Family-forest Owners' Willingness to Harvest Sawlogs and Woody Biomass: The Effect of Price on Social Availability

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Understanding willingness to harvest (WTH) is essential to assessing the social availability of woody biomass from private land. Currently, the only economically feasible way to harvest woody biomass is in conjunction with sawlogs. We examined WTH sawlogs and woody biomass from owners of family forests using data from a survey of Missouri forest owners. While their WTH increased with revenue expected from woody biomass, revenue expected from sawlogs was a stronger influence. Incentive payments for woody biomass thus are unlikely to increase its supply, and the social availability of woody biomass will remain limited unless sawlog prices rise significantly.

Key Words: integrated harvest, ordered choice, public incentive, sawlog, woody biomass

Use of woody biomass to generate bioenergy has been the subject of much discussion in the scientific literature in recent years. Woody biomass generally is defined as "trees and woody plants, including limbs, tops, needles, leaves, and other woody parts, grown in a forest, woodland, or rangeland environment that are the by-products of forest management" (U.S. Department of Agriculture (USDA) Forest Service 2008, p. 16). A combination of the historically high price for fossil fuel and public policies aimed at addressing the United States' energy independence and climate change has been a major driver of this research thrust (Aguilar and Garrett 2009). Research in the forestry sector has primarily focused on biophysical assessments, analyses of the economic feasibility of providing biomass for fuel, and the social availability of such biomass.

Investigative efforts such as the *Billion-ton Biomass Report* by the U.S. Departments of Agriculture and Energy in 2005 (Perlack et al. 2005) and its update in 2011 (U.S. Department of Energy 2011) have aimed to provide an overview of the potential biophysical availability of woody biomass for renewable power and biofuel. State-level studies of the potential supply of such biomass have also been conducted (Becker et al. 2010). Regional assessments, such as Goerndt et al. (2012), have explored potential availability in the vicinity of power plants to calculate the maximum sustainable capacity to generate

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renewable power from forests. Galik, Abt, and Wu (2009), for example, identified large quantities of forest residue in the southeastern United States but warned of the long-term feedstock supply that would be needed to meet continuous energy demands.

A number of economic analyses have evaluated the feasibility of using woody biomass to produce various forms of energy. Those studies have found that such production is economically feasible only when the biomass is harvested in conjunction with sawlogs (commonly referred to as an integrated harvest) because of the high cost associated with collecting the low-density biomass material (Hall 1997, Hubbard et al. 2007, Saunders et al. 2012). Saunders et al. (2012) determined break-even points for integrated harvests and estimated a maximum procurement distance of about 140 kilometers from a power plant. White, Alig, and Stein (2010) identified wood from municipal solid waste facilities, milling residue, and some timber harvest residue as the woody biomass feedstocks most likely to be used for energy since they are relatively inexpensive to procure. Harvesting of logging residue can generate new jobs and stimulate rural economies by creating demand for traditionally unmarketable materials. This, in turn, has important implications for forest management; the biomass previously left on the ground could be removed, which would reduce fuel loads and enhance wildlife habitat for some species (Aguilar and Garrett 2009). Moreover, the resulting biofuel could simultaneously promote greater energy independence and reduce concerns regarding use of food crops as feedstocks (e.g., corn) (Skipper et al. 2009, Bartuska 2010). Consequently, the overall economic impact of harvesting and converting woody biomass to energy could be substantial (Perez-Verdin et al. 2008).

The social availability of woody biomass relates to factors that influence landowners' willingness to harvest (WTH) materials for bioenergy. Social availability was defined by Butler et al. (2010, p. 151) as "the social factors that determine the desirability of the potential goods and services and the propensity for those who control a resource, such as wood, to use it themselves, allow others to do so, or do nothing with it." However, the literature so far has not thoroughly evaluated the social availability of woody biomass because the concurrent price of sawlogs has not been incorporated into estimates of landowners' WTH. For example, Markowski-Lindsay et al. (2012) elicited preferences of owners of family forests in Massachusetts for woody biomass harvesting by asking about their willingness to accept an offer to harvest timber and/or woody biomass but included only the price for woody biomass in the explanatory variables, leaving out timber prices. Likewise, Joshi and Mehmood (2011) elicited WTH woody biomass among nonindustrial private forest owners in Arkansas, Florida, and Virginia but did not include revenue for sawlogs as an explanatory variable (they included an ordinal explanatory variable capturing the importance of timber production objectives to land ownership). Moreover, the effect of public policies that provide incentive payments for biomass has not been evaluated. The existing literature has demonstrated that forest owners' decisions regarding harvesting are influenced by financial incentives (e.g., Kurtz and Lewis 1981). One program designed to increase the social availability of biomass is the USDA Farm Service Agency's (2012) Biomass Crop Assistance Program (BCAP), which was originally introduced in the 2002 Farm Bill (Public Law 107-171) and later amended under the 2008 Farm Bill (Public Law 110-234). BCAP allows landowners to receive matching payments for qualified biomass crops.

This research explores family-forest owners' WTH sawlogs and woody biomass as a function of select explanatory factors. Specifically, we evaluate the effect of (i) sawlog and woody biomass revenues from an integrated harvest, (ii) public support payments, and (iii) land resource and socioeconomic characteristics on family-forest owners' WTH woody biomass. We concentrate on the marginal effects of sawlog and woody biomass revenue to determine the likelihood that a family-owned forest will be harvested for both products and are particularly interested in the social availability of woody biomass. Empirically, we address these questions by analyzing data collected from owners of family-forest properties in Missouri, where 83 percent of the forests are privately owned and there is a considerable swath of forest that is overstocked and could benefit from integrated harvesting. In addition, there is no market for woody biomass or comparable materials in Missouri (because there is no pulp industry there), and revenue from sales of woody biomass in a bioenergy market could offset some of the cost associated with reducing the basal area in overstocked stands and enhancing wildlife habitat (Moser, Piva, and Treiman 2012, Shifley et al. 2012, Aguilar, Daniel, and Narine 2013).

