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Landowner willingness to supply marginal land for bioenergy production

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ABSTRACT

This study elicits willingness to supply marginal land for biomass cultivation in Southern Lower Michigan. Most of the surveyed landowners are not interested in renting land for bioenergy crop production. Those who are interested offer relatively little land for bioenergy crops, even at rental rates three times current levels. Willing landowners would prefer to grow a significant portion of these crops on cropland rather than non-crop, marginal land. Hence, the area of marginal land that owners are willing to supply for bioenergy crop production falls far short of area estimates based on remote sensing that ignore landowner preferences.

1. Introduction

Despite being a renewable fuel that is potentially carbon neutral, ethanol has raised concerns that policies intended to promote it may also raise food prices and trigger indirect land use effects that accelerate climate change (Rajagopal et al., 2007; Searchinger et al., 2008; Dumortier et al., 2009). Ethanol can be produced either from starch- and sugar-based feedstocks or from cellulosic feedstocks. Starch- and sugar-based feedstocks come overwhelmingly from corn grain and sugarcane, both important food and feed sources. Cellulosic feedstocks may come from the inedible parts of food crops (e.g., corn stover and sugarcane bagasse) or from dedicated biomass crops (e.g., switchgrass). Policies that augment demand for bioenergy feedstocks from edible parts of food crops directly raise food prices (Rajagopal et al., 2007; Dumortier et al., 2009). Policies that raise demand for cellulosic feedstocks do not increase food prices directly, though they may do so indirectly by competing with food crops for cropland and other productive resources (Searchinger et al., 2008). While cellulosic ethanol remains costly to produce, the intensive scientific search for cost-effective ways to process cellulosic feedstocks into ethanol prompts the need to understand the likely repercussions of growing such feedstocks at large scale.

In theory, food price feedbacks and attendant indirect land use effects from biofuel policies could be avoided if the production of cellulosic feedstocks did not reduce food supplies. Avoiding such competition could occur by increasing output of cellulosic feedstocks either by intensification of byproduct crops or by extensification of dedicated cellulosic biofuel crops. In the United States, intensification of corn production on current crop land would entail raising output of stover and cobs as byproducts for cellulosic ethanol. However, even if this could be done without changing the flow of corn grain to the grain ethanol market, this increased demand for corn land would trigger indirect land use effects through reducing the supply of cropland for other crops (Ciaian and Kancs, 2011). Extensification would mean expanding cellulosic biomass production onto land at the extensive margin. By occupying land that is not used for crops, bioenergy crop production on marginal land could mitigate competition for cropland and associated upward pressure on food prices (Campbell et al., 2008; Carroll and Somerville 2009; Swinton et al., 2011).

The existing literature on the availability of non-crop marginal land ignores landowner willingness to supply land, focusing chiefly on biophysical production potential. Cai et al. develop a global estimate of land availability using remotely sensed land cover data (Cai et al., 2010). Gelfand et al. (2013) also use remote sensing with vegetation modeling to identify eleven million hectares of marginal lands in the US Midwest where native vegetation would be

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sufficient to meet one-quarter of biomass needs to meet the national cellulosic ethanol target set by the US Energy Independence and Security Act of 2007. Another relevant current of literature in agricultural economics uses optimization models to project the potential supply of land for bioenergy crops as a function of available cropland and some percentage of non-crop land (Khanna et al., 2011). Such studies assume that landowners would treat non-crop lands as they do cropland. While certainly more plausible than the 100% land availability assumption implicit in the remote sensing studies, these economic projections still lack empirical evidence on landowner willingness to make non-crop lands available for bioenergy crops.

There is a growing literature that assesses landowner willingness to grow energy crops on cropland. Cope et al. (2011) examined farmers' willingness to grow perennial energy grasses in central Illinois and reported that around one third of the surveyed farmers were willing to adopt these energy crops. A similar study from Illinois shows that 24 percent of the questioned landowners were willing to grow bioenergy crops (Villamil et al., 2012). In a study assessing Swedish farmers' willingness to allocate land for energy crop production, Paulrud and Laitila (2010) noted that expected net income and the crops' growing characteristics affect farmers' adoption decisions. Jensen et al. (2007) investigated Tennessee's farmers' willingness to grow switchgrass and reported a lack of knowledge among many of the surveyed farmers on growing this crop for energy. The same study found that around 30 percent of the surveyed farmers were willing to adopt switchgrass for energy production. Mooney et al. (2015) employed a contingent valuation (CV) approach to investigate farmers' willingness to grow bioenergy crops on marginal lands in Southwest Wisconsin. Their findings show that marginal lands for bioenergy production are scarce and costly and potential spatial agglomeration of bioenergy production could arise.

In short, there are two major literatures on the supply of land for bioenergy crops. One looks at the theoretical supply of non-crop marginal land while ignoring human land use decisions. The other looks at the supply of cropland and includes farmers' expressed intentions. In between, there lies an important gap of knowledge regarding the amount of non-crop marginal land that could be supplied for energy biomass. As already documented by remote sensing studies (e.g., Cai et al., 2010; Gelfand et al., 2013), that total area is large. The unanswered question is how much non-crop land its owners would choose to make available for bioenergy crop production. This study answers that question by examining the economic availability of non-crop, marginal land to grow bioenergy crops through eliciting the willingness of all owners of marginal land to supply this land for bioenergy production. The study explicitly incorporates key price variables (rental rates) to derive supply functions for bioenergy crops from marginal lands. Looking at four major bioenergy crops across three land use categories, it examines the conditions for making each land category available, and the amount of land these landowners would be willing to make available for bioenergy crops. It further investigates the underlying factors that drive decisions to make land available for energy crops.

2. Methods and data

2.1. Conceptual model

Landowners are assumed to maximize utility that is derived from consumption of both marketed products and amenities that come from land (Lopez et al., 1994; Brunstad et al., 1999; Deaton et al., 2007). Marketed products must be purchased with income that can come from a variety of sources such as salary, wages, social security, rental properties, investments, or any other monetary generating source. Amenities from land can take a variety of forms, such as scenery, hunting, fishing, recreational vehicle use, or other physical activities. Following Dupraz et al. (2003) and Ma et al. (2012), the utility maximization problem for a landowner in the case of biomass crop production is as follows:

$$\mathrm{Max}_{\mathrm{LU}^U} = U\left[a, c\right] \tag{1}$$

s.t.

$$c = r_{\mathrm{land}} + r_{\mathrm{other}} \tag{1a}$$

$$a = a_{\mathrm{land}} + a_{\mathrm{other}} \tag{1b}$$

In Eq. (1) utility (U) is a function of amenity values a, and expenditure on consumption goods c that is maximized over the land use decision (LU). A landowner maximizes utility subject to a consumption constraint (composed of land income (r_{land}) and income from other sources (r_{other}) and the availability of amenities from land (a_{land}) and other sources (a_{other}). Growing bioenergy crops can affect both income and amenities from land. Landowners will maximize utility from land by equating individual preferences for income and amenities from land given land resource constraints. Income from land and amenities from land are both functions of land use:

$$r_{\mathrm{land}} = f\left(\mathrm{LU}\right) \tag{2}$$

$$a_{\mathrm{land}} = g\left(\mathrm{LU}\right) \tag{3}$$

A change in land use ΔLU results in a change in income from land (Δr_{land}) and therefore consumption Δc as well as a change in amenities from land (Δa_{land}). Changes in consumption and amenities affect utility so the decision to change land use will cause a net change in utility. Equation (4) shows the base case utility and Eq. (5) the utility after a change in land use:

$$U_0 = U\left[c_0, a_0\right] \tag{4}$$

$$U_1 = U\left[c_0 + \Delta c, a_0 + \Delta a\right] \tag{5}$$

A landowner decides to change land use (ΔLU = 1) if utility after the change is greater than the utility in the base case:

$$\Delta \mathrm{LU} = \begin{cases} 1 \text{ if } U_0 < U_1 \\ 0 \text{ otherwise} \end{cases} \tag{6}$$

