ESTIMATING SUPPLY CURVES FOR GREEN RESIDUALS FROM PRIMARY FOREST PRODUCT MILLS

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ABSTRACT

The forest products industry is in a favorable position to utilize mill residuals as an alternative fuel source. This study was designed to estimate the volume and price of available residuals and to develop statewide residual supply curves for Arkansas. The study sample was drawn from 163 different mills. Data included the total volume of residuals produced by type and species group; where the residuals were used; sale price; buyer type; and, end use of residuals sold. Four types of residuals were considered: hardwood and softwood barky residuals and bark; and hardwood and softwood woody residuals.

Volume of residuals produced did not vary significantly by mill size or type. The supply schedules for both hardwood and softwood barky residuals showed a well-defined kink at upper price levels. For barky residues, no pulp/paper mills were present at the highest price levels. All supply curves were inherently inelastic. Supply curves showed substantially more hardwood than softwood residuals available at every price level. The supply curves for softwood residuals displayed steeper slopes than hardwoods. The kinked supply curves for softwood and hardwood barky residuals indicate both were selling into two different markets. Sales in the upper segment of the hardwood barky supply curve (above the kink) were to bark mulch plants, agricultural users, and a charcoal producer. Sales in the upper segment of the softwood barky supply curve were to poultry producers, for use as litter, and to other agricultural users. Purchasers showed a marked preference for barky over woody residuals, and hardwood over softwood. Managers preferred barky residuals for lower moisture content and ease of handling; they preferred hardwood residuals for lower price and better availability. Residuals were price-ordered in terms of their utility in other markets as well as for their value as fuel.

Residual production is a fixed-proportion joint-production function. A problem associated with this type function is assignment of production costs to different products. Operators concentrated on production of their traditional products rather than maximizing returns from residual sales. In the absence of a definitive costing structure, residual prices were driven by what buyers were willing to pay for them. This applies primarily to the lower segments of the demand curves for hardwood and softwood barky residuals, and for hardwood woody residuals.

INTRODUCTION

The forest products industry leads most other sectors of U.S. industry in energy self-sufficiency. Pulp and paper mills, for example, currently are about 80 percent energy self-sufficient (Delaski 1984). This condition can be attributed in large part to the 1974 oil embargo and subsequent oil price shocks since that time. With each price spike U.S. energy dependency has been accentuated. As early as 1974 forest industry firms began using increased volumes of wood for fuel. Because of their close association with timber through every stage of production, harvesting, and processing, these firms were in a favorable position to utilize wood as an alternative fuel source.

Government and industry-sponsored research in the late 1970s concentrated on use of woody biomass from harvest residues and energy plantations as prospective fuel sources. Biomass sources have continued to attract the attention of researchers and financial analysts (e.g., Stuart et al. 1981, Cushman

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Data Collection and Analysis

The study sample was drawn from 438 sawmills, pallet mills, post/pole plants, panel mills, pulp/paper mills, chip mills, and miscellaneous primary mills listed in the Arkansas Forest Industry Directory (Easterling 1987). The mills were stratified by type and size class. All mills in the large size class (productive capacity ≥ 5 MMBF equivalent per year) were contacted for the study. Nearly all the managers of large mills agreed to an interview, but those refused could not be replaced. The number of small mills (productive capacity < 5 MMBF equivalent per year) sampled was calculated to yield ± 5 percent precision in the estimate of total residuals produced (Mendenhall et al. 1971). The specific mills contacted were selected at random. Any small mill where an interview was refused was replaced with another of the same type from a prepared list of alternates.

Altogether, interviews were completed with the managers of 163 mills. The information collected included the total volume of residuals produced at the mill, by type and species group; whether the residuals were used on-site, sold, or discarded; the sale price or value (FOB the mill) assigned to them; and the buyer type and end use of residuals sold. Residuals used on-site were considered removed from the market and were removed from the analysis. Discarded residuals were considered available at $0 per ton.

Green residuals were combined into four types: hardwood and softwood barky residuals, consisting of bark/sawdust mix, sawdust, and bark; and hardwood and softwood woody residuals, consisting of fuel chips, slabs, shavings, and chunkwood. All residuals were assumed to be green, at or near 50 percent moisture content on a wet weight basis. Many of the mills surveyed also produced dry residuals, but there were too few observations to provide reliable statistics. For this reason, only the findings for green residuals are reported here.

