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Southern Pulpwood Harvesting Productivity and Cost Changes Between 1979 and 1987

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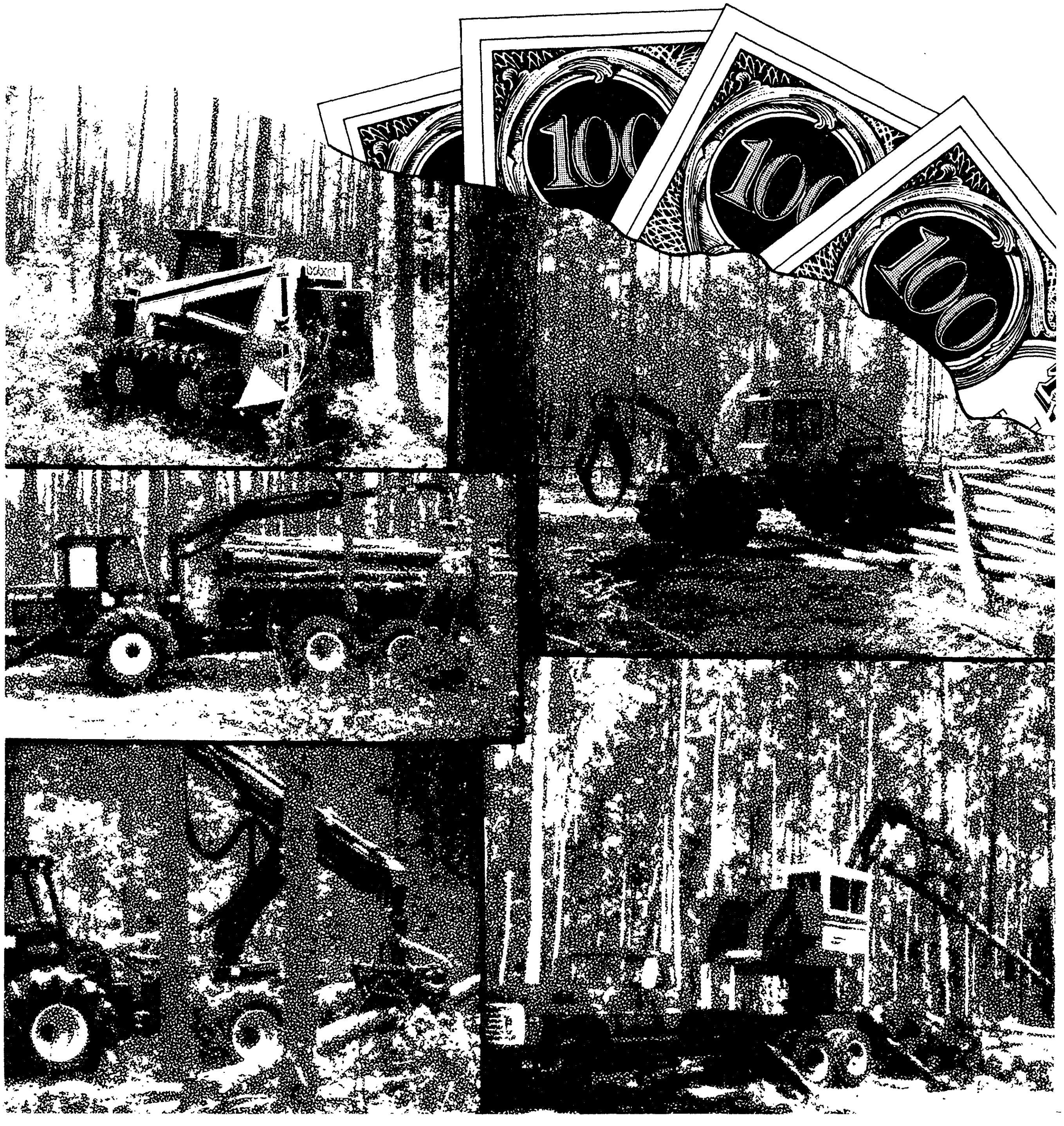

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Timber harvesting costs are of continuing interest to loggers, procurement foresters, and forest land managers. The costs of harvesting pine pulpwood in the South make up almost one-half of the delivered-to-mill costs; southern (and northern) hardwood harvesting costs exceed the costs of hardwood pulpwood stumpage. Timber harvesting costs—and their magnitude trends over time—are an important factor determining the relative competitiveness of the forest industry in different regions and countries in the world. In this paper, we use data from two surveys, in 1979 and 1987, of the southern pulpwood harvesting work force to estimate aggregate regional harvesting production functions and costs. This research provides the bases for analyzing changes in the structure of the industry over the last decade and for estimating production cost decreases achieved by adoption of new or existing equipment and technology.