When this conceptual model is applied to the case of growing bioenergy crops on marginal land, an individual landowner may or may not convert the land depending on the income and amenities received from it. While growing the bioenergy crops may prove to be profitable on marginal land and thus raise the income of landowners, the extra consumption made possible may not provide greater utility than the amenities the land provides when it is not in use for bioenergy crops. In this case, a utility maximizing landowner would not change land use despite a potential income increase.

Empirically it may be difficult to observe all consumption tradeoffs. However, the foregoing conceptual model implies that land use decisions will depend upon (i) land-based income $\mathrm{r}_{\mathrm{land}}$, a function of land management and uses m, (ii) relative prices (i.e., rental rates and contract length) p, and (iii) amenities a, given a set of heterogeneous attitudes and demographic variables, z:

$$\mathrm{LU}_{ij} = h_i(\mathrm{r}_{\mathrm{land}}, m, p, a_{\mathrm{land}}|z) \tag{7}$$

where LU_{ij} is the supply of land in use j by each landowner i, subject to land area availability in each land use category.

Table 1
Descriptive statistics of 599 landowner respondents, Michigan 2012.

Variable	Units	Mean
Total cropland	acre	86.8
Total pasture	acre	13.0
Total farmable non cropland	acre	17.1
Total land in Conservation Reserve Program (CRP)	acre	4.6
Currently rents land	Percent	33
Age	Years	62
Male	Percent	79
Farmer	Percent	41
Grows crops oneself	Percent	22
Landowner used land for scenery	Percent	62
Landowner used land for physical activities	Percent	53
Landowner used land for hunting or fishing	Percent	69
Landowner used land for grazing livestock	Percent	19
Landowner used land for commercial crop income	Percent	26
Landowner used land for conservation income (CRP payments)	Percent	28
Pre-tax income		
less than $25.000	Percent	10
$25.000–49.999	Percent	25
$50.000–99.999	percent	43
$100.000–149.999	percent	11
$150.000–199.999	Percent	4
$200.000 and above	Percent	7
Education		
Less than 12 years	Percent	5
Completed high school or GED	Percent	28
Technical training beyond high school	Percent	14
Some college (including AA, AS degrees)	Percent	21
Four-year college degree	Percent	16
Some graduate work	Percent	4
Graduate degree	Percent	12

Table 2
Marginal effects for the Probit Participation model for cropland rented for prairie, poplar, switchgrass and corn.[a]

	Corn Coef.	($n = 266$) Z-score	Poplar Coef.	($n = 252$) Z-score	Prairie Coef.	($n = 251$) Z-score	Switchgrass Coef.	($n = 247$) Z-score
Experimental variables								
Ln rental rate ($/acre)	0.27	5.05***	0.18	4.72***	0.21	4.43***	0.25	4.68***
Contract length (yrs)	-8.1×10^{-3}	−0.57	2.3×10^{-3}	0.22	−0.01	−1.5	−0.01	−1.08
Current land management								
Currently rents land (0/1)	0.54	7.12***	0.07	1.09	0.17	2.29**	0.31	3.68***
Current land owned								
Total cropland (acres)	1.8×10^{-4}	2.51**	5.8×10^{-5}	0.88	-1.7×10^{-4}	−1.34	7.05×10^{-5}	0.65
Total pasture (acres)	2.1×10^{-4}	0.97	-9.8×10^{-5}	−0.46	6.6×10^{-5}	0.32	-2.9×10^{-4}	−0.86
Total other land (acres)	-8.02×10^{-4}	−1.98**	-9.9×10^{-5}	−0.43	-3×10^{-5}	−0.08	-4.73×10^{-6}	−0.02
Total CRP land (acres)	1.4×10^{-4}	0.24	4.8×10^{-4}	0.91	1.01×10^{-3}	1.51	-9.4×10^{-4}	−1.1
Current land uses								
Group of non-land based uses	0.07	2.72**	0.06	2.7***	0.11	4.27***	0.08	3.2***
Group of hunting related uses	0.13	2.46**	0.02	0.64	0.01	0.23	0.06	1.2
Grazing livestock (0/1)	0.03	0.39	-9.7×10^{-3}	−0.15	−0.09	−1.23	−0.09	−1.25
Commercial income (0/1)	−0.04	−0.59	0.11	1.61	2.7×10^{-3}	0.04	−0.01	−0.13
Conservation income (0/1)	−0.24	−3.62***	−0.11	−2.04**	−0.08	−1.09	−0.14	−1.8*
Environmental factors								
Renewable energy supporter	-4×10^{-3}	−0.15	0.01	0.74	−0.01	−0.48	8.2×10^{-3}	0.22
Environmental critic	4.4×10^{-3}	1.4	0.04	1.71*	0.03	1.04	0.04	1.14
Concerns factors								
Agricultural based	−0.09	−2.6***	−0.02	−1.02	−0.01	−0.31	−0.03	−0.85
Renting land based	−0.07	−2.08**	−0.06	−2.27**	−0.02	−0.83	−0.06	−1.86*
Demographic information								
Age (years)	1.5×10^{-3}	0.56	-1.3×10^{-3}	−0.62	2.6 × 10-3	0.87	5.3×10^{-4}	0.18
Male (0/1)	0.01	0.18	0.04	0.75	−0.02	−0.31	−0.05	−0.58
Farmer (0/1)	0.05	0.89	−0.13	−1.88*	−0.03	−0.5	0.05	0.66
Income (scale 1–6)	-5.02×10^{-7}	−1.2	-2.4×10^{-7}	−0.59	6.11×10^{-7}	1.33	-8.49×10^{-7}	−1.8*

[a] *** – significant at 1% level, ** – significant at 5% level, * – significant at 10% level. Dummy coefficients are excluded.

