Factors Influencing Utilization of Woody Biomass from Wood Processing Facilities in Mississippi

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Abstract

Mill residues obtained from wood processing industries are potentially important feedstocks for the wood-based bioenergy industry. Although many mills recognize the value of their residue as an integral fuel for energy production, some recent studies suggest that ample mill residues are available to expand wood-based bioenergy in United States. This study analyzed factors that influence the availability of residues from mills in Mississippi. Information pertaining to available residues from forest products industries in Mississippi was obtained by a mail survey instrument. Generalized least square and Tobit models were used to analyze the data. Results indicated that availability of residues was higher in primary wood processing manufacturers than secondary manufacturers and that feedstocks availability would be higher if wood-based bioenergy firms were located near larger, year-round, forest products industry operations. Residue availability may be constrained by lack of awareness regarding market opportunities for bioenergy products. The study results are useful for entrepreneurs interested in creating sustainable bioenergy production in Mississippi.

Wood-based bioenergy has recently received attention in national policy and research, and numerous benefits pertaining to energy security, the environment, and rural economies have been recognized (Foster et al. 2005, Gan and Smith 2007, Guo et al. 2007, G.C. and Potter-Witter 2011, US Department of Energy 2011, Susaeta et al. 2012). The term wood-based bioenergy implies that different sources of woody biomass, such as logging and thinning residues, woody urban wastes, mill residues, and fuel treatment residues, are used as feedstocks to generate this form of energy (Foster et al. 2005). While private forest lands in the United States are considered to be key contributors in supplying unused logging and thinning residues (e.g., Joshi and Mehmood 2011, Gruchy et al. 2012), mill residues are primarily obtained from primary and secondary wood processing facilities. Reportedly, nearly 25 percent of the existing biomass energy consumption in the United States has been contributed by primary and secondary wood processing facilities (US Department of Energy 2011). A substantial amount of the wood residues obtained from mills are currently used to generate energy in the United States (Guo et al. 2007).

Although many mills recognize the value of their residue as an integral fuel for energy production, some recent studies suggest that ample mill residues are available to expand wood-based bioenergy in the United States. Vlosky (2003) reported total generated volumes of wood and bark residues in southern mills. Southern mills generated 3.2 billion cubic feet of residues, of which 40 percent were contributed by coarse residuals. In Alabama, 56 percent of the residuals were used for industrial fuel, 30 percent were used to produce fiber products, and less than 1 percent were unused. In Arkansas, 51 percent of the residuals were used for industrial fuel, 38 percent were used to produce fiber products, and less than 1 percent were not used (Vlosky 2003). The author reported that 51 percent of the total wood residue available in Mississippi was used as industrial fuel, and 2 percent were not used. In their effort to estimate the amount of wood waste produced from wood products companies, Garrard and Leightley (2005) found that 61 percent of the total wood waste produced in northern Mississippi was sold. However, they noted that given a declining interest in wood waste purchases and problems

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associated with its disposal, many mill owners were willing to collaborate with other companies to find a better way of using wood waste.

Thus, it can be argued that even though the use of woody residues for energy generation is an established practice in the forest products industry (Foster et al. 2005), some volumes of internally unused woody residues could still be better used to generate wood-based bioenergy if a reasonable price were paid to feedstock suppliers (Walsh 2008). Because woody residues generated in forest products industries such as sawdust and chips are clean and free from dirt particles, they can be efficiently used as feedstock to generate wood-based bioenergy (Foster et al. 2005). Moreover, transportation and operational costs associated with clean woody residues from mills are relatively lower than those associated with logging and thinning residues (Foster et al. 2005). If wood-based bioenergy facilities could be integrated with, or located near, forest products facilities, transportation cost for feedstocks, which plays an important role in economic viability of wood-based bioenergy (Grebner et al. 2009), would be reduced. Because some quantity of woody biomass is currently disposed of or given away by forest products firms, energy generated from mill waste would also be less expensive and have a competitive advantage over fossil fuel alternatives.

