MARKET DEFINITION FOR HARDWOOD TIMBER IN THE SOUTHERN APPALACHIANS

by
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Abstract

Direct estimation of aggregate hardwood supply is seriously complicated by the diversity of prices, species, and site conditions in hardwood stands. An alternative approach is to aggregate regional supply based on stumpage values of individual stands, arguably the real driver of harvest decisions. Complicating this approach is that species-specific prices are only available for logs delivered to the mill. To derive stumpage values, delivered prices must be reduced by the costs of harvesting and transport to the mill; hence, the spatial characteristics of the market may be important in defining the aggregate timber supply responsiveness to price. This paper represents an intermediate step in estimating an aggregate supply model for hardwood timber, where we tested the more limited hypothesis that harvest probability and hence stand age is positively related to timber value and negatively related to factors which reduce timber value. We regressed stand age on distances to three types of mills, slope of site, distance from the stand to the nearest road, site quality, and broad management type. We found that stand age increases with distance from mills for NIPF-, industry-, and government-managed stands in the Southern Appalachians. Stand age is negatively related to site quality, positively related to slope of stand, and not significantly affected by distance from the stand to the nearest road. Stand ages also vary by broad management type.

INTRODUCTION

Theory suggests that both price and the amount of inventory would influence the supply of hardwood timber, but generating aggregate estimates of such responses which are both statistically significant and theoretically consistent has remained an elusive goal of forest economics. One complication in hardwood supply model estimation is identifying stand value, which is dependent on prices and on an aggregation across a mix of species, quality, and space. Prices of individual species are available at the mill, but translating these delivered prices into stumpage values, the real driver of harvest decisions, requires adjusting for costs of harvesting and transport to the mill. Our objective in this paper is to estimate the influence of cost factors on expected stand age in mixed hardwood and softwood stands of the Southern Appalachians. This research is an initial step in the eventual development of a detailed hardwood timber supply model.

METHODS

A correctly-specified harvest choice model–i.e., a Faustmann (1849) model or some stochastic variant—makes the harvest timing decision a function of net timber value, opportunity costs, and management costs, excluding for this paper any nontimber objectives. Harvest occurs at the age when discounted net value of timber is maximized. The familiar first order condition of the Faustmann model identifies the age at which stands should be cut. This time, T, corresponds with the stand age where the change in the net value of timber, V_T, equals the costs of holding the timber and renting the land another period (year):

$$V_T = rV(T) + rS \tag{1}$$

where the land rent is r (the discount rate or alternative rate of return) times S (the land value), and the carrying cost of timber capital is r times $V(T)$ (the net timber value). Standing timber value in any period t is determined by:

$$V(t) = \mathbf{p}'\mathbf{q}_t(\mathbf{z}) - c(\mathbf{q}_t, \mathbf{d}, \mathbf{z}) \tag{2}$$

where **q** is a vector of timber volumes by species and quality, **p** are corresponding delivered log prices, and c(•) is a timber harvest and transport cost function that is dependent on timber

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volumes, distances to mills of various types (**d**), and site characteristics (**z**) of the stand.

There may be stands for which the change in timber value is always less than capital costs: $V_t < rV(t)+rS$ for all $t>0$. If this is true, then the land will be dedicated to its highest-earning alternative use. In some places, the alternative land use may be as forest in an unmanaged state, in other places, land may be best employed in agriculture, residential, or commercial. For lands that are already forested, the forest is either managed for timber–i.e., equation (1) holds as an equality at some point in the life of a stand of trees–or it is not managed for timber. Given delivered prices, whether equation (1) holds as an equality must depend on the volumes of timber that can be produced on the site (**q**) and on the other factors that determine extraction and delivery costs. Logically, the higher the value of the timber, the greater the chance that land is dedicated to timber production and will experience a timber harvest. If we specify the cost function as:

$$c(\mathbf{q}_t, \mathbf{d}, \mathbf{z}) = c_0 + \mathbf{c}_1'\mathbf{q} + \mathbf{c}_2'\mathbf{d} + \mathbf{c}_3'\mathbf{z} \qquad (3)$$

where all parameters are nonnegative and **z** is a vector of cost-related factors. Combining equations (2) and (3), we have:

$$V(t) = \mathbf{p}'\mathbf{q}_t - (c_0 + \mathbf{c}_1'\mathbf{q} + \mathbf{c}_2'\mathbf{d} + \mathbf{c}_3'\mathbf{z}) \qquad (4)$$