Cubbage *et al.* (1988) analyzed production and costs in the southern pulpwood harvesting industry in 1979. They concluded that increased mechanization of harvesting systems decreased average costs of production, and that trends towards increased mechanization would continue. The 1979 cross-sectional survey provided a snapshot of a heterogeneous industry. Pulpwood harvesting systems ranged from one employee and a bobtail truck to highly capitalized systems with more than 20 employees. Putting these systems into "technology classes" based on equipment type and primary product (i.e., shortwood or longwood) provided a means for comparing the relative efficiency and profitability of each system.

This paper extends the results of the 1988 publication by describing changes that occurred in the southern pulpwood logging industry between 1979 and 1987. Comparisons will concentrate on cost and production characteristics between survey periods. The findings help describe the changing nature of the industry that is a substantial component of the southern forest economy.

METHODS

We used data from two American Pulpwood Association (APA) surveys of southern loggers to analyze trends in productivity and costs. The APA data were then used to estimate aggregate production and cost functions for harvesting technology systems or classes—i.e., sets of similar harvesting equipment configurations—for all systems throughout the South. These broad economic analyses are based on estimating the (microeconomic) production and costs for each harvesting firm, and then aggregating them into industry-wide averages and functions using statistical analyses. These aggregate harvesting sector analyses allow us to examine changes in the structure of the southern pulpwood industry during the 1980's.

Data

The data used in the analysis were obtained from two comprehensive cross-sectional APA surveys of pulpwood logging firms in the Southern United States. These surveys were conducted in 1979 (Weaver *et al.* 1981) and 1987

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(Watson *et al.* 1989). The surveys gathered information on several firm characteristics, including owner age, education level, years in business, number of employees, equipment owned, product type, weekly productivity, firm location, and other information. The 1987 survey was slightly more thorough in describing firm production, labor, and capital characteristics than the 1979 survey. Our analysis used only similar information from both surveys to examine changes in the industry over time.

Both surveys covered APA Southwest and Southeast Technical Divisions, including 12 Southern States, ranging from Texas to Tennessee to Virginia and south. The 1979 survey concentrated on operators that produced 50 percent or more of total output as pulpwood (Weaver *et al.* 1982), but it had some drawbacks. Larger scale producers were considered underrepresented, which led to another survey in 1980 of "high-volume" pulpwood producers who may have been missed in the 1979 survey (Weaver *et al.* 1982). High-volume producers were not restricted to a special product, so may have produced some sawtimber as well as pulpwood. Also, Cubbage *et al.* (1988) were only able to obtain about 70 percent of the original 1979 data; the rest were destroyed. Thus, we used information on the actual number of high-volume producers (> 250 cords per week) in the 1979 survey, as well as information on the total production of pulpwood in 1979 (Hutchins 1989), to expand the 1979 survey to the total volume produced so that we could compare the 1979 and 1987 surveys. The adjustments were reasonable because there were enough responses available across all groups in the 1979 data.

The findings of the 1987 survey were close to the total pulpwood production in the South, as reported by the APA. The 1987 survey considered all loggers who produced some pulpwood, even those who may have produced more logs than pulpwood. To make the data sets from the 1979 and 1987 surveys comparable, we considered only 1987 responses where more than 50 percent of the total production was in pulpwood. This slightly reduced the amount of data available for analysis, but allowed for a more accurate description of population movements and production levels between harvesting technologies. This analysis focused only on pulpwood producers—firms producing at least 50 percent of total output as pulpwood, either softwood or hardwood, and producing more than 10 cords per week. Approximately 21 percent of survey responses were deleted from both data sets because they: (1) did not fall into one of the technology classes, (2) produced more chips than pulpwood, (3) produced more logs than pulpwood, (4) produced fewer than 10 cords per week (considered part-time producers), or (5) had incomplete or incomprehensible responses.

