Social availability of residual woody biomass from nonindustrial private woodland owners in Minnesota and Wisconsin

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Abstract

An important and potentially underused source of biomass that could be utilized in energy production is from nonindustrial private woodlands. We employ the Theory of Planned Behavior to estimate the social availability of woody biomass as a function of landowner behavior intent, landowner characteristics, forest land characteristics, and biomass price on stated willingness to harvest biomass in conjunction with a commercial timber harvest. A mail survey was administered to 1109 nonindustrial private woodland owners in a 26-county region in northeast Minnesota and northwest Wisconsin during the fall of 2009. Using binary logistic regression, we found payment level offered to harvest biomass plays a significant role in landowners’ decisions, but that non-monetary factors are also important. Landowner attitudes and opinions regarding soil impacts, aesthetics, and energy independence were important predictors of stated willingness to harvest. Social norms as manifested through the influence of neighbors were also significant. These findings expand existing research and are useful for profiling nonindustrial private woodland owners to identify sustainable sources of biomass to supply a burgeoning bioenergy sector in the Lake States.

Keywords: Nonindustrial woodland owners, Biomass supply, Theory of Planned Behavior, Behavior intent, Logistic regression

1. Introduction

Nonindustrial private woodland owners own approximately 49% (372 million acres) of all forest land in the United States [1]. In Minnesota, they own 39% (6.5 million acres) of forest land [1] and contribute approximately 30% of harvested timber [2]. Previous studies identify important characteristics of nonindustrial private woodland owners such as that recreation, hunting and wildlife habitat are among the primary reasons for ownership, and that timber production is a lower priority [3]. Less is known about landowner preferences for harvesting woody biomass despite its increasing importance for energy production [4], wildfire fuels reduction [5], and carbon mitigation [6]. Biomass production is also increasingly important for economic development and forest products diversification [7]. Assuming a mix of ownerships across a procurement region, and the need for sustainable and consistent delivery of biomass feedstocks from within an economically feasible distance, nonindustrial woodland owners are an increasingly important resource. Because...
woodland owners control a large portion of the nation’s forest resources, their forest management decisions are vital for the supply of biomass and growth of the burgeoning bioenergy industry.

The appeal of biomass utilization has generated considerable interest in recent years. Utilizing the residual biomass left after timber harvesting (tops and limbs) or small diameter trees removed in conjunction with hazardous fuels reduction activities, for instance, can increase revenue used to offset treatment costs [7]. Extensive research is emerging on the technical aspects including in-woods harvesting [8], conversion technologies [9], and product feasibility [10]. Much is also known about the physical availability of biomass [4,11]. Much less is known about social availability, which is that portion of total physically availability accessible in the marketplace after accounting for social factors influencing landowner propensity to harvest [12].

The purpose of this study is to investigate how nonindustrial private woodland owner attitudes and beliefs about their forest land affect their propensity to harvest biomass. We use information from a survey of woodland owners in Minnesota and Wisconsin to estimate their willingness to harvest biomass as an indicator of social availability. A recent analysis of the region’s biomass resources serves as the basis for our inquiry, which identified more than one million dry tons of unutilized biomass in Minnesota that could be physically available on an annual basis [13]. That proportion that is socially available is likely much less and so being able to accurately predict landowner willingness to remove biomass is critical for projecting industry potential.

2. Landowner preferences for biomass harvesting

The literature describes nonindustrial private woodland owners as having varying attitudes, motivations, and management priorities [1,14]. Previous research, for instance, identifies landowner motivations and preferences for timber production [3,15,16] and recreation [17,18]. Much less is known about their motivations for biomass production. Some research exists on biomass availability relative to policy incentives [19,20], or predicted elasticity of demand based upon market price [21,4], but those studies fail to consider the non-financial factors affecting landowner preferences for harvesting biomass.