The concept of integrating with a new industry such as wood-based bioenergy is important for North American forest products manufacturers because these firms are facing increased competition from their international counterparts for their product lines (Heiningen 2006). Domestic markets have suffered from structural changes and competition has increased because of globalization; tropical nations can produce value-added products at lower costs, partially because of a readily available and significantly inexpensive labor market (Schuler and Buehlmann 2003, Ince and Nepal 2012). Clustering also helps forest products industries compete in the global marketplace because firms can benefit from each other by sharing inputs, technology, and labor required for an industrial manufacturing processes (Hagadone and Grala 2012). Therefore, supplying woody residues as a feedstock or integrating with a wood-based bioenergy facility may be important for increasing competitiveness of traditional US forest products industries. Undoubtedly, sustainable feedstock supply is an important prerequisite for establishing a wood-based bioenergy industry. Entrepreneurs would want to ensure a sustainable feedstock supply before considering an investment in the wood-based bioenergy industry. Therefore, factors influencing woody biomass availability would be of interest to entrepreneurs in their decision to establish bioenergy industry. It is worth noting that persons involved in wood processing activities, unlike a majority of smaller nonindustrial private forest (NIPF) landowners (Joshi and Arano 2009), would seek monetary benefits in their business. Their benefit maximizing behavior was reflected in a study conducted by Aguilar (2009), in which the author reported that stumpage prices, better road networks, availability of raw materials, energy costs, and land values were significant determinants of an entrepreneur's decision to select a county for establishing a sawmill in the southern United States. In short, given the corporate nature of the forest products industry, factors affecting a mill decision to supply woody biomass will likely be different from those of NIPF landowners. Therefore, literature pertaining to NIPF landowner timber or woody biomass harvesting (Dennis 1989, Kuuluvainen et al. 1996, Amacher et al. 2003, Conway et al. 2003, Joshi and Arano 2009, Joshi and Mehmood 2011, Gruchy et al. 2012, Susaeta et al. 2012) is less relevant when accounting for the availability of mill residues for wood processing facilities.

As previously indicated, although mill residues are considered to be a high-quality feedstock for wood-based bioenergy, only a few studies (Carter 2010, G.C. and Potter-Witter 2011) have analyzed issues related to their availability for use in the wood-based bioenergy industry. A review of the literature indicated that a detailed analysis on factors associated with the availability of mill residues for bioenergy use has yet to be undertaken. One possible reason could be attributed to the small unused portion of wood residues in the forest industry. The bioenergy industry, however, can obtain feedstocks from those mills that, despite their current involvement in woody residue sales, are seeking better ways to use woody residues generated in their facilities. It can be argued that mills are likely to receive a higher premium if the volume of woody residues currently used in livestock bedding, mulching, or some other domestic needs, could be better used as feedstocks in the wood-based bioenergy industry. Walsh (2008) supported the above argument at the time of his study and reported that 22.80 million dry tons (dt) of mill residues would be potentially available for bioenergy uses in the United States at $40/dt in the year 2010. Given that wood residues from the forest products industry can play an important role in creating sustainable bioenergy production in the United States, it was apparent that a study was necessary to explore issues that could help explain the factors affecting availability of woody residue that is not used on-site by mills.

Objectives

The objectives of this study were (1) to identify potential factors that could influence the availability of mill residues for bioenergy use in Mississippi and (2) to highlight the role of mill characteristics, market opportunities, and demographic variables in mill owners' decisions to sell, give away, or reuse mill residues.

Data and Estimation Procedures

Data sources

The data for this research were generated based on a mail survey of wood products industries in Mississippi. The requisitic data were supplemented by county specific (1) industrial electricity price obtained from electricity providers with the help of Mississippi Development Authority's interactive utility map, and (2) per acre livestock numbers obtained from Web portal of national agricultural statistics service of the US Department of Agriculture. Mailing addresses of individuals owning primary and secondary wood processing industries in Mississippi were identified from the Mississippi Development Authority's online searchable Standard Industrial Classification (SIC) Codes 24/25 (lumber and wood products/furniture and fixtures) and 26/27 (paper and allied products, printing and allied industries). Total population for this census survey, including the list of owners from SIC Codes 24/25 and 26/27, was 582 mills. The survey instrument consisted of three sections, whereby the first section contained queries on the type of forest products firm, amount of woody residue generated in the respondent's plant(s) on an annual basis, and methods of woody residue use. The second section included questions about woody residue disposal methods, mill interest in collaborating with others to determine better ways to use residues, existing markets, average hauling distances from the forest, price of mill residues, and technical and operational capabilities of the forest products firm. The last section covered the facility location, employment size, years in operation, and annual forest products sales.