Theoretical Framework

Our study of family-forest owners' WTH sawlogs for timber and woody biomass for energy is based on a review of the literature on landowner harvest decisions (e.g., Kurtz and Lewis 1981, Becker et al. 2010, Joshi and Mehmood 2011, Amacher, Conway, and Sullivan 2003) and rooted in random utility theory. As a decision-maker, a family-forest owner aims to maximize utility (U) from a decision about whether to conduct an integrated harvest. However, the ith owner's utility may not derive simply from the potential revenue generated from selling sawlogs and biomass. Kurtz and Lewis (1981), for example, suggested that decisions by owners in the Missouri Ozarks to engage in forest management were also correlated with their ownership motivations and objectives and by constraints on the parcel of woodland. Hence, we assume that maximization of utility (U) is not solely a function of revenue and other monetary incentives (P). A landowner instead will maximize welfare, which is a function of monetary and nonmonetary factors that include the landowners' demographic characteristics (D) (Amacher, Conway, and Sullivan 2003, Butler et al. 2007, Joshi and Arano 2009), reasons for owning forest land (O) (Binkley 1981, Kurtz and Lewis 1981, Kline, Alig, and Johnson 2000, Gruchy et al. 2012), perceptions about harvesting and bioenergy (B) (Becker et al. 2010, Joshi and Mehmood 2011), and land management practices (M) (Joshi and Arano 2009) plus the biophysical characteristics of the land (L) (Joshi and Mehmood 2011, Markowski-Lindsay et al. 2012). Thus, the utility derived by the ith family-forest owner from harvesting can be expressed as a function of various explanatory factors:

$$U_i = f\{P, D_i, O_i, B_i, L_i, M_i\}. \tag{1}$$

The actual utility derived from harvesting of forests, U_i^*, is not observable, but the explanatory factors' coefficients can be estimated in a latent variable model:

$$U_i^* = \mathbf{X}_{i,k+1}\beta + \varepsilon_i \qquad \varepsilon \mid \mathbf{X} \sim \text{Normal } (0,1). \tag{2}$$

In the model, U_i^* is a latent variable representing the ith individual's utility derived from an integrated harvest, $\mathbf{X}_{i,k+1}$ is an information matrix with k variables, the intercept β is a vector of coefficients capturing the effects of explanatory factors, and ε is the random error term. Since we could not observe U_i^* directly, we collected forest owners' WTH by way of their responses to a survey regarding an offer to harvest their forests' sawlogs and woody biomass. The survey used a five-point ordinal rating scale (1 = I would definitely not accept this offer, 2 = I would probably not accept this offer, 3 = I would probably accept this offer, 4 = I would very likely accept this offer, 5 = I would definitely accept this offer) and a monetary public incentive (described later under methods). The ordered response for this latent variable model assumed the following relationship:

$$WTH = \begin{array}{ll} 1 & \text{if } U_i^* \leq \mu_1 \\ 2 & \text{if } \mu_1 < U_i^* \leq \mu_2 \\ 3 & \text{if } \mu_2 < U_i^* \leq \mu_3 \\ 4 & \text{if } \mu_3 < U_i^* \leq \mu_4 \\ 5 & \text{if } \mu_4 \leq U_i^* \end{array} \tag{3}$$

in which WTH is the ith respondent's rating for a particular harvest offer and μ represents unknown threshold parameters of cut points between preference levels. Under an assumption of a normally distributed random error,

$$\begin{aligned} &\text{Prob}(WTH = 1) = \Phi(-x_{ik}'\beta) \\ &\text{Prob}(WTH = 2) = \Phi(\mu_1 - x_{ik}'\beta) - \Phi(-x_{ik}'\beta) \\ &\text{Prob}(WTH = 3) = \Phi(\mu_2 - x_{ik}'\beta) - \Phi(-x_{ik}'\beta) \\ &\text{Prob}(WTH = 4) = \Phi(\mu_3 - x_{ik}'\beta) - \Phi(-x_{ik}'\beta) \\ &\text{Prob}(WTH = 5) = 1 - \Phi(\mu_4 - \mathrm{x}_{ik}'\beta) \end{aligned} \tag{4}$$

where Φ denotes the normal cumulative distribution and β corresponds to regression coefficients of the k independent variables in the model. The coefficients in the model are estimated using maximum likelihood (McKelvey and Zavoina 1975, Hausman and Ruud 1987, Wooldridge 2002).

Ordinal scales are commonly used to capture stated preferences for a specific issue (Beggs, Cardell, and Hausman 1981, Getzner and Grabner-Krauter 2004), which in this case is family-forest owners' willingness to conduct an integrated harvest given a particular offer. Ordinal scales gather more information from a single observation than choice-based models, which only identify the most preferred alternative (Hausman and Ruud 1987). A motivation for using an ordinal scale rather than a binary choice in the survey was to reduce both uncertainty effects in the estimation and respondent fatigue. Several studies have discussed stated-preference uncertainty in designed scenarios (e.g., contingent valuation), including Shaikh, Sun, and van Kooten (2007), Akter, Bennett, and Akhter (2008), and Markowski-Lindsay et al. (2012), who accounted for this issue when estimating the WTH of family-forest landowners. Use of an ordinal scale better captures stated-preference uncertainty when

Representative forest stand in the study area

After traditional commercial timber harvesting

After integrated commercial timber and woody biomass harvesting

Figure 1. Photographs of Forest Stands Included in the Survey

using a single construct as opposed to a two-step approach as suggested by Champ et al. (1997) in which respondents' (un)certainty is recorded following their responses to a scenario.[1] Ordered models have also been applied in studies eliciting WTH preferences of nonindustrial private landowners (e.g., Gruchy et al. 2012).