Differentiating equation (4) with respect to each vector of variables, we find that net timber value is a negative function of distance to mill and cost factors. The effects of timber volumes of different species and classes is indeterminate, since volumes are positively related to value (**p'q**) and are part of the cost function ($\mathbf{c}_1'\mathbf{q}$).

A well-known result of the Faustmann (1849) model is that the higher the cost incurred at harvest, the later the optimal harvest date (see Hyde 1980). As long as there is a variable wood transport cost component (i.e., $\mathbf{c}_2>0$), then, other things being equal, stands far from mills should be cut less often than stands close to mills. Other kinds of extraction costs–those associated with steeper slopes and wet sites, for example–should have a similar influence on the harvest age and, at least for stands that are managed for timber, expected stand age. Accordingly, average or expected stand age may serve as an observable proxy for the propensity to harvest at a particular location.

Empirical Model

Stand age is likely related to several other variables besides the site factors previously mentioned. For example, harvest decisions are affected by the discount rate, and the discount rate may vary from owner to owner (Newman and Wear 1993). Further, preferences for nontimber values may differ among owners. If categories of owners with similar decision models can be identified, then these ownership groups should be recognized in an empirical model relating stand age to factors deriving from decision theory.

The products produced by the stand should also affect the optimal harvest decision. Pulpwood, sawtimber, and veneer-quality timber all have different markets. Hence, because harvested stands may contain materials suitable for pulpwood, lumber, and veneer, proximity to each of these kinds of mills may affect the optimal harvest age of a particular stand.

A properly specified model should also account for the influence of growth rate on harvest timing and on the potential of the site to produce saleable products. Slower growing stands, for example, have higher optimal harvest ages, so a model that recognizes site quality differences among stands would account for systematic differences in site qualities among owners, for example. Further, some species are more valuable than others. Because timber value per unit is generally related to broad management types (natural pine, plantation pine, oak-pine, upland hardwood, and bottomland hardwood), an accounting for these types must enter the stand age model.

Given these realities, the following empirical model was specified:

$$A_i = f(d_{saw}, d_{pulp}, d_{ply}, \mathbf{z}, \mathbf{b}, q) \qquad (5)$$

where A_i is stand age (years) for ownership group *i* (where *i* equals non-industrial-private, industry-managed, or government); d_{saw}, d_{pulp}, and d_{ply}, are distance to the nearest sawmill, pulpmill, and plywood-veneer mill (miles), respectively; **z** is a vector of harvest-cost variables (distance to nearest road in miles, slope in percent, and physiographic class–which measures the degree of wetness); **b** is a vector of five dummies representing broad management types (natural pine, plantation pine, oak-pine, upland hardwood, bottomland hardwood); and q is site quality (from 1=high productivity to 6=low productivity).

Many of the above factors could relate to age in nonlinear ways. For example, very close to a sawmill it may pay landowners to wait for stands to reach large sawtimber size since the returns to sawtimber management may be highest there. Farther away from a sawmill the mill's influence may disappear, meaning that the stand lies outside of the zone of profitable sustained management (though timber outside the zone could be cut). Further, slope may matter only for stands steeper than some threshold because the harvest technology used on gentle slopes and flat areas (skidders) is relatively cheaper than that used on steep slopes (cables). All of these possible nonlinearities, we believe, should be accounted for by a quadratic term (except for dummy variables), so our model is initially specified as such.