The survey instrument was pilot tested among a randomly selected group of mills in July 2011, and their suggestions were incorporated into the survey instrument. The survey was then mailed during the first week of August 2011 to all 582 mills involved in the wood processing business, which included mill owners, managers, and/or their representatives. Following Dillman (2000), the survey included a reminder postcard and two mailings, but the total number of responses ultimately received was not adequate to conduct an econometric study. Therefore, telephone interviews of randomly selected non-respondent mills were conducted, using the identical mail survey after the first two mailings. Given the low response rate of the survey, the issue of nonresponse bias was a concern. Thus, differences between socio-demographic variables such as total number of employees, total annual sales, and ownership duration from the first and second mailings were statistically tested because sometimes it is argued that those who respond with delays are typically different from those who respond early. As a further check, the survey results on key socio-demographic attributes were compared with information available on the entire population of wood products industries in the existing literature.

Econometric model

Rational behavior implies taking the best opportunity or minimizing the opportunity cost of actions taken (Nicholson 1995). A mill owner's decision to reuse, sell, or give away produced woody residues will, thus, depend on his expectations as to which option will maximize profit. A regression equation was posited to analyze this economic proposition empirically. Because volume of available mill residues (Y_i) was a continuous dependent variable, a multiple linear regression equation (Eq. 1) would be appropriate to analyze its relationship with explanatory variables (x_i).

$$Y_i = \beta_i x_i + \varepsilon_i \tag{1}$$

where β_i represents the vector of parameter coefficients and ε_i is the random component. The availability of mill residues is likely to be affected by a variety of factors, including the mill characteristics, market, and respondent demographic attributes (Table 1). The empirical relationship between the availability of unused woody residues and these factors can be written as

$$\begin{aligned}\text{WOODRESIDUE} &= \beta_0 + \beta_1\text{PRI} + \beta_2\text{BETTER} + \beta_3\text{EMPLOYEE} \\ &\quad + \beta_4\text{ORG} + \beta_5\text{SEASON} + \beta_6\text{WORK} + \beta_7\text{ULIVEN} \\ &\quad + \beta_8\text{PRICERES} + \beta_9\text{ELECP} + \beta_{10}\text{EDU} + \varepsilon_i\end{aligned} \tag{2}$$

The dependent variable WOODRESIDUE was constructed as the sum of wood residue sold, given away, or disposed of by a forest products firm. The econometric model proposed here is based on a linear regression framework (Greene 2008) and assumed to satisfy the associated underlying assumptions (e.g., linearity, full rank, zero conditional mean of disturbance, independence of mean and variance, homoscedasticity, no autocorrelation, and normality).

Note, however, that irrespective of the total volume of wood residue generated at a particular mill, actual volume of unused wood residue would be zero if it is internally reused. This could pose a modeling issue if a significant number of mills fit this description. Specifically, this would warrant a careful application of the ordinary least squares (OLS) model or the use of a more appropriate model such as a censored Tobit. To allow for this possibility (Long 1997), Equation 1 is rewritten as

$$y_i^* = \beta_i x_i + \varepsilon_i \tag{3}$$

where y^* is the latent variable observed for values $>\tau$ and censored for other values $<\tau$, x's are observed for all cases, and $\varepsilon_i \sim n(0, \sigma^2)$,

$$y = y_i^* \text{ if } y_i^* > \tau_y \tag{4}$$

$$y = y_i \text{ if } y_i^* \le \tau_y \tag{5}$$

Consequently

$$P_r(\text{censored}) = P_r(y_i^* \le \tau) = \Phi(\tau - \mu|\sigma) \tag{6}$$

and

$$P_r(\text{uncensored}) = 1 - \Phi(\tau - \mu|\sigma) = \Phi\Big((\mu - \tau)|\sigma\Big) \tag{7}$$

Finally, the expected value of censored variable is written as

$$\begin{aligned}E(y) = &\Big\{\Phi\Big((\tau-\mu)|\sigma\Big)\Big[\mu + \sigma\lambda\Big((\mu-\tau)|\sigma\Big)\Big]\Big\} \\ &+ \Phi\Big((\tau-\mu)|\sigma\Big)\tau_y\end{aligned} \tag{8}$$

where

Φ = function of $\Big((\mu - \tau)|\sigma\Big)$,
μ = mean of latent dependent variable,
σ = standard deviation of the latent variable, and
λ = the inverse mill ratio, obtained as the ratio of the identities in normal distribution function.