Methods

Questionnaire and Model Variables

The survey instrument eliciting Missouri family-forest owners' WTH sawlogs and woody biomass in an integrated harvest was based on prior studies and our theoretical framework. We included a definition of woody biomass and its applications in bioenergy generation in the survey to avoid potential bias caused by variations in respondents' knowledge of woody biomass (Joshi et al. 2013). We also included a description of an integrated harvest accompanied by three photographs that depicted a forested stand that was representative of the study region: (i) preharvest, (ii) after a traditional commercial harvest of sawlogs only, and (iii) after an integrated harvest (see Figure 1).

[1] The two-step approach and an ordinal response were tested in focus groups. We chose to use the latter because of its simplicity and the ability of respondents to report uncertainty in a single answer. Past studies that used both approaches (e.g., Gruchy et al. 2012) determined that the coefficients obtained from ordinal logit, binary logit, and Tobit regressions for forest owners' WTH biomass were consistent.

According to the USDA Forest Service's Forest Inventory and Analysis (FIA) database, a representative acre of forest is capable of producing an average of about 4,000 board feet (bf) of saw timber and 30 short tons (1 short ton equals 0.907 metric tons) of green woody biomass (Miles 2011). However, clear-cutting (removing every standing tree) is not commonly used because of the region's hilly landscape and shallow soils (Beilmann and Brenner 1951). A representative silvicultural aim of an integrated harvest is to remove 50 percent of the saw timber and woody biomass, which is thus equivalent to 2,000 bf of timber and 15 short tons of green woody biomass per acre. We selected this level of removal for our study based on recent integrated harvests in the region (Saunders et al. 2012), consultation with local state agencies (Daniel 2012), and standards included in Missouri's best management practices for such harvests (Missouri Department of Conservation 2008). Unlike other regions of the country where tree plantations (even-age forests) are the norm, Missouri timberlands are predominantly (95 percent by area) uneven-age broadleaf forests that are allowed to naturally regenerate following a harvest (Moser et al. 2006).

The survey introduced nine hypothetical scenarios in the form of harvest offers that differed in prices paid for sawlogs, woody biomass, and biomass incentive payments and asked respondents to rate their willingness to accept the offers (Adamowicz et al. 1998). The sawlog prices presented were based on stumpage prices reported in Missouri's Timber Price Trends quarterly reports published by the state Department of Conservation (2012). We used a three-year average price for oak species, the dominant species group in the region, to set the mid-level price per bf of $0.1. The three-year average was used because of depressed prices observed in recent years (Woodall et al. 2012). Revenue from product sales was calculated on a per-acre basis as in Markowski-Lindsay et al. (2012). Based on harvesting of 2,000 bf per acre, we set the mid-level sawlog price at $200 per acre ($494 per hectare) and minimum and maximum levels of $100 per acre ($247 per hectare) and $300 per acre ($741 per hectare).

Corresponding prices for woody biomass were set to represent local energy markets with the mid-level biomass price based on an energy equivalence to coal (Saunders et al. 2012). Our mid-level revenue for 15 short tons of green woody biomass was $50 per acre ($123 per hectare) and the minimum and maximum revenues were $25 per acre ($62 per hectare) and $75 per acre ($185 per hectare). Notice that woody biomass prices are treated as being independent of sawlog prices. This is a fair assumption in the short term, although any significant change in demand for woody biomass in the future, and thus in its price, could create price pressure for timber (Ince and Nepal 2012).

The public incentive payments were established following guidelines from USDA's Biomass Crop Assistance Program (USDA Farm Service Agency 2012). Since USDA would match eligible dry short tons of woody biomass dollar for dollar up to $45 per ton, we estimated that the average incentive price would be $25 per green short ton per acre ($62 per hectare) with a minimum of $0 and a maximum of $50 ($123 per hectare). The conversion factor for dry (moisture-free) to green short tons per acre was 50 percent.

Table 1 summarizes the offers presented in the survey. For each variable, there was a minimum, medium, and maximum level, creating a balanced research design that addressed potential problems related to correlation of attributes with the model intercept and differences in statistical power of individual attributes (Lusk and Norwood 2005). With our three-level design,

Table 1. Prices Offered for Harvested Sawlogs, Harvested Woody Biomass, and Public Incentive Payments

Sawlogs	Woody Biomass	Public Incentive
$100 per acre *$247 per hectare*	$25 per acre *$62 per hectare*	None
$200 per acre *$494 per hectare*	$50 per acre *$123 per hectare*	$25 per acre *$62 per hectare*
$300 per acre *$741 per hectare*	$75 per acre *$185 per hectare*	$50 per acre *$123 per hectare*

no individual variable possessed more weight than the other two, minimizing design bias (Elfenbein and Ambady 2002).

We created the offers using a fractional orthogonal design in Bretton-Clark's conjoint designer program (Bretton-Clark 1988). The analysis software generates subsets of profiles based on specified attribute levels and orthogonal production combinations, and those subsets minimize confounding of attribute main effects. Nine price and public incentive profiles, each representing an offer in the survey, were generated from the 27 possible combinations (three saw log prices times three biomass prices times three incentive payments). This fractional factorial design overcomes information overload for respondents, a frequent problem in complete factorial experiments (Green and Srinivasan 1990, Louviere, Hensher, and Swait 2000). To further reduce the risk of information overload, we randomly selected three scenarios to present to each respondent. Thus, as in Aguilar (2009), we had three versions of the survey, each containing a unique set of three scenarios.