Recent research validates the importance of landowner attitudes and beliefs in predicting social availability. Butler et al. [12] model indicators from the National Woodland Owner Survey to illustrate how preferences affect timber and biomass supply. They found that landowner attitudes and harvest intentions had a greater impact on availability than did physical factors like site productivity or slope; only 38% of biomass identified as physically available was socially available in their analysis of northern forested states. Joshi and Mehmood [22] employed a market segmentation approach in Arkansas, Florida and Virginia with forest parcels greater than 20-acres in size to identify landowner willingness to harvest biomass in that region. Their cluster analysis indicates that landowners who were more likely to harvest biomass were retired and highly valued using their woodlands for nature, wildlife habitat, and engaging in recreation. More than half (55%) of those landowners also intended on harvesting timber, and among those 63% were willing to supply biomass for energy production. Joshi and Mehmood [23] apply these same data to a logistic regression and found that willingness to harvest was significantly related to ownership objectives, total acreage owned, tree species, and landowner demographics. Contrary to their earlier findings, younger landowners owning large tracts of forest land were more likely to supply biomass for energy production. However, biomass price was not analyzed in conjunction with non-financial factors in any of these studies.

A smaller number of studies model financial as well as non-financial factors influencing biomass availability. Gruchy et al. [24], for instance, incorporate biomass price using a contingent rating approach in Mississippi. They modeled landowner stated willingness to accept payment relative to tradeoffs for wildlife habitat, climate change mitigation, aesthetics and financial benefit, and found that the corresponding harvesting technique (e.g., clear cutting) was a significant indicator of availability. Markowski-Lindsay et al. [25] estimate the probability that Massachusetts landowners would harvest biomass using a logistic regression model with measures of biomass price ($0–$500/acre), forested acres owned (greater than 10 acres), existence of a management plan, and demographic variables. The results indicate the likelihood of biomass harvesting is quite low in Massachusetts, and that willingness to participate is largely inelastic with respect to price offered. The opposite was found in Arkansas, Florida and Virginia where GC and Mehmood [26] examined the likelihood of southern nonindustrial private landowners (greater than 20 acres) participating in biomass markets. Participation ranged from a low of 16% in Virginia assuming 2008 pulpwood prices, up to 74% in Florida when the price was doubled for biomass. They also found significant association between bid acceptance rate and forest parcel size, tree size, absenteeism, landowner age, and previous harvesting experience. These later studies inform our analysis and serve as a reference to compare regional findings.

3. Theoretical framework

3.1. Landowner behavioral intent

The methods used in this study are similar to those employed in the Markowski-Lindsay et al. [25] study. However, the theoretical framework is different in that we employed multiple measures of landowner behavioral intent absent from previous studies. Landowner attitudes, which are identified in previous studies as an important predictor of availability [12,25], are but one dimension of behavioral intent [27]. The broader theoretical framework adopted for this study is based on the Theory of Planned Behavior and considers the cumulative effect of landowner attitudes, the influence of social norms on individual behavior, and the perceived control landowners have over their desired outcome [28]. The Theory of Planned Behavior posits that these three factors interact to influence whether an individual will act on their beliefs and
the likelihood of harvesting biomass given external pressures and control over the outcome.

More specifically, attitudes are the sum of one’s beliefs about a behavior and their evaluation of expected outcomes [28]. In the context of biomass harvesting, these attitudes could include beliefs about impacts of harvesting on the environment [29], aesthetics [30], and local economies [31]. Social norms include the subjective beliefs about how others think we should act, choices of which activities to engage in, and motivations to comply with the wishes of others [32]. In the context of biomass harvesting, this could include landowner perceptions about how family members and friends perceive the management of their woodlands and if biomass production is compatible with those views [33]. Also, the manner in which harvesting is conducted and landowner exposure to ideas and market opportunities can be positively affected by trusted professionals, such as foresters or loggers [16]. Lastly, behavioral control, which is the perceived ease or difficulty of performing a specified task or achieving a desired outcome, is an important predictor of behavioral intent [28]. This could include knowing whom to contact to set up a biomass harvest, existence of a forest management plan, or control over harvest activities such as the aesthetics or location of skid trails and brush piles [33]. Collectively, these indicators of behavioral intent are incorporated into our analytical model to predict willingness to harvest biomass. The measures chosen to represent each dimension were derived from these literature and tested during focus groups held prior to the survey, which is discussed below.