While this model is fundamentally sound and addresses censoring, it is estimated based on maximum likelihood, which requires a large sample. Estimates might be biased when sample size is small, and observations are obtained from a finite population as in the case of this study, while OLS models avoid this pitfall for the reason that they are based upon finite sample properties (Greene 2008). Therefore, the data set was analyzed with both regression models.

Construction of variables

We grouped explanatory variables influencing availability of mill residue for sale in three categories. The first category of independent variables measure mill characteristics and include PRI, BETTER, EMPLOYEE, ORG, and SEASON. PRI is a descriptive measure of the respondent's wood

Table 1.—Description of the variables used to determine availability of unused mill residues in Mississippi in 2011 based on a mail survey of wood processing facilities.

Variables	Description	Mean	SD[a]
WOODRESIDUE	Amount of wood residue, measured in tons, that was sold, given away, or disposed by respondent mill in logarithmic scale	4.30	2.83
PRI	Type of respondent mill; 1 if primary, 0 otherwise	0.55	
BETTER	Technical capability of mill; 1 if better than nearby mills, 0 otherwise	0.37	
EMPLOYEE	Number of employees in a mill	108	264.4
PRICERES	Mill residue price in logarithmic scale	1.23	1.51
ULIVEN	Per acre number of livestock in logarithmic scale	0.40	0.23
ELECP	Price of electricity within respondent county	5.61	0.79
SEASON	Season in which forest products industry was fully operational for 8-hour shift; 1 if all seasons, 0 otherwise	0.94	
WORK	Mill interest in working with others to determine better ways to utilize wood residues; 1 if interested, 0 otherwise	0.81	
ORG	Organization structure; 1 if sole ownership or partnership, 0 otherwise	0.17	
EDU1	Highest level of respondent education; 1 if high school degree, 0 otherwise	0.29	
EDU2	Highest level of respondent education; 1 if bachelor degree, 0 otherwise	0.51	
EDU3	Highest level of respondent education; 1 if postgraduate degree, 0 otherwise	0.21	

[a] Standard deviation (SD) is only reported for quantitative variables.

processing facility. It was assigned as 1 for a respondent having a primary wood processing facility, which included the forest products such as hardwood lumber, softwood lumber, hardwood dimensional parts, softwood dimensional parts, hardwood plywood, softwood plywood, hardwood logs, particleboard, medium-density fiberboard, hardboard, oriented strandboard, and wood veener, and 0 otherwise. As the name implies, since these facilities use the primary forest products directly obtained from the forest as a raw material, it is likely that the amount of wood residue generated in such facilities will be higher than other secondary wood processing facilities. Therefore, the sign of PRI was expected to be positive.

Mississippi mills were asked to rate their wood processing facilities in terms of technological capabilities when compared with other nearby primary and/or secondary wood processing facilities. A respondent rating of a facility (BETTER) was assigned as 1 if the facility, in the respondent's opinion, was better than other similar nearby facilities, and 0 otherwise. Since wood processing facilities using better technology would likely generate less waste, it was expected that this variable would be negatively related with the dependent variable. Another attribute of concern was firm size and its relationship with available volumes of woody residues in mills. Admittedly, because larger firms produce more output, actual forest products volumes would be the best measure of size for a wood processing facility. However, many respondents did not report forest products volumes, perhaps because of the propriety nature of this information. Therefore, following the approach used by Garrard and Leightley (2005) in their study, number of employees (EMPLOYEE) was used as a proxy to account for firm size. Because larger firms process larger volumes of woody materials than smaller firms in a specified timeframe, they are likely to generate more residues. Therefore, this variable was expected to have a positive association with wood residue availability. The attribute accounting for the organization structure (ORG) was also measured in a qualitative scale. It was assigned as 1 for the firms that were in sole ownership or in partnership and 0 for others. Without a priori expectation for definitive sign, this variable was retained in the model to see the variations, if any, in economic assessment of residue among different mill organization types. Finally, the attribute measuring a season in which the forest products firm was fully operational and using an 8-hour shift (SEASON) was qualitative in nature. It was assigned as 1 for the firms that were fully operated in all seasons and 0 otherwise. Since all-season–operated firms process larger volumes of wood in a year, there can be more unused residues available in such firms in comparison with facilities that only operate in a particular season. Therefore, this variable was expected to have a positive sign.