The scenarios mimicked the process that commonly occurs in Missouri; landowners typically are approached by a logger with a particular offer. The offers in our survey were presented in the following form:

> You are approached with an offer from a professional logger to harvest your woodlands following best management practices. The offer is (a) $_____ per acre to harvest timber (sawlogs), (b) an additional $_____ per acre to also remove 15 short tons of woody biomass from your property, and (c) an additional $_____ per acre for a public incentive payment that requires you to have a professional forest management plan by the time of harvest. Would you seriously consider this offer and harvest part or all of your property?

Participants responded to each offer using the five-point WTH scale (1 = would definitely not accept, 2 = would probably not accept, 3 = would probably accept, 4 = would very likely accept, 5 = would definitely accept).

Table 2 presents a summary of the explanatory variables in the model. The demographic variables included in the questionnaire section were age, education, income, gender, and presence of children under the age of 18 in the household (Amacher, Conway, and Sullivan 2003, Butler and Leatherberry 2004, Joshi and Arano 2009, Young and Reichenbach 1987). Constructs that captured respondents' reasons for owning forest land were based on information in the USDA Forest Service National Woodland Owner Survey (NWOS) discussed by

Table 2. Explanatory Variables Used to Model Private Forest Owners' Willingness to Harvest

Sources	Variables	Descriptions
Prices and Public Incentive		
Missouri Department of Conservation 2012; Saunders et al. 2012; USDA Forest Service 2012	Timber price (dollars per acre)	Continuous variables
	Biomass price (dollars per acre)	
	Public incentive price (dollars per acre)	
Demographics[a]		
Amacher, Conway, and Sullivan 2003; Butler and Leatherberry 2004; Joshi and Arano 2009; Young and Reichenbach 1987	Age	Equals 1 if older than 55 years; Equals 0 otherwise
	Education	Equals 1 if at least 4-year college degree Equals 0 otherwise
	Income of $50,000 per year or more[b]	Equals 1 if annual household income from all sources of at least $50,000 Equals 0 otherwise
	Gender	Equals 1 if male Equals 0 otherwise
	Children under 18 years live in household	Equals 1 if children under 18 live in household Equals 0 otherwise
Reasons for Owning Forest Land		
Butler et al. 2007; Marty, Kurtz, and Gramann 1988; Broderick, Hadden, and Heninger 1994; Finley and Kittredge 2006	As a part of the farm or ranch	Equals 1 if not important Equals 2 if slightly important Equals 3 if moderately important Equals 4 if very important Equals 5 if extremely important
	To pass land on to children or other heirs	
	For production of sawlogs, pulpwood, or other timber products	
Bioenergy Views		
Gruchy et al. 2012; Galik, Abt, and Wu 2009; Joshi and Mehmood 2011; Markowski-Lindsay et al. 2012	Supports harvesting woody biomass for energy	Equals 1 if agree or strongly agree with statement Equals 0 otherwise
	Harvesting woody biomass is not likely to result in soil erosion	

Continued on following page

Table 2. (continued)

Sources	Variables	Descriptions
Biophysical Characteristics of the Land		
Bliss and Martin 1989; Joshi and Arano 2009; Erickson, Ryan, and De Young 2002	Wooded parcel size	Equals 1 if woodland is 1,000 acres or more in size Equals 0 otherwise
	Saw timber volume[c]	Continuous; estimates in board feet were divided by 100,000 to downscale figures
	Biomass volume[d]	Continuous; estimates in short tons were divided by 1,000 to downscale values
Management Characteristics		
Joshi and Arano 2009; D'Amato et al. 2010; Greene and Blatner 1986	Primary residence	Equals 1 if woodland (or part of it) was located on a parcel adjoining the primary residence Equals 0 otherwise
	Had sold timber since owned	Yes = 1 No = 0
	Had no plan to harvest in the future regardless of price	Yes = 1 No = 0
	Had a professionally written forest management plan	Yes = 1 No = 0
	Had sold timber since owning the land and planned to sell timber in the future	Yes = 1 No = 0

[a] Both dummy coding and effect coding can be applied to demographic variables. In this study, we applied dummy coding because of the ease of effect interpretation in this context. The dummy-variable trap was solved by dropping one category of the variable from the model.

[b] The actual median household annual income in Missouri was $46,262 (U.S. Census Bureau 2012) but the information collected was in $10,000 intervals. Respondents who selected income of $50,000 or more were thus classified as exceeding the median. Interaction variables between income and harvest revenue were generated to detect sensitivity across income levels.

[c] Estimates of standing saw timber volume were derived from the USDA Forest Service's FIA database.

[d] Biomass volume estimates were derived from the USDA Forest Service's FIA database.

Butler et al. (2007). We included three variables in the model to capture the importance of woodland ownership: (i) as part of a farm, (ii) production of wood products, and (iii) for bequests.

In the survey, respondents were asked to self-report the importance of two statements related to bioenergy as a way of gathering their perceptions of the impacts of harvesting woody biomass. The first statement asked the respondents whether they supported the general concept of harvesting woody biomass to produce energy. The second assessed their view of the potential for an integrated harvest to cause soil erosion to measure environmental impacts. These metrics are based on Galik, Abt, and Wu (2009), Joshi and Mehmood (2011), and Gruchy et al. (2012) and were motivated by identification of two latent factors (overall support of biomass harvesting and possible environmental concerns) associated with views of biomass energy production suggested by Daniel (2012) and Markowski-Lindsay et al. (2012).

