What Drives the Potential Supply of Timber Residues from Private Lands in the Northern Tier of the Great Lakes?

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Abstract

Timber residues, a wood production byproduct, are a low cost source of biomass that avoids the environmental and food market consequences of other energy feedstocks. We studied the effect that price, acreage owned, bio-energy attitudes, environmental amenities, and environmental disamenities have on the decision to harvest for non-commercial private forest owners in northern Michigan and Wisconsin. Over 60% of landowners were willing to provide timber residues at timber harvest or stand improvement (tree thinning) at prices starting at just $15 per acre. Important drivers of willingness to supply timber residues include the price offered for timber residue, single-species forest acreage owned, duration on land, and the aversion to environmental disamenities. The propensity to supply timber residues was highest among educated owners of larger scale, single-species forest who made less than $133,000/year.

Key words: Bioenergy, timber residue, willingness to accept, non-industrial private forest.

JEL codes: Q23, Q42

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I. Introduction

Timber residues serve as a potentially significant biomass source in meeting growing U.S. energy needs. As low cost byproducts of existing wood production activities, timber residues provide an alternative to dedicated biomass crops while circumventing the environmental and food market consequences that come with growing dedicated energy crops on agricultural land. Additionally, utilizing byproduct feedstocks such as timber residues avoids the price feedback issues associated with diverting land that produces products for existing markets (DOE, 2011).

The production of dedicated bioenergy crops (including tree crops) comes with several implications. Using edible crops as an energy feedstock contributes to food price changes that ripple worldwide. Most notably, some of the global cereal food price spikes that occurred from 2005 to 2011 are attributed to the shift of U.S. cropland into corn grown for ethanol production following the passage of the renewable fuel standards in 2005 and 2007 (DOE, 2011; IFPRI, 2010; NRC, 2011; Oladosu, 2013). Rising food prices such as the cereal price spikes not only hurt the poor, they also create environmental harm via indirect land use change (ILUC). The conversion of existing forest to food crops causes a large, one-time release of CO_2 that may not be recovered by the consequent use of land for the production of biofuels (NRC, 2011), seriously undermining and potentially reversing the greenhouse gas (GHG) offset intended by the initial bioenergy mandate policy (Searchinger, 2010). Increasing productivity and conversion efficiency could alleviate food price and ILUC challenges (DOE, 2011), but increased corn production leads to other forms of environmental damage, including an increase of nitrates in waterways, erosion (Pimentel, 2009), hypoxia, algal blooms, eutrophication (NRC, 2011), and a decrease in wildlife (Fargione et al, 2009). The use of marginal agricultural lands in place of fertile lands for bioenergy feedstock production is another solution, but the economic availability of such lands remains questionable (Mooney et al, 2015; Skevas et al, 2016; Swinton et al, 2016).

Obtaining bioenergy feedstocks from byproducts can avoid the price feedback problems associated with dedicated bioenergy crops. Literature local to Michigan and Wisconsin support this claim; Skevas et al (2016) found that the use of one agricultural byproduct as an energy feedstock was more profitable than other perennial cellulosic crops such as switchgrass and carried less risk. Common feedstocks include corn stover, wheat straw, and timber residue. Timber residues, also known as “thinnings,” “removal residues,” “logging residues,” or “timber slash,” is the material left after timber harvest or stand improvement (thinning) on forested land (DOE, 2011). Byproducts such as timber residues provide this profit advantage over dedicated bioenergy crops because their production costs are already covered by the sale price of the base product.

Timber residues have the advantage of dynamic end-use and show promise as a low-cost avenue toward meeting CO_2 emission reduction goals. Timber residues may be processed into ethanol at a dedicated bio-refinery (NRC, 2011) or burned for bioelectricity. Burning timber residues in a power plant can be done in an existing plant with a relatively low-cost retrofit (Hughes, 2000). The use of timber residues for bioelectricity could be one of the most cost-effective ways of meeting voluntary CO_2 reductions due to the utilization of existing infrastructure (De et al, 2009). Moreover, co-firing timber residues along with coal has the potential to create positive local economic impact for areas that both ship coal from far away and have abundant timber resources, such as Mississippi (Perez-Verdin et al, 2008).

How available is energy biomass from timber residues? This remains a key question. Timber residue supply remains uncertain and limited (EPA, 2015). The potential for a large national timber residue supply is relatively modest due to high marginal costs, and the lack of federal subsidies to ameliorate these costs. Market uncertainties such as these are likely to curtail private investment (NRC, 2011). Many studies have been conducted to estimate the biophysical availability of wood and timber residues in the past (Butler et al, 2010; DOE, 2011), but less is known about the economic determinants of that availability. As much of the U.S. timber supply grows in non-industrial, private forests (NIPFs), the contribution of large quantities of timber residue to meet demands for renewable energy is not possible without the voluntary cooperation of these private forest owners.

Understanding NIPF landowner behavior and willingness to harvest timber residues is crucial to understanding the availability of the material. Considerably less attention in the literature has been given to forest residue harvesting preferences of NIPF landowners, though this literature has grown substantially in recent years. Existing literature indicates that socio-demographic characteristics, forest management objectives, and stand characteristics are all important determinants of the NIPF landowner’s decision to supply/harvest timber residues from their forest land (Joshi & Mehmood, 2011; Gruchy et al, 2012; Becker et al, 2013). In their study of the availability of logging residues for bioenergy production by NIPF landowners in the southern United States, Joshi & Mehmood (2011) found that characteristics such as age, acreage, ownership objectives, and species were all important determinants of the landowner's decision. However, their study omitted biomass price, a key economic variable. Knowledge of wood-based bioenergy is another key driver, according to Joshi et al (2013), who call for developing strong extension services to inform landowners with small tracts of land of the potential of woody biomass as an energy feedstock. Landowner attitudes towards forest management and bioenergy as well as opinions about the importance of climate change are also important drivers of willingness to supply timber residues (Gruchy et al, 2012; Markowski et al, 2012).

A large share of existing research on the availability of timber residues for energy biomass comes from the southern United States (Gruchy, 2012; Joshi et al, 2011; Joshi et al, 2013), which is home to 80% of U.S. forest cover (NRC, 2011). While the Midwest is represented in the literature (Aguilar et al, 2014; Becker et al, 2013), the presence of economic drivers in these papers' models are largely absent with the exception of Aguilar et al (2014). Aguilar et al (2014) found that marginal willingness to supply timber residues was far more sensitive to the offer price for saw logs than to changes in the price of timber residues. Although they include a variable related to environmental disamenities as well as one related to attitudes about energy, the study lacks a rich set of covariates that cover environmental amenities and disamenities. Moreover, it omits controls for level of knowledge regarding bioenergy concepts, zoning restrictions, or tree type. The addition of these variables could better isolate the effect of timber residue price on the decision to harvest.