The second category of variables characterizes woody residue market opportunities. The variable PRICERES, which accounted for the price of mill residue, is quantitative in nature. Zero residue prices were assigned for the mills that did not involve any woody residue sale. Because higher price would motivate mills to sell residue, it was expected to have a positive sign. Another quantitative attribute considered in the econometric model was price of electricity (ELECP) in a respondent mill's county. Given that a higher price of electricity would lead mills to generate energy internally from residues, it was expected to have a negative sign. Finally, the number of livestock per unit area (ULIVEN) was also considered as an appropriate explanatory variable explaining mill residue market. Given that mill residues are commonly used for animal bedding, mills located in an area with a higher livestock density are likely to have more market opportunities compared with others. Therefore, this variable was expected to have a positive sign in the econometric model.

The third category of explanatory variables included respondents' education and attitude toward bioenergy opportunities. The respondent's highest level of education was a dummy variable with three levels: postgraduate, undergraduate, and high school or less. Because using all three dummy variables in a single regression model would create a specification error called a dummy variable trap, two dummy variables representing postgraduate and undergraduate degrees were only used, while high school or less served as the base (excluded) category. The respondent group having a high school education or less (EDU1) served as the base category in the econometric model. The educational category (EDU2) was assigned as 1 for the respondent who received an undergraduate degree and 0 otherwise. Similarly, EDU3 was assigned as 1 for the respondent who received a postgraduate degree and 0 otherwise. Despite the fact that education generally helps to enhance managerial skills, it was not certain as to whether there was a positive or negative association of this attribute on the dependent variable. Therefore, the sign of this variable could not be predicted. The attitudinal variable (WORK) expressed mill interest in working with other manufacturers to determine better ways to use wood residues for value-added products. This variable was assigned as 1 for respondents interested in collaborating and 0 for others who were not. Because availability of unused residues might have motivated mills to look for a better way to use by-products, this variable was also expected to have a positive sign.

Results

Descriptive statistics

In response to the mail survey to all wood products manufacturers listed in the Mississippi Development Authority's online searchable database with SIC Codes 24/25 and 26/27, we received 99 from 458 delivered mailings, which suggested an adjusted response rate of 21.6 percent. This adjusted response rate seemed low, but it was comparable with other mill owner surveys recently conducted in the United States (Hansen et al. 2006, Aguilar 2009, Carter 2010, G.C. and Potter-Witter 2011). Differences between early and late respondents were statistically insignificant. Similarly, there were no statistical differences between this study's respondents with available information on employees of Mississippi's forest products industry, suggesting that respondents were representative of forest products industries in Mississippi. Since non-respondents were reluctant to answer the survey instrument in spite of multiple requests, their absence in the survey would likely have a minimal impact on the validity of the findings. Curtin et al. (2000) found that the overall effects of non-respondent opinion, especially those who prefer not to answer after multiple attempts, were minimal.

On a monthly basis, approximately 208,493 dry tons of mill residues were produced in 99 responding firms in Mississippi (Table 2). The majority of these respondents (54%) had a primary wood processing facility, and in terms of volume, accounted for 92 percent of woody residues generated by all respondent wood processing facilities (Fig. 1). Of all the mill residues generated by respondent facilities, 30 percent were sold in Mississippi. About 40 percent of survey respondents were looking for better ways to use mill residues in the state. In terms of biomass utilization capacity of different firms, among those who responded, 79 percent of the wood processing facilities have used residues to burn for generating energy and 21 percent have either manufactured another product or used residues for finger jointing (Fig. 2).

Table 2.—Some quantitative information of mill residues in Mississippi based on the survey.