Data

We used data on 2,509 United States Forest Inventory and Analysis (FIA) permanent plots from the fifth and sixth FIA survey cycles for the southern Appalachians of North Carolina (1982, 1990) and Virginia (1984, 1992). Plot data include stand age or estimated stand age of the primary overstory (for stands with mixed ages), broad management type, slope, site quality, and latitude and longitude coordinates.

Mill information was obtained from FIA offices of the Southern and Northeast Research Stations, in Asheville, NC, and Radnor, PA, respectively for all mills the Southern and Northeastern US. Mill types were classified into five types: sawmill, pulp mill, plywood-veneer mill, composite board mill, and post-pole-piling mill. Software from Etak, Incorporated, was used to geocode mill mailing addresses, returning latitude and longitude for each mill based on street address and/or zipcode.

We created two GIS coverages projected to the same Albers equal-area. This projection causes map-projected land areas to be proportional to the true land area and directions to be true in limited areas. This projection is commonly used in the United States and other large countries with a larger east-west than north-south extent. The first GIS coverage was of FIA plots based on the rough latitude and longitude provided by FIA. The second was a coverage of mills based on the latitudes and longitudes from Etak. ArcView was used to calculate the straight-line distance from each FIA plot to the nearest mill of each mill type.

Logging trucks rarely take straight-line routes from stand to mill. To account for the effect of circuity of road networks on travel distance we estimated a quadratic relationship between straight-line and quickest road distance for the routes of interest. We took a stratified random sample of stand-to-nearest-mill pairs, five observations for each type of mill. We used Expedia Streets & Trips 2000 software (Microsoft Corp.) to calculate the road distance for the quickest route between each pair of points.

Road distance was then regressed on straight-line distance, straight-line distance squared, and an intercept, using ordinary least squares (OLS). Because the initial analysis the quadratic distance term was not significantly different from zero (p=0.05), in a second estimate the squared term was dropped. The intercept in the second estimate was not significantly different from zero at 5%, so a third estimate, in which the intercept was constrained to equal zero, was estimated. In this model road distance equals 1.45 times straight-line distance with an R^2 of 0.94. The 1.45 factor was applied to all straight-line distances to estimate road distances.

RESULTS

We pooled data from North Carolina and Virginia for analysis but ran separate regressions for the two survey cycles. Within each survey cycle, separate regressions were done for NIPF-owned and -managed stands ("NIPF"), industry-owned or industry-managed stands ("Industry"), and government-owned stands ("Government"). Results of full and parsimonious model estimates for each survey cycle and each ownership group are shown in tables 1 and 2.

Parsimonious forms were identified from the fully-specified forms by dropping variables with absolute t-values less than one. Dummy variables identify natural pine, planted pine, oak-pine, and upland hardwoods, with the bottomland hardwood type as the null case. Therefore, the coefficients on these dummies indicate years of departure from the expected age of the bottomland hardwood type, other variables held constant.

Results show that distance to nearest mill is significantly related to stand age, and this holds true for the three ownership groups and both survey cycles. F-tests (not reported here) that constrained the fully-specified (quadratic) separate ownership models to have zero coefficients on distance variables confirmed this, as well. Only for the case of industry-managed stands for Survey 6 did distance to at least one mill type (each tested separately) not significantly (p=0.10) explain variations in stand age. Taking the parsimonious equation estimates as valid, sawmill distance showed the strongest relationship with stand age in terms of the magnitude of the estimated coefficient. When evaluated at the mean road distance from sawmill to plot (about 10 miles), an additional mile adds 0.3 to 0.4 year for all owners. The exception to this was for industry in survey 6, where a mile added to the mean provides about one year.

Distance to nearest pulpmill and distance to nearest plywood-veneer mill also were significantly correlated with stand. In the parsimonious model estimates, at the mean road distance to the nearest pulpmill (about 50 miles), an additional road mile adds about 0.1 to 0.2 year to the expected stand age. Evaluated at the mean road distance between plots and the nearest plywood or veneer mill (60 miles), each mile adds about 0.1 year to the expected stand age.