Land characteristics included as explanatory variables were the relative size of the wooded parcel, whether the respondent's primary residence was adjacent to the woodland, and the volume of saw timber and aboveground woody biomass in each county (Romm, Tuazon, and Washburn 1987, Bliss and Martin 1989, Erickson, Ryan, and De Young 2002, Joshi and Arano 2009). The volumes of saw timber (board feet) and woody biomass (short tons) were gathered from the FIA database and estimated at a county level (USDA Forest Service 2012). These variables capture differences in the amount of standing timber and woody biomass among the counties included in the study. We initially planned to gather the information from survey participants but found little awareness among landowners regarding their lands' standing timber and woody biomass after several focus group meetings. We thus determined that data generated through self-reporting could suffer from significant sampling error and chose to rely on our second-best source of information, the FIA data. The estimates of saw timber volume on productive forest lands by county were retrieved directly from the FIA database. We estimated the volume of woody biomass using information in the FIA database for volumes of small diameter trees (5–11 inches in diameter), rough rotted cull trees, and biomass from the tops and limbs left over from processing sawlogs.

Variables for land ownership characteristics identified whether each respondent had sold timber since acquiring the property, planned to sell timber in the future, and had a professionally written management plan (Greene and Blatner 1986, Joshi and Arano 2009, D'Amato et al. 2010). We included an interaction variable that identified landowners who had harvested timber in the past and also were willing to sell timber in the future. This interaction variable allowed us to distinguish landowners who planned to harvest in the future from those who did not.

Data Collection

The forest owner survey was conducted by mail between March and May of 2011 in fourteen counties in southeastern Missouri where more than 55 percent of the state's forests are located. Following tailored design methods (Dillman 2000), we mailed an introductory/educational postcard, the survey, and reminders to owners who had at least 20 acres of forest, an amount previously defined as the minimum viable size for commercial forest management activities (Row 1978, Butler and Leatherberry 2004). Full details of the data collection procedures can be found in Daniel (2012).

Econometric Analysis

We used an ordered probit regression to estimate the latent variable model (equation 2). This model was selected because of the ordinal nature of the

WTH dependent variable under the 1–5 scale that captured the strength of respondents' preferences (Greene 2011). Sy et al. (1997) and Harrison, Gillespie, and Fields (2005) have discussed the suitability of ordered probit models for interval rating scales since these are usually measured in discrete variables and ordinal preferences. Because the respondents provided three ratings for each harvest offer, it was reasonable to expect a certain degree of correlation between their responses. We controlled for this issue in the model by estimating cluster-robust standard errors. Crouchley (1995) presented a model for ordered categorical data with the presence of a cluster effect resulting from multiple observations recorded from a single individual. A Brant test for the homogeneity of the parameters (Brant 1990) and goodness-of-fit measures using a chi-squared test for the log-likelihood ratio and the Bayesian information criterion (BIC) were also estimated.

Two models were estimated in this regression. The first included only the product revenue and public incentive attributes. It is a generalized model in which the effects of the variables are estimated for the average forest owner before controlling for the other explanatory variables. The second model controlled for all of the factors included in equation 1 using the variables presented in Table 2. As discussed by Wooldridge (2002), the direction of the effect of the kth variable on the ordered dependent variable is invariably determined by the signs of its associated β coefficients, but its marginal effect has to be determined at specific values of $\mathbf{X}$ and the cutting point thresholds (μ). To determine the actual marginal effects of the explanatory variables, we estimated cumulative probabilities between the thresholds (e.g., the marginal effect of the price received for woody biomass between the cumulative probabilities associated with a landowner's choice regarding accepting the offer. For example, the marginal effects on the cumulative probability of WTH given the price of sawlogs were evaluated at each sawlog price (\$100, \$200, and \$300 per acre) between thresholds:

$$\text{(5)} \quad \partial \text{Prob}\,(WTH) / \partial \mathbf{X}_{sawlog\ price} = \beta_{sawlog\ price}\,[\Phi(\mu_2 - \mathbf{X}_{k+1}'\beta) - \Phi(\mu_1 - \mathbf{X}_{k+1}'\beta)]$$

$$\partial \text{Prob}\,(WTH) / \partial \mathbf{X}_{sawlog\ price} = \beta_{sawlog\ price}\,[\Phi(\mu_3 - \mathbf{X}_{k+1}'\beta) - \Phi(\mu_2 - \mathbf{X}_{k+1}'\beta)]$$

$$\partial \text{Prob}\,(WTH) / \partial \mathbf{X}_{sawlog\ price} = \beta_{sawlog\ price}\,[\Phi(\mu_4 - \mathbf{X}_{k+1}'\beta) - \Phi(\mu_3 - \mathbf{X}_{k+1}'\beta)].$$

In the regression, $\beta_{sawlog\ price}$ was set at 100, 200, and 300 while $\mathbf{X}_{k+1}$ and β captured information for the remaining explanatory variables in model 1.[2] We report only the results of the marginal effects of timber and woody biomass prices estimated between all μ thresholds in the generalized model since they answer our research questions and eliminate the need to provide a lengthy description of the values set for each explanatory variable. The effects of prices for sawlogs and woody biomass on WTH were analyzed individually for each revenue level reported in Table 1 while holding all of the other variables constant. Marginal effects for the public incentive were not included in this marginal analysis because funding for such incentives for woody biomass has dried up and the prospects for their return are not promising. Hence, in all cases, public payments equaled zero. All of the estimations were calculated using Stata version 11.

[2] See Harrison, Gillespie, and Fields (2005) for a detailed discussion of marginal effect estimations in ordinal models.

Results

The adjusted response rate for the survey was 34 percent, which is comparable with other family-forest owner WTH studies. Narine (2013) surveyed family-forest owners in Michigan, Wisconsin, and Minnesota and reported response rates of 31 percent, 32 percent, and 45 percent, respectively. A similar study conducted by Gruchy et al. (2012) of nonindustrial private landowners in Mississippi reported a response rate of 21 percent.