2.2. Data

Data for this study come from a 2012 mail survey of owners of non-crop marginal land in southern Michigan (counties south of 43.9° N. latitude). We use an area frame sample (Cotter et al., 1987) built from GIS databases of non-crop marginal lands. The area frame consisting of all current marginal lands in Michigan was

Table 3
Marginal effects for the probit participation model for pasture and hay land rented for prairie, poplar, switchgrass and corn.[a]

	Corn Coef.	($n=275$) Z-score	Poplar Coef.	($n=274$) Z-score	Prairie Coef.	($n=274$) Z-score	Switchgrass Coef.	($n=268$) Z-score
Experimental variables								
Ln rental rate ($/acre)	0.23	4.42***	0.13	3.21***	0.17	3.57***	0.19	3.61***
Contract length (years)	0.01	0.64	1.1×10^{-3}	0.11	−0.01	−0.4	-4×10^{-3}	−0.28
Current land management								
Currently rents land (0/1)	0.3	3.55***	−0.01	−0.14	0.04	0.54	0.11	1.38
Current land owned								
Total cropland (acres)	8.4×10^{-5}	0.84	3.1×10^{-5}	0.41	-6.5×10^{-4}	−1.71*	-4.7×10^{-5}	−0.41
Total pasture (acres)	4.7×10^{-4}	1.64	7×10^{-5}	0.37	3.8×10^{-4}	1.1	1.8×10^{-4}	0.71
Total other land (acres)	-1.9×10^{-4}	−0.44	1.7×10^{-5}	0.05	-4.7×10^{-4}	−0.91	1.6×10^{-4}	0.31
Total CRP land (acres)	1.3×10^{-4}	0.26	-6.4×10^{-4}	−1.1	6×10^{-4}	1.15	9.9×10^{-3}	−1.48
Current land uses								
Group of non-land based uses	3.1×10^{-3}	0.12	0.01	0.59	0.05	1.69*	0.04	1.31
Group of hunting related uses	0.07	1.4	−0.02	−0.43	−0.02	−0.41	−0.01	−0.23
Grazing livestock (0/1)	−0.08	−1.07	−0.03	−0.44	−0.11	−1.39	−0.14	−1.88*
Commercial income (0/1)	−0.18	−2.67**	−0.1	−1.65	−0.06	−0.7	−0.06	−0.74
Conservation income (0/1)	−0.22	−3.08***	−0.1	−1.68*	0.06	0.62	−0.04	−0.44
Environmental factor								
Renewable energy supporter	0.01	0.37	0.01	0.24	-7.8×10^{-4}	−0.02	0.03	0.94
Environmental critic	0.08	2.6**	0.05	1.7*	0.02	0.5	0.05	1.5
Concerns factors								
Agricultural based	−0.04	−1.14	−0.01	−0.18	−0.01	−0.26	−0.04	−1.06
Renting land based	−0.05	−1.48	−0.05	−1.71*	0.01	0.4	−0.01	−0.32
Demographic information								
Age (years)	-1.9×10^{-3}	−0.65	-3.8×10^{-3}	−1.57	-2.3×10^{-3}	−0.73	-1.7×10^{-3}	−0.56
Male (0/1)	0.1	1.29	0.08	1.28	-0.08	−0.98	−0.11	−1.28
Farmer (0/1)	3.6×10^{-3}	0.05	−0.13	−2.13**	−0.15	−1.97*	−0.02	−0.26
Income (scale 1–6)	-6.2×10^{-7}	−1.26	-2×10^{-7}	−0.5	9.9×10^{-7}	1.94*	-2.7×10^{-7}	−0.54

[a] *** – significant at 1% level, ** – significant at 5% level, * – significant at 10% level. Dummy coefficients are excluded.

Table 4
Marginal effects for the Probit participation model for other marginal lands rented for prairie, poplar, switchgrass and corn.[a]

	Corn Coef.	($n=354$) Z-score	Poplar Coef.	($n=349$) Z-score	Prairie Coef.	($n=354$) Z-score	Switchgrass Coef.	($n=354$) Z-score
Experimental variables								
Ln rental rate ($/acre)	0.18	4.32***	0.23	5.13***	0.18	4.24***	0.11	2.42**
Contract length (yrs)	0.03	2.31**	0.01	0.63	-0.01	−0.91	−0.01	−0.69
Current land management:								
Currently rents land (0/1)	0.03	0.49	−0.16	−2.6**	−0.04	−0.52	−0.07	−0.94
Current land owned								
Total cropland (acres)	1.4×10^{-4}	1.97*	-2.9×10^{-5}	-0.39	-1.2×10^{-4}	−0.99	-1.8×10^{-5}	0.2
Total pasture (acres)	-9.8×10^{-5}	−0.49	-1.5×10^{-4}	−0.73	-5.9×10^{-5}	−0.25	-3.3×10^{-4}	−1.32
Total other land (acres)	2.8×10^{-4}	0.81	6.4×10^{-4}	1.76*	5.8×10^{-4}	1.55	9.7×10^{-4}	2.24**
Total CRP land (acres)	-2.2×10^{-3}	−1.52	1.1×10^{-4}	0.17	1.2×10^{-3}	1.9*	-1.2×10^{-3}	−1.42
Current land uses								
Group of non-land based uses	−0.03	−1.41	−0.01	−0.62	0.02	0.73	0.02	0.86
Group of hunting related uses	0.09	2.3**	0.01	0.17	0.04	0.88	0.03	0.62
Grazing livestock (0/1)	−0.1	−1.67	−0.09	−1.26	−0.07	−0.92	−0.12	−1.56
Commercial income (0/1)	−0.02	-0.3	0.17	2.08**	0.05	0.56	0.11	1.31
Conservation income (0/1)	−0.22	−3.73***	−0.01	−0.1	−0.14	−1.86*	−0.16	−2.2**
Environmental factors								
Renewable ernergy supporter	0.03	0.88	0.04	1.24	-4.7×10^{-3}	−0.14	0.02	0.67
Environmental critic	0.1	3.62***	0.04	1.45	0.05	1.51	0.03	0.81
Concerns factors								
Agricultural based	−0.06	−2.19**	0.01	0.49	−0.05	−1.4	−0.01	−0.34
Renting land based	−0.04	−1.21	−0.07	−2.25**	0.04	1.28	−0.05	−1.77*
Demographic information								
Age (years)	1.3×10^{-3}	0.55	-3.2×10^{-3}	−1.21	4.1×10^{-4}	0.15	1.5×10^{-4}	0.05
Male (0/1)	−0.03	−0.4	0.08	1.18	−0.02	−0.28	−0.17	−2.19**
Farmer (0/1)	1.8×10^{-3}	0.03	−0.13	−1.94*	−0.05	−0.77	−0.03	−0.37
Income (scale 1–6)	7.3×10^{-8}	−0.16	2.7×10^{-7}	0.65	2.9×10^{-7}	0.62	-2.3×10^{-7}	−0.53

[a] *** – significant at 1% level, ** – significant at 5% level, * – significant at 10% level. Dummy coefficients are excluded.