The goal of this study is to shed light on what drives the supply of timber residues by NIPFs in a region underrepresented in the literature as well as to test the effects of price, bioenergy attitudes, acreage, amenities, and disamenities while controlling for stand and socio-demographic characteristics. In this study, we focus on the Northern Tier of the Great Lakes, specifically the subregion that includes northern Michigan and northern Wisconsin. This area has a well-established wood products industry that produces saw logs and biomass for paper pulp among other forest products (Dickmann & Leefers, 2003).

II. Conceptual Model

We assume that all private forest owners are seeking to maximize their utility with respect to the use of their forested land. Utility is driven in part by the forest owner's consumption behavior as well as the environmental amenities and disamenities associated with the harvest of timber residues. Empirically, a forest owner's utility is also conditioned upon variables such as demographic characteristics, knowledge of timber residues, beliefs about bioenergy, and concerns about the removal process.

Define the utility that the forest owner derives from their forested land as U, as in equation (1). The function U is assumed to be differentiable and increasing concavely in consumption *(c[.])*, environmental amenities, a, knowledge of/attitudes toward bioenergy, b, but decreasing in disamenities, d. These arguments, in turn, are affected by choice variable *A,* the number of acres that a landowner makes available for the harvest of timber residues. A is represented by $A = s + o$, composed of *s,* the number of single species acres supplied, and o, the number of acres of mixed forest supplied.

$$\text{(1)} \qquad \max_A U = [c[m + \pi(pA)], a(A), b(A), d(A) | \boldsymbol{X_n}]$$
$$s.t. \quad A = \{\bar{A}, 0\}$$

The consumption function represents the utility derived from goods and services purchased with monetary income. Total income from personal and all forest sources other than timber residues is denoted by the variable m. Timber residue income is $\pi = pA$, the forest owner's revenue from timber residues at payment p per acre for the area of timber residues that is made available. Revenue and hence consumption and utility are increasing in A. Environmental amenities, a, (such as biodiversity) are decreasing in A, while the utility that a forest owner gains from the knowledge that their harvest of timber residues will aid the supply of bioenergy, b, is increasing in A. Disamenities, d, (such as reduced privacy) are also increasing in A.

For each $n[n = 1 \ldots, N]$ individual forest owner, all other observable variables that affect the forest owner's utility in this choice scenario are denoted by the vector $\boldsymbol{X_n}$, whose components are described in Table (1).

The forest owner's optimal decision of whether to supply land for timber residue harvest is represented by equation (2). The decision of A^* is binary, with the option of providing timber residues from the fixed total available number of acres, $\bar{A}$, or none. The value $\bar{A}$ is determined by the total number of forested acres owned, the age of the forest, and other factors that determine timber logging or stand improvement timing. Timber residue harvest is treated as all-or-none in nature; it is not economically feasible to selectively harvest a number of forested acres that is less than the total amount available for harvest due to the cost of harvesting and equipment.

(2) $$A^* = A(p, s, a, b, d|\bar{A}, m, \boldsymbol{X_n}) = \begin{cases} \bar{A}, & U(\bar{A}) > U(0) \\ 0, & U(\bar{A}) \leq U(0) \end{cases}$$

Table 1: Class vectors of the control variable vector, $\boldsymbol{X_n}$

Component of X_n	Description
$\boldsymbol{dem}$	Demographic variables such as age and education
$\boldsymbol{for}$	Forest characteristics such as tree age
$\boldsymbol{use}$	Existing plans that the forest owner has regarding her/his forest, existing forest uses, and participation in forest programs
$\boldsymbol{beliefs}$	Beliefs that the forest owner has about energy issues relating to timber residues
$\boldsymbol{concerns}$	Concerns that the forest owner has about the process or consequences of harvesting timber residues

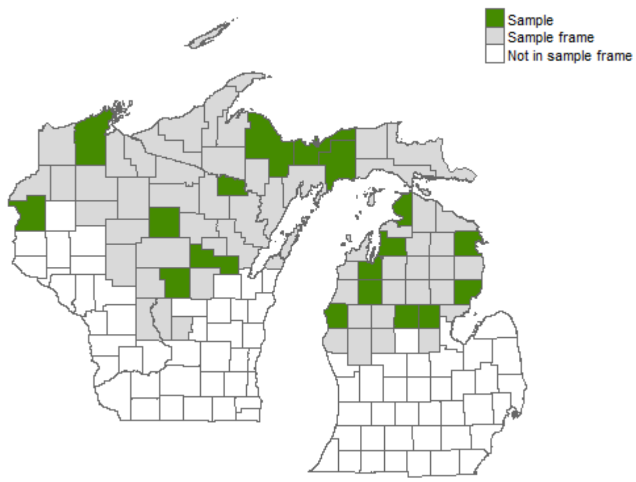
III. Data

This study utilizes data from a contingent valuation survey distributed by the Great Lakes Bioenergy Research Center (GLBRC) from October 2014 to May 2015. The geographical area for the sample frame is the Northern Tier of the Great Lakes: a 76-county subregion of northern Michigan and Wisconsin with ample forested land and limited agricultural growing capacity. The sample was stratified at both county and household levels. At the county level, the GLBRC stratified the 76 counties by high (>20%) and low (<20%) grassland cover, randomly selecting six counties in Wisconsin and twelve in Michigan (Michigan counties are approximately half the size of Wisconsin's) (Swinton et al, 2016).

Within each county, GLBRC targeted 96 (Michigan) or 192 (Wisconsin) non-institutional landowners that owned ten or more acres of rural land, identified from county-level property tax records (Swinton et al, 2016). GLBRC stratified the second stage of the sample by large (>100 acres) and small (10-100 acres) landholdings as well as participation or non-participation in forest management programs such as "Conservation Stewardship Program." This created four strata within each county from which GLBRC selected 24 and 48 participants for Michigan and Wisconsin, respectively, with the goal of creating a balanced sample.

After culling the 2304 addresses mailed for 134 undeliverable surveys, the final sample of 2170 achieved a 51.8% response rate (Swinton et al, 2016). Of these respondents, 91.5% of the sample owned at least some forested land. For the purpose of this analysis, non-forest owners were dropped from the original sample because they are not participants in the timber residue market and are not relevant for this particular analysis.