The characteristics of the respondents in the sample closely resembled those of family-forest owners in the state overall as reported in the NWOS; the majority of the participants were men, annual household incomes exceeded Missouri's statewide median level, and their education levels also exceeded the state average. One difference between our sample and the state overall was the number of respondents who indicated they had a written forest management plan—6 percent in our sample versus 2 percent in the NWOS. The higher rate of adoption of a management plan in our sample is likely a result of our excluding properties that had less than 20 acres of forest and our focus on the southeastern area of the state.

Ordinal Models for Willingness to Harvest

We present the results of the ordinal probit regressions for models 1 and 2 in Table 3. Model 1 used 1,569 responses from 529 forest owners.[3] Results of a Brant test suggested that our data set did not satisfy the proportional odds assumption, which would raise concerns about the validity of the estimated coefficients. However, Kim (2003) and Capuano, Dawson, and Gray (2007) argued that the proportional odds assumption in the Brant test is a strong and restrictive assumption that is commonly violated in large samples. The generalized ordered logit model, which estimates slope-parameter estimates across response categories, has been proposed as a less restrictive alternative to the ordered probit model. Williams (2006) suggested using an iterative Wald-test method to estimate a generalized ordered logit model in which only the coefficients that differed across response categories would be re-estimated. We tested Williams' suggested model, the results of which are available upon request. In those results, only the coefficients for the sawlog price differed between ordinal categories and the differences were subtle. However, when we compared the goodness of fit of the ordered probit model with the generalized ordered probit model, the log-likelihood ratio test showed that the former had a smaller BIC (4,012.19 versus 4,044.10).

Since a lower BIC suggests a better fit and, as pointed out by Greene and Hensher (2009), rejection of the null hypothesis in the Brant test in empirical applications does not provide a conclusive argument in favor of a nonproportional odds model, we selected the ordered probit regression for interpretation of the results. Furthermore, we compared the results from the ordered probit model with a Tobit model as suggested by Harrison, Gillespie, and Fields (2005). Results from both models were similar, providing further assurance of the direction and significance of the model coefficients.

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[3] Since each respondent was asked to rate three harvest offers, 529 forest owners should have provided a total of 1,587 responses. However, some respondents did not answer all three WTH questions so the model was estimated based on 1,569 complete observations.

Table 3. Results of Ordinal Probit Regressions Modeling Forest Owners' Willingness to Harvest Woodland

	Model 1			Model 2		
Variable	**β**	**Std Error**	**p-Value**	**β**	**Std Error**	**p-Value**
Product Prices and Public Incentive						
Sawlog prices	0.002	<0.001	<0.001	0.002	<0.001	<0.001
Woody biomass prices	0.003	0.001	0.003	0.002	0.002	0.292
Public incentive	0.003	0.001	0.003	0.003	0.001	0.045
Demographic Characteristics						
Age				–0.224	0.127	0.079
Education level				0.313	0.105	0.003
Income of $50,000 per year or more				–0.318	0.228	0.164
Gender				–0.060	0.131	0.650
Children under 18 years of age in the household				0.258	0.134	0.055
Sawlog price × Income of $50,000 or more				0.001	0.001	0.061
Woody biomass price × Income of $50,000 or more				0.002	0.002	0.303
Public incentive price × Income of $50,000 or more				–0.001	0.002	0.734
Reasons for Owning Forest Land						
As a part of the farm or ranch				–0.105	0.039	0.007
To pass on to children or other heirs				–0.070	0.040	0.081
For production of sawlogs, pulpwood, or other timber products				0.068	0.051	0.187
Bioenergy Views						
Supports harvesting woody biomass for energy				0.271	0.108	0.012
Harvesting woody biomass is not likely to result in soil erosion				–0.073	0.058	0.209
Biophysical Characteristics of Land						
Wooded parcel size of 1,000 acres or more				–0.296	0.202	0.143
Saw timber volume				<0.001	<0.001	0.049
Woody biomass volume				<0.001	<0.001	0.022
Land Management						
Primary residence				–0.162	0.100	0.106
Had sold timber since owned				0.299	0.122	0.017
No plan to harvest in the future regardless of price				–0.346	0.063	<0.001
Had sold timber since owned and planned to sell timber in the future				–0.447	0.180	0.008
Had a professionally written forest management plan				–0.316	0.216	0.144
Number of observations		1,569			1,301	
Log pseudo-likelihood		–1,980.3419			–1,511.8028	
Prob > chi-square		<0.001			<0.001	

Notes: Robust standard errors are used to correct for correlation within the WTH ratings of each respondent. There were 529 respondents in model 1 and 438 in model 2.

Model 1 revealed a direct relationship between WTH and revenue from sawlogs, woody biomass, and public incentive payments. As expected, greater revenue results in higher, statistically significant WTH ratings. The values of the coefficients were remarkably similar. This is associated with the values for the attributes all being included as dollars per acre (i.e., a one-dollar increase in revenue per acre across a price or public incentive option would have about the same effect on WTH). However, in actual terms, the prices set for sawlogs varied more ($100 to $300 per acre) than the prices for woody biomass and the public incentive, which results in the timber price having a greater impact since it dominates revenue from an integrated harvest (discussed further in the marginal probability analysis).

Model 2 used 1,301 observations from 438 landowners. Again, the smaller number of observations is a result of surveys that were excluded from the analysis because of missing responses regarding WTH or other questions. After controlling for demographic characteristics, we examined reasons for owning forest land, perceptions of harvesting biomass for energy, biophysical characteristics of the land, and management practices to determine their impacts on family landowners' WTH. The product revenue and public incentive variables kept a positive sign, and the sawlog price (p-value of less than 0.05) and public incentive (p-value of 0.045) variables had a statistically significant effect on WTH.