Table 5
Truncated acreage model for cropland committed to prairie, poplar, switchgrass and corn.[a]

	Corn Coef.	(n = 77) Z-score	Poplar Coef.	(n = 52) Z-score	Prairie Coef.	(n = 70) Z-score	Switchgrass Coef.	(n = 77) Z-score
Experimental variables								
Ln rental rate ($/acre)	35.91	1.97**	4.68	0.89	−5.99	−0.9	14.61	1.58
Contract length (years)	2.71	0.53	4.41	2.26**	1.16	0.78	−1.29	−0.75
Current land management								
Currently rents land (0/1)	−86.31	−2.31*	0.28	0.04	14.88	1.73*	27.02	2.12**
Current land owned								
Total cropland (acres)	1.02	41.15**	0.99	169.18***	0.78	9.36***	1.02	79.6***
Total pasture (acres)	−1.85	−20.11**	−0.27	-2**	−0.04	−0.4	0.33	2.35**
Total other land (acres)	0.07	0.28	0.18	3.26***	−0.11	−1.57	−0.21	−1.82*
Total CRP land (acres)	-0.28	-1.84*	0.06	1.38	0.28	3.03***	0.23	1.65
Current land uses								
Group of non-land based uses	−6.16	−0.8	−11.07	−4.95***	4.76	1.69	−1.31	−0.59
Group of hunting related uses	−6.5	−0.4	−7.22	−1.33	−5.93	−0.96	14.23	2.2**
Grazing livestock (0/1)	118.2	3.79***	2.9	0.41	−5.24	−0.63	26.62	2.06**
Commercial income (0/1)	19.91	0.81	−5.01	−0.64	−14.32	−1.86**	−19	−1.78
Conservation income (0/1)	107.73	3.71***	−6.17	−0.79	13.34	1.58	−9.67	−1.05
Environmental factors								
Renewable energy supporter	−3.28	−0.24	−0.34	−0.09	12.83	2.27	10.85	1.9*
Environmental critic	2.66	0.25	3.25	0.95	8.69	1.91**	0.77	0.15
Concerns factors								
Agricultural based	−8.91	−1.04	5.59	2.25**	1.21	0.33	−8.91	−1.98**
Renting land based	14.84	1.26	−3.15	−1.04	−1.58	−0.38	3.06	0.77
Demographic information								
Age (years)	1.91	2.09**	0.4	1.63	0.82	2.43**	1.34	2.68**
Male (0/1)	59.19	2.31**	−10.24	−1.07	−2.91	−0.31	−4.41	−0.32
Farmer (0/1)	9.19	0.42	11.59	1.19	8.5	0.93	−23.2	−1.85*
Income (scale 1–6)	4×10^{-4}	1.91***	2×10^{-5}	−0.53	1.2×10^{-5}	0.26	9*10^{-5}	1.06
Constant	−220.95	−1.95	5.56	0.1	−41.28	−1.01	−229.78	−1.8
Log likelihood values	−6254		−3061		−4664		−4910	
Wald Chi-squared	.1e		.9e		59.01		.9e	
Probability Chi-squared	0		0		0		0	

[a] *** – significant at 1% level, ** – significant at 5% level, * – significant at 10% level. Dummy coefficients are excluded.

created using the Cropland Data Layer (CDL) (CropScape, 2010). Of the 53 land cover categories in the CDL database, marginal land was defined as including: (a) fallow cropland, (b) shrubland, (c) grassland, and (d) pasture or hay. A random sample of twelve counties from among the 37 non-metropolitan counties in southern Michigan included the counties of Allegan, Barry, Branch, Ionia, Isabella, Lenawee, Livingston, Newaygo, Saginaw, Sanilac, Tuscola, and Van Buren. In each county, we randomly sampled up to 100 landowners from county tax records who owned individual parcels of non-crop marginal land greater than 10 acres (i.e., 4 hectares). Parcels smaller than 10 acres were intentionally excluded due to the higher costs of production and harvest of biomass from small areas. While exclusion of very small parcels may have reduced the estimated supply of land available for energy biomass, the effect is likely to be both small and notable only at very high biomass prices. The sampling method resulted in a total of 1152 potential respondents, including 3 counties with fewer than 100 suitable landowners (Hayden, 2014).

The survey questionnaire elicited information on current land management and land uses, willingness to supply land for bioenergy crops, attitudes towards the environment, concerns they might have with renting their land for bioenergy crops, and general socioeconomic characteristics. Concerning land management and land uses, respondents were asked whether they currently rented any of their land, and whether they used it for any non-agricultural uses. The section on landowner willingness to supply land for bioenergy crops included binary choice questions on willingness to rent specific types of land (i.e., cropland, pasture, other land) for different bioenergy crops (i.e., corn, switchgrass, poplar, and prairie). Those landowners willing to rent were asked to state, for the given rental rate and contract length, how many acres they would be willing to make available for each type of land they owned.

The range of values assigned to the rental rate was based upon real rental rates in Michigan (Wittenberg and Harsh, 2011). Rental rates for cropland in Michigan in 2011 vary based upon crop, tillage practices, and irrigation, but in the Southern Lower Peninsula $111 per acre was the average rate for tiled cropland and $84 per acre was the average rate for non-tiled cropland. Using these values as reference points, this study used values of $50, $100, $200, or $300 as the rental rate per acre. The low $50 rate was chosen to represent a level linked to the low production potential of marginal land that is not currently in crop use. The upper limit was three times the current typical rate of $100 per acre. Two contract lengths were offered 5 and 10 years.

To elicit underlying attitudes, respondents were asked to what extent they agreed or disagreed with 22 statements concerning attitudes towards the environment and concerns they might have with renting their land. The rating of each statement was based on a five-point Likert scale, including 'strongly disagree' (1), 'disagree' (2), 'neutral' (3), 'agree' (4), and 'strongly agree' (5). These statements were organized in different categories, in particular on willingness to rent land (six statements), bioenergy and the environment (seven), and concerns on renting land for bioenergy crops (nine). Finally, landowners were asked about their socioeconomic characteristics, including age, education, gender, income, and land area.

Given the levels of variation for rental rate and contract length, the challenge was to put them into the questionnaire in a way that results in the best potential analysis of the responses. Since each cropping system is independent (i.e., cropping systems are not alternatives) the resultant combination of all possible levels across

Table 6
Truncated acreage model for pasture and hay land committed to prairie, poplar, switchgrass and corn. [a]

	Corn Coef.	(n = 79) Z-score	Poplar Coef.	(n = 58) Z-score	Prairie Coef.	(n = 102) Z-score	Switchgrass Coef.	(n = 88) Z-score
Experimental variables								
Ln rental rate ($/acre)	−23.42	−1.16	−3.6	−0.62	0.19	0.05	0.23	0.06
Contract length (yrs)	−1.52	−0.34	0.47	0.28	0.59	0.85	1.38	1.7*
Current land management								
Currently rents land (0/1)	−19.49	−1.34	7.83	0.8	−2.22	−0.61	−5.21	-1.22
Current land owned								
Total cropland (acres)	−0.04	−1.23	4×10^{-3}	0.59	0.02	0.64	0.01	1.98**
Total pasture (acres)	0.67	4.35***	1.16	15.31***	1.06	52.79***	0.97	18.65***
Total other land (acres)	0.4	1.17	−0.12	−0.94	−0.15	−3.3***	−0.18	−3.44***
Total CRP land (acres)	0.3	1.87*	−0.07	−0.47	−0.02	−1.09	−0.28	−5.08***
Current land uses								
Group of non-land based uses	2.97	0.37	−5.26	−1.94	−3.44	−2.68***	−1.34	−0.95
Group of hunting related uses	-8.21	-0.6	2.62	0.54	3.3	0.93	5.51	1.29
Grazing livestock (0/1)	−4.96	−0.39	−15.16	−1.43	−8.29	−1.29	−0.32	−0.04
Commercial income (0/1)	3.5	0.21	26.22	2.49***	−4.86	−1	-5.15	−1.04
Conservation income (0/1)	10.96	0.5	0.15	0.02	9.72	1.93**	8.72	1.58
Environmental factors								
Renewable energy supporter	2.17	0.2	−0.93	−0.33	-3	−1.48	−1.54	−0.74
Environmental critic	−3.57	−0.42	4.69	1.51	−0.7	-0.37	0.18	0.11
Concerns factors								
Agricultural based	−5.04	−0.61	7.77	2.36	−1.75	−0.77	0.71	0.38
Renting land based	−13.67	−1.31	0.32	0.09	−3.66	-2.03**	−4.26	−2.15
Demographic information								
Age (years)	0.56	1.07	0.16	0.5	0.19	1.05	0.38	1.98
Male (0/1)	−22.63	−0.94	−17.33	−2.07	−7.62	−1.61	−3.11	−0.6
Farmer (0/1)	0.12	0.01	6.42	0.8	1.32	0.36	9.01	2.52
Income (scale 1–6)	1.2×10^{-4}	−0.89	3.4×10^{-5}	0.62	3×10^{-5}	−0.65	9.5×10^{-5}	2.96***
Constant	56.44	0.91	28.24	0.82	−12.09	−0.83	−46.69	−1.93
Log likelihood values	−6213		−3456		−6103		−5427	
Wald Chi-squared	4.18		361.14		.4e		.2e	
Probability Chi-squared	0		0		0		0	