Analysis of co-variance was used to test the data for differences by mill size and type, and buyer type, at the α = 0.05 level of significance. Tests were run both on volume of residuals produced, with price as the covariate, and on price per ton, with volume produced as the covariate (Norusis 1989).

Although they ordinarily are classified as secondary mills, pallet mills that used sawlogs or green lumber as raw material were included in the sample because they resemble sawmills in the volumes and types of residuals they produce.
Following data analysis, the residual volume figures for each type and size of mill were converted to statewide estimates by multiplying them times an expansion factor equal to the number of similar mills listed in the Directory (Easterling 1987) divided by the number of mills sampled. Since nearly all large mills listed were sampled, their expansion factors were approximately one. The expansion factors for small mills ranged from to 2.25 for post/pole plants to 8.08 for combination sawmills.

Next, the observations were sorted in ascending order of sale price in a Quattro spreadsheet (Borland 1991). Cumulative supply schedules, showing the volume of each residual type available at or below given price levels were calculated, using the method described by Gregory (1987). Best-fit supply curves were fit to these expanded supply schedules by regression analysis, using Systat (Wilkerson 1990). Several functional forms were attempted for each supply curve, including linear, power, logarithmic, and polynomial. Visual analysis was done using Sygraph, the graphing module of Systat (Wilkerson 1990).

Arc-elasticity values were calculated for each observation along the supply curves (Samuelson 1970). The energy replacement value of residuals was calculated for natural gas, the principal energy source of many large wood-burning facilities in the Arkansas, using the method described by Kluender (1980). This value was used as the starting point in developing a derived demand curve for residuals.

RESULTS

Statistical Analysis

Volume of residuals produced did not vary significantly by mill size or type, for any of the residual types. Neither did it vary by buyer type for hardwood barky, softwood barky, or softwood woody residuals. A difference was found for hardwood woody residuals. Inspection of the hardwood woody supply schedule with buyer type identified showed that buyers were mixed at all price levels except the highest, where no pulp/paper mills were present. No significant variation was found in the covariate, price.

Price per ton did not vary significantly by any of the test parameters for hardwood or softwood woody residuals. The price of hardwood barky residuals, however, was found to vary by mill type, mill size, and buyer type; and the price for softwood barky residuals by mill and buyer type. The market conditions that led to these variations are discussed below. No significant variation was found in the covariate, volume produced.

Residual Supply Curves

Table 1 presents the best-fit supply equations for all four residual types: hardwood barky, softwood barky, hardwood woody, and softwood woody. In each case, simple linear models provided the best fit with the study data. The supply curves for hardwood and softwood barky residuals are graphed against the expanded observations in Figure 1; those for hardwood and softwood woody residuals are similarly displayed in Figure 2.

The supply schedules for both hardwood and softwood barky residuals showed a well-defined kink at their upper price levels. Each required separate equations to adequately model both segments (Table 1, Figure 1). In contrast, the schedules for hardwood and softwood woody residuals both fit a single equation through their entire range (Table 1, Figure 2).

With negative Y-intercepts, the supply curves for all four residual types were inherently inelastic. The calculated arc-elasticities for hardwood and softwood barky residuals increased—became less inelastic—with increasing price until reaching the kink. At that point, both supply curves became near-perfectly inelastic (Table 1). Hardwood residuals were the less price-responsive of the two products, with arc-elasticity values ranging from 0.07 near the origin to 0.84 just below the kink. The equivalent values for softwood barky residuals ranged from 0.30 to 0.80 (Table 1).
The arc-elasticities for hardwood and softwood woody residuals increased uniformly with price over their entire supply curves. As above, hardwood residuals were the less price-responsive of the products, ranging from extremely inelastic (0.08) near the origin to slightly inelastic (0.70) at the upper end of the supply curve. Softwood woody residuals varied from moderately inelastic (0.49) near the origin to near-unitary elasticity (0.98) at the upper end of the curve.

Energy Replacement Value

The delivered price for natural gas in Arkansas currently is $1.51 per thousand cubic feet (MCF), plus a $0.96 per MCF delivery fee. Given our assumption of 50 percent moisture content (wet weight), and taking into account latent heat and combustion efficiency, one ton of green wood contains the energy equivalent of 7.38 MCF of natural gas (Kluender 1980), making its energy replacement value:

\[ 7.38 \text{ MCF per ton} \times 2.47 \text{ per MCF} = 18.23 \text{ per ton}. \]

Buyer mills deduct transportation and on-site handling costs from energy replacement value to determine the amount they can afford to pay for residuals. For this study, transportation costs were calculated using the method described by Koger (1981), updated to the present. Handling costs were assumed to be $1.00 per ton.