Figure 1: Sample frame for the 2014-2015 GLBRC survey



The survey included questions about demographics such as age, income sources, and education level, as well as forest characteristics, plans, and management practices. The survey also included belief variables associated with opinions regarding the environmental amenities offered by harvesting timber residues. In addition, the survey included concern variables that pertained to levels of comfort surrounding the disamenities that come with the harvest of timber residues such as noise, smell, and privacy. Respondents were asked to react to the 11 belief and nine concern statements on a Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree). The explanatory variables that we include in this study and their descriptive statistics are in Table (2).

The contingent valuation section for timber residues included two scenarios where forest owners were asked (1) "if [the company harvesting your timber] offered you a contract for $___ per acre to remove woody biomass from your forested land at the time of your next <u>timber harvest</u>, would you agree to the offer?" and (2) "if [the company harvesting your timber] offered you a contract for $___ per acre to remove woody biomass from your forested land at the time of your next <u>stand improvement</u>, would you agree to the offer? (such as forest thinning, junk wood removal, or habitat restoration)." The dollar payment for timber slash varied randomly across surveys ($15,

$30, $60, $ 90). For each of the timber residue questions, respondents could answer (a) "yes, I would be willing to sell my woody biomass," (b) "no, I do not have plans to harvest timber/conduct stand improvement from my forested land," (c) "no," with no detail, (d) "no, I would sell my biomass if the payment were higher," or (e) "I would never sell woody biomass from a timber harvest."

Table 2: Selected explanatory variables from the 2014-2015 GLBRC survey

Variable	Description	Units	N	Mean	Std. Dev.
Decisions					
harvest_decision	Agree to harvest biomass next harvest	0/1*	865	0.6208	0.4855
stand_decision	Agree to harvest biomass next stand improvement	0/1	869	0.5501	0.4978
Income					
price	Price offered	$/acre	939	48.802	28.447
income	Household income	$	765	91536	62802
ag_income	Forest used for ag income	0/1	933	0.0782	0.2687
rec_income	Forest used for rec income	0/1	933	0.0279	0.1647
Demographics					
age	Age	years	881	62.417	11.763
male	Male gender	0/1	883	0.8618	0.3453
farmer	Farmer	0/1	877	0.3067	0.4614
education	Education	years	939	0.5027	0.5003
ag_zone	Agriculture zoning	0/1	903	0.3422	0.4747
residential	Residential zoning	0/1	903	0.1251	0.3311
forest	Forest zoning	0/1	903	0.2004	0.4006
duration	Duration of land ownership	years	872	27.733	18.339
family_land	Land has family legacy	0/1	887	0.5299	0.4994
resident	Is resident of rural land	0/1	888	0.6486	0.4777
Forest Characteristics					
mix_forest_acres	Mixed natural forest	acres	896	212.58	2044.7
single_spec_acres	Single-species tree plantations	acres	905	13.263	80.952
other_forest_acres	Other forest	acres	908	5.3823	108.79
old_mix	Mixed forest is over 10 years old	0/1	939	0.8829	0.3218
old_sing	Single-species tree plantation is over 10 years old	0/1	939	0.4462	0.4974
Uses					
prev_harv	Has previously harvested timber	0/1	913	0.7612	0.4266
other_use	Plans to convert land to other use within 10 years	0/1	816	0.0159	0.1253
forest_personal	Forested land used for personal use	0/1	933	0.7792	0.4150
forest_other	Forested land used for other uses	0/1	933	0.0740	0.2618
forest_prog	In a forest program	0/1	939	0.5474	0.4980
cons_ease	Conservation easement	0/1	905	0.0840	0.2775
reserve	Located within a forest reserve	0/1	907	0.0441	0.2054

Variable	Description	Units	N	Mean	Std. Dev.
Knowledge					
bioenergy	Landowner has heard of bioenergy	0/1	930	0.9043	0.2943
slash_ethanol	Knows forest slash could be used for bioenergy	0/1	920	0.5946	0.4912
seen_slash	Landowner has seen forest slash	0/1	922	0.7028	0.4573
Beliefs					
renewable_belief	Renewable energy important to future of the US	0-5†	911	4.1866	0.8934
bioenergy_belief	Bioenergy should be prioritized over other renewables	0-5	908	2.9703	0.9215
no_coal_belief	Bioenergy should be burned over coal even with extra cost	0-5	905	3.0022	0.9301
climate_change_belief	Substituting bioenergy feedstocks for fossil fuels will help mitigate climate change	0-5	907	2.9680	0.9923
food_issue_belief	Growing bioenergy feedstocks on cropland will increase competition with food needs	0-5	907	3.4410	0.9144
forest_loss_belief	Bioenergy will result in forest loss	0-5	907	2.9008	0.8568
public_for_belief	Government should allow harvesting of public forest and CRP land for bioenergy	0-5	906	3.2627	1.0645
biodiversity	Biodiversity should be maintained when land use is changed	0-5	898	3.5445	0.8425
biofuels_belief	Liquid biofuels are a promising alternative energy technology	0-5	900	3.2600	0.7162
fossil_harm_belief	The use of fossil fuels can be harmful to health and the environment	0-5	903	3.3544	1.0553
fossil_limit_belief	The world will run out of fossil fuels in the next 50 to 120 years	0-5	907	2.7894	0.9713
Concerns					
smell	The potential smell	0-5	841	2.4643	0.9200
noise	Noise from harvesting, planting, or other activities	0-5	842	2.3824	0.9348
insurance	The possible need for insurance	0-5	840	3.3619	0.9328
privacy	Having other people on my land	0-5	842	3.4525	1.1070
change	The land changing in a way that I can no longer use it as I want	0-5	841	3.7051	1.0182
profit	How profitable it will be	0-5	841	3.6421	0.8572
questions	Lack of information	0-5	837	3.3130	0.8872
loss_biodiversity_concern	Loss of biodiversity	0-5	839	3.5077	1.0878
loss_soil_concern	Risk lower soil and water quality	0-5	841	3.4732	1.0700

* 0 = no, 1 = yes
† 1= strongly disagree, 2= disagree, 3= uncertain, 4= agree, 5= strongly agree
Sampling weights are applied.
“No plans” for “next timber harvest” variable was dropped because these respondents are not participants in the timber residue market.

IV. Empirical Methodology

We estimate the relationships between acreage offered and the variables explained in Table (1) by estimating an indirect utility function, or the probability that a forest owner will accept the offer to harvest timber residue at randomly varying levels of payment per acre, $price\_slash$.

