionnaire mailing (October 22), (3) reminder postcard (November 3), and (4) second questionnaire mailing to nonrespondents from the first round (November 13). Although nearly all responses were received by the end of February 2015, the survey continued to accept late questionnaire returns until April 30, 2015. A two-page summary of results was mailed to respondents on October 29, 2015.

The landowners contacted were drawn from a list frame consisted of private landowners, farms, and clubs that owned ten or more acres of rural land. The two-stage sampling process used to develop the list frame first entailed selecting a stratified random sample of 18 counties and then continued with secondary stratification within each county. Stratification at the county level involved the designation of land cover classifications for high (≥20%) and low (<20%) levels of crop and grassland cover, respectively (Fig. 1). This ensured an adequate representation of counties with relatively higher levels of cropland and grassland, where planting bioenergy crops is likely to be more viable as compared to more highly forested counties. Data on land cover in cropland or grassland came from the USDA-NASS Cropland Data Layer (2014). In total, six counties were selected at random in Wisconsin (three per stratum) and twelve in Michigan (six per stratum). Twice as many counties were sampled in Michigan because they are roughly half the size of Wisconsin counties. Sampled counties are denoted by stars in Fig. 1.

The second-stage stratification occurred within counties, dividing potential respondents who own at least ten acres of rural land into four strata. The goal was to assure that responses represented (1) landowners who did and did not participate in forest-management programs that could constrain biomass supply possibilities, and (2) landowners with large- and small-scale landholdings. The identification of landowners with land in state forest programs relied on property tax records obtained from county assessor offices. In Michigan, the relevant programs include the Qualified Forest

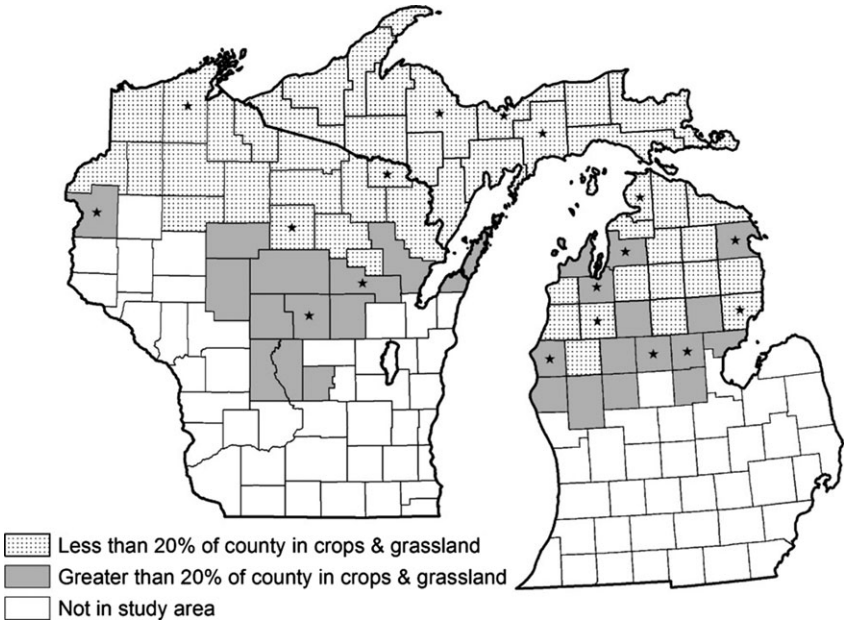

Fig. 1 Northern Tier study zone with county-level land cover stratification categories based on percent of land in crop and grassland from the USDA-NASS Cropland Data Layer (2014). Starred counties were included in the sample.

and Commercial Forest programs, with parcels zoned as 'timber cutover' also counted. In Wisconsin, the Managed Forest Law is the relevant program. The same records identified landowners with 10–100 acres and those with over 100 acres of rural land. The final sample included four strata per county: small-scale landowners not in forest-management programs, small-scale landowners in forest-management programs, large-scale landowners not in forest-management programs, and large-scale landowners in forest-management programs.

To complete the sample selection process, we drew 24 addresses at random from each stratum in (the smaller) Michigan counties and 48 from each stratum in (the larger) Wisconsin counties.[1] This resulted in a balanced final sample frame with 1152 landowners per state. Upon mailing out the study questionnaire to the selected landowner mailing addresses, 134 were returned as undeliverable or otherwise invalid. The final sampled population therefore consisted of 2170 valid addresses, 1124 of which returned completed questionnaires. The final response rate of 51.8% was high enough to provide good assurance of representing the underlying population of private, noncorporate landowners.

Survey experimental design

The questionnaire included sections on current land use and management practices, willingness to rent land for bioenergy crops, opinions about bioenergy, concerns about renting, and demographics. In the land use and management section, respondents were asked how many acres of land they owned of each of the following types – agricultural cropland, farmable noncropland, forestland, and other (e.g., wetlands, lawn). They were further asked whether they used each land type for income or recreation.

The contingent valuation portion was framed as a land rental decision. For each of three potential bioenergy crops – corn, switchgrass, and poplar (*BC* in question example below) – respondents were asked whether they would be willing to rent out land at a given rental rate ($\$\gamma$ in question example below, ranging from \$15 to \$90) on each of three specified land types: cropland, farmable noncropland, and forested land[2] (*LT* in question example below). The question was phrased as follows, 'If somebody offered to rent your *LT* land to grow *BC* for $\$Y$ an acre per year, would you rent any of it out?' If the answer was yes, the respondent was asked to state the number of acres they would be willing to rent.