DISCUSSION

Although forest industry in Arkansas is predominantly softwood-based, the supply curves showed substantially more hardwood than softwood residuals available at every price level (Figures 1 and 2). In part, this can be attributed to closer utilization standards for pine timber, owing to its higher value and better form. More important, however, is the finding that a much larger portion of softwood residuals--62 percent as opposed to 10 percent for hardwood--was used on-site by the mills that produced it and did not enter the market.

The supply curves for softwood residuals sloped more steeply than those for hardwoods (Figures 1 and 2), indicating the species groups were not perfectly substitutable or served slightly different markets. because they contain resin, softwoods do produce slightly more heat per unit of weight than hardwoods--9,000 versus 8,500 BTU per pound dry weight--increasing their value as fuel. But in addition, survey interviews indicated that a substantial fraction of softwood residuals was purchased for remanufacture as pulp chips and particleboard or fiberboard furnish rather than fuel. It is reasonable to infer that competition from these higher-value uses bid up the prices for softwood residuals in general (Table 1, Figures 1 and 2).

Residual Supply

The strongly kinked supply curves for softwood and hardwood barky residuals suggest that both products were selling into two different markets (Figure 1). The study data support this interpretation. Sales in the lower segments of both curves were primarily to forest product mills, for use as fuel. But as price approached the $18.23 energy replacement value, other types of buyers entered the market. Sales in the upper segment of the hardwood barky supply curve were to bark mulch plants, agricultural users, and a charcoal producer. Sales in the upper segment of the softwood barky supply curve were to poultry producers, for use as litter, and to other agricultural users. Clearly, buyers in the upper segment of both supply curves were not for fuel, but as an input to other production processes.

The shapes and ranges of the hardwood and softwood woody residual supply curves were consistent with the hypothesis that the primary use of these residuals is for fuel. With the exception of four observations, all hardwood woody residuals were sold at prices below the $18.23 per ton energy replacement value. The data show that all four exceptions represented small sales to local homeowners, for use as firewood.
Only two sales of softwood woody residuals exceeded the energy replacement value. Both exceptions came within a few cents of the value and may represent marginal purchases of material used for fuel (see below). The data show, however, that the outlying buyers were a pulp/paper mill and a fiberboard plant. This raises the possibility that the residuals were purchased for remanufacture into mill furnish, not fuel. Note that without these observations the softwood woody supply curve would have been substantially steeper and more inelastic.

Residual Market Characteristics

The managers of mills that bought residuals were aware of and responded to the characteristics of residual markets described above. In survey interviews, they showed a marked preference for barky over woody residuals, and for hardwood over softwood. The managers preferred barky residuals for their lower moisture content and ease of handling; they preferred hardwood residuals for their lower price and better availability. Recall that softwood—particularly softwood woody—residuals often were purchased for remanufacture into mill furnish. Demand for this use would be greatest when markets for paper or panel products were good and mills eased their quality restrictions. Residuals thus are price-ordered in terms of their utility in other markets as well as for their value as fuel.

Inspection of the slope coefficients further confirms the ordering of unit costs and marginal costs of residuals. The coefficients for the first segments of the hardwood and softwood barky supply curves and the hardwood woody curve are nearly coincide (Table 1). Slope increases by only 0.014 - 0.019 = 0.005 moving from hardwood barky to softwood barky residuals and by 0.019 - 0.025 = 0.006 moving from softwood barky to hardwood woody residuals. But it increases by 0.025 - 0.047 = 0.022 moving from hardwood woody to softwood woody residuals (Table 1). From these findings it appears clear that the principal demand for wood fuel is met from the first three types of residuals, with softwood woody comprising the final, marginal purchases.

From their many conversations with mill operators, study interviewers collected information and impressions about residual markets beyond the numerical data. Here we address some of the more subjective findings on manager attitudes, markets for specialty products, and the effect of transportation cost on residual sales.