3.2. Individual landowner characteristics

The second component of our analytical model addresses individual landowner characteristics such as age, income, residence, and reason for ownership. Previous research suggests that as landowners get older they become more interested in bequeathing the value of their forests and are less likely to harvest timber [3,34] or biomass [26]. In terms of income, wealthier landowners have been shown to be more willing to pursue innovative or novel forest management strategies [35]. In the context of the current study, this could lead to greater biomass removal by way of more forest thinning or habitat restoration.

In terms of place of residence, absenteeism has been found to affect the rate at which landowners seek information and assistance from professional foresters [36]. Contact with professional foresters, which overlaps with the control dimension of behavioral intent, has also been found to be predictive of willingness to engage in forest management activities [1]. The degree to which absentee landowners own woodlots for wildlife or recreation purposes may influence their willingness to engage in biomass harvesting, both positively in conjunction with habitat maintenance or negatively for protection [25]. Conversely, on-site woodland owners in Minnesota were found in a previous study [1] to be more likely to have harvested timber (67%) than absentee owners (49%). Vokoun et al. [37] applied a discrete choice model in which they identified residence as a determinant for timber harvesting intensity. Finally, several studies identify income generation as a positive predictor of willingness to engage in a variety of forest management activities [14,38–40]. However, the degree to which biomass harvesting decisions are analogous to timber harvesting is unknown. Therefore, we include indicators of biomass harvesting as well as timber harvesting in our analytical model.

3.3. Forest land characteristics

Forest land characteristics, which relate to parcel size and site characteristics, are included as a third category in our analytical model. Multiple studies find parcel size to be a predictor of willingness to harvest timber [34,41,42], as well as biomass [22,26].Parcel size, for instance, has had a positive impact because profitability tends to increase as the project area increases [3]. The frequency of equipment mobilization, and thus mobilization costs are greater and return on investment can be smaller for smaller parcels. Larger parcels may also reflect indices of owner wealth and interest in forest management. Another factor is site quality, which influences willingness to engage in management activities in that higher quality sites have the potential to be more profitable for timber harvesting [43], or has a high volume of small diameter trees suitable for biomass markets [26].

3.4. Biomass price

Compensation for the biomass removed in conjunction with a conventional timber harvest is treated as the fourth component in our analytical model. Markowski-Lindsay et al. [25] provide a useful example where biomass price is a function of landowner willingness to accept payment based upon predetermined harvest criteria such as volume of biomass removed, size, and post-harvest characteristics. Costs incurred by the logger for equipment mobilization, fuel, harvesting, and transportation are assumed a function of the price offered. Markowski-Lindsay et al. [25] report harvest probabilities based upon payment offerings ranging from $0/acre to $500/acre. GC and Mehmood [26] use a payment offering based upon the 2008 pulpwood market price for the southern US, but do not report the actual price. Both studies assume biomass removal in conjunction with a commercial timber harvest. In reality, biomass may be procured in a variety of ways not associated with timber harvesting, including whole-tree harvesting for clean chips, timber stand improvement activities like thinning, pruning or removing less desirable trees, wildfire fuels reduction treatments, or wildlife habitat improvement.

4. Methods

A mail survey was developed to examine the likelihood of nonindustrial private woodland owner participation in biomass harvesting in a 26-county region in northern Minnesota and northwest Wisconsin. Two focus groups were held in the region prior to administering the survey to pre-test payment offering levels, gauge comprehension of survey questions, probe for language used, and general attitudes toward biomass removal. Participants were randomly selected from the sample population. A survey questionnaire
was then developed based upon these findings and pre-tested with a random sample of 100 landowners from the same population. Following our theoretical framework, the final survey consisted of questions about landowner behavioral intent (attitudes, social norms, and perceived control), individual landowner characteristics, forest land characteristics, and biomass price.