Rental rates were varied across surveys. Each crop was given one of four rental rates: 15, 30, 60, or 90 dollars per acre. The average rental rate in the region during 2011–2013 was \$30/acre (\$46/acre for cropland; \$18/acre for pasture) according to the USDA's Cash Rents Survey (2014). In each questionnaire, the two grassy crops (corn and switchgrass) were assigned the same rental rate, and the two sources of woody biomass (poplar and slash) also had the same rate in dollars per acre, for a complete factorial design of sixteen (4×4) rental rate treatments that corresponded to 16 different questionnaire versions.

Attitudes toward bioenergy issues were elicited using a series of statements to which respondents were asked to rate their level of agreement on a scale of 1 (strongly disagree) to 5 (strongly agree). Attitudes toward renting were elicited in a similar manner with respondents rating the degree to which they were concerned about noise, potential legal costs, and having people on their land, along with other potential disamenities from renting.

A complete list of variables used in the econometric models is given in Table 1. The table includes constructed variables from factor analysis of the bioenergy attitude and rental concern variables that are described below and in Tables 2 and 3.

Econometric model

The econometric model is designed to capture a two-stage decision process in which the first decision is whether to rent land for bioenergy crops and, if yes, the second decision is how much land to rent. This class of hurdle model, introduced by Cragg (1971), makes it possible to identify whether the same variables differ in their effects on the first- and second-stage decisions. The first stage, the decision on whether to participate in land rental markets for the bioenergy crops corn, switchgrass, and poplar, was estimated as a binary probit model. For those willing to participate, the second stage on how much land they are willing to rent was estimated using a truncated regression to estimate the number of acres made available (conditional on agreement to rent more than zero acres).

Explanatory variables in both the probit and truncated regressions include current land use, acres of each land type, bioenergy attitudes, rental concerns, and socioeconomic characteristics. There were eleven statements regarding bioenergy attitudes and twelve regarding rental concerns in the questionnaire. Because these variables were measured on a 5-point Likert scale, some were highly correlated. Factor analysis is a method of reducing large numbers of variables by searching for joint variation in response to unobserved factors. Using factor analysis, the eleven attitude variables and twelve concern variables were reduced to four factors each.

For each of the raw variables related to bioenergy attitudes and concerns about land rental, we present the factors and the associated factor loadings after orthogonal varimax factor rotation in Tables 2 and 3. The bioenergy attitude factors are labeled and their loadings of the original Likert-scaled variables are as follows:

- 'Antifossil fuels' factor has high loadings on statements about the need to replace fossil fuels;
- 'Pro-bioenergy' factor has high loadings on bioenergy as superior to other renewable energy sources and liquid biofuels as a promising technology;
- 'Antibioenergy' factor has high loadings on bioenergy crops competing with food needs and leading to loss of forest;
- 'Bioenergy skeptic' factor has positive loadings on the importance of renewable energy and the need to protect biodiversity, with negative loadings on prioritizing bioenergy over other forms of renewable energy.

[1]In several counties, there were fewer than 24 landowners in the forest management program. In those cases, we surveyed all landowners in the stratum and increased the sample nonprogram participants to maintain equal sized county samples within each state.

[2]In addition to the three crops, landowners were also asked whether they would be willing to contract for woody biomass removal the next time they had timber harvested or thinned. Results from these questions are analyzed separately from this article.

Table 1 Variables included in econometric models of willingness to rent land for bioenergy crops (northern Michigan and Wisconsin landowners, October 2014–April 2015) (n = 1077)

Variable name	Definition	Units	Mean	SD
Current land use and management				
rent_out	rented out land in 2013	(0/1)	0.25	0.04
rent_in	rented in land in 2013	(0/1)	0.06	0.02
farm_land	landowner farmed land in 2013	(0/1)	0.25	0.05
grew_corn	landowner has grown corn	(0/1)	0.38	0.05
timber_harvest	landowner has had timber harvested	(0/1)	0.54	0.05
acres_cropland	acres cropland	acres	34.21	9.94
acres_noncrop	acres farmable noncropland	acres	14.71	2.96
acres_mx_forest	acres mixed natural forest	acres	63.53	6.34
acres_single_spec	acres in single species tree plantations	acres	10.64	6.79
acres_other	acres other rural land	acres	4.16	0.96
forest_program	land enrolled in a state forest program	(0/1)	0.25	0.04
ag_income	cropland used for income	(0/1)	0.22	0.04
ag_personal	cropland used for personal recreation	(0/1)	0.56	0.05
noncrop_income	farmable noncropland used for income	(0/1)	0.06	0.02
noncrop_personal	farmable noncropland – personal recreation	(0/1)	0.54	0.05
forest_income	forestland used for income	(0/1)	0.03	0.01
forest_personal	forestland used for personal recreation	(0/1)	0.88	0.03
Bioenergy attitudes				
BA-1	antifossil fuels		0.09	0.04
BA-2	pro-bioenergy		−0.01	0.03
BA-3	antibioenergy		0.01	0.03
BA-4	bioenergy skeptic		−0.03	0.02
Rental concerns				
RC-1	environmental concern		0.12	0.05
RC-2	rental process		0.02	0.05
RC-3	smell and noise		0.09	0.05
RC-4	unwanted land use change		0.03	0.03
Background information				
age	age	years	57.94	1.22
gender	male gender	(0/1)	0.81	0.04
h_size	household members	count	2.58	0.10
farmer	farmer	(0/1)	0.21	0.04
income	household income	$1000	91.42	4.50
educ	education	1–6*	3.46	0.14
own_duration	duration of land ownership	years	22.95	1.41
family_land	land previously owned by family relative	(0/1)	0.44	0.05
residence	residence on rural land	(0/1)	0.71	0.04

*Education scaled from 1 (less than 12 years) to 6 (graduate degree).