[a] *** – significant at 1% level, ** – significant at 5% level, * – significant at 10% level. Dummy coefficients are excluded.

all factors, or full factorial design, for a given cropping system is quite small (Keppel 1991). Three attributes vary: rental rate, contract length, and bioenergy crop. For each crop, rental rate has four levels, contract length has two levels, and these two attributes vary across all four bioenergy crops for a full factorial design of $4 \times 2 = 8$ combinations (Hayden, 2014). Using the full factorial design for each crop ensures orthogonality of the design attributes.

Data were collected using a mail questionnaire that was pretested in face-to-face interviews. An initial letter informed all landowners in the sample that in a few days they would be receiving an important survey for which their responses were highly valued. After the initial letter landowners received questionnaire packets including a cover letter introducing the questionnaire, the questionnaire itself, a one dollar bill as incentive, and a prepaid return envelope for the questionnaire. This was followed by a reminder postcard (sent a week later) urging recipients to respond if they had not yet. A second questionnaire packet was sent out about two weeks after the first reminder postcard. Three months after the first questionnaire wave, a total of 599 responses were collected. An additional 124 questionnaires were returned to sender by the Postal Service due to moved individuals, deceased individuals, and address errors. This resulted in the effective response rate for the survey being 58.3% (Hayden, 2014). The socioeconomic characteristics of the respondents are reported in Table 1.

2.3. *Framing the CV question*

The central goal of this research is to elicit landowner willingness to supply land for bioenergy crops in exchange for income. Landowner expression of willingness-to-accept (WTA) could be elicited by at least two broad means. In the first approach, landowners might be offered a price of biomass, with the elicitation question focusing on their willingness to supply biomass at that price (and land supply being derived from assumptions about biomass yield). Given that a large share of rural landowners in southern Michigan are not farmers, such a question runs the risk of underestimating WTA because the landowner lacks the equipment or the expertise to produce bioenergy crops—even if he or she would be willing to supply the land to do so. In the second approach, landowners could be offered a rental rate, with the elicitation question focusing on their willingness to lease land for the purpose of bioenergy crop production. For rural land owned by farmers, this formulation too could lead to underestimates of land supply for bioenergy crops if those farmers prefer not to rent land out, but rather to grow the bioenergy crops directly. Upon weighing the risks, we chose to frame the CV question as a land rental question. However, we collected data on whether the owner was a farmer and whether land had been rented in the past, allowing *ex post* assessment of differences in land rental behavior between farmers and non-farmers in the sample of landowners. Among respondents, 41% identified as farmers and 59% as non-farmers. Among farmers, 61% did not rent out land and 35% did, while among non-farmers 66% did not rent out land and 29% did. As land rental behavior did not differ meaningfully between the two groups, we find scant evidence of probable bias in framing the CV question as willingness to rent out land for bioenergy crop production.

2.4. *Empirical model*

Landowner willingness to supply land for bioenergy crops was modeled empirically as a two-step decision process. First, landowners indicate whether they are willing to rent any of their land to

Table 7
Truncated acreage model for other marginal lands committed to prairie, poplar, switchgrass and corn. [a]

	Corn Coef.	(n = 102) Z-score	Poplar Coef.	(n = 112) Z-score	Prairie Coef.	(n = 137) Z-score	Switchgrass Coef.	(n = 121) Z-score
Experimental variables								
Ln rental rate ($/acre)	−10.01	−0.12	206.45	5.05***	10.55	1.05	−4.02	-0.4
Contract length (yrs)	11.3	0.86	4.03	0.33	0.04	0.02	−6.07	−2.09**
Current land management								
Currently rents land (0/1)	6.17	0.07	−15.72	−0.18	34.41	3.15***	13.93	0.9
Current land owned								
Total cropland (acres)	−0.01	−0.18	0	−0.07	−0.05	−0.99	0.06	4.73***
Total pasture (acres)	−0.02	−0.07	1.01	1.17	0.15	1.27	0.15	1
Total other land (acres)	0.62	1.76*	0.19	0.69	0.27	2.34**	0.07	1.81*
Total CRP land (acres)	3.46	1.61	−1.9	-0.86	−0.14	−1.11	0.24	0.78
Current land uses								
Group of non-land based uses	22.36	0.78	−45.13	−2.48***	−12.79	−2.96***	-19.63	−2.89***
Group of hunting related uses	−141.01	−1.62	−18.76	−0.5	4.6	0.63	10.78	0.96
Grazing livestock (0/1)	189.38	1.5	103.01	1.29	31.34	1.94**	29.46	1.66
Commercial income (0/1)	−183.83	−1.54	25.3	0.55	−20.05	−1.9**	-5.32	−0.28
Conservation income (0/1)	182.27	1.37	64.98	0.66	49.81	3.34***	6.06	0.28
Environmental factors								
Renewable energy supporter	3.67	0.09	−18.67	−0.59	15.49	3.07***	-8.27	−1.38
Environmental critic	9.68	0.26	36.27	0.76	-4.85	−1.26	6.75	1.02
Concerns factors								
Agricultural based	−70.14	−1.7	−45.12	−0.96	−7.03	−1.98**	4.99	0.82
Renting land based	−109.91	−1.64	−47.71	−1.72*	−25.92	−3.73***	−18.25	−1.99**
Demographic information								
Age (years)	2.67	0.77	4.31	1.25	0.13	0.33	0.99	1.6
Male (0/1)	135.29	0.87	4.14	0.05	−1.1	−0.07	6.96	0.31
Farmer (0/1)	44.92	0.5	48.65	0.51	21.75	2.1**	21.46	1.36
Income (scale 1–6)	1.2×10^{-3}	1.51	1.3×10^{-4}	−0.28	9.7×10^{-5}	1.34	1.5×10^{-4}	1.41
Constant	−506.32	−1.36	−1139.7	−1.45	5.32	1.23	96.77	1.78
Log likelihood values	−7614		−8581		−9198		−8335	
Wald Chi-squared	69.62		49.35		55.74		17.02	
Probability Chi-squared	0		0		0		0	

[a] *** – significant at 1% level, ** – significant at 5% level, * – significant at 10% level. Dummy coefficients are excluded.

grow each bioenergy crop at a given rental rate and contract length. Second, for those willing to rent any land, they indicate how much land they would be willing to rent. This two-step process was modeled with an econometric hurdle model that separates the decision on whether to participate from the decision on how many acres to commit.