A. Probit Model

Let the observed decision of every forest owner $n[n = 1 \ldots, N]$ be represented by $y \in \{0,1\}$, where 1 signifies that n accepts offer to harvest timber slash, and 0 means that n declines the offer. The probability that a forest owner accepts the offer is also the probability that the forest owner's utility from forested land (from equation (1)) is greater with acceptance than it is without acceptance and vice versa, as in equations (3-4).

$$\text{Pr}[\text{y} = 1] = Pr[U(\bar{A}) > U(0)] \tag{3}$$

$$\text{Pr}[\text{y} = 0] = Pr[U(\bar{A}) \leq U(0)] \tag{4}$$

For the timber residue question, the forest owner either commits all of their forested acres to timber residue harvest, or none (see equation (5)).

$$y = \begin{cases} 1, & A = \bar{A} \\ 0, & A = 0 \end{cases} \tag{5}$$

$$\text{Pr}[\text{y} = 1] = \alpha + \beta_p p + \boldsymbol{\beta_m m} + \boldsymbol{\beta_d dem} + \boldsymbol{\beta_f\, for} + \boldsymbol{\beta_a activities} + \boldsymbol{\beta_k knowledge} + \boldsymbol{\beta_b\, belief} + \boldsymbol{\beta_c\, concerns} + \varepsilon \tag{6}$$

Equation (6) is the chosen model for the indirect utility function. The explanatory variables for the model are captured by price *p,* and the vectors ***m, dem, for, use, knowledge, belief***, and

concerns which are described in table (1). The variable p and the vector $\boldsymbol{m}$ and are meant to estimate the consumption function from equation (1), *c[.]*.

Under the assumption that ε from equation (6) is approximately normal, we use the cumulative distribution function of the standard normal distribution, $\Phi(z)$, in order to map equation (7) to a measured probability (Wooldridge, 2002).

(7)
$$\Phi(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}z^2\right) d\varepsilon$$

The standard normal distribution is applied to the binary choice faced by the forest owner in our sample. An owner that accepts is represented by equations (8). A rejection of the harvest offer is $1 - \Phi(\boldsymbol{X_n}'\boldsymbol{\beta})$.

(8)
$$\Pr(y_n = 1|\boldsymbol{X_n}) = \Phi(\boldsymbol{X_n}'\boldsymbol{\beta}) = \int_{-\infty}^{\boldsymbol{X_n}'\boldsymbol{\beta}} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}z^2\right) d\varepsilon$$

The density function, conditional on the forest owner's characteristics and their respective coefficients is then defined by equation (10).

(9)
$$\mathrm{f}(y_n|\boldsymbol{X_n};\boldsymbol{\beta}) = \Phi(\boldsymbol{X_n'\beta})^{y_n}[\mathbf{1} - \Phi(\boldsymbol{X_n'\beta})^{\mathbf{1}-y_n}]$$

From the conditional density function, we derive the likelihood function, equation (12). The likelihood function may be transformed into a log function, L($\boldsymbol{\beta}$), which is then maximized via iterative numerical computation in order to estimate the vector of coefficients $\boldsymbol{\beta}$.

(10)
$$L(\boldsymbol{\beta}) = \prod_{n=1}^{N} \mathrm{f}(y_n|\boldsymbol{X_n};\boldsymbol{\beta})$$

We assume that the individuals who cite (b) "no, I do not have plans to harvest timber/conduct stand improvement from my forested land," for each of the respective questions are not in the market for selling timber residues, and we therefore exclude them from the analysis. All of the other "no's" (c-e) are members of the market and are assumed to say "yes" at some finite payment (see table (4)).

Since the data set was of complex survey type, likelihood-ratio tests were inappropriate (Binder, 1983). We used the Wald Test to carry out exclusion restrictions for the most collinear variables that were not strongly grounded in theoretical relevance. As a result of these tests, we dropped a forest management plan variable and two types of zoning dummy variables.

B. Factor Analysis

Intuitively and empirically, 5-point Likert belief and concern variables were correlated with one another. In order to reduce the number of variables and detect latent structural relationships between variables, we conducted a factor analysis. After analyzing the number of factors that returned eigenvalues over 1 (Kaiser, 1960) and the Scree plots (Cattell, 1966), we reduced the 11 belief variables and nine concern variables to a total of three factor variables. After a factor-based axis rotation (Harman, 1960), we analyzed the loadings for the retained factors, which appear in Table (3). The first factor was characterized by high loadings in two beliefs pertaining to pro-bioenergy energy concepts such as a belief that the use of bioenergy feedstocks in place of fossil fuel will help mitigate climate change. The second factor carried two high loadings, both in concepts pertaining to a loss of environmental amenities such as biodiversity and soil quality. The third factor also carries two high loadings and seems to represent concerns over disamenities, such as noise and smell.

Table 3: Factor analysis from belief and concern variables

Component	Pro-Bioenergy Loading	Conservationist Factor Loading	Anti-rent Factor Loading
Developing renewable energy (e.g., wind, solar, bioenergy, hydro-electrical) is important to our nation's future.	0.5658	0.0818	-0.0911
Bioenergy should be prioritized over other forms of renewable energy such as wind or solar power.	0.0427	-0.0798	-0.0027
Burning bioenergy feedstocks to generate electricity instead of burning coal is worth the extra cost.	0.6777	0.0124	-0.0372
Substituting bioenergy feedstocks for fossil fuels will help mitigate climate change.	0.7176	-0.0189	0.0558
Growing bioenergy feedstocks on cropland will increase competition with food needs.	-0.0371	0.1264	0.0253
Increased bioenergy feedstock production will result in significant forest loss.	-0.0164	0.2823	0.2154
Government should allow regular harvesting of public forest land and CRP land for bioenergy purposes.	0.1138	-0.3123	-0.162
Biodiversity should be maintained when land use is changed.	0.3661	0.2189	-0.0542
Liquid biofuels are a promising alternative energy technology that will be successful in the future.	0.2844	-0.0789	-0.058
The use of fossil fuels can be harmful to human health and the environment.	0.6055	0.1895	-0.0025
The world will run out of fossil fuels (e.g., oil, natural gas) in the next 50 to 120 years.	0.5628	0.0926	0.1169
The potential smell	-0.0001	0.172	0.7563
Noise from harvesting, planting, or other activities	0.0189	0.2533	0.7573
The possible need for insurance	-0.0218	0.2614	0.3012
Having other people on my land	-0.0065	0.396	0.3096
The land changing in a way that I can no longer use it as I want	-0.0372	0.5151	0.2254
How profitable it will be	-0.0554	0.1035	0.0503
A lack of information about the potential feedstocks	0.033	0.2422	0.2702
The loss of biodiversity on my land (e.g., insects, birds, mammals, plants, etc)	0.1164	0.7698	0.1848
The risk of lower soil and water quality	0.0614	0.7447	0.2101

Results are from the factor analysis of the "next timber harvest" scenario, which are nearly identical to the "stand improvement" scenario loadings.