Most mill managers considered the time they spent on residual sales as taken from their primary business. Many expressed a desire for an affordable EPA-approved residual burner. A number of managers, however, marketed their residuals aggressively. Some had installed chippers or hogs to convert their solid residuals to higher-value chips or hogged fuel. Others offered their mills as concentration centers for residuals from all mills in their areas and were prepared invest in the equipment necessary to separate and convert the residuals into more marketable form.

The best-established specialty market for residuals was for poultry litter. Broiler and turkey production are major industries in Arkansas, with most producers located in the northern and eastern parts of the state. Producers typically replace the litter in production houses twice annually, in the spring and the fall. At these times, supplies of wood residuals drop dramatically, since poultry producers offer much higher prices than other residual buyers. Other buyers prepare for the shortage by stockpiling residuals.

The market appeared to be developing for sale of solid residuals—slabs, edgings, trimmings, and chunk wood— as firewood to local homeowners. Small sawmills, pallet mills, and miscellaneous mills were most active in this market, which had expanded rapidly since the mid-1980s (Greene 1987). A lucrative market also had developed for bark residuals. Sales were to nurseries and bark plants—hardwood bark for mulch and potting medium, and pine bark for mulch. This market was most active in east central Arkansas, near Memphis.

Most mill managers cited transportation cost as the limiting factor in residual sales. Current prices were too low to make sales economically feasible for mills located some distance from major residual buyers. In their comments, the managers of these mills credited buyers with extreme precision in calculating their procurement circles, saying they offered prices just high enough to bring in the volume of residuals they required.
Derived Demand Analysis

Buyers of green residuals use a process similar to if less formal than that used in this study to develop local supply curves, upon which they superimpose their mill demand curves. A mill's derived demand curve is a schedule of the maximum prices it can pay, on average, for residuals from supplier mills at varying distances. Maximum price can be calculated by subtracting transportation and on-site handling costs for the residuals from the $18.23 per ton energy replacement value:

$$\text{Maximum price} = 18.23 - \text{Transportation cost} - \text{Handling cost}.$$

Transportation cost per ton can be estimated using Koger's (1981) equation, updated to the present:

$$\text{Transportation cost} = 0.84 + (0.059 \times \text{Distance}).$$

Handling cost is estimated at $1 per ton. The equation for maximum price then becomes:

$$\text{Maximum price} = 18.23 - [0.84 + (0.059 \times \text{Distance})] - 1.00$$

$$= 16.39 - (0.059 \times \text{Distance}).$$

And the furthest a mill can go for residuals if it always pays the maximum price is:

$$\text{Maximum distance} = \frac{16.39}{0.059} = 278 \text{ miles}$$

provided it can obtain residuals at $0 cost at the extreme distances.

As an example, say a mill located in central Arkansas requires 150 thousand tons each of hardwood and softwood barky residuals to fuel its boilers. To cover the entire state, the mill would face a maximum hauling distance of about 150 miles. If the mill pays the maximum price for all residuals it obtains at shorter distances, the most it can afford to pay at this distance is:

$$\text{Maximum price} = 16.39 - (0.059 \times 150)$$

$$= 7.54 \text{ per ton}.$$

As a practical matter, however, the mill can pay whatever price the market dictates as long as it maintains an average price no higher than the maximum for a circle with half the area of the full procurement circle hauling distance, or 106 miles:

$$\text{Maximum average price} = 16.39 - (0.059 \times 106)$$

$$= 10.14 \text{ per ton}.$$

At this price level, the mill would have access to some 886 thousand tons per year of hardwood woody residuals:

$$P = -2.275 + 0.014Q$$

$$Q = 71.4P + 162.5$$

$$= (71.4 \times 10.14) + 162.5$$

$$= 886.5 \text{ thousand tons}$$

and 659 thousand tons per year of softwood woody residuals:

$$P = -2.382 + 0.019Q$$

(Table 1a)
\[ Q = 52.6P + 125.4 \]
\[ = (52.6 \times 10.14) + 125.4 \]
\[ = 658.8 \text{ thousand tons}. \]

In both cases, the estimated available supply far exceeds the mill's requirement.

If it desired access to equal amounts of the two types, the mill could offer a somewhat lower price for hardwood woody residuals:

\[ P = -2.275 + 0.014Q \]
\[ = -2.275 + (0.014 \times 772.5) \]
\[ = $8.54 \text{ per ton} \] (Table 1a)

and a premium for softwood woody:

\[ P = -2.382 + 0.019Q \]
\[ = -2.382 + (0.019 \times 772.5) \]
\[ = $12.30 \text{ per ton} \] (Table 1b)

The price differential is proportional to the difference in the slopes of the two residual supply curves, adjusted for their slightly different Y-intercepts.