The survey questionnaire was administered to a random sample of 1109 nonindustrial private woodland owners during the fall of 2009. The sample was stratified by county based upon total forested acres. Eligible parcels consisted of land classified for tax purposes as forested (MN 2b and 2c classifications; WI Forested, Forest Crop Law, and Managed Forest Law classes) and at least 20 acres in size, which based upon our experience was determined to be an adequate breakpoint for commercially viable forest management activities in the region. Mail-back survey procedures developed by Dillman et al. [44] were used in which a pre-survey postcard was sent followed by the survey one week later, which was followed by a postcard reminder. A second survey was sent to non-respondents followed by a final postcard reminder. A total of 610 usable questionnaires were returned (11 returned with bad addresses, and 28 were unusable) for a 56% response rate. A nonresponse bias check indicated no statistical difference ($p \leq 0.05$) between respondents and non-respondents based upon parcel size, county of residence, or region.

Responses were analyzed using the binary logit model outlined in Equation (1). Logistic regression allows for analysis of binary choice responses (yes/no) to estimate the effects of a vector of independent variables on a response variable. The independent variables consisted of continuous and categorical responses; continuous variables were converted to binary responses based on the median value, and categorical variables consisting of 4-point scales were converted to binary responses by coding negative responses to “0” (i.e., “strongly disagree” or “slightly disagree”), and positive responses to “1” (i.e., “slightly agree” or “strongly agree”). Missing continuous data were converted to the series mean for deeded acres and respondent age (2% and 5%, respectively, of total responses missing), which allowed for the use of questionnaires in which a valid payment response was provided.

The response variable was a measure of the conditional probability $\pi_i$ of landowner willingness to accept payment offered. Each respondent was asked to assume that they were conducting a timber harvest and those trees larger than 5-in in diameter would be harvested at present market prices. The biomass to be removed was described in the survey as trees smaller than 5-in diameter, and tree limbs and tops created from the primary timber harvesting activity. After being presented with a scenario describing the mechanical equipment used to remove the biomass, and how much biomass would be removed versus left on site, landowners were asked, “Would you accept the logger’s offer to pay you an additional $[X]/acre to remove the residual woody biomass after the commercial harvest is complete (in addition to the payment received from selling the timber)?” Respondents were presented with one of five payment offerings ($0, $2, $5, $10, and $15/acre) established from focus group results, regional biomass productivity (3–5 green tons/acre), and the public biomass stumpage price at the time of the survey ($1–3/green ton). We estimate the cumulative probability of accepting the bid offer based on these payment levels.

$$\pi_i = \text{Prob}(Y_i) = \text{Logit}(Y = 1|x) = \frac{e^\eta}{1 + e^\eta},$$

$$\eta = \alpha + \beta'x$$

and so,

$$\pi_i = P(\eta_i) = P(\alpha + \beta'x)$$

Where:

$$P(\cdot) = \text{cumulative distribution function}$$

$Y = \text{landowners’ likelihood of harvesting biomass} (\text{Yes} = 1, \text{No} = 0)$

$\alpha = \text{intercept}$

$\beta' = \text{vector of regression coefficients}$

$x = \text{vector of predictor variables}$

$$\pi_i = e^{\alpha + \beta'x}$$

$$\frac{1}{1 - \pi_i} = e^\alpha$$

$$\log \frac{1}{1 - \pi_i} = \alpha = \beta'x$$

5. Results

5.1. Landowner and forest land characteristics

Among those who responded, landowners reported owning on average 115 acres across all their forested parcels; 75% of the surveyed parcels were smaller than 120 acres with a median parcel size of 41 acres. The median respondent was 60 years of age, and more than 80% were male. Almost 55% of respondents in the 26-county region lived more than 50-miles from the surveyed parcel and are considered absentee owners for the purpose of this study. This is more than the national absenteeism rate of 40% and 35% for Minnesota reported from the National Woodland Owner Survey [1]. In terms of distance to a major biomass processing facility, which was defined as a biomass electricity or thermal heating plant, surveyed parcels were on average 56-miles away via the fastest route. About 40% of respondents reported having consulted a forester about management activities on their land, and 15% reported having attended a logger education program in the past.

Respondents’ reasons for owning their woodlands, as rated on a 4-point scale of “not important” to “very important”, most commonly was to view wildlife (91%), for solitude and quiet (87%), creating a legacy (78%), and a place to hunt (73%). The least common reasons were for motorized recreation (32%), firewood production (36%), and agriculture/timber income generation (49%). These results are consistent with previous studies indicating that landowners highly value the non-monetary benefits of nonindustrial private woodlands [3,18].