A final difference between the 1979 and 1987 surveys was the sampling design used. The 1979 survey was intended to canvass all firms that produced 50 percent or more of total output in pulpwood (along with the 1980 survey). The 1987 survey used a two-stage sampling procedure. The total number of firms was identified in Stage I, and cursory information was taken on each firm. Randomly sampled firms were then intensively surveyed in Stage II (Watson *et al.* 1989). A weighted random sample was used depending on State and production characteristics identified in Stage I. This weighting was used throughout the analysis to estimate 1987 population characteristics. The 1987 method captured the total pulpwood production better than did the incomplete 1979 canvass.

Harvesting Systems

Survey responses were classified into one of eight equipment classes because southern pulpwood harvesting systems are quite heterogeneous. They range from labor-intensive shortwood systems with low capitalization levels to highly mechanized longwood systems where capitalization levels are very high, often reaching $500,000. These technology classes were the same as those used by Cubbage *et al.* (1988).

Responses were classified into one of two product classes, shortwood or longwood. Shortwood classes were further divided into six technology classes, A through F. Technology class A was considered the most labor intensive, capital poor class. This system typified hand loading with straight or bobtail trucks where no mechanized skidding was available except perhaps animal skidding. Technology class B was one step above technology class A, and included at least one bigstick cable, pallet rig, or side loader but still had no mechanized skidding equipment. Technology class C was one step above technology class B by inclusion of at least one cable skidder or farm tractor with the loading equipment. Technology class D used forwarders for in-woods log transport. Technology class E used knuckleboom or front-end loaders and had at least one cable skidder. Technology class F used knuckleboom or front-end loaders and had at least one grapple skidder. Longwood systems were further divided into two technology classes, G and H. Technology class G had cable skidding and a knuckleboom or front-end loader. Technology class H had at least one grapple skidder and knuckleboom or front-end loader.

A summary of technology class definitions and the number of available responses for analysis are given in table 1. The estimated total number of 1979 operations was calculated by multiplying individual responses by the appropriate factor used to expand the data to the level of pulpwood production reported by the APA pulpwood production surveys. The number of 1987 operations was estimated by using the weighting factor used in the two-stage sampling process.

Employment, Production, and Assets

Each survey respondent identified the number of employees, weekly production by product type, and equipment spread. Some firms indicated that they had more than one crew. In this analysis, all summary statistics and regressions are based on a per crew basis. The owner was added to the employee total and given a wage as an employee. The number of employees per crew was calculated by dividing the total number of employees by the number of crews for each firm. The average number of employees for each technology class was computed as an arithmetic mean.

Total weekly production per crew was defined as the sum of hardwood and softwood pulpwood, logs, and chips. Most firms indicated that they produced a mixture of hardwoods and softwoods.

Assets also were calculated on a per crew basis, based on average depreciated values for each piece of equipment (Cubbage *et al.* 1988), thus providing a replacement value for assets. Asset values for both surveys were calculated in 1988 dollars. Several assumptions were made to accurately estimate total firm assets and costs. In addition to the reported equipment spread, all firms were assumed to have $1,000 in base

Table 1.—*Harvesting equipment technology classes, survey responses, and number of operations for pulpwood producers surveyed in 1979 and 1987*[a]

Technology class	Characteristic equipment	1979		1987	
		Number of responses	Number of operations[b]	Number of responses	Number of operations[b]
Shortwood					
A. Manual bobtail	Hand loading, bobtail truck	429	987	11	120
B. Semimanual bigstick	Bigstick, pallet or side loader; bobtail truck	1,923	4,429	479	957
C. Manual/skidder	Bigstick, pallet or side loader; farm tractor or cable skidder	402	925	28	340
D. Forwarder	Forwarder, supplemental loader	155	362	16	91
E. Cable skidder	Cable skidder, front-end or knuckleboom loader	191	451	19	142
F. Grapple skidder	Grapple skidder, front-end or knuckleboom loader	27	98	13	88
Total (shortwood)		3,127	7,252	166	1,738
Longwood					
G. Cable skidder	Cable skidder, front-end or knuckleboom loader	383	1,061	97	1,070
H. Grapple skidder	Grapple skidder, front-end or knuckleboom loader	170	787	200	1,595
Total (longwood)		553	1,848	297	2,665
Total (all classes)		3,680	9,100	463	4,403