**CONCLUSIONS**

Abundant supplies of all four residual types were available at prices well below the energy replacement value. The supply curves for all products remained inelastic over their entire range, indicating that residual supply did not expand or contract proportionately with shifts in price. An estimated 3.0 million tons of residuals were available at the energy replacement value of $18.23 per ton; 2.9 million tons per year remained available at $15 per ton, 2.4 million tons at $10 per ton, and 1.5 million tons at $5 per ton. That no statistical difference was found in price per ton by volume produced, mill size or type, or buyer type indicates that the market is well integrated.

Wood fuel demand was supplied first from hardwood barky, softwood barky, and hardwood woody residuals. Softwood woody residuals were the least favored fuel source because of their higher price—attributable to their alternative uses—and the problems of handling a product in non-fluid form.

Residual production is an example of a classical fixed-proportion joint production function. The problem associated with this type function is assignment of production costs to the different products. The operators of most mills concentrated on production of their traditional products rather than maximizing returns from residual sales. In the absence of a definitive costing structure, residual prices were driven by what buyers were willing to pay for them. This was notably the case in the lower segments of the demand curves for hardwood and softwood barky residuals, and for hardwood woody residuals.

Producers of softwood woody residuals also were price takers in most instances, but had the advantage of a weak but separate market for their product as raw material for paper and panel production. Only in the upper segments of the supply curves for hardwood and softwood barky residuals did producers actively participate in setting prices for their product. Enterprising mill operators identified high-value markets for residuals as poultry litter and mulch products, and made the investment in equipment and promotion to meet those markets.

As a closing caveat, it seems likely the curves presented here will be particularly short-term in nature. While markets for residuals as fuel are well advanced in other states, they are just becoming established in Arkansas. As the markets mature, price expectations should rise rapidly, particularly among those mills that presently place quite low values on their residuals.


Patterson, D. W., and S. M. Brock. 1986. Electricity usage and residues production at West Virginia sawmills. West Virginia Forestry Notes, Circular 138. West Virginia University, Agricultural Experiment Station, Morgantown, W.V. Pages 1-3.


Table 1. Empirical supply equations for green residuals from primary forest product mills in Arkansas.

<table>
<thead>
<tr>
<th>Residual Type</th>
<th>Best-Fit Supply Equation*</th>
<th>Adjusted R²</th>
<th>Applicable Range</th>
<th>Elasticity Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Hardwood Barky</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment 1</td>
<td>( P = -2.275 + 0.014Q )</td>
<td>0.977</td>
<td>0 to 989</td>
<td>0.069 to 0.835</td>
</tr>
<tr>
<td>Segment 2</td>
<td>( P = -1.551.581 + 1.570Q )</td>
<td>0.775</td>
<td>990 to 1,020</td>
<td>0.002 to 0.030</td>
</tr>
<tr>
<td>b. Softwood Barky</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment 1</td>
<td>( P = -2.382 + 0.019Q )</td>
<td>0.936</td>
<td>0 to 664</td>
<td>0.296 to 0.804</td>
</tr>
<tr>
<td>Segment 2</td>
<td>( P = -2.079.834 + 3.124Q )</td>
<td>0.834</td>
<td>665 to 680</td>
<td>0.068 to 0.011</td>
</tr>
<tr>
<td>c. Hardwood Woody</td>
<td>( P = -7.411 + 0.025Q )</td>
<td>0.873</td>
<td>0 to 1,000</td>
<td>0.076 to 0.689</td>
</tr>
<tr>
<td>d. Softwood Woody</td>
<td>( P = -0.294 + 0.047Q )</td>
<td>0.854</td>
<td>0 to 450</td>
<td>0.491 to 0.985</td>
</tr>
</tbody>
</table>

* P = Price, in dollars per ton; Q = Quantity sold, in thousands of tons per year.
Figure 1. Hardwood and softwood barky (bark and sawdust) supply curves for mill residuals in Arkansas.
Figure 2. Hardwood and softwood woody (chunks and wood pieces) supply curves for mill residuals in Arkansas.