39% of respondents reported having conducted a timber sale on their property within the past 10 years and 36% were planning a timber sale within the next 10 years. Related to timber stand improvement, 46% of respondents reported engaging in activities within the past 10 years, and 66% were planning to do so in the future. Approximately two-thirds (67%) of respondents had engaged in past wildlife habitat improvement on their land, and nearly 80% were planning to do so in the future.
5.2. Probability estimation

This section analyzes the effect of payment offering on stated willingness to remove residual biomass in conjunction with a commercial timber harvest. Payment amount was randomly assigned to each sampled landowner so that one fifth of all landowners was offered one of the five payments described. A total of 522 surveys contained valid responses to the payment question for a model response rate of 48% (Table 1).

Respondents were given the choice of “don’t know” if they felt insufficient information was provided about the process of biomass removal on their property, which was selected by 98 respondents (18%). To test whether to pool these responses to “yes” or “no” following the likelihood ratio procedures described by Cramer and Rider [45], we ran separate binary and multinomial logit models. In one model we recoded the “don’t know” responses as “yes,” in another they were recoded as “no,” and in a third model they were removed entirely. No significant difference was observed in coefficients for the independent variables among the three models, so the “don’t know” responses were recoded to “yes.”

A total of 16 variables were included in the final logit model representing each dimension in our theoretical model (landowner behavioral intent, individual landowner characteristics, forest land characteristics, and biomass price). Table 2 describes these variables and the hypothesized effect on stated willingness to accept payment. Table 3 displays the descriptive statistics for each variable with the reported mean values, which were transformed into binary responses to the payment question for a model response rate of 48% (Table 1).

Table 2 describes these variables and the hypothesized effect on stated willingness to accept payment. Table 3 displays the descriptive statistics for each variable with the reported mean values, which were transformed into binary responses as described and used in the logit model reported in Table 4.

### Table 1 – Landowner stated willingness to accept payment for biomass harvested.

<table>
<thead>
<tr>
<th>Payment offered per acre</th>
<th>Response</th>
<th>No. of responses</th>
<th>Percent of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>46</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>50</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Don’t know</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>$2</td>
<td>Yes</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Don’t know</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>$5</td>
<td>Yes</td>
<td>66</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>31</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Don’t know</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>$10</td>
<td>Yes</td>
<td>58</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Don’t know</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>$15</td>
<td>Yes</td>
<td>54</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Don’t know</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

5.3. Significant predictors of residual woody biomass removal

Eleven variables were significant predictors of the probability of biomass removal in conjunction with a commercial timber harvest (Table 4). At the $p \leq 0.05$ level they included biomass price, impact on soil nutrients and aesthetics, effect on United States energy independence, knowing whom to contact, desire for additional income, parcel size, and having previously engaged in timber stand improvement activities. At the $p \leq 0.10$ level the influence of neighbors, knowledge of the steps to take to harvest and sell biomass, and participation in logger education programs affected stated willingness. Local economic impact, opposition from family and friends, absenteeism, landowner age, and having engaged in past wildlife improvement activities were not statistically significant. Hosmer–Lemeshow goodness of fit yielded a chi-squared estimate of 4.829 and was insignificant suggesting that the model fit the data well (0.7757) and that we cannot reject the null hypothesis. The marginal effects reported in Table 4 are estimated using the mean value of the explanatory variables.

Landowners were responsive to the amount of payment offered with each additional payment amount resulting in approximately 3% increase in participation. Fig. 1 displays the estimated probability of biomass removal at the different payment offering levels when the explanatory variables are held at their mean value. The overall probability of removing biomass was 65.9% with a mean of 2.966. At a payment offering of $5/acre, approximately 85% of landowners are predicted to participate, which is a much higher than in Massachusetts [25], and closer to findings in the south [26]. However, it is important to note that there was no correction for hypothetical bias and thus actual participation rates could be lower if respondents had been asked the confidence in their stated responses, which should be included in future studies.