Following Cragg (1971) and Ma et al. (2012), a probit model was used for the binary response of whether the landowner *i* is willing to participate in renting a specific type of land (i.e., cropland, pasture, other land) for bioenergy crops (i.e., corn, switchgrass, poplar, and prairie). Maximum likelihood was used to estimate the probit model. The specification of the probit model is as follows:

$$Pr\left(Y_i = 1|X_i\right) = \Phi\left(\frac{\beta_p X_i^{'}}{\sigma_p}\right) \quad (8)$$

where Y is the binary choice of whether to rent land to grow a given bioenergy crop, Pr denotes probability, Φ is the normal cumulative distribution function, X is a vector of explanatory variables, $\beta_p$is a vector of parameters and $\sigma_p$is the standard deviation for the participation model.

A second-stage truncated regression estimates the area of land offered for rental, conditional on willingness to participate. This model is as follows:

$$A_i = \beta_a X_i^{'} + \epsilon_{ai} \quad (9)$$

where A is acres rented,β_a the vector of coefficients, X the explanatory variables, and $\epsilon_{ai}$the independently and normally distributed error term with mean zero and variance σ. Enrolled acres are only observed if $A_i > 0$, so conditional on renting acres, the expected value of acres rented is:

$$E(A_i|A_i > 0) = \beta_a X_i^{'} + \sigma\lambda_i \quad (10)$$

where $\lambda_i = \frac{\phi\left(\frac{-X\beta\alpha}{\sigma}\right)}{1-\Phi\left(\frac{-X\beta\alpha}{\sigma}\right)}$.

Here,λ_i is the inverse Mills ratio, $\phi(.)$is the standard normal probability density function and $\Phi(.)$ is the standard normal cumulative distribution function.

The hurdle model allows for the variables and coefficients to differ between the participation and the acreage commitment models. The two models are then combined, following Ma et al. (2012), to show how many acres would be expected of an individual landowner, and by extension, to build regional supply functions for bioenergy crops on marginal land.

The explanatory variables included the design variables (i.e., rental rates and contract length for bioenergy production), the landowners' current land use and management decisions, socioeconomic characteristics, and amenity related characteristics identified and quantified through factor analysis of attitudinal statements measured in a five-point Likert scale. Factor analysis was employed to reduce the number of attitudinal variables for the supply functions as well as to detect structure in the relationships among variables, thus contributing to a better understanding of landowners' preferences on bioenergy production. The criteria for acceptability of a factor solution were based on (a) exclusion of items with factor loadings less than 0.60 (Guadagnoli and Velicer, 1988) and (b) minimum factor eigenvalues of 1.0 (Kaiser 1960).

2.4.1. Weighting and scaling model to Southern lower Michigan

In order to permit extrapolation from survey respondents to the population of the region as a whole (scaling up), the observations were weighted according to the probability that an observation was included given the sampling design. In this study, we sampled owners of ten acres or more of marginal land from 12 counties; however, not all counties had the same number of such tracts of land. The probability that an observation was included given the sampling design was created by dividing the number of responses for each county by the number of tracts of at least ten acres of marginal land in that county. Probability weights, formed as inverse probability of sampling, mean that counties that were under-sampled according to their number of tracts of ten acres or more of marginal land would have the correct impact on the model.

Creating a supply curve for all of southern Michigan involved taking results from the participation and acreage commitment models, and scaling them up to the total area in southern Michigan. The GIS analysis showed that 2.85 million acres of marginal land exist in southern Lower Michigan; however, much of that land is in areas less than ten acres. In the 12 counties sampled, only 21% of the acres of marginal land were in tracts of at least ten acres and these tracts averaged 23 acres in size. Twenty one percent of 2.85 million is about 600 thousand acres. Dividing these 600 thousand acres by an average tract size of 23 acres yields a total of 26,000 tracts of marginal land of at least ten acres in southern Michigan. This number was then multiplied by the willingness to supply marginal land of our average respondent to provide an estimate of the supply of marginal land for bioenergy crops from southern Michigan.

3. Results

3.1. Factor analysis to identify attitudinal structure

Factor analyses of statements regarding environmental attitudes and land rental concerns revealed two major factors underlying each group. The internal consistency of the factors was examined using Cronbach's alpha statistic, and moderate to high values were reported ($a \geq 0.6$). The factors related to environmental attitudes are named "renewable energy supporter" (RE) and "environmental critic" (EC) (Table A1). The RE factor has high positive loadings on the statements "growing crops for auto fuel is necessary" and "burning renewables is worth it over coal," with a high negative loading on "renewable energy is not urgently needed." The EC factor had high positive loadings on the statements, "humans have the right to modify the environment" and "the ecological crisis has been exaggerated," with negative loadings on "humankind is severely abusing the environment" and "the balance of nature is easily upset."

The major factors associated with land rental concerns involve general "concerns with renting land" (CRL) and more specific "concerns with agricultural production" (CAP) (Table A2). The CRL factor has high positive loadings on statements related to, the potential legal costs of contracting, length of land rental contract, possible need for insurance if renting land, having others on one's land, and "land use changing so that I can no longer use it as I have." The CAP factor focuses on concerns about agricultural land use, with high positive loadings on statements related to the potential smell, noise from farming activities, and dust in the air.

3.2. Willingness to rent land (participation probit)

The estimation results of the probit models are presented in Tables 2–4. County fixed effects estimates are not presented due to space limitations, but are available on request. County-specific dummies were included to control for differences between the counties that are not accounted for by the explanatory variables. Indeed, many of the county-specific dummies turned out to be significant, implying that cross-county differences in landowner decisions to make land available for bioenergy production. Determinants of landowner willingness to engage in renting land for bioenergy crops were consistent with expectations from microeconomic theory across all four bioenergy crops, (mixed prairie, hybrid poplar trees, switchgrass, and corn) on all three different land types, (cropland, pasture land, and other marginal lands), with the exception of poplar, the one tree crop, on pasture and other marginal lands (Table 2; details in Tables 2–4). Across all 12 probit participation models, the rental rate offered has a strong, positive influence on whether to participation. The predicted probability of land rental for any of the grass crops increased from a range of 6–13% at a rental rate of $50/acre to a range of 33–75% at a rate of $300/acre.

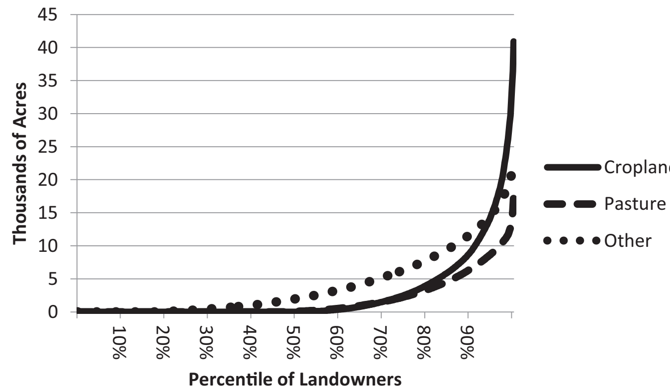

Fig. 1. Total acreage owned at each percentile of land owners by land type.