In terms of demographic characteristics, our results show that education level has a positive and statistically significant effect on WTH (p-value of less than 0.01). Landowners who had at least a four-year college degree were more willing to conduct an integrated harvest than owners with less education. This finding is consistent with Amacher, Conway, and Sullivan (2003). Our model identified a negative effect associated with owners aged 55 or older; when holding all other variables constant, those landowners systematically reported lower WTH. The model also demonstrated that households in which there is at least one child under 18 years living at home reported greater WTH. The effects for income and gender were statistically insignificant. The interaction between an income of at least $50,000 per year and timber prices was significant with a p-value of 0.061 and had a positive sign. Thus, while households with median annual income of at least $50,000 were less likely to harvest their woodlands than households with smaller incomes, the higher income group was also more sensitive to price changes.

Ownership of woodlands as either part of a farm or ranch operation or as an estate to be passed on to the next generation was inversely correlated with WTH as indicated by the negative signs of the coefficients (p-values of 0.007 for farm/ranch operations and 0.081 for estate purposes). Interestingly, the variable representing ownership for production of wood products had the expected sign but was not statistically significant. This finding suggests that a timber production goal did not have a large influence on WTH after controlling for other explanatory factors.

Finally, landowners who support woody biomass harvesting for energy exhibit a greater WTH than owners who do not while the variable capturing views of the potential environmental impacts of woody biomass harvests had a negative but nonsignificant coefficient since the type-I error level was 0.05. Thus, although both environmental impacts and economic benefits drive landowners' views of woody biomass harvesting, support for bioenergy seems to be the more influential factor when evaluating WTH. Note that the coefficient that captures owners' opposition to harvesting biomass was negative regardless of price offered so it could have already captured negative environmental perceptions regarding harvesting.

Regarding the effects of county land characteristics, the results show that forest owners in counties with relatively large amounts of saw timber and woody biomass exhibit greater WTH. This finding suggests that, *ceteris paribus*, forest owners are likely to harvest not only when there is a good supply of high quality timber but also when there are overstocked stands since a large quantity of biomass is indicative of woodlands in need of thinning. The effect found for the relative size of the woodland owned was not statistically significant (p-value of 0.143). Although a similar result was reported by Markowski-Lindsay et al. (2012), this result generally is not consistent with other studies. For example, Conway (1998) found that landowners whose parcels were less than 15 acres in size were less likely to harvest, and Kline, Alig, and Johnson (2000) reported a positive relationship between larger parcel sizes and family landowners' WTH. The apparent inconsistency between our results and those of previous studies may be related to our limiting the study sample to owners of at least 20 acres of forest. A direct comparison with other studies may not be possible because of different target populations.

In terms of forest management characteristics, our results for previous harvest experience are similar to those of other studies (Young and Reichenbach 1987, Broderick, Hadden, and Heninger 1994); respondents who had harvested timber in the past were more likely to be willing to harvest in the future. However, our results point to the importance of controlling for attitudes against harvesting as we found a negative, statistically significant effect for the variable that captures opposition to future harvesting and its interaction with past harvesting. These results suggest that WTH cannot be accurately elicited solely from past harvest behavior since some individuals who harvested in the past were opting not to harvest in the future. This information has often been excluded in empirical estimations of WTH.

Our model suggests that an owner having a forest management plan has no significant effect on WTH (p-value 0.144). This result is consistent with a study of WTH of private forest owners in West Virginia (Joshi and Arano 2009).

Marginal Effects of Timber and Woody Biomass Prices

Using model 1, we estimated the marginal probability effects of various prices for sawlogs and woody biomass on WTH when no public incentive payment was offered and present the results in Figure 2. In each chart, the timber price is constant while the biomass price varies, and we analyzed marginal probability effects between the cut points for owners' willingness to accept the proposed offer.

When we set the sawlog price at $100 per acre, we found marginal probability effects of around 0.35 for a biomass price of $25 or $50 per acre and 0.34 for a price of $75 per acre between the μ_1 (definitely would not accept the offer) and μ_2 (probably would not accept the offer) thresholds. Between μ_2 and μ_3 (probably would accept the offer), the marginal probabilities were 0.23 at $25, 0.24 at $50, and 0.26 at $75 per acre of woody biomass. The marginal probabilities between μ_3 and μ_4 (would very likely accept) showed marginal probabilities of 0.07 at $25, 0.08 at $50, and 0.09 at $75 per acre, but their effects were not statistically significant. The distribution of the marginal effects suggests