Land rental concerns were similarly reduced to four factors, as follows:

- 'Environmental impact' factor has heavy loadings on increased use of pesticides and fertilizers, loss of biodiversity, reduced soil and water quality, and negative land use changes;
- 'Rental process' factor loads heavily on potential legal costs, contract length, and need for insurance;
- 'Smell and noise' factor loads heavily on potential smell and noise from machinery, with lesser loading from potential legal costs;
- 'Unwanted land use change' factor loads chiefly on the concern about land changing in undesirable ways.

Results

The Northern Tier of Wisconsin and Michigan is dominated by forest. Survey respondents reported owning 299 000 acres of land. Extrapolating from the survey stratum sampling probabilities, forest cover accounts for 55% of rural land cover (50% mixed species; 5% single species) (Fig. 2). Agricultural cropland is the second most important land type, with 28% of area. Farmable noncropland represents the category of agriculturally marginal land that is not currently in crops but could easily be converted to agricultural use. This land type

Table 2 Bioenergy attitude factor analysis: Rotated factor loadings (pattern matrix), northern Michigan and Wisconsin, 2014

Bioenergy attitude variables	BA1-Antifossil fuels	BA2-Pro-bioenergy	BA3-Antibioenergy	BA4-Bioenergy skeptic
Developing renewable energy (e.g., wind, solar, bioenergy, hydro-electrical) is important to our nation's future.	0.546	0.052	−0.112	0.192
Bioenergy should be prioritized over other forms of renewable energy such as wind or solar power.	0.032	0.392	−0.009	−0.170
Burning bioenergy feedstocks to generate electricity instead of burning coal is worth the extra cost.	0.645	0.223	−0.042	−0.085
Substituting bioenergy feedstocks for fossil fuels will help mitigate climate change.	0.707	0.147	−0.009	−0.061
Growing bioenergy feedstocks on cropland will increase competition with food needs.	−0.030	0.022	0.416	0.080
Increased bioenergy feedstock production will result in significant forest loss.	0.003	−0.177	0.462	−0.033
Government should allow regular harvesting of public forestland and CRP land for bioenergy purposes.	0.050	0.418	−0.198	0.093
Biodiversity should be maintained when land use is changed.	0.357	0.083	0.058	0.317
Liquid biofuels are a promising alternative energy technology that will be successful in the future.	0.236	0.356	−0.100	0.108
The use of fossil fuels can be harmful to human health and the environment.	0.641	−0.188	0.046	0.202
The world will run out of fossil fuels (e.g., oil, natural gas) in the next 50 to 120 years.	0.588	−0.143	0.019	0.118

Table 3 Concerns with renting land factor analysis: Rotated factor loadings (pattern matrix) and unique variances, northern Michigan and Wisconsin, 2014

Concerns with renting land variables	RC1-Environ impact	RC2-Rental process	RC3-Smell and noise	RC4-Unwanted land use change
The potential smell	0.156	0.202	0.712	0.068
Noise from harvesting, planting, or other activities	0.238	0.189	0.745	0.025
Potential legal costs of contracting	0.183	0.600	0.452	0.021
The length of the contract	0.219	0.689	0.175	0.074
The possible need for insurance	0.184	0.722	0.194	0.093
Having other people on my land	0.371	0.350	0.285	0.258
The land changing in a way that I can no longer use it as I want	0.463	0.162	0.206	0.375
How profitable it will be	0.056	0.336	−0.043	0.320
A lack of information about the potential feedstocks	0.233	0.354	0.157	0.297
The use of pesticide and fertilizer on my land	0.601	0.233	0.142	0.030
The loss of biodiversity on my land (e.g., insects, birds, mammals, plants)	0.768	0.137	0.176	0.039
The risk of lower soil and water quality	0.734	0.188	0.199	0.077

constituted 11% of the total, with the remaining 5% described as 'other' noncropland (chiefly wetlands).

The overarching finding is that less than 30% of landowners are willing to rent out their land for any bioenergy crop at the rental rates offered (Figs 3–5). Given that these rates ranged up to three times the prevailing $30/acre cash rental rate, landowners are clearly quite reluctant to make their land available for this purpose. Among those who are willing to rent cropland, they generally prefer to do so for corn (Fig. 3), while those willing to rent out farmable noncropland prefer to do so for switchgrass (Fig. 4). Landowners are especially reluctant to rent out forestland for any bioenergy crop (Fig. 5). But if they do, poplar trees are the preferred bioenergy crop (still with fewer than 20% willing to do so). Extremely few (under 10%) are willing to rent out forestland for planting of grassy crops.

The determinants of willingness to supply land to grow bioenergy crops depend importantly on the interaction among land type (three categories) and crops (3),

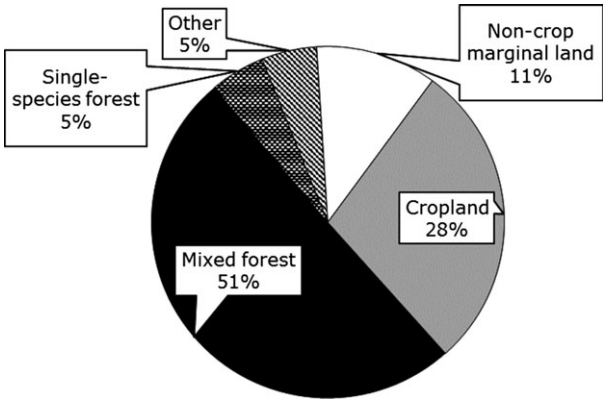

Fig. 2 Land cover type shares, adjusted with survey sampling probability weights, 1077 respondents, northern tier of Michigan and Wisconsin, 2014.