A probit model with the three factors in place of the 20 original explanatory variables was jointly significantly different from zero via a Wald Test for both the harvest and the stand improvement scenarios. We tested squared transformations for all continuous variables in order to capture quadratic behavior and we retained those that were significantly different from zero, also via Wald test, in one or both scenarios. These squared terms included those for single-species acres and mixed forest acres.

In estimating the factors that contribute to the willingness to supply timber residues, we are interested in causal effects. As such, the decision as to whether or not to weight the data is a complicated one. For this section of the paper, we are not principally interested in describing or extrapolating over the population of interest, therefore we explored the possibility of unweighted models. According to Solon et al (2015), "if sampling probabilities vary exogenously…weighting might be unnecessary for consistency and harmful for precision." Upon regressing the sampling probabilities on the standard errors from an OLS version of the probit model, we found that the inverse probability of sampling to be exogenous because the errors were not correlated with the inverse sampling weights. To further ensure that the error terms were not correlated with the sampling process, we added county-level dummy variables so that the chosen model included all of the factors that would control for the sampling process. Thus, it is reasonable to assume that our chosen model provides consistent and unbiased estimates (Solon et al, 2015).

C. Hypotheses

The variables included in equation (6) are grounded in theoretical expectations stemming from equation (1). These expectations can be formulated as testable hypotheses. Rejection of the null hypothesis in each of the following expectations supports the theoretical explanation.

We expect that because the forest owner gains utility from marketed goods and services, the higher the offered payment for timber residues, the more the landowner will earn and the more likely the landowner will be to accept the offer to harvest timber residues ($U'(c)c'(\pi)\pi'(p) > 0$). To state the first hypothesis in formal, null form:

- H1: Price offered for timber residue has no effect on the decision to sell timber residues.

We believe that when a forest owner owns a large tract of single species forest, this is a signal that the forest owner gains more utility with respect to her or his forested land when using it for commercial purposes, such as the harvest of timber residue. Single species tracts lend themselves well to harvesting slash due to the intensive stand improvements or timber harvests that take place in these tracts. In one harvesting method common to single species tracts, large amounts of residue are cut and piled at a central location. Thus, we expect that the more acres of single species forest that a forest owner possesses, the more likely that forest owner will be to harvest timber residue ($U'(c)c'(\pi)\pi'(s)s'(A) > 0$).

- H2: The area of acres of single species trees that a forest owner possesses has no effect on the decision to sell timber residue.

We also expect that the higher the value a forest owner places on the environmental amenities on her or his land that can be harmed by the harvest of timber residues, the less likely she or he is to offer up forested land for timber residue harvest ($U'(a)a'(A) < 0$). These amenities can be expressed through the "conservationist" factor that is positively loaded on concerns about loss of biodiversity and land use change. Stating the second null hypothesis formally, we have:

- H3: Value placed on environmental amenities associated with the harvest of timber residue has no effect on the decision to harvest.

We expect the "pro-bioenergy" attitude factor to have a positive effect ($U'(b)b'(A) > 0$) due to the fact that higher Likert scores in the base variables with high loadings correspond to a more favorable view of bioenergy with respect to the variables that have a high loading in this factor.

- H4: Bioenergy knowledge and attitudes have no effect on the decision to sell timber residue.

We expect that disamenities associated with harvesting timber residues will increase with timber residue harvest, lowering the likelihood that a forest owner will harvest timber residues from her or his land ($U'(d)d'(A) < 0$). Disamenities can be expressed through the "anti-rent" factor that captures concern variables such as noise, smell, and privacy. We state the third null hypothesis as:

- H5: Concern over disamenities associated with the harvest of timber residue has no effect on the decision to harvest.

V. Results and Discussion

Frequency percentages of landowner willingness to sell timber residues at four different prices per acre is presented in table (4). "Yes," is monotonically increasing for all price levels. Overall willingness to sell is high at over 64% and 60% overall both at next harvest and at next stand improvement. The difference between $15 and $30 is sometimes less marked, as with "no," for both scenarios. The changes between $15 and $30 and from $30 to $60 in "no, maybe with higher payment," and "no, never" go against expectation. In general, the descriptive statistics remain consistent with our hypothesis H1 that price has a positive effect on the probability of accepting an offer to harvest timber residues.

Table 4: Forest owners willing to sell timber residues at four price levels

	At next timber harvest					**At next stand improvement**				
	Price ($/acre)					**Price ($/acre)**				
Response (%)	**15**	**30**	**60**	**90**	**Overall**	**15**	**30**	**60**	**90**	**Overall**
Yes	56	58	68	72	64	49	52	68	71	60
No	4	4	4	3	4	4	5	4	3	4
No, maybe with higher payment	20	17	19	9	16	26	18	21	9	18
No, never	20	21	9	16	16	21	25	7	18	18
N =	**845**					**806**				

"No plans" for "next timber harvest" variables are dropped because these respondents are not participants in the timber residue market.

The results from the probit analysis appear in Table (5) (additional variables are reported in Table (6) in the appendix). Results are presented as marginal effects at the mean, or the marginal change in the probability of acceptance given a change in the explanatory variable at its mean. Presenting variables at their marginal effects improves the ease of interpreting probit results generally as well as providing basic comparisons between different variables. Other marginal changes computed between specific values reported in this results section are computed separately.