Other drivers of the participation decision are whether the landowner currently rents land, current land uses[1], and whether the landowner has concerns about renting. Landowners who currently rent out their land are more likely to participate in renting land out for bioenergy crops as well. The effect of current land uses depends on whether the uses are tied to a specific land cover.

Landowners who generally use their land for scenery, recreation, or physical activities–uses that are independent of the specific vegetative cover–are more likely to rent out their land for bioenergy crops. Using land for commercial income, increases the probability of renting land for bioenergy production. On the other hand, landowners who use their land for conservation income are less likely to rent their land. Although environmental attitudes did not influence the land rental decision for bioenergy crops, concerns about land rental did. Both of the landowner concern factors—general concerns about renting land and concerns specific to agricultural activities—tended to discourage participation in growing bioenergy crops.

3.3. Acreage offered (truncated regression)

The truncated regression results for acreage offered conditional on participation are presented in Tables 5–7 (we refer to these as the acreage commitment models). As with the probit results, county fixed effects estimates are not reported, but can be obtained from the authors upon request. While rental rate was the biggest driver

[1] While current land use is pre-determined relative to the land rental decision offered in the survey, it may be endogenous statistically if unmeasured errors associated with the prior land use decisions are correlated with the unmeasured errors associated with the participation decision which can lead to biased parameters. To test for endogeneity, we dropped the current land use variables and reran the probit and truncated regression models. The results showed no major effect on parameter estimates.

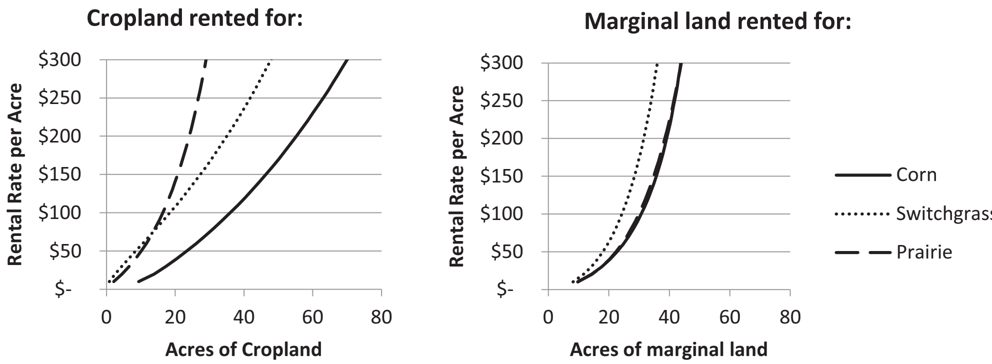

Fig. 2. Average landowner supply of cropland (left panel) and marginal land (right panel) (i.e., pasture and other marginal lands) for bioenergy crops (combined participation and acreage commitment models).

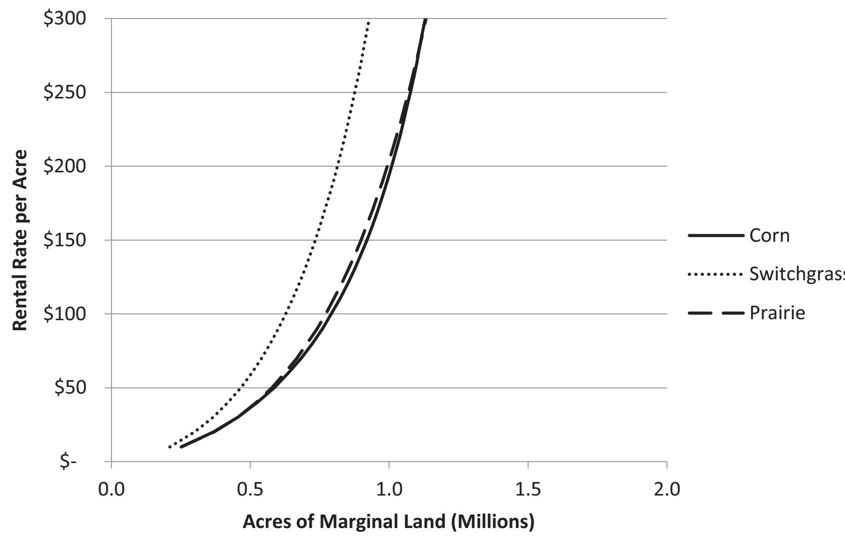

Fig. 3. Supply of marginal land (Pasture + Other Marginal Lands) for three bioenergy crops in Southern lower peninsula of Michigan.

of the decision on *whether* to rent land for bioenergy crops, the area of land available was the biggest driver of how much land willing renters would offer. However, the proportion of land that owners were willing to offer varied from one land type to the next. Landowners would rent essentially all cropland available, as seen by the coefficients 1.02, 0.99, 0.78, and 1.02 across the four bioenergy crops (i.e., corn, poplar, prairie, and switchgrass, respectively) in Table 5. On pasture and hay land the coefficients are similar (i.e., 0.67, 1.16, 1.06, and 0.97) (Table 6). However, on other marginal lands these coefficients fall sharply for all crops except corn to 0.62, 0.19, 0.27, and 0.07 across the four bioenergy crops (Table 7).

Unlike the participation model, in the acreage commitment truncated regression model the variable “non-land based uses,” which captures use of lands for scenery, recreation, or physical activities had negative coefficient estimates on all three land types. This pattern suggests that the higher the reservation value of land for amenity uses, the less land the owner is willing to devote to bioenergy crops. Landowners who use their land for conservation income, however, are willing to rent more land for bioenergy crops, many of which would continue to meet conservation objectives. While the rental rate offered does affect the decision to rent, it generally does not affect the amount they will rent once they have agreed to rent. In pretest interviews, landowners explained that they view their land in sections or fields; if they like a rental rate they are likely to convert the whole section over to the new use rather than just a portion of it.

How much land is the average landowner willing to rent for cropland compared to pasture and other marginal lands? The amount of cropland that the average landowner who owns cropland would rent at a typical $100/acre rental rate was generally over 120 acres, while the average owner of pasture or other marginal lands was willing to rent a combined total of 90 acres. This difference arises from the fact that on average, landowners owned larger areas of cropland than pasture and other marginal lands. A Lorenz curve displaying the relation between proportion of respondents and proportion of land owned by type (Fig. 1) shows that even though survey respondents were targeted by ownership of marginal land, as a group, they own in total as much cropland as of pasture, hay, and other marginal lands. The Lorenz land ownership curve also shows that larger landowners own a significant share of the land, with cropland particularly concentrated. The top 10% of cropland owners own 80% of the cropland, the top 10% of pasture and hay landowners own 70% of the pasture and hay lands, and the top 10% of other marginal land landowners own 50% of the other marginal land.

3.4. Scaling up results to southern lower Michigan

The supply of land for bioenergy crops from an average individual southern Michigan landowner was calculated by combining the results from the participation and the acreage commitment models

(Fig. 2)[2]. These results show that at a typical rental rate of $100 per acre, the average owner of marginal land is willing to rent out 16–35 acres of cropland and 24–30 acres of marginal land (defined here as the sum of pasture and all other marginal land including hay, pasture, scrubland, grassland, idle land, and other farmable non-crop lands). From the truncated regression results and the Lorenz land ownership curve (Fig. 1), it is apparent that owners of marginal land often own more cropland than marginal land. But on average they are willing to rent similar amounts of it at the same price. However, the price elasticity of land supply is much greater for cropland than pasture and other marginal land, meaning that a change in price will affect the supply of cropland much more than the supply of pasture or other marginal land.