Total available volumes from mills per month (tons)	208,492
Total volume contribution by primary mills (%)	92
Total volume contribution by secondary or both mills (%)	8
Total percentage of internal use mill residues (%)	69
Total percentage of sold mill residues (%)	30
Total unused mill residues (%)	1
Major internal use	Burned for generating energy

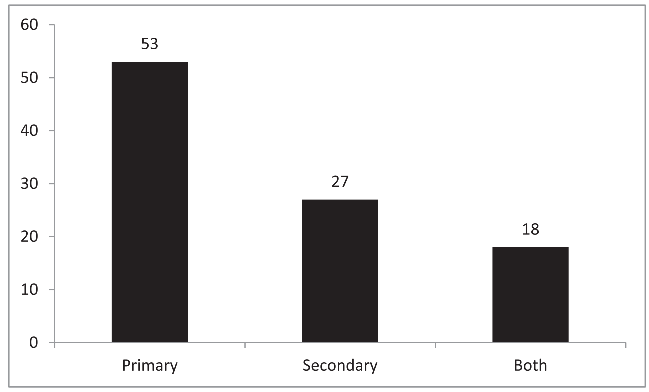

Figure 1.—Distribution of respondent mills based on the type of facility.

Econometric results

Diagnostic tests revealed that autocorrelation and multicollinearity were not significant. However, the data were not normally distributed, nor were the error terms homoscedastic. Model fit improved after a logarithmic transformation of the dependent variable and using White's heteroscedasticity consistent standard errors as proposed in the literature (Zar 2007, Greene 2008). Results based on the generalized least square regression model using White's heteroscedasticity consistent standard errors are reported in Table 3, and the results of the censored Tobit model are reported in Table 4. All coefficients obtained from the generalized least square model and the censored Tobit model had the same signs, suggesting that the results were robust to changes in modeling the data. Inasmuch as only a few mills reported zero available volumes of unused mill residues, OLS regression did not suffer from potential censoring bias. However, to avoid the pitfall of a low sample size for study results, findings based on a generalized least square (Table 3; Fig. 3) regression framework were used for the remainder of the analysis.

The global F test was significant at 5 percent, indicating that the model provided a good fit to the data. Among the variables included in the final model, five variables were significant at the 10 percent level. Specifically, the

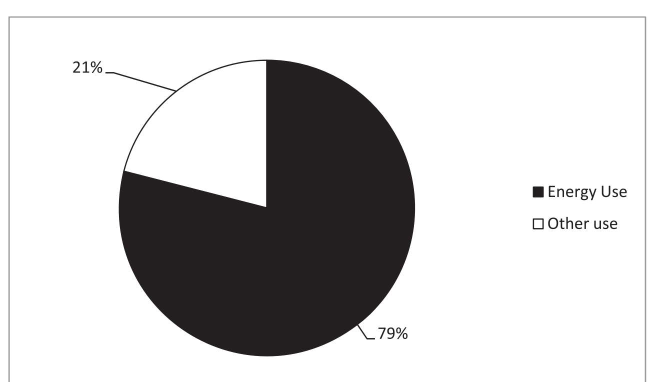

Figure 2.—Distribution of respondent mills in Mississippi in terms of internal biomass use.

Table 3.—Generalized least square regression model results to determine availability of the unused mill residues in Mississippi in 2011 based on a mail survey of wood processing facilities.[a]

Variable	Coefficient (SE)	t
PRI	0.838 (0.610)	1.37
BETTER	0.227 (0.524)	0.43
EMPLOYEE	5.9E−05 (5.15E−04)	0.11
ORG	0.241 (0.655)	0.37
SEASON	2.335* (1.213)	1.92
PRICERES	0.733*** (0.225)	3.25
ULIVEN	2.087* (1.187)	1.76
ELECP	−0.299 (0.392)	0.76
WORK	1.222* (0.612)	2.00
EDU2	−0.405 (0.694)	0.58
EDU3	−2.093** (0.780)	2.68
Intercept	1.343 (3.068)	0.47
Global F test	3.14 (0.0042)	

[a] $n = 50$. *** = significant at the 1 percent level; ** = significant at the 5 percent level; * = significant at the 10 percent level.