Table 5: Willingness to supply timber residues under two different scenarios

	At Next Timber Harvest			At Next Stand Improvement		
Variable	Marginal Probability	Std. Dev.	p-value^{+}	Marginal Probability	Std. Dev.	p-value^{+}
Income						
Price offered	0.0032***	0.0008	0.0000	0.0041***	0.0008	0.0000
Income	7.34x10^{-7}*	5.03x10^{-7}	0.0740	8.54 x10^{-7}	5.14 x10^{-7}	0.1220
Income squared	*		0.0840			0.1930
Has forest income	-0.0146	0.0864	0.8660	-0.0206	0.0911	0.8210
Has rec income	-0.0497	0.1274	0.6960	0.0140	0.1438	0.9220
Demographics						
Age	0.0017	0.0025	0.4890	0.0019	0.0026	0.4640
Male	0.0268	0.0729	0.7130	-0.0465	0.0762	0.5430
Farmer	-0.0420	0.0597	0.4800	-0.0304	0.0623	0.6250
Education	0.0832	0.0520	0.1050	0.1391***	0.0524	0.0070
Ag zoning	-0.1488***	0.0542	0.0050	-0.0624	0.0556	0.2600
Residential zoning	0.0069	0.0679	0.9190	-0.0998	0.0690	0.1490
Forest zoning	0.0212	0.0610	0.7290	0.0515	0.0625	0.4100
Duration on land	-0.0032**	0.0016	0.0470	-0.0039**	0.0016	0.0160
Is family land	0.0766	0.0473	0.1050	0.0060	0.0480	0.9010
Is resident of land	-0.0445	0.0556	0.4250	0.0334	0.0559	0.5500
Forest Characteristics						
# of mixed forest acres	-0.0001	0.0002	0.5550	0.0001	0.0003	0.7000
# of mixed forest acres squared			0.7740			0.4220
# of single-species acres	-0.0032*	0.0018	0.0590	-0.0017	0.0019	0.3110
# of single-species acres squared	*		0.0990			0.2460
# of acres of other forest	0.0002	0.0009	0.7890	0.0004	0.0010	0.6650
Has mixed forest over 10 years old	0.1470	0.0895	0.1020	0.0749	0.0892	0.4010
Has single-species forest over 10 years old	0.0182**	0.0504	0.7170	0.0241	0.0521	0.6420
Use						
Has previously harvested timber	0.0390	0.0586	0.5040	0.0455	0.0582	0.4330
Will convert land to other use	0.3678	0.2466	0.1350	0.3546	0.2460	0.1480
Uses forest for personal use	0.0648	0.0678	0.3360	0.0202	0.0706	0.7740
Uses forest for other use	0.0767	0.0938	0.4140	0.0504	0.1007	0.6170
Is in forest program	0.1269**	0.0534	0.0170	0.1581***	0.0540	0.0030
Has conservation easement	-0.0308	0.0947	0.7450	-0.0221	0.0982	0.8220
Land in forest reserve	-0.1663	0.1087	0.1260	-0.1739	0.1123	0.1210
Knowledge						

	At Next Timber Harvest			At Next Stand Improvement		
Variable	**Marginal Probability**	**Std. Dev.**	**p-value+**	**Marginal Probability**	**Std. Dev.**	**p-value+**
Landowner has heard of bioenergy	-0.2411	0.3109	0.4380	-0.0617	0.1066	0.5630
Knows slash can be feedstock	-0.2572*	0.1468	0.0800	-0.1214**	0.0517	0.0190
Has seen a pile of slash	0.0119	0.1671	0.9430	-0.0556	0.0594	0.3490
Factors						
Pro-bioenergy	0.1096	0.0762	0.1500	0.0148	0.0273	0.5870
Conservationist	-0.0900	0.0813	0.2680	-0.0390	0.0287	0.1750
Anti-rent	-0.1694**	0.0850	0.0460	-0.0770***	0.0298	0.0090
n=		**523**			**522**	
Pseudo R^2=		**0.1872**			**0.1987**	

+ p-values reported are from the original probit regression coefficients.
* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level
Marginal probabilities are reported at the mean value of the respective explanatory variable.

Additionally, we report the elasticities of all statistically significant variables graphically in Figure (2). Elasticities, like marginal effects, are reported at the mean. The elasticity is the change in the natural log of the probability of acceptance as a function of the change in the natural log of a given explanatory variable. In other words, the elasticity is the percentage change in the probability of acceptance for a percentage change in a given explanatory variable. Reporting elasticities is helpful in viewing the sensitivity of pertinent variables that have very different measurement units.

The predictive power of both models is generally high. When assuming a probability over 0.5 predicts acceptance, the timber harvest model has 99.2% accuracy and the stand improvement one has 91.5% accuracy. Both models have pseudo R^2 values of .1872 and .1987. Pseudo R^2 values between 0.2 and 0.4 communicate an "excellent" fit (McFadden, 1978).

Based on the highly significant coefficients on the price variables in both scenarios, we reject the first null hypothesis that price offered has no effect on the decision to allow the harvest of timber residues (H1). Price carried a positive coefficient under both scenarios, with a larger effect in the "stand improvement" scenario. It is also clear from Figure (2) that price is the most elastic to demand at the mean of all of the significant variables in the timber harvest scenario. At the mean price of about $50 per acre, a $30 increase in price would make a forest owner 9.6% more likely to harvest timber residues at the next timber harvest and 12.3% more likely at the next stand improvement. In both scenarios, price had a smaller marginal effect on the probability of acceptance at higher prices, implying that it has a slightly diminishing effect on probability as it increases (see Figure (3)). Additional calculations from our predicted results (not shown) estimate that a $30 increase in price at $60 raised the probability of acceptance by 9% for timber harvest and 13.4% at stand improvement. A $30 increase in offered price per acre at $90 would increase the probability of acceptance by 7.3% at next timber harvest and 8.8% at stand improvement.

Figure 2: Elasticities of statistically significant coefficients in the "timber harvest" scenario