The aggregate supply function of land for bioenergy crops in southern Michigan appears in Fig. 3. This figure shows a maximum of around 1.1 million acres becoming available at very high rental rates of $300 per acre, with around 0.8 million acres being available at a typical rental rate of $100 per acre of rainfed land.

Given that the estimated amount of marginal land in southern Michigan is around three million acres, at typical rental rates only about 27% of existing marginal land likely would be supplied for bioenergy crops.

4. Discussion and conclusions

Using marginal land to grow bioenergy crops instead of cropland would result in reduced effects on food prices and spillovers on environmental sensitive lands. Examining the social and economic availability of marginal land for bioenergy production is essential in assessing the potential of this type of land for biomass cultivation (De Laporte et al., 2014). Survey responses indicate low willingness to participate in bioenergy markets among owners of marginal land in southern Michigan.

The empirical results of the predicted probabilities of land rental prompt three important observations. First, regardless of the bioenergy crop, the type of land the crop is being grown on, or the rental rate offered, less than 64% of rural landowners are willing to rent out any amount of land to grow bioenergy crops. At a typical crop rental rate of $100 per acre this proportion falls to less than 31% of rural landowners. This finding is consistent with the feedback from pretesting the survey with Michigan landowners. Many landowners simply were unwilling to rent their land regardless of the price offered and have revealed that they do not want to rent their non-cropland at current prices paid in the markets for agricultural land rental (e.g., corn, etc).

Second, landowners are less likely to rent out any type of land for the one tree crop proposed—hybrid poplar. On all three land types, landowners were most willing to rent out their land for switchgrass and prairie, but the statistical difference between these two crops and corn was very small. By contrast, with hybrid poplar trees the difference was larger, anecdotally because hybrid poplar trees are thought to be less desirable given that they have greater root systems that are more involved to remove if any potential future land use change is desired. This finding partially supports the hypothesis that at the same rental rate, landowners will have a higher probability of renting out land to grow mixed prairie or switchgrass crops over poplar trees or corn.

Third, landowners are less likely to rent out marginal land than cropland. If we look at just the bioenergy crop that performs best on each land type (the crop for which land is most likely to be rented), we see that the probability of renting cropland for switchgrass is 25% at a typical rental rate of $100 per acre while renting pasture lands and other marginal lands for prairie is only 17% and 18%, respectively.

When the individual landowner responses were scaled up to cover southern Michigan, we found that at a typical crop rental rate of $100 per acre only 27% of the marginal land was projected to be offered for bioenergy crops. There is reason to view this estimate of marginal land available for bioenergy crop production in southern Michigan as an optimistic upper bound for two reasons. First, our supply schedule corresponds to marginal land from owners of parcels greater than 10 acres. Since the truncated regression results show that landowners with more land are willing to supply more marginal land for bioenergy crops, we expect that expanding the supply estimate to all marginal land would result in a lower percentage supplied at any rental rate, because the total supply would add owners of smaller parcels who are willing to supply disproportionately less land. Second, current demand for dedicated bioenergy crops in the United States is insufficient to support typical cropland rental rates, because energy demand for cellulosic biomass remains patchy and tied to pilot projects. In sum, the estimate that 27% of marginal land would be available for bioenergy crop production in southern Michigan at typical land rental rates may be inflated both because it was estimated from data that omitted small parcels and because bioenergy crops other than corn grain currently do not support typical land rental rates.

While recent articles about bioenergy supply have implied that energy crops might be targeted toward marginal lands (Cai et al., 2010; Gelfand et al., 2013), we find that the supply of land for bioenergy crops cannot be restricted to one type of land. Many owners of marginal land own cropland as well. When asked what land they would be willing to rent for bioenergy crops, landowners on average were willing to provide the same amount of cropland as marginal land. Apparently the amenity value of keeping non-crop land in its current use often outweighs the utility that would be gained from additional land-based income.

Drawing on the stated preferences of real landowners, these findings point to three major hurdles for bioenergy crops on marginal land. First, they show that owners of marginal land are willing to make available for bioenergy crops much less marginal land than had been estimated by remote sensing and biophysical simulation modeling studies that ignore landowner behavior (Gelfand et al., 2013). Second, if a market to grow bioenergy crops did exist, then landowners would choose to grow a significant portion of these crops on cropland rather than marginal non-crop land. This, in turn would lead to bioenergy production having a significant impact on food prices. Third, the low willingness to rent land for bioenergy crops implies that a much larger catchment area would be required to keep a biorefinery operating at capacity. Such spatial fragmentation of the energy biomass supply will trigger higher transportation costs and/or the need to incur costs of biomass densification (Bals and Dale, 2012).

The supply of land for bioenergy feedstock production depends critically upon decisions by landowners. This economic estimate finds that the supply of non-crop marginal land for bioenergy crops is much smaller and spatially dispersed than biophysical estimates of the supply of marginal land supply. Equally important, the economic supply of non-crop marginal land for bioenergy crops is inseparable from the supply of current cropland (because landowners prefer to grow bioenergy crops on existing cropland, given the choice). Finding space to grow bioenergy crops will come at a greater cost than implied by studies that ignore landowner preferences and economic behavior.

[2] Hybrid poplar on marginal land is omitted from Fig. 2 because the rental rate coefficient estimate was statistically insignificant in both the poplar participation model and the poplar acreage commitment model.

Table A1
Rotated factor loadings for environmental attitudes.

Observed variable	RE[a]	EC
Growing crops for auto fuel is necessary	**0.8681**	−0.0595
Burning renewables is worth it over coal	**0.8469**	−0.1565
Humans have the right to modify the environment	0.2550	**0.7297**
Humankind is severely abusing the environment	0.4614	**−0.6710**
This ecological crisis has been exaggerated	−0.4189	0.6268
The balance of nature is easily upset	0.3280	**−0.6581**
Renewable energy is not urgently needed	**−0.7077**	0.2200

Note: Factor loading scores after orthogonal Crawford-Ferguson rotation. Loadings in bold show values of 0.6 and above.
[a] RE and EC denote renewable energy supporter and environmental critic, respectively.

Table A2
Rotated factor loadings for landowner concerns.

Observed variable	CRL[a]	CAP
The potential smell	0.1199	**0.8641**
Noise from harvesting planting or other activities	0.2236	**0.8359**
Dust in the air	0.2333	**0.8638**
Potential legal costs of contracting	**0.6195**	0.4702
Length of contract	**0.7658**	0.1960
Possible need for insurance	**0.7780**	0.2216
Having others on my land	**0.7709**	0.2644
Land use changing so that I can no longer use it as I have	**0.6902**	0.1211
Use of pesticide and fertilizer on my land	0.4786	0.3702

Note: Factor loading scores after orthogonal Crawford-Ferguson rotation. Loadings in bold show Cronbach's alpha values of 0.6 and above.
[a] CAP and CRL denote concerns with agricultural production and concerns with renting land, respectively.

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Appendix A.

Appendix A Supplementary data.

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2015.09.027.

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