[a]*Those respondents producing 50 percent or more of their total production in pulpwood. Breakdowns are by technology class and primary product.*

[b]*Number of 1987 operators obtained by multiplying individual responses by the appropriate weighting factor used in sampling. Number of 1979 operators estimated by weighting high-volume producers higher than other firms and expanding the survey to coincide with reported pulpwood production in 1979.*

assets. For the least mechanized firms, this would help account for chain saws, tools, and other equipment. Crews using grapple skidders were assumed to have a feller-buncher. Other equipment probably owned by the firm but not reported included crew trucks, lowboys or equipment transport, and bulldozers for road building. These assumptions were based on the crew size and profile. An additional 20 percent of these assets (except base assets) were added to the total to account for repair and miscellaneous type assets such as shop maintenance. These assumptions were held constant across both survey periods.

Cost Functions

Reported equipment information such as age, type, and number, as well as the reported number of employees and weekly production, was used to calculate average costs of production per cord of pulpwood. Both fixed and variable costs were calculated in 1988 dollars.

Fixed Costs.—The two primary determinants of fixed costs were equipment (asset) depreciation and labor wages. The reported age distribution of equipment was used to allocate depreciation. This was calculated via the estimated drop in market value of equipment from one age class to the next. Estimates of yearly depreciation were derived from Burgess and Cubbage (1990), who calculated average percent reduction in retail prices for different age and equipment classes. The same depreciation schedules were used in both surveys. Annual depreciation on assumed assets such as base, repair, and road building assets was calculated as 15 percent of asset value. Annual depreciation was then allocated to the reported weekly production level of pulpwood based on a 44-week work year for all technology classes except classes A and B, which were assumed to have a 36-week work year. The bobtail systems A and B can only work in dry weather (and on dry ground), so had less productive time per year than the more flexible mechanized systems.

Labor is typically considered a variable cost. For this analysis, however, labor was considered fixed by assumption of full employment (at a 40-hour-week average). Therefore, average costs for part-time operations will naturally be higher. In the long run however, part-time operations may not be able to stay in business because of the opportunity costs to employees of missed wages. This opportunity cost then represents a real cost to the firm. Wage rates for the 1979 survey were taken from Cubbage *et al.* (1988). Increases in base wage rates, net of workers' compensation and social security insurance for the 1987 survey were based on increases in the federal minimum wage level. As a result, real base wage rates in the analysis declined slightly. The more than threefold increase in workers' compensation insurance rates between surveys for high-risk, manual shortwood operations raised their labor costs significantly. We applied rates for workers' compensation classification 2705 (pulpwood only) to shortwood technology classes A, B, C, and D, and 2701 (pulpwood and sawtimber) to technology classes E, F, G, and H. The resulting wage rates, including fringe benefits, are given in table 2.

Other fixed costs such as equipment insurance and taxes, as reported in Cubbage (1981) and used in Cubbage *et al.* (1988), were used in this analysis. Contacts with insurers and local governments indicated that equipment insurance and tax rates remained the same in both time periods after accounting for inflation.

Table 2.—*Hourly wage rates per person by harvesting system technology class, 1979 and 1987*[a]

Technology class	Average wage/hour 1979	1987
Shortwood		
A. Manual bobtail	$ 6.60	$ 9.10
B. Semimanual bigstick	6.60	9.10
C. Manual/skidder	8.01	11.04
D. Forwarder	8.01	11.04
E. Cable skidder	8.88	9.34
E. Cable skidder with tractor-trailer	9.78	10.28
F. Grapple skidder	10.66	11.21
F. Grapple skidder with tractor-trailer	11.55	12.15
Longwood		
G. Cable skidder	8.88	9.34
G. Cable skidder with tractor-trailer	9.78	10.28
H. Grapple skidder	10.66	11.21
H. Grapple skidder with tractor-trailer	11.55	12.15