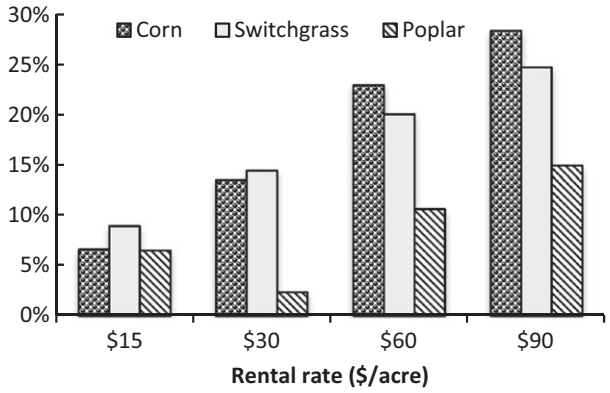

Fig. 3 Willingness to rent out cropland to grow bioenergy crops, adjusted with survey sampling probability weights (n = 690–698), northern tier of Michigan and Wisconsin, 2014.

as well as the two hurdle model stages. In reporting results of the 18 econometric models (Tables 4–9), we describe the consistently influential drivers of land supply before parsing them more carefully at the level of land type, bioenergy crop, or hypothesis area.

Several explanatory variables favored land rental for bioenergy use in nearly all of the nine probit models (Tables 4, 6, and 8). Owners who already rented out land (6 of 9 probit models) and who held pro-bioenergy attitudes (8/9 probits) were more likely to be willing to rent any type of land for bioenergy crops. Likewise, those who had more land, whether cropland (6/9), farmable noncropland (5/9), or mixed forest (7/9), were willing to rent more acres, contingent on being willing to rent out land for bioenergy crops in the first place (Tables 5, 7, and 9). Landowners who held concerns about the rental process were less willing to rent out land for grassy bioenergy crops (corn and switchgrass; Tables 4 and 6).

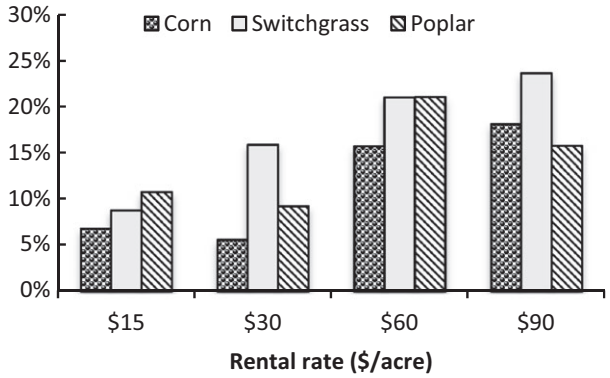

Fig. 4 Willingness to rent out farmable noncrop marginal land to grow bioenergy crops, adjusted with sampling probability weights (n = 732–745), northern tier of Michigan and Wisconsin, 2014.

Results by land type

On cropland (Table 4), as more generally, factors favoring willingness to devote the land to bioenergy crops included having rented out land previously and holding pro-bioenergy views (making, respectively, a typical grower 29% and 6% more likely to rent land). It appears that landowners perceive a connection between their cropland and their farmable noncropland. Landowners who use farmable noncropland for income are 13% less willing to rent out land for corn or switchgrass on cropland, whereas those who use farmable noncropland for personal use are 12–18% more willing to rent out land to grow these bioenergy crops on cropland. In addition, owners who hold concerns about the rental process are also 4–5% less likely to rent out land for bioenergy crops.

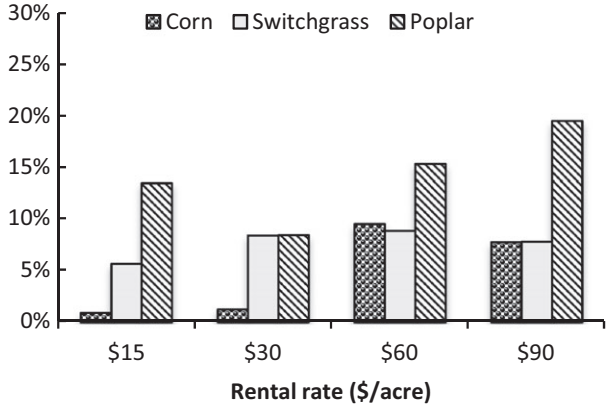

Fig. 5 Willingness to rent out forestland to grow bioenergy crops, adjusted with sampling probability weights (n = 740–748), northern tier of Michigan and Wisconsin, 2014.

Table 4 Marginal effects of determinants of willingness to rent (survey-weighted probit) for 3 bioenergy crops on cropland, northern Michigan and Wisconsin, 2014

	Corn $n = 698$	Switchgrass $n = 692$	Poplar $n = 690$
Rental rate	0.0017***	0.0009	0.0009
Rented out land	0.2939***	0.1931***	0.0467
Rented in land	0.0028	−0.019	−0.3166***
Grew corn	−0.0364	−0.1070**	−0.0603
Had timber harvested	0.1007**	0.0200	0.0193
Acres cropland	−0.0006***	0.0001	0.0002**
Use cropland for income	−0.0374	0.0271	0.0292
Use farmable noncropland for income	−0.1334**	−0.1250**	−0.0615
Use forestland for income	0.0526	0.0779	0.0838**
Personal use for cropland	−0.0177	−0.0445	0.0140
Personal use for farmable noncropland	0.1248**	0.1790***	0.0218
Personal use for forestland	−0.1260**	−0.0729	0.0540
Age	0.0011	−0.0013	−0.0024
Income	−0.0001	0.0001	0.0004*
BA2-pro-bioenergy	0.0637**	0.0807**	0.0678*
RC2-rental process	0.0112	−0.0137	−0.0412**
RC3-smell and noise	−0.0400*	−0.0509*	−0.0240

P-value of chi-square from likelihood ratio test = zero for all models.
Significance (*t*-test probability > 0): ***1%; **5%; *10%.