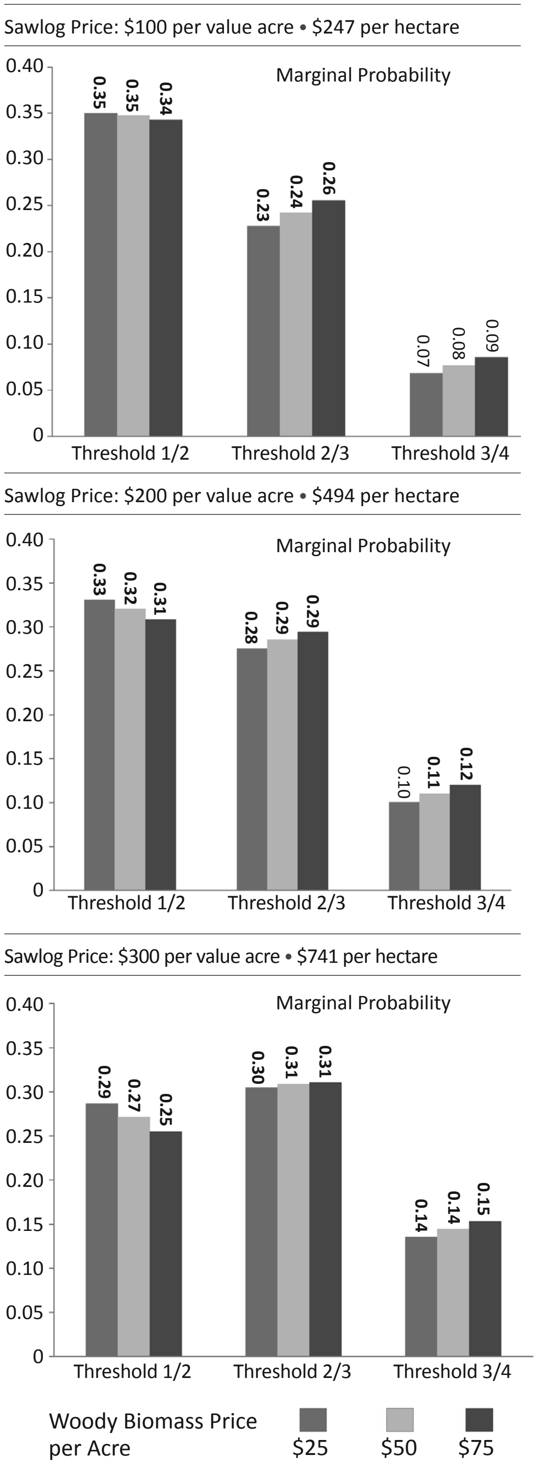

Figure 2. Marginal Probability Effects of Revenue from an Integrated Harvest on Forest Owners' Willingness to Harvest

Note: Marginal probabilities that have p-values of less than 0.05 are shown in **bold**.

that changes in WTH occurred mostly at lower thresholds of acceptance, which suggests that landowners were unlikely to accept an offer to harvest their woodland at $100 per acre. The effect of revenue from woody biomass was small and was not statistically significant so would not encourage owners to accept an offer to harvest their lands.

The charts for sawlog prices of $200 and $300 per acre can be interpreted similarly. The marginal effect of the price for woody biomass was statistically significant in all but one case—between threshold μ_3 and μ_4 at a sawlog price of $200 per acre and biomass price of $25 per acre. In addition, there was an increase in the marginal probabilities as sawlog and woody biomass prices rose. For example, when we set the price of woody biomass at $75 per acre, raising the price of sawlogs from $100 to $300 per acre increased the marginal probability from 0.09 to 0.15. Likewise, as the biomass price rose, the marginal probabilities between thresholds μ_1 and μ_2 tended to decline. This finding provides evidence of the direct effect of the price of both products on WTH and of the dominant influence being sawlogs. For instance, at the highest sawlog price, the greatest marginal effect occurred between thresholds μ_2 and μ_3. At that sawlog price, the average forest owner was 30 percent more likely to shift from probably not willing to accept the offer to probably would accept it.

We observe several trends in the results. First, there was a general skewedness in how marginal probabilities were distributed across the price levels with concentration in lower thresholds at all three prices, which suggests that relatively low WTH was predominant given the price ranges in the study. The distribution and actual values of marginal probability changed little in response to the woody biomass price, but all were significant and statistically different from zero (across sawlog prices) only when the woody biomass price was $75 per acre. Consequently, it appears that forest owners' WTH is not very sensitive to changes in woody biomass prices. Based on this, we suggest that family-forest landowners' willingness to conduct an integrated harvest is primarily a function of sawlog prices.

Conclusion

The price for sawlogs and woody biomass had a direct, statistically significant impact on whether the average forest owner in Missouri would be willing to conduct an integrated harvest (model 1) according to the coefficients and p-values for sawlog and woody biomass revenue. However, when the model controlled for demographic characteristics, reasons for owning woodlands, perceptions of harvesting and bioenergy, the biophysical characteristics of the land, and management characteristics (model 2), the effect of the price offered for woody biomass was no longer statistically significant.

Ceteris paribus, forest owners who had more education, who were younger than 55, and whose households included children younger than 18 were more likely to be willing to conduct an integrated harvest than other forest owners. Forest owners in households that had an annual income of at least $50,000 consistently reported lower levels of WTH, but their responses were more sensitive to changes in timber prices compared to individuals who had lower annual household income. Individuals who owned woodland as part of their farms or to pass on to their children or other heirs were less likely to be willing to harvest their properties. A positive effect on WTH was found for forest owners who supported use of woody biomass for bioenergy and in counties that had larger amounts of standing timber and woody biomass. Holding everything else constant, forest owners who had prior experience with harvesting were more likely to harvest in the future. However, measures of the effect of past harvest experience should control for owners who decided against it in the future. When we controlled for those explanatory factors, we found that WTH was not affected by productive ownership objectives, concerns about the environmental impacts of woody biomass harvesting, the relative size of the woodlands owned, whether the woodland property was the primary residence, or whether a forest management plan was adopted, although the coefficients had the expected signs.

Our results indicate that family-forest owners in Missouri had relatively limited interest in integrated harvests. The low prices that currently dominate the market are expected to continue for the foreseeable future. Operators of projects that rely on woody biomass should be mindful of these findings and expect the supply of biomass from privately owned land to be small. Instead, it likely will come primarily from by-products of saw timber harvests. The private supply might increase if timber prices rise to at least $200 per acre. Given our results, regional estimates and evaluations of forest owners' WTH may need to be re-evaluated.

Our results provide weak support for provision of public incentives and show that the greatest influence on WTH comes from sawlog prices. Thus, any public effort to boost the supply of woody biomass from privately owned land in areas where removal of the biomass is contingent on integrating the harvest with timber is likely to be ineffective if payments are linked to the woody biomass price. Family-forest owners are heavily influenced by sawlog prices so those prices dictate whether they will choose to harvest biomass, and current prices for sawlogs are too low to motivate integrated harvesting. Given the results of our study, the best public policy tool for increasing woody biomass harvesting from privately owned land would be approaches that support higher timber prices.

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