Other variables also significantly explained variation in stand ages. These included site quality, slope, and physiographic class. Generally, the faster that the stand grows, the younger the stand; and the steeper the slope, the older the stand. Dry and mesic stands are youngest, with hydric stand substantially older. Of the broad management types, plantation pine stands are estimated to be 20 to 30 years younger than natural pine, bottomland hardwood, and oak-pine. Upland hardwood is estimated to be slightly older than the bottomland hardwood type, other things being equal.

Equality of fully-specified models among and between owners was evaluated with Wald tests, applying two kinds of model constraints. First, tests of model equality were done by testing if all parameters were equal including the intercept (top half of Table 3). Second, tests of model equality permitted different intercepts but identical coefficients on variables (bottom of Table 3).

Equality of parameters including the intercept was rejected at 1% significance for both survey cycles for (i) equality of NIPF, industry and government; (ii) equality of NIPF and government; and (iii) equality of industry and government. Equality of NIPF and industry models could not be rejected at even 44% significance.

The test for equality of parameters besides intercepts for survey 6 was only rejected at 12% significance, and a hypothesis of industry and government model equivalence could not be rejected at low levels of significance for either survey 5 or survey 6. NIPF and government model equivalence was rejected under this slightly less-constrained model, while NIPF and industry models remained statistically equivalent.

Table 1. Full and parsimonious estimates of stand age relationships for NIPF, industry, and government stands in the Southern Appalachians for the fifth FIA survey cycle of North Carolina (1982) and Virginia (1984).

Variable	NIPF		Industry		Government	
	Full Model	Par. Model	Full Model	Par. Model	Full Model	Par. Model
Intercept	38.25***	44.30***	46.48***	52.14***	24.74	24.12***
	(7.57)	(6.36)	(19.35)	(6.72)	(17.90)	(10.39)
Sawmill distance	0.58	0.29***	1.49*	1.50*	1.09	0.40*
	(0.37)	(0.12)	(0.88)	(0.86)	(1.02)	(0.22)
Sawmill distance^2	-0.013		-0.057	-0.056	-0.026	
	(0.015)		(0.035)	(0.035)	(0.036)	
Pulpmill distance	0.29***	0.30***	-0.28		0.22	0.09*
	(0.10)	(0.10)	(0.26)		(0.20)	(0.05)
Pulpmill distance^2	-0.0018*	-0.0019**	0.0031		-0.0011	
	(0.0010)	(0.0010)	(0.0025)		(0.0019)	
Ply-veneer distance	0.26***	0.27***	-0.09		0.34*	0.09**
	(0.09)	(0.09)	(0.21)		(0.17)	(0.04)
Ply-veneer distance^2	-0.0014*	-0.0014*	0.0018	0.0012***	-0.0019	
	(0.0007)	(0.0007)	(0.0017)	(0.0004)	(0.0013)	
Site Class	-10.62***	-10.51***	0.00		-8.96	2.72***
	(3.43)	(3.47)	(7.19)		(6.99)	(1.23)
Site Class^2	1.70***	1.67***	0.39		1.66	
	(0.53)	(0.54)	(1.11)		(1.02)	
slope	0.09		0.22		-0.32	-0.29
	(0.11)		(0.27)		(0.29)	(0.28)
slope^2	-0.0009		-0.0026		0.0061*	0.0058*
	(0.0014)		(0.0032)		(0.0037)	(0.0036)
Distance to Road	3.70		11.01		-11.65	
	(9.84)		(20.07)		(13.72)	
Distance to Road^2	-6.98		-15.86		11.31	
	(14.42)		(24.06)		(14.05)	
Physiogr. Class	-4.43***	-4.43***	-4.40*	-5.76***	0.83	
	(0.89)	(0.88)	(2.32)	(2.08)	(1.70)	
Physiogr. Class^2	0.36***	0.36***	0.42*	0.54**	-0.09	
	(0.09)	(0.09)	(0.24)	(0.22)	(0.18)	
Natural Pine	3.72		-10.01	-11.19**	17.78	12.53
	(4.00)		(12.03)	(4.51)	(11.03)	(8.94)
Plantation Pine	-19.06***	-22.08***	-33.30***	-31.53***	-16.78	-23.66***
	(4.86)	(3.39)	(12.08)	(3.46)	(11.76)	(8.58)
Oak-Pine	12.33***	9.34***	-3.93		15.59	9.54
	(4.26)	(2.51)	(12.61)		(11.12)	(9.01)
Upland Hardwood	16.47***	13.55***	0.13		23.42**	17.27**
	(3.85)	(1.70)	(11.88)		(10.87)	(8.01)
observations	1573	1573	345	345	591	591
s	23.45	23.42	26.68	26.46	27.42	27.38