Table 5 Determinants of area rented of cropland for 3 bioenergy crops among willing renters (survey-weighted truncated regression), northern Michigan and Wisconsin, 2014

	Corn $n = 143$	Switchgrass $n = 128$	Poplar $n = 68$
Rental rate	−0.1814	0.4494	−0.0038
Rented in land	−34.6315	−70.4944	−2286.642**
Farmed land	14.4131	43.8403	18.0394
Acres cropland	0.7204***	0.2174***	1.3107***
Acres noncropland	0.4905*	1.0911***	0.4080
Acres mixed forest	0.2491***	0.3866***	0.9206***
Acres single species	0.3966	0.0468	1.0528***
Acres other	0.4824	2.2534***	1.1808
Enrolled in forest program	−19.9057	−18.9259	21.601
Use cropland for income	46.9705**	70.0677***	25.9531
Use farmable noncropland for income	−14.9797	23.8311	−81.4256*
Use forestland for income	2.4199	40.5554	−84.7840*
Personal use for cropland	−29.8684*	−70.4109***	−152.5169***
Farmer	49.3676*	56.2523*	58.8810
Income	0.2712*	0.5113***	−0.1669
Education	−5.4484***	−12.5929***	−7.3265**
Duration of land ownership	0.5233*	0.2620	−1.3221
Land previously in family	25.4351	44.3883**	56.9597
BA1-antifossil fuels	3.2794	−28.4319	−51.7005*
BA4-bioenergy skeptic	−55.6504**	−103.2028***	−30.5390
RC1-environmental impact	−17.1396	−6.2123	−53.3789***
RC3-smell and noise	23.5600*	46.9646**	63.8777***

P-value of chi-square from likelihood ratio test = zero for all models.
Significance (*t*-test probability > 0): ***1%; **5%; *10%.

The determinants of willingness to rent out cropland for bioenergy poplar (Table 4) differed somewhat from those for bioenergy corn or switchgrass. Those with higher income and more cropland were more willing to rent it out for poplar, especially if they already used forestland for income.

The area of cropland offered by those landowners who were willing to rent it out (Table 5) was increased among the ones who owned more land (of any type), who used cropland for income, who were farmers, whose land was previously in the family, who earned more income, and who held concerns about the rental process (suggesting that those concerns had been assuaged when they decided to rent out land at all). Less land was offered for rental among landowners willing to rent for bioenergy crops who were more educated, who had a personal use for cropland, and who were bioenergy skeptics.

On farmable noncropland, as with cropland, willingness to rent the land out for bioenergy crops (Table 6) was 13–18% greater among owners who already rented out land, while it was 5–8% less among those with rental process concerns. It was also 8–20% less among those who grew corn – at least to make the noncropland available for corn or switchgrass. Those who favor bioenergy were 5–8% more willing to rent out land for the grass crops.

Table 6 Marginal effects of determinants of willingness to rent (survey-weighted probit) for 3 bioenergy crops on farmable noncrop marginal land, northern Michigan and Wisconsin, 2014

	Corn $n = 745$	Switchgrass $n = 738$	Poplar $n = 732$
Rental rate	0.0012***	0.0010	0.0010
Rented out land	0.1342***	0.1817***	0.1523***
Grew corn	−0.0813**	−0.1967***	−0.0996*
Acres cropland	−0.0005**	0.0002*	0.0003*
Acres farmable noncropland	0.0004**	0.0005	0.0000
Enrolled in forest program	−0.0613*	−0.0532	0.0237
Use noncropland for income	−0.0939**	−0.0591	0.0663
Use forestland for income	0.1336***	0.0926	−0.0193
Personal use for noncropland	0.0370	0.0880**	0.0730
Income	0.0002	0.0003	0.0002
BA1-antifossil fuels	−0.0157	0.0252	0.0394
BA2-pro-bioenergy	0.0470**	0.0710*	0.0367
BA3-antibioenergy	−0.0189	−0.0386	−0.0861**
RC3-smell and noise	−0.0456**	−0.0812***	−0.0619**

P-value of chi-square from likelihood ratio test = zero for all models.
Significance (*t*-test probability > 0): ***1%; **5%; *10%.

Table 7 Determinants of area rented of farmable noncrop marginal land for three bioenergy crops among willing renters (survey-weighted truncated regression), northern Michigan and Wisconsin, 2014

	Corn $n = 86$	Switchgrass $n = 106$	Poplar $n = 101$
Rental rate	0.2217	0.4764	−0.9638
Farmed land	16.6768	27.7282	321.3955**
Has had timber harvested	37.3231**	23.5186	124.103
Acres cropland	0.2133**	0.0996***	0.2166*
Acres noncropland	0.0888	0.3920***	1.8026**
Acres mixed forest	0.2884***	0.0517	0.7016***
Acres single species forest	−1.0029	−0.3494	2.9794***
Enrolled in forest program	−61.3598**	−26.1975	−34.0651
Use cropland for income	55.6611**	5.9788	91.6095
Use noncropland for income	−72.7822**	6.9606	−74.6996
Personal use for cropland	−28.5437**	−20.8304	−164.5243
Personal use for noncropland	−31.8586**	−40.0688**	−169.7366
Age	−0.2413	0.9791	0.4235
Male	−3.2353	−52.3486**	−212.5848
Farmer	3.9624	−32.2367	−205.6984
Income	0.0165	0.3477**	−0.0068
Duration of land ownership	−0.5742*	−0.2128	−0.8408
BA1-antifossil fuels	9.4527	−16.8962*	−80.4048
BA4-bioenergy skeptic	−20.4121	57.1869**	181.4276*
RC1-environmental concern	−27.0000***	−39.6014***	−218.4342***
RC2-rental process	21.0484**	−0.5186	−96.9972*
RC3-smell and noise	30.1475**	44.7237**	93.5486
RC4-unwanted land change	2.6550	−16.2695	3.9270

P-value of chi-square from likelihood ratio test = zero for all models.
Significance (*t*-test probability > 0): ***1%; **5%; *10%.