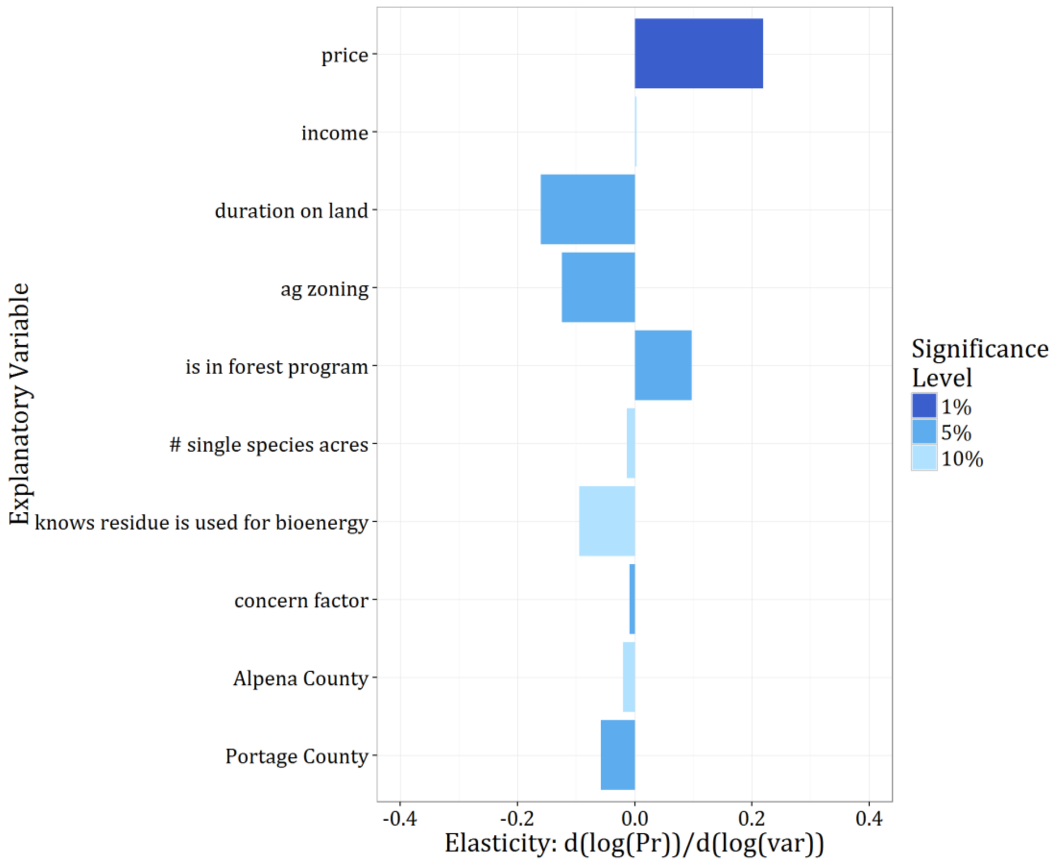
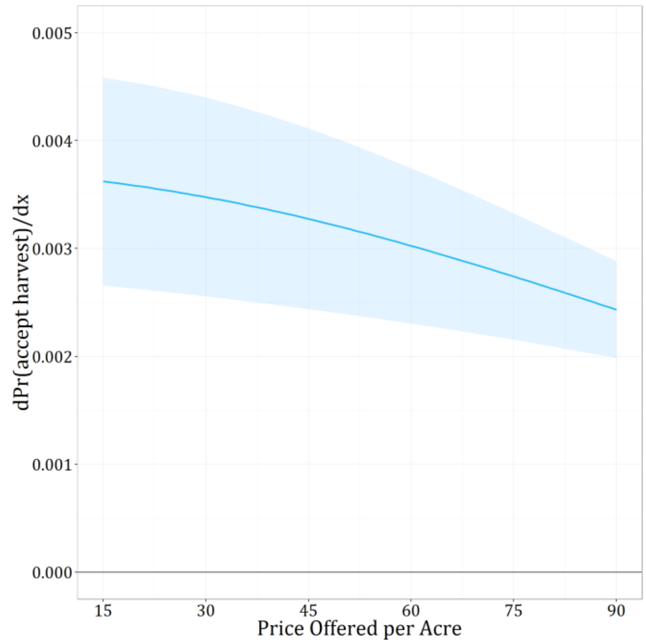
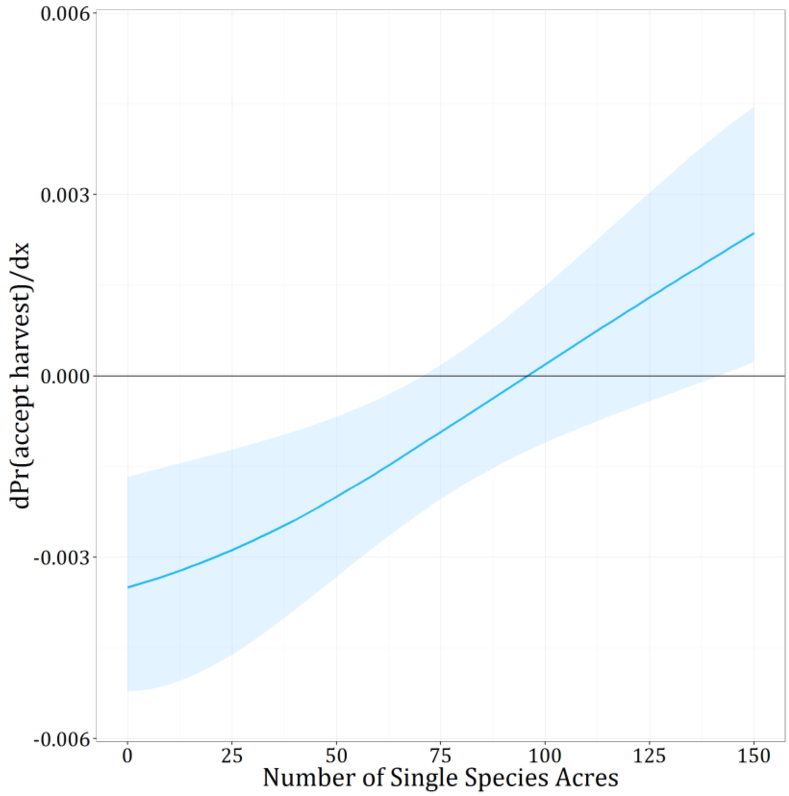


Figure 3: The marginal effect on probability of acceptance by price offered at varying dollar amounts for the timber harvest scenario (similar to the stand improvement scenario). Confidence intervals of 95% are shown shaded in blue.



Based on the significant coefficient on single species acres in the timber harvest scenario, we reject H2, the null hypothesis that the possession of single species acres does not affect the likelihood that a forest owner will allow the harvest of timber residues. The addition of 10 more acres of single species forest at 150 acres would increase likelihood of harvesting timber residues by 2.3% for the timber harvest scenario. Single-species trees are associated with commercial timber harvest and the presence of such trees could imply that a forest owner is more commercially-driven with respect to her or his forest. Both the greater willingness of single-species forest owners and the fact that they were most willing to supply residues at timber harvest are consistent with the finding of Aguilar et al (2014) that forest owners with higher timber revenue are more likely to allow the harvest of timber residues. Additionally, the effect of forest land area owned (number of mixed forest and single species acres) had a U-shaped quadratic effect in both scenarios, with negative linear coefficients and positive squared terms. Both terms were significant for acreage of single-species forest for the timber harvest scenario, indicating that owners of smaller areas were less inclined to sell timber residues than owners of larger tracts. The effect of single species acreage on the probability of accepting harvest changed signs at approximately 100 acres at timber harvest (see Figure (4)) and 80 acres at stand improvement, though in the latter scenario neither term was significant. This suggests larger scale forest owners, at least at timber harvest, are more willing to seize the additional economic opportunity of timber residue sales.

Figure 4: The marginal effect on probability of acceptance by single species acres at varying points of single species acreage for the timber harvest scenario (similar to the stand improvement scenario). Confidence intervals of 95% are shown shaded in blue.



We cannot reject the hypothesis H3 that value placed on environmental amenities affects the probability of accepting harvest of timber residue. The "conservationist" factor, which is positively weighted with environmental amenity attitudes, carried a negative coefficient but was not significantly different from zero for either scenario. Other variables that would aid in measuring environmental amenities, such as whether or not the owner used her or his forest for personal use, were also not significantly different from zero.

We fail to reject H4, the hypothesis that bio-energy knowledge and attitudes do not affect willingness to harvest timber residues. The "pro-bioenergy" factor carried positive coefficients in both scenarios but was not significantly different from zero with at least 90% confidence.