***, **, and * indicates statistical difference from zero at 1, 5, and 10 percent, respectively.

Table 2. Full and parsimonious estimates of stand age relationships for NIPF, industry, and government stands in the Southern Appalachians for the sixth FIA survey cycle of North Carolina (1990) and Virginia (1992).

Variable	NIPF		Industry		Government	
	Full Model	Par. Model	Full Model	Par. Model	Full Model	Par. Model
Intercept	36.74***	40.60***	45.96***	40.47***	34.91**	36.86***
	(7.44)	(6.87)	(13.02)	(13.45)	(16.68)	(12.44)
Sawmill distance	0.61	0.28**	1.71**	1.68**	1.17	0.36
	(0.43)	(0.14)	(0.83)	(0.82)	(1.03)	(0.23)
Sawmill distance^2	-0.014		-0.064*	-0.063*	-0.031	
	(0.018)		(0.033)	(0.033)	(0.037)	
Pulpmill distance	0.21*	0.12***	-0.31	-0.33	0.07	0.08
	(0.11)	(0.03)	(0.22)	(0.21)	(0.21)	(0.05)
Pulpmill distance^2	-0.0009)		0.0036*	0.0038*	0.0001	
	(0.0010		(0.0021)	(0.0020)	(0.0020)	
Ply-veneer distance	0.22**	0.21**	-0.09		0.18	0.09**
	(0.09)	(0.09)	(0.21)		(0.18)	(0.04)
Ply-veneer distance^2	-0.0010	-0.00095	0.0009		-0.0007	
	(0.0008)	(0.00078)	(0.0016)		(0.0013)	
Site Class	-12.29***	-12.31***	-25.68***	-27.27***	-10.60	-11.19
	(3.39)	(3.37)	(7.92)	(7.15)	(7.76)	(7.20)
Site Class^2	2.14***	2.14***	4.04***	4.42***	1.94*	2.02*
	(0.53)	(0.53)	(1.20)	(1.06)	(1.11)	(1.03)
slope	0.22*	0.24**	0.23	0.17***	-0.47	-0.45*
	(0.11)	(0.11)	(0.26)	(0.07)	(0.29)	(0.29)
slope^2	-0.0028**	-0.0029**	-0.0008		0.0084**	0.0081**
	(0.0014)	(0.0011)	(0.0030)		(0.0037)	(0.0036)
Distance to Road	7.55		-2.17		-8.18	
	(10.21)		(18.79)		(14.97)	
Distance to Road^2	-13.09		-3.80		8.25	
	(14.25)		(22.09)		(15.68)	
Physiogr. Class	-4.85***	-4.84***	-1.36		-0.78	
	(1.01)	(1.01)	(2.17)		(2.04)	
Physiogr. Class^2	0.47***	0.47***	0.05		0.10	
	(0.12)	(0.12)	(0.24)		(0.24)	
Natural Pine	9.31***	9.12**	26.62***	27.15***	19.80**	23.12***
	(3.88)	(3.89)	(7.05)	(6.48)	(8.62)	(5.79)
Plantation Pine	-13.68***	-13.17***	-0.55		-5.90	
	(5.03)	(5.07)	(9.95)		(9.00)	
Oak-Pine	14.23***	14.13***	33.55***	33.19***	23.54***	26.69***
	(4.04)	(4.06)	(7.37)	(6.21)	(8.18)	(5.34)
Upland Hardwood	21.65***	21.57***	44.92***	45.66***	29.23***	32.72***
	(3.65)	(3.68)	(7.15)	(5.45)	(7.89)	(4.21)
observations	1551	1551	340	340	618	618
s	24.76	24.75	24.87	24.70	29.78	29.63