Interestingly, the model also estimates that about 70% of landowners would be willing to accept a $0 payment offering in the scenario described. A follow-up survey question asked respondents about the circumstances in which they would pay a logger to have biomass removed. 23% of landowners were “moderately willing” or “very willing” to pay for biomass removal for the purpose of wildlife habitat improvement; 12% and 6% of landowners were respectively willing to pay in conjunction with timber stand improvement activities or a commercial timber harvest. We did not ask the amount that respondents about the circumstances in which they would be willing to pay, but these findings provide some justification for the high number of landowners stating they would accept no payment.

Parcel size had the most significant impact on willingness to harvest biomass; respondents were about 10% more likely to harvest biomass from larger parcels than smaller ones, which corroborates previous research [34,41]. Landowners having previously engaged in timber stand improvement activities were 8% more likely to harvest biomass under the conditions presented. Also positive was the desire to generate extra income, and the belief that biomass utilization for energy improves energy independence, which resulted in a 7% and 5% respective increase in likelihood of harvesting
biomass. Participating in a landowner education program increased the likelihood of harvesting biomass by about 5%, and knowing whom to contact to carry out a biomass harvest increased the likelihood by 4%.

Alternatively, landowners who were concerned about soil nutrient impacts or aesthetics were respectively 5% and 4% less likely to harvest biomass, which too is consistent with previous research [30,46]. Also negative was the effect of social norms in which landowners were 4% less likely to harvest biomass when influenced by their neighbors, which was contrary to our hypothesized relationship. This may reflect landowners being more likely to hear about negative experiences than positive ones. Also contrary to our hypothesized relationship was knowledge of the steps to take to harvest biomass, which resulted in 3% decreased likelihood to remove biomass. We hypothesized that as landowners obtained more information about the process they would have a greater sense of control over the outcome, but in this case perhaps the details of timber harvesting caused them to have greater concern over the outcome or increased difficulty to performing the specified tasks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Hypothesized effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioral intent</td>
<td>Soil</td>
<td>Binary variable indicating whether landowner agrees with the statement “removing residual woody biomass on my property depletes soil nutrient levels.”</td>
</tr>
<tr>
<td>Energy</td>
<td>Binary variable indicating whether landowner agrees with the statement, “utilization of residual woody biomass for energy could positively impact the United States’ energy independence.”</td>
<td>Positive</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Binary variable indicating whether landowner is deterred from harvesting biomass because of the resulting forest aesthetics.</td>
<td>Negative</td>
</tr>
<tr>
<td>Economy</td>
<td>Binary variable indicating whether the landowner agrees with the statement “utilization of residual woody biomass for energy could positively impact the local economy.”</td>
<td>Positive</td>
</tr>
<tr>
<td>Oppose</td>
<td>Binary variable indicating whether landowner thinks “opposition from family and friends” is a limiting factor for residual woody biomass harvesting.</td>
<td>Negative</td>
</tr>
<tr>
<td>Neighbor</td>
<td>Binary variable indicating whether the landowner’s biomass harvesting is influenced by neighbors.</td>
<td>Positive</td>
</tr>
<tr>
<td>Knowledge</td>
<td>Binary variable indicating whether the landowner agrees with the statement “I know what steps to take to harvest residual woody biomass on my property.”</td>
<td>Positive</td>
</tr>
<tr>
<td>Contact</td>
<td>Binary variable indicating not knowing whom to contact to remove residual woody biomass is a limiting factor.</td>
<td>Positive</td>
</tr>
<tr>
<td>Landowner characteristics</td>
<td>Absentee</td>
<td>Binary variable indicating landowner’s primary residence is within 50 miles of the surveyed parcel (1), or is greater than 50 miles (0).</td>
</tr>
<tr>
<td>Age</td>
<td>Binary variable indicating landowner is 60 years or older (1), or younger than 60 years (0); 60 years is the respondents’ median age.</td>
<td>Negative</td>
</tr>
<tr>
<td>Extra income</td>
<td>Binary variable indicating whether landowner agrees with the statement “I would be willing to allow removal of residual woody biomass on my property if I received additional payment for the material”.</td>
<td>Positive</td>
</tr>
<tr>
<td>ED program</td>
<td>Binary variable indicating whether the landowner participated in a forest landowner education program.</td>
<td>Positive</td>
</tr>
<tr>
<td>Forest land characteristics</td>
<td>Deeded acres</td>
<td>Binary variable indicating the size of surveyed parcel is greater than 37 acres (1), or smaller than or equal to 37 acres; 37 acres is the respondents’ median parcel size.</td>
</tr>
<tr>
<td>Past TSI</td>
<td>Binary variable indicating landowner’s timber stand improvement (TSI) activities in the past 10 years.</td>
<td>Positive</td>
</tr>
<tr>
<td>Past wildlife</td>
<td>Binary variable indicating landowner’s wildlife habitat improvement activities in the past 10 years.</td>
<td>Negative</td>
</tr>
<tr>
<td>Biomass price</td>
<td>Payment</td>
<td>Categorical variable indicating payment amount offered for biomass removal in conjunction with a timber harvest ($/acre).</td>
</tr>
</tbody>
</table>