Table 4.—Results based on censored Tobit regression model to determine availability of unused mill residues in Mississippi in 2011 based on a mail survey of wood processing facilities.[a]

Variable	Coefficient (SE)	t
PRI	0. 739 (0.621)	1.19
BETTER	0.204 (0.629)	0.32
EMPLOYEE	8.9E−05 (8.9E−03)	0.01
ORG	0.401 (1.075)	0.37
SEASON	2.232* (1.188)	1.88
PRICERES	0.764*** (0.218)	3.50
ULIVEN	2.131 (1.326)	1.61
ELECP	−0.306 (0.402)	0.76
WORK	1.351 (0.952)	1.42
EDU2	−0.418 (0.746)	0.56
EDU3	−2.146** (0.892)	2.40
Intercept	1.349 (2.771)	0.49
Log likelihood	−110.802	

[a] $n = 50$. *** = significant at the 1 percent level; ** = significant at the 5 percent level; * = significant at the 10 percent level.

coefficient of the variable SEASON, characterizing mill characteristics, had a positive and significant impact on availability of wood residue at the 10 percent level. Note that since the generalized least square model was set up as a semi logarithmic regression, dummy variables were interpreted following Halvorsen and Palmquist (1980).[1] For instance, available median volumes of mill residues in year-round mills will be 10.3 times more than a seasonal mill. However, the coefficient of the statistically significant variable PRICERES, which was converted into a logarithmic scale, provides the direct measurement of elasticity (Greene 2008). This result indicated that a 1 percent increase in residue price would increase the availability of mill residue by 0.73 percent. Among other variables characterizing woody residue market opportunities, ULIVEN was positive and significant at the 10 percent

[1] Halvorsen and Palmquist (1980) suggested that an antilog of an estimated dummy coefficient should be multiplied by 100 after subtracting 1.

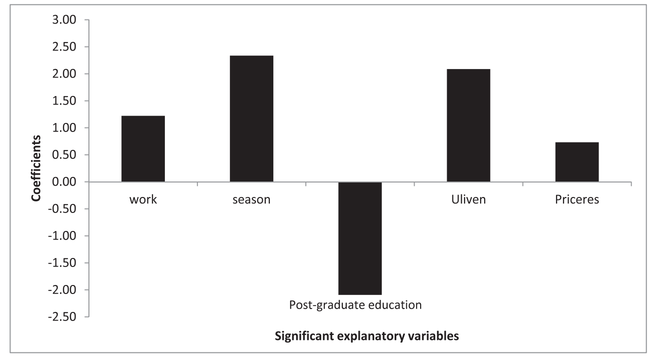

Figure 3.—Representation of coefficients for significant explanatory variables.

level, and WORK was positive and significant at the 10 percent level. Finally, the variable measuring a respondent's highest level of education as postgraduate degree (EDU3) was negative and significant at the 5 percent level.

Discussion and Conclusions

The findings of this study provide important insights about the role of various factors in the decisions of wood processing mills to use residues internally, sell them, or simply give them away. Consistent with a priori expectations, variables representing processing technology, quantity of production, and the market demand had the expected signs but differed in their impact on the availability of mill residues in Mississippi. For example, descriptive statistics indicated that most mill residues were obtained from primary wood processing facilities. This result was consistent with the findings by Alderman (1998), who reported that 80 percent of total wood residues in the commonwealth of Virginia were produced in primary wood processing facilities, and with Walsh (2008), who reported higher availablity of unused mill residues in primary wood processing firms than others. However, the statistical insignifance of this variable, along with the variable representing employee numbers, indicated that greater production of residues does not necessarily ensure higher chances of having unused mill residues. Perhaps the larger quantity might provide enough feedstock to justify the plant modifications needed to use it internally. Clearly, these are important insights to think upon while considering mill residues as a potential source of bioenergy in the United States.

One significant determinant of available woody residues was year-round versus seasonal operation of a wood processing facility. This indicated that year-round operational mills are a more reliable source of feedstock than seasonal mills. These results, however, need a cautious interpretation for the reason that most respondents had year-round operational mills (Table 1). Therefore, seasonality will severely impact the smaller number of mills in Mississippi. While this is good news for investors interested in bioenergy in Mississippi, supplies of forest products are generally significantly influenced by weather conditions (Georgia Timber Report 2005). Therefore, production curtailments, given weather-related causes, are possible in these facilities. Moreover, Vila et al. (2006) noted that strategies such as a modification in production technology or the temporary shutdown of production, to account for the impact of potential market fluctuations in the supply chain network, are common in the forest products industry.