***, **, and * indicates statistical difference from zero at 1, 5, and 10 percent, respectively.

Table 3. Results of Wald tests on equality of NIPF, industry, and government stand age models.				
Type of Constraint	Period	Ownership Equality Constraints	F-ratio	P-value
All Parameters Equal	Survey 5	All Ownerships	3.16	0.00
		NIPF & Industry	1.01	0.45
		NIPF & Government	5.04	0.00
		Industry & Government	2.72	0.00
	Survey 6	All Ownerships	2.56	0.00
		NIPF & Industry	0.84	0.65
		NIPF & Government	4.08	0.00
		Industry & Government	2.14	0.00
Only Intercepts Differ	Survey 5	All Ownerships	2.89	0.00
		NIPF & Industry	0.98	0.48
		NIPF & Government	4.64	0.00
		Industry & Government	1.28	0.19
	Survey 6	All Ownerships	1.29	0.12
		NIPF & Industry	0.88	0.60
		NIPF & Government	1.85	0.02
		Industry & Government	0.77	0.74

CONCLUSIONS

Economic theory suggests that optimal stand harvest ages should vary with factors that affect harvest costs. Beginning from a Faustmann specification of the harvest decision model, if costs vary with distances to market then as market distance increases, stand optimal harvest age should increase, other things being equal. Similar relationships should exist for steepness of slope, pull distance, and wet conditions. Because optimal harvest ages are related to growth rate, species, and discount rates, empirical versions of the models also account for variations among stands in ownership, site quality, and broad management type. Model estimates indicate significant relationships between these variables and expected stand ages consistent with the theoretical model.

Tests of model equality imply that, at least for purposes of understanding how stand ages vary across a landscape, NIPF-managed and industry-managed stands respond similarly to factors expected to affect harvest age. In fact, at more stringent levels of confidence, even industry-managed stands and government-owned stand ages respond in similar fashion once a dummy shifter is included in the stand age model specification.

Among our more important findings is that, for most ownerships and both survey cycles, stand ages at FIA plots increase with distance to sawmills, pulpmills, and plywood-veneer mills. This implies that, at least for the Southern Appalachians of North Carolina and Virginia, the market defined for all three of the products that these mills consume–sawlogs, pulpwood logs, and veneer logs–should be included in a harvest choice model. Indeed, a properly specified harvest choice model would express timber values in the context of the stumpage. The optimal decision would therefore relate to the spatial characteristics of demand, since stumpage values are the sum of delivered prices times product volumes minus harvest and transport costs to each of the various product demand centers.

The techniques outlined in this paper could be tested more broadly, across the South for example. Understanding how mill locations are related to stand ages would enhance understanding of how the market affects the spatial distribution of timber inventories and the environmental services provided by forests.

Further research could examine how mill locations are related to the incentive to keep land in actively managed forest. Land use is responsive to the prices for products that can be obtained from the land (Parks and Murray 1994, Plantinga 1996). If timber management is a profitable activity only within some limited distance of mills, then it follows that providing a new market for forest outputs in a region where a market currently does not exist would encourage those lands to be in active forest management. Based on this study, creation of new markets implies that stand ages will decline relative to the status quo. However, having a market for forest outputs may keep some forested lands from being converted to other uses (e.g., agriculture, residential). In those cases, forests would continue to provide environmental services where none would otherwise flow.

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