6. Discussion

6.1. Social availability

Ample research exist characterizing nonindustrial private woodland owners and their willingness to harvest timber, participate in landowner education and stewardship programs, and engage in recreation and related forest management activities. Much less is known about their motivations for biomass production. Our findings add to an emerging body of knowledge that considers financial as well as non-financial factors affecting landowners’ preferences for harvesting biomass. Our research importantly expands that body of knowledge through the application of the Theory of Planned Behavior in an effort to predict behavioral intent. Previous research identifies the importance of attitudes and beliefs but lacks analogous measures for investigating the interaction of landowner attitudes, norms, and perceived control. Our results validate using behavioral intent in conjunction with other landowner and forest land characteristics found in the
6.1.1. Behavioral intent
Within the attitudes dimension of the behavioral component, landowners’ concerns about soil impacts and aesthetics where negatively associated with their willingness to harvest biomass \( (p > 0.05) \). Alternatively, belief that biomass harvesting would enhance energy independence positively affected their stated willingness to harvest \( (p < 0.01) \). Within the social norms dimension, family and friends did not significantly influence landowner decisions; however, neighbors influenced those decisions in a negative manner making them slightly less willing to harvest \( (p > 0.10) \). Within the behavioral control dimension, respondents were more likely to harvest biomass when knowing whom to contact to complete the task \( (p > 0.05) \). Also significant but not in the hypothesized manner was having knowledge about the steps necessary to accomplish the task \( (p > 0.05) \). One speculation is that greater awareness of biomass removal practices, either through personal experience or interaction with neighbors having experience, leads to greater concern about the impacts through a heightened awareness of the harvesting process. More research is needed to better understand the behavioral control dimension, which some scholars suggest is a weaker indicator of intent than measures of self-efficacy and observational learning \([27,47]\). In the context of biomass harvesting, future research might consider the ability of landowners to succeed in task accomplishment and the role of landowner education programs in the context of adult learning theory \([48]\).

6.1.2. Landowner characteristics
Within the landowner characteristics component of the analytical model, neither age nor absenteeism had an effect on stated willingness to harvest biomass, which is contrary to past research \([26]\). The desire to earn additional income had a positive effect \( (p > 0.01) \), as did participation in forest landowner education programs \( (p > 0.10) \) suggesting a possible link to self-efficacy measures discussed above.

6.1.3. Forest land characteristics
Parcel size had a positive effect on willingness to harvest biomass, with landowners of larger parcels being more
willing to participate \((p > 0.05)\). This corroborates previous findings of parcel size in relation to timber harvesting \([34,41]\) as well as biomass \([26]\). Past landowner activities relating to timber stand improvement were also significantly related to willingness to harvest \((p > 0.05)\), whereas past wildlife habitat improvement activities had no effect. We did not include measures of the quality of biomass, site productivity, volume of timber removed, or price received for the timber. It would be useful to examine the interaction effects of these variables in future studies and to compare across regions of the country.