Availability of unused residues was positively associated with its price and market. This is understandable because mills having a demand for woody residue (e.g., livestock bedding) near their facilities are likely to have more options for using it in their best interests. Economic rationality dictates that mills having a nearby market for woody residues will not use them internally for energy generation unless the marginal benefits of doing so outweigh the forgone opportunities. However, mills not having a nearby woody residue market would not have such flexibility. In other words, these owners have limited options for reusing by-products in their own facilities or giving them away. It is important to note that lower than unit elasticity (0.73) suggests that mill residues—a typical wood by-product—is generally inelastic to price in Mississippi. As described by Nepal et al. (2013), many studies in the US south indicated that timber products were inelastic to price and were even below 0.5 for softwood and hardwood products. Interestingly, our findings suggest that mill residues are relatively more price sensitive compared with conventional product types such as softwood and hardwood sawlogs. Likewise, price of electricity was negative but insignificantly associated with the availability of unused mill residue. Because current electricity prices in Mississippi are lower than the national average (Energy Information Administration 2012), and there is not much variation in price of electricity within the state, the insignificant role that electric power costs play in the availability of unused mill residue is not surprising. There was a direct and statistically significant relationship between the likelihood of mill interest to work with other forest products industries for better use of woody residues and amounts of wood residues potentially available for other uses. Perhaps these mills are looking for new economic opportunities to use by-products generated in their facility. The availability of unused woody residues might have prompted mills to explore these opportunities.

In addition to mill characteristics and market condition, managers' education and skills could be important. The results of this study indicated that respondents having a postgraduate education were more effective in using mill residues obtained from their facilities than otherwise similar wood products firms. A possible explanation is that managerial skills obtained through a postgraduate education might have helped such respondents to efficiently use woody residues obtained from their facility. It is worth noting that we requested that the person with the best information on mill residues and product market and with a vision for the future collaboration plan of the mill fill out the survey. While unlikely, it is possible that the survey respondent might not be a sole decision maker for the mill. Therefore, the influence of the education attribute on availability of mill residue needs to be interpreted accordingly.

Overall, these results indicate that mill residues that can be used to develop wood-based bioenergy are available in Mississippi. Availability of mill residue for bioenergy use largely depends upon its market price and demand. This is evident from the fact that most mill residues were either internally used or sold in Mississippi. Therefore, potential bioenergy firms need to pay competitive prices to use them as feedstock. This suggests that decisions on locating new bioenergy facilities should consider other sets of potential feedstocks such as logging residues, thinning residues, and mill waste. Of note, Aguilar (2009) reported that some wood processing facilities, such as sawmills, prefer to be located near raw materials rather than final markets. Hagadone and Grala (2012) also noted similar findings in Mississippi. Thus, wood-based bioenergy facilities, if located near sawmills, can use both mill and logging residues obtained during timber harvesting at a relatively lower price. Similarly, the likelihood of obtaining bioenergy feedstocks is greater if wood-based bioenergy could be located near a year-round operational forest products firm.

The findings of this study indicate that mill owners in Mississippi are interested in supplying wood-based bioenergy feedstock, if competitive feedstock prices could be offered to them. But the findings need to be cautiously interpreted, keeping bioenergy markets in mind. As descriptive statistics revealed, most volumes were internally used for energy production. Owing to inadequate observations, we could not account for this issue in the econometric model. Of importance, mills without the capability to reuse residues on site would have a higher proportion available for others to use. Seasonal variations of the production activity within the forest products industry are not uncommon, and the bioenergy industry might suffer from it, and while the available amount of woody residues is greater in mills located in a nearby market, there might be competition among buyers to purchase woody residues from such facilities. Therefore, an appropriate location of a wood-based bioenergy industry should be an important consideration to ensure low cost and sustainable wood-based bioenergy production. Moreover, given the existing competition in forest products markets in Mississippi, integrating existing facilities with wood-based bioenergy operations might be a better option than starting a stand-alone bioenergy facility.

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