The area of farmable, noncropland that willing owners would avail for bioenergy crops echoes results from cropland (Table 7). Those with more land were willing to rent more land for bioenergy crops, as were those with rental process concerns (assuming those concerns could be addressed). Factors that reduced the area that respondents were willing to rent for bioenergy crops were personal use of noncropland and environmental concerns about bioenergy crop production. Several additional factors worked against renting out land for corn production.

On forestland, owners were much less willing to rent for corn and switchgrass production (Table 8, Fig. 5) – fewer than 10%, even at the highest rental rate (which was over double prevailing cash rents). Those who held pro-bioenergy attitudes, who were offered higher rental rates, and who used cropland for income were relatively more willing. Those who grew corn, held antibioenergy attitudes, and who were concerned about change in land use or loss of profitability tended to offer less land to rent out for bioenergy crops. Surprisingly, those who used forestland for personal use were more willing to rent it out for poplar production.

As for the area of forestland that owners would be willing to rent out for bioenergy crop production (Table 9), renting land for poplar was much preferred to the grass crops. Those with more forestland would rent out more of it for poplar (and those with more cropland would rent out less forestland for poplar). Environmental concerns linked to bioenergy crop production also detracted from the area that owners would

Table 8 Marginal effects of determinants of willingness to rent (survey-weighted probit) for 3 bioenergy crops on forestland, northern Michigan and Wisconsin, 2014

	Corn $n = 748$	Switchgrass $n = 740$	Poplar $n = 742$
Rental rate	0.0011***	0.0003	0.0012*
Rented out land	0.0875***	0.0021	0.0822
Grew corn	−0.0977***	−0.1756***	−0.1944***
Has had timber harvested	0.0672**	0.0466	0.0170
Acres noncropland	−0.0001	−0.0005*	−0.0007
Acres mixed forest	−0.0000	0.0000	−0.0000
Acres single species forest	−0.0003	−0.0008	−0.0000
Acres other	0.0001	0.0006**	0.0000
Enrolled in forest program	−0.0220	−0.0514*	0.0480
Use cropland for income	−0.0148	0.0817**	0.1458**
Use forest for income	0.0059	−0.0403	−0.0096
Personal use for noncropland	−0.0162	0.0193	−0.0715*
Personal use for forest	0.0102	−0.0676	0.1325***
Income	−0.0000	−0.0005**	0.0001
BA1-antifossil fuels	−0.0238***	−0.0011	0.0072
BA2-pro-bioenergy	0.0631***	0.0924***	0.1438***
BA3-antibioenergy	−0.0385**	−0.0449*	−0.0233
RC2-rental process	0.0148	0.0607***	0.0694***
RC4-unwanted land change	−0.0258	−0.0856***	−0.1169***

P-value of chi-square from likelihood ratio test = zero for all models.
Significance (*t*-test probability > 0): ***1%; **5%; *10%.

rent for poplar. Higher rental rate favored offering more forestland, a notable difference from other land types where the rental rate did not affect the area that would be rented for bioenergy crops.

Results by bioenergy crop

Although land type was a dominant factor shaping the willingness of landowners to rent out land for bioenergy crops, there were also clear differences by proposed crop. Corn tended to be the preferred bioenergy crop for rental of cropland. For corn on all land types, a $10/acre increase in rental rate tended to increase the probability of renting out land for bioenergy corn by 1.1–1.7% (on forestland and cropland, respectively). Prior land rental favored willingness to rent out land for corn by 9–29%. Neither rental rate nor prior land rental affected the decision on how many acres to rent. Landowners who already grew corn were disinclined to rent out land to grow more of it on forest or noncropland. As for area of land to rent, the use of cropland or noncropland for income led to more land rented out. By contrast, use of any land type for recreation reduced willingness to rent and/or the area that owners were willing to rent out for corn.

Switchgrass was the preferred bioenergy crop on farmable noncropland. Rental rate did not significantly affect the decision to rent out land for switchgrass, although having rented out land in the past and having a positive attitude toward bioenergy favored doing so. Concerns about land rental and environmental effects of bioenergy crops detracted from willingness to rent land out for switchgrass, as did the use of noncropland or cropland for recreation.

Renting land out for poplar was strongly favored by rental rate, past land rental, and acres of land available (especially forestland). On forestland, those who had had recently harvested timber were more willing to rent land for poplar, whereas those with more single species forest and with environmental concerns about bioenergy were not.

Hypothesis tests

Our conceptual model motivated four hypotheses about determinants of willingness to rent land for bioenergy crops. The null hypotheses turn out to have different effects on the two sides of the econometric hurdle model: the participation probit vs. the area commitment truncated regression.

Rental rate (the price variable in these models) turned out to affect the probability of renting land for corn. More formally, we reject null hypothesis H1 of no rental rate effect in the probit models for corn on all land types, as well as for poplar on forestland. Rental rate did not significantly affect the decision to plant switchgrass on any land type or to plant poplar on cropland or farmable noncropland. Rental rate also affected the area of land rented (at 10% probability of Type I Error) for three cases: switchgrass on cropland, corn on noncropland, and poplar on forestland. Of these, the last is most meaningful, as it implies that rental rate affects both the decision to rent and the area rented for poplar on the land type that is by far the most common.