6.1.4. Biomass price

Lastly, level of financial compensation was a significant predictor of willingness to harvest \((p > 0.01)\). The higher the payment offered, the greater the level of stated participation. The model estimated a probability of almost 85% of landowners would be willing to sell their biomass at a price of $5/acre. Nearly 70% were motivated to harvest biomass without receiving any financial compensation \([3]\). This is higher than expected but generally consistent with our focus group findings where the desire to enhance wildlife habitat or conduct restoration activities were significant motivators. Our survey results identify timber stand improvement, wildlife habitat improvement, and removal of invasive species and dead or dying trees as situations where landowners were most likely to pay for biomass removal \((p > 0.05)\). Over 30% of respondents indicated a willingness to pay for biomass removal in conjunction with these activities. However, the level of payment landowners were willing to make was not investigated. It should also be noted that existing markets for biomass in the region during the time of the study were inconsistent with regards to price offered and continuity of demand. As markets become better established and the price paid more transparent, landowners may be much less willing to accept a $0 payment offer. Our findings are also constrained by the timber harvesting scenario presented in conjunction with the payment offerings. Additional research is needed to better understand the model accuracy for respondents for which timber harvesting is not a common management practice. More research is also needed to present payment offerings for non-timber related activities. In the meantime, these findings indicate that a majority of nonindustrial private woodland biomass in the region could be procured for a relatively low price.

6.2. Opportunities to expand landowner participation

Many of the factors found to have a significant impact on landowner decisions suggest a certain level of physical biomass that would be socially available. Policy makers and proponents of biomass utilization have several tools available to increase landowner participation and the research findings offer insights into how to best mobilize them. Among the most common tools applied to nonindustrial private woodland owners are financial incentives \([49,50]\) and landowner education programming \([51]\).

Financial incentives can increase the price paid to loggers or landowners for the harvest and removal of biomass. As illustrated in Fig. 1, the percentage of landowners willing to harvest biomass increases with the price paid, although participation within the study region may already be at a high level. Incentives may be particularly important where the cost of biomass removal is the greatest such as in association with typical timber stand improvement activities like removing invasive species and dead and down material, pruning, and culling of less desirable trees. Consideration is also necessary regarding the volume generated per unit of incentive provided. Timber stand improvement activities are not likely to generate as much biomass as a commercial timber harvest. Regardless, our findings suggest landowners would be willing to sell biomass in conjunction with these activities and underscores the importance of loggers and professional foresters presenting the option of biomass harvesting in conjunction with all operations, not solely commercial timber harvests.

Nonindustrial private woodland owners have a diverse set of objectives and values when it comes to forest management that encompasses more than just financial incentive. For instance, the findings identified the importance of minimizing soil impacts. Landowner education programs, which significantly increased landowner participation, could be made to target soil and related ecological impacts from biomass harvesting. Minnesota and Wisconsin were among the first states to employ biomass harvest guidelines directing loggers in appropriate removal techniques to retain key soil and related ecological features \([52]\). Adherence to these guidelines could reduce landowner concerns and thus potentially increase the number of willing participants. However, additional research is warranted to better understand under what conditions these landowners are open to harvesting biomass, and in particular how biomass harvesting helps them achieve their visions for their woodlands.

7. Conclusion

Nonindustrial private woodland owners are but one actor in the bioenergy supply chain, but given the physical supply of biomass within their control in states like Minnesota and Wisconsin, the future of the regions’ bioeconomy is very much influenced by their management decisions. Furthermore, accurate assessments of biomass supply are an important function of social availability, which we modeled as a function of behavioral intent, individual landowner characteristics, forest land characteristics, and biomass price. These components allow us to collectively profile potential biomass market participants.

The theoretical framework modeled in this study provides an expanded analysis of landowner willingness to harvest biomass, which is applicable in other regions of the United States where nonindustrial private woodland owners are a substantial component of the bioenergy supply chain. Participation rates will vary, as indicated in the handful of studies conducted thus far, but these methods allow for the establishment of realistic expectations of that industry. The findings also offer useful information about areas of needed model refinement. Finally, this research provides loggers, foresters and policy makers with information to establish relevant markets in the context of non-financial factors affecting landowner decisions. It is important that ongoing
research and coordination occur so that biomass removal is done in a sustainable manner and complementary to these landowner values.

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