The results from our probit analysis lead us to reject null hypothesis H5 that concerns over disamenities associated with the harvest of timber residue will not affect the willingness to harvest said residue. The coefficient on the "anti-rent" factor, which carried high loadings for smell and noise concerns, had a negative, significant effect in both scenarios (95% confidence at timber harvest and 99% confidence at stand improvement).

Variables other than price, environmental amenities, and disamenities are also relevant in the timber residue discussion. In the timber harvest scenario, household income and its squared term had a small, significant effect. Household income's positive effect and negative quadratic term imply that "lower" income forest owners (at or below about $133,000/year) are more apt to be willing to harvest residue, whereas "higher" income (above $133,000) are less likely. The fact that a forest owner had at least a college education made a forest owner 14% more likely at time of stand improvement to accept the price offer, with a confidence level upwards of 99%. This finding is consistent with both Gruchy et al (2012) and Aguilar et al (2014), who report positive, significant coefficients associated with the prediction of accepting an offer to pay for woody biomass.

Other demographic characteristics worth noting include agricultural zoning and land ownership duration. Agricultural zoning was associated with 14.9% less likelihood of acceptance in the timber harvest scenario. It is possible that the agricultural zoning classification is associated with other commercial enterprise that would warrant a landowner to be less motivated to extract additional value from her or his land. Additionally, forest owners that had resided on her or his land for longer periods were less apt to harvest residue in both scenarios. Forest owners who participate in state forest management programs are 12.7% more likely at timber harvest and 15.8% more likely to accept harvest at time of stand improvement.

Counter to our prediction, knowledge that timber residues could be a bioenergy feedstock decreased likelihood of acceptance for the harvest and stand improvement scenarios. Both of these coefficients were negative and significantly different from zero with over 90% confidence. It is possible that associating timber residues with ethanol, which can be controversial, could hurt the probability that a forest owner will sell her or his residues.

The general congruence between variables across the two scenarios communicate that these two situations tend to have overlapping answers. The stand improvement model, however, tends to have marginal probabilities with a larger magnitude. It is possible that forest owners that are not expecting commercial value from a necessary, typically non-commercial chore are more likely to grasp at an opportunity to create value from said chore.

VI. Summary and Conclusion

Willingness to supply timber residues is generally high on private forest lands in the Northern Tier. Over 60% of non-industrial private forest owners surveyed were willing to supply timber residues at some price level. At $90 per acre, willingness was 70% or more for both scenarios. When controlling for demographic and forest, and other characteristics, our results show that several factors contribute to the willingness to supply timber residue.

The price effect was significant in both situations and notable in magnitude. College-educated forest owners with larger single species tree landholdings that made under $133,000/year were more likely to be willing to harvest, whereas higher income forest owners with small tracts of single species forest were less likely. We did not find the forest owners' value of environmental amenities or bio-energy attitudes to affect the decision to harvest timber residues with our chosen level of confidence. Disamenities, on the other hand, did significantly affect willingness to harvest as characterized by a factor that blended underlying concerns over smell, noise, and privacy. Moreover, we found that knowledge of the fact that timber residues were a bioenergy feedstock hurt acceptance.

While economic drivers such as price remain important, they are by far not the only factor in the equation. The implication of tree species makeup combined with acreage heavily implies the influence of commercially-leaning private forest owners. This finding supports Aguilar et al's (2014) finding that landowners with larger timber revenues were more willing to sell residues and that timber residue markets are bound to the commercial wood market. It also lends further credence to Gruchy et al (2012)'s result that forest acreage had a negative effect on the probability of harvesting woody biomass only for the smaller scale owners of forest land. Not only that, but the attitudes that these forest owners hold will affect their decision. The political climate of timber-producing areas could very well affect the supply of timber residues.

Based on the findings of this study, most owners of non-industrial private forest lands in areas of northern Michigan and Wisconsin are favorably disposed to supply timber residues for energy biomass. As byproducts, such residues would have a negligible effect on timber product prices and none at all on food prices, while preserving several environmental advantages. The price offered for timber residue, ownership of large tracts of single-species forest, and aversion to disamenities are the main drivers behind the provision of timber residues, along with factors such as age, gender, and zoning restrictions. The implication of previous studies that large forest owners with a commercial predilection are more likely to supply timber residues has merit. Based on our results, the most effective way to increase timber residue supply beyond the already high levels of support is to target pro-bioenergy owners of over 100 acres of single-species forest, particularly at time of timber harvest, rather than simply offering a higher price for timber residues in isolation.

VII. Appendix

Table 6: Willingness to supply timber residues, County Dummies

Variable	At Next Timber Harvest			At Next Stand Improvement		
	Marginal Probability	Std. Dev.	p-value+	Marginal Probability	Std. Dev.	p-value+
County Dummies						
Alger	0.1485	0.3804	0.6960	-0.0250	0.1340	0.8520
Alpena	-0.8553*	0.4615	0.0640	-0.3751**	0.1661	0.0240
Antrim	-0.0375	0.4307	0.9310	-0.0913	0.1545	0.5540
Bayfield	0.1846	0.3697	0.6180	-0.0614	0.1281	0.6320
Clare	-0.6879	0.5286	0.1930	-0.1762	0.2024	0.3820
Emmet	-0.4825	0.3999	0.2280	-0.1437	0.1454	0.3220
Gladwin	-0.3960	0.4799	0.4090	-0.0353	0.1761	0.8410
Grand Traverse	-0.9743	0.6069	0.1080	-0.3507	0.2150	0.1020
Iosco	0.8128	0.8031	0.3110	0.2822	0.2888	0.3290
Lincoln	-0.3998	0.3432	0.2440	-0.1073	0.1229	0.3830
Marquette	-0.2081	0.3802	0.5840	0.0029	0.1424	0.9840
Mason	-0.0113	0.4229	0.9790	-0.1159	0.1456	0.4260
Polk	-0.3713	0.3286	0.2580	-0.2099*	0.1186	0.0760
Portage	-0.7673**	0.3251	0.0180	-0.3174***	0.1200	0.0080
Schoolcraft	-0.0616	0.4486	0.8910	-0.0955	0.1578	0.5450
Shawano	-0.4110	0.3288	0.2110	-0.2250*	0.1210	0.0620
Wexford	-0.4378	0.4412	0.3210	-0.1267	0.1700	0.4570
Florence	-0.4279	0.3113	0.1690	-0.1394	0.1139	0.2190
n=		**523**			**522**	
Pseudo R^2=		**0.1872**			**0.1987**	

VIII. + p-values reported are from the original probit regression coefficients.
IX. * Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level
X. Marginal probabilities are reported at the mean value of the respective explanatory variable.

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