Environmental amenities tended to have little effect on the decision to rent land out for bioenergy crops, but more effect on the area offered, leading to rejection of H2 for the area offered models. Based on the factor analysis, the 'environmental concerns' factor had positive loadings on three Likert-scaled questions regarding concern about the use of pesticide and fertilizer, the loss of biodiversity, and the risk of lower soil and water quality. Environmental concerns reduced the area of land rented out for both corn and switchgrass on

Table 9 Determinants of area rented of forestland for 3 bioenergy crops among willing renters (survey-weighted truncated regression), northern Michigan and Wisconsin, 2014

	Corn $n = 42$	Switchgrass $n = 47$	Poplar $n = 126$
Rental rate	0.0890	−0.7482**	1.0592***
Rented out land	−15.8086	−98.1590***	−95.7849
Farmed land	−102.9061***	−80.3244**	−7.8465
Has had timber harvested	84.0684***	52.2233*	15.1255
Acres cropland	0.0553	0.0414	−0.2069**
Acres noncropland	0.2677	−0.7829*	−0.8205
Acres mixed forest	0.0977***	0.0725	0.7422***
Acres single species forest	−0.6079***	−0.2546	1.4862***
Acres other	−0.1081	0.5861*	0.9125***
Enrolled in forest program	46.1883**	56.4403*	25.0419
Use cropland for income	−4.8840	42.0171	99.4685
Use noncropland for income	35.7989	12.9629	0.1143
Use forest for income	−50.7284***	−12.4012	45.9190
Personal use for cropland	120.6784***	−84.0853**	−45.3676*
Personal use for noncropland	−87.6434***	106.2819**	10.4705
Personal use for forest	−34.3131***	−94.9490**	−46.6516
Age	−2.4832***	1.3602	−0.9723
Male	−37.3785***	−125.5723**	17.2692
Farmer	−7.8139	72.0467**	42.8510
Income	0.2277***	0.4232**	−0.19614
Education	2.5208**	−3.3241	−7.1597**
Duration of ownership	0.37854	0.1197	0.7592
Residence on land	−58.4296***	81.3367***	33.1348
BA1-antifossil fuels	23.5741***	24.5973**	−15.5943
BA2-pro-bioenergy	3.1775	−0.4279	−5.9331
BA3-antibioenergy	79.0707***	26.9548*	0.0228
BA4-bioenergy skeptic	37.1143***	9.3018	39.9936
RC1-environmental impact	0.5209	−50.4690**	−74.7638***
RC2-rental process	2.2534	−17.6661	49.9649***
RC3-smell and noise	78.3871***	−14.9422	16.5576
RC4-unwanted land change	−87.2139***	−8.5021	−7.8919

P-value of chi-square from likelihood ratio test = zero for all models.
Significance (*t*-test probability > 0): ***1%; **5%; *10%.

farmable noncropland as well as on forestland. They had the same effect for area of land rented for poplar on cropland and forestland.

Concerns about the rental process had a surprising contrapuntal effect: Rental process concerns reduced the probability of renting land to grow bioenergy crops, but among those willing to rent land, rental process 'concerns' had apparently been dealt with, as this factor was associated with renting more land. More formally, hypothesis H3 that rental concern would have no effect was rejected for five of the participation probits. Rental process concerns reduced the probability of renting cropland for switchgrass or poplar, as well as renting farmable noncropland for any of the three bioenergy crops. A related concern – that of irreversible land use change – detracted from the probability of renting forestland for any of the three bioenergy crops.

The rental process 'concerns' factor had a positive effect on the second-stage area commitment truncated model in six instances. This was true for all three bioenergy crops on cropland, corn and switchgrass on farmable noncropland, and corn on forestland. Presumably this result follows because the landowners who were willing to rent out land for bioenergy crops were those who had resolved any rental process issues.

The land resource constraint clearly affected how much land area was supplied by willing landowners. A robust result for almost all bioenergy crops on all land types was that more land area owned increased the area of land that the owner was willing to make available, implying rejection of H4 for the truncated models. However, in certain instances, land area owned also affected the decision of *whether* to rent land for bioenergy crops. In particular, owners with more cropland

were more willing to rent land for switchgrass on noncropland and for poplar on cropland or noncropland, but, oddly, less willing to rent out land for corn on cropland. Land area owned had no effect on the decision to rent out forestland.

Discussion

Land supply for bioenergy crops

Agriculturally marginal regions, including those at the frost-limited northern extensive margin, are potentially attractive for bioenergy crops both because such crops tend not to replace food crops and because the opportunity cost of land is lower. However, this study of the Northern Tier zone of the Great Lakes region in Michigan and Wisconsin finds that the private, noncorporate landowners are willing to supply relatively little land at foreseeable rents more than double current agricultural cash rents in the region. Moreover, most of the land they would supply either has forest cover or crop cover, meaning that bioenergy crops would displace desirable current land covers.

More specifically, the most widespread land cover among the private, noncorporate landowners in the Northern Tier is forest, accounting for 55% of land cover reported.[3] Landowners in the region are reluctant to replace forest with bioenergy crops. Even at rental rates of $90/acre (2–5 times average rental rates for cropland and pasture, respectively), less than 10% of landowners would rent out land for corn or switchgrass, and less than 20% would do so for poplar. Over the range of rental rates reviewed, only 6–14% of landowners would rent forestland for a bioenergy crop (with poplar the preferred choice on forestland). Not only is this a limited land supply, but removing timber to plant bioenergy crops would create a 'carbon debt' that would significantly lengthen the time period before bioenergy crops would make a net reduction in greenhouse gas emissions (Fargione *et al.*, 2008).

Cropland is the second most common land use, at 28% of area managed by respondents. At double the prevailing $45/acre rental rate for cropland in the region, 28% of landowners expressed willingness to rent out land for corn as a bioenergy crop. But this still amounts to just 8% of the aggregate land area, and it carries the opportunity cost of reduced crop output, particularly of livestock feed.

[3]This percentage is lower than the mean for forest land cover generally, because private, non-corporate landowners use a smaller share of their lands for forest than corporate land owners and state/federal forest services.

Farmable noncrop marginal land is the category of greatest interest, due to its low opportunity cost. However, it is the least common type of land, accounting for only 11% of the land held among private, noncorporate landowners in the Northern Tier. Such land typically rents for $15–20/acre, at which rates only 11% of owners would rent out the land. At $90/acre, roughly 5 times the norm, 23% would rent out noncrop marginal land for switchgrass, for an area supply range of 1–2% of total area from these Northern Tier lands with the lowest opportunity cost.

The willingness of landowners to supply noncrop marginal land for bioenergy crops turns out to be similar to the agricultural zones just south of the Northern Tier region. In southern Michigan at rents that range from one-half to three times the $100/acre norm for cropland ($50–300/acre), landowners were willing to supply 20–40% of their noncrop marginal land for bioenergy crops (with corn preferred) (Skevas *et al.*, 2016). Focusing on comparable rents in the $15–90/acre range (when average is $30/acre), Northern Tier landowners were willing to supply an estimated 10–25% of their noncrop marginal land (based on figure 3 of Skevas *et al.*, 2016). In southern Wisconsin, farm landowners with marginal agricultural land would provide less than 5% of their land for bioenergy crops at prices providing similar income (Mooney *et al.*, 2015).

In terms of the overall supply of marginal lands for bioenergy crops, the Northern Tier does not appear any more attractive than more southerly agriculturally dominated regions. In both areas, potential bioenergy supply is quite limited and geographically fragmented, which would in turn increase costs of collection for demand points such as biorefineries or power plants.

Landowner preferences among land types and bioenergy crops

The determinants of land use decisions for cropland and farmable noncropland from this study in the Northern Tier are comparable to those for similar land use categories (cropland, pasture, and other marginal lands) in related studies conducted in southern Michigan and Wisconsin (Mooney *et al.*, 2015; Skevas *et al.*, 2016).

A common finding is that current land cover tends to dictate the preferred bioenergy crops. Respondents preferred not to convert their land from one broad type of cover to another. On agricultural land and farmable noncropland, owners preferred to grow grassy bioenergy crops. On cropland, they tended to favor corn, while on noncrop marginal land, they tended to favor switchgrass. On forestland, they strongly preferred not to convert to bioenergy crops, but the few who were

willing to do so strongly preferred to grow poplar, a tree crop, rather than corn or switchgrass.

Land use decisions among Northern Tier landowners appear less motivated by income generation and more motivated by nonmonetary amenities than in the more agricultural zones of southern Michigan and Wisconsin. Evidence of less income orientation in the Northern Tier comes from the coefficients on the rental rate variable in the probit models for both studies. In the cropland and marginal land use categories, rental rate mattered only in 2 of 6 probit models for the Northern Tier (both times for corn). Yet, rental rate mattered in all 6 probit models for southern Michigan, while in southern Wisconsin, biomass price was a significant driver of farm landowners' initial decision of whether to supply land for bioenergy crops.

By contrast, environmental amenities and bioenergy attitudes were stronger drivers of land use decisions in the Northern Tier. In this region, pro-bioenergy views affected willingness to rent land for bioenergy crops in 5/6 probits, with two other bioenergy attitudes also significant. By contrast, in the southern Michigan study, only 1 of 6 probit models had an influential environmental attitude variable. The same pattern is true of the truncated regression models that predict the area of land supplied by willing renters. In the Northern Tier, the pro-environment 'bioenergy skeptic' attitude factor figured in 3 of 6 models (with environmental impact in one other), while in the southern region, environmental or bioenergy attitudes mattered in only 1 of 6 of truncated models (Skevas *et al*., 2016). In southern Wisconsin, favorable views toward renewable energy and concern for environmental quality boosted the supply of land for bioenergy crops, but the magnitude of these effects was relatively small (Mooney *et al*., 2015).

Rental concerns, generally disamenities, also played a bigger role in land use decisions in the Northern Tier than in the south. In the Northern Tier, the smell and noise factor mattered in 5 of 6 of probits and 6 of 6 truncated models (with rental process also figuring in 2 of 6 truncated regressions). By contrast, in southern Michigan, land rental concerns mattered in just 2 of 6 of probits, with agricultural production concerns mattering in 1 of 6 of probits and 2 of 6 truncated models.

Conclusion

In conclusion, private, noncorporate landowners in the Northern Tier of the Great Lakes are largely unwilling to supply land for production of bioenergy crops, even at land rental rates 2–5 times prevailing values in 2014. Their reluctance appears to stem in part from caring more for environmental amenities and renting disamenities than for income generation on these lands. Hence, even though the economic opportunity costs of rural land in this region appear lower than in agriculturally dominated lands to the south, the potential supply of land for bioenergy crops is limited in this landowner population. While some biomass could come from timber residues associated with thinning or harvesting commercial forests, such supply is likely to be too dispersed to cost-effectively meet the needs of medium- to large-sized biorefineries or bioenergy-powered electrical generating plants (Epplin *et al*., 2007).

There remain two potentially attractive avenues for bioenergy crop production in this region that deserve future research. The first is to examine the current data with greater spatial discrimination. Although the percentage of bioenergy-available land in aggregate is small, future research can use spatial analysis to determine whether there exist geographic clusters of landowners who are more willing to supply their land.

The second avenue is to look beyond private, noncorporate landowners. Apart from this group, there exist two other major types of landowners in the Northern Tier: governments and corporations (McDonough *et al*., 1999; Leefers *et al*., 2003; Vasievich & Leefers, 2006). Most government forest managers are required to target 'mixed use' criteria, but revenue generation is one important objective. Likewise, corporate land (including real estate investment trusts) is typically managed for income generation. Future research into the availability of land for bioenergy crops in the Northern Tier should examine the potential supply from these institutional and corporate landowners.

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