[a]*Indexed to 1988 dollars; including fringe benefits.*

Variable Costs.—Variable costs were calculated for equipment and labor use. Fixed and variable costs per operating hour, production capacity, and number of operating hours were taken from Cubbage (1982) for the 1979 survey and from Burgess and Cubbage (1989) for the 1987 survey. Operating costs for each piece of equipment (except hauling) were allocated by taking machine production capacity for a phase (i.e., skidding, loading) and computing a percentage of that machine's contribution to total production. The percentage was then used to calculate the operating hours (and costs) per piece of equipment based on reported weekly production. Operating costs were further delineated by considering equipment age. Older equipment was assumed to have slightly higher operating costs, increasing to about 50 percent more than new equipment. Higher hauling costs per mile also were associated with older equipment.

Hauling equipment variable costs (per mile) were calculated by assuming a 60-mile round-trip hauling distance and using truck capacities to proportion weekly production to each piece of hauling equipment. Truck capacities used in this analysis were the same as those in Cubbage *et al.* (1988).

Regression Equations.—The average total cost per cord for each firm was calculated as explained above. These average costs per firm or crew then provided the basis for calculating average costs by harvesting technology class and by product form—shortwood or longwood. The average firm costs also provided data points for use in regression equations to estimate average costs for each technology class as a function of output produced per week.

The regressions used all the data for each technology or product form class, as appropriate, for both the 1979 and 1987 data sets. Differences between average costs for each technology were estimated using dummy variables and slope shifters for the 1979 and 1987 data sets. In this case, the 1979 data set was coded as a zero (0), and the 1987 data set was coded as a one (1). Significant differences between the intercept values or slopes between surveys provided evidence that costs of production were either increasing or decreasing.

Although many specifications of an average cost function are possible, only two were chosen for ease of exposition and interpretation. The equations were estimated using simple quadratic and log/log forms. Examples of quadratic and cubic forms of average and total cost functions can be found in Cubbage *et al.* (1989) and Intriligator (1978). The quadratic form used is somewhat ad hoc and cannot be directly derived from a total cost function where differentiation between fixed and variable costs is possible, but justification for its use can be found in Intriligator (1978). Other quadratic and cubic forms were examined, but did not always provide estimates consistent with a priori expectations. The specific forms examined were:

(simple quadratic)

$$AC = \beta_0 + \beta_1 WP + \beta_2 WP^2 + \beta_3 D + \beta_4 DWP + \beta_5 DWP^2 \quad [1]$$

and

(log/log)

$$lnAC = \beta_0 + \beta_1 lnWP + \beta_2 D + \beta_3 DlnWP \quad [2]$$

where AC = average total cost per cord, WP = weekly production in cords, D = 1987 survey intercept and slope shifters, ln = natural log transformation.

As noted earlier, a weighted random sample was used to obtain the 1987 survey, and high-volume producers were weighted more heavily in the 1979 survey. This information was incorporated into the estimation to provide more precise parameter estimates through the procedure of weighted least squares. Additionally, we found heteroskedasticity in the average cost functions at low production levels. Therefore, we weighted the parameter estimates by production level, giving more importance to cost information provided by higher volume producers.

Production Functions

Production functions were estimated for each technology class. As with the average cost functions, dummy variable intercept and slope shifters were used to delineate the effects of time. Significance of these shifters provided evidence of structural (and hence technological) change within previously defined technology classes between survey periods.

The specified production functions followed a classical economics model, in that they regressed output (cords per week) against capital (asset value) and labor (number of employees) inputs. Two functional forms were chosen, linear and log/log. The log/log form is a transformation of the traditional Cobb-Douglas form. Both forms are inflexible because they place several a priori restrictions on the underlying technology. For example, the linear form assumes that inputs (i.e., capital and labor) are perfect substitutes in production, whereas the Cobb-Douglas form assumes a constant, unitary elasticity of substitution (Beattie and Taylor 1985). Thus, these allow only technologies with elasticities of substitution of infinity or one. Parameter estimates should therefore be viewed with these restrictions in mind. The specific forms examined were:

(linear)

$$WP = \beta_0 + \beta_1 AST + \beta_2 EMP + \beta_3 D + \beta_4 DAST + \beta_5 DEMP \quad [3]$$

and

(log/log)

$$lnWP = \beta_0 + \beta_1 lnAST + \beta_2 lnEMP + \beta_3 D + \beta_4 DlnAST + \beta_5 DlnEMP \quad [4]$$

where WP = weekly production in cords, AST = firm assets in thousands of 1988 dollars, EMP = number of employees per firm (including owner), D = 1987 survey intercept and slope shifters, and ln = natural log transformation. Parameter coefficients β_1 and β_2 in [3] are marginal products for the 1979 data; β_3 is a 1987 intercept shifter; and β_4 and β_5 are the 1987 slope shifters, which added together with β_1 and β_2, indicate the marginal products of capital ($\beta_1 + \beta_4$) and labor ($\beta_2 + \beta_5$) in 1987. Note that β_1 and β_2 in [4] are partial output elasticities and are expected to lie between 0 and 1 for a Stage II (zone of feasible production) process, consistent with the concept of diminishing marginal returns. Summed together, these coefficients measure returns to scale or the function coefficient (Beattie and Taylor 1985). The dummy intercept and slope shifters in [4] are interpreted similarly. Estimates were also obtained using a weighted least squares procedure to take into account the sampling design (1987 survey) and data adjustment and expansion (1979 survey). In addition, heteroskedasticity in the data was corrected for by assuming multiplicative heteroskedasticity. Although estimates are unbiased without this assumption, they are inefficient and normal tests of hypotheses are not valid. Full details of the method can be found in Judge *et al.* (1988).

Harvesting Margins

An estimate of the price paid for logging services was defined as the difference between delivered and stumpage prices for southern yellow pine pulpwood because contract prices were unknown for each firm at the time of the survey. This would include all logging services from stump to mill, including transportation. This estimated price can be referred to as the harvesting margin. South-wide unweighted average harvesting margins were calculated for 1979 and 1987, and measured in 1988 dollars. Prices were taken from Timber Mart-South for the relevant years. Table 3 shows that the Timber Mart-South harvesting margin (based on the production-weighted average of State prices) declined by $6.02 per cord between 1979 and 1987.

Table 3.—*Estimated harvesting margin (delivered minus stumpage price) by State, 1979 and 1987*[a]

State	Logging price/cord 1979	Logging price/cord 1987
Alabama	$ 34.85	$ 31.86
Arkansas	42.44	30.97
Florida	27.80	27.23
Georgia	29.29	23.52
Louisiana	45.15	34.78
Mississippi	41.36	31.04
North Carolina	40.54	32.35
Oklahoma	42.71	37.36
South Carolina	34.44	30.23
Tennessee	38.24	29.25
Texas	44.07	30.52
Virginia	34.58	32.61
Southwide[b]	37.02	30.52
Southwide[c]	36.51	30.49

[a]*Based on southern pine pulpwood stumpage prices; indexed to 1988 dollars.*
[b]*Arithmetic average of State prices.*
[c]*Production-weighted average of State prices.*
Source: Timber Mart-South 1988.

RESULTS

Technology Class Population Shares and Production

Table 4 summarizes the number of operations and weekly production by technology class and survey period for firms producing at least 50 percent of total production in pulpwood, based on data used in the analysis. The results summarize the relative population movements and production between products (shortwood and longwood) and defined technology classes. The total number of firms declined dramatically, from 9,100 in 1979 to 4,403 in 1987. All shortwood systems had fewer firms in 1987 than in 1979. Relative pulpwood production declined drastically in the shortwood systems, supplanted by increased longwood production. Longwood production made up only 59 percent of pulpwood production in 1979, but 90 percent of the total in 1987. The number of longwood firms increased from 20 percent to 61 percent of the total during this period. Nearly all of this increase was due to increases in longwood grapple skidder systems (system H).

Different harvest system characteristics were compared by product, technology class, and survey period (tables 5 through 11). For each table, t-tests were conducted to determine if significant differences existed for average values across survey periods.

Operator Size

Characteristics of operator size in southern pulpwood harvesting systems are given in tables 5 through 7. Three characteristics were measured: employees per crew, assets per crew, and number of crews per operator.

Employees per crew.—Table 5 provides summary statistics and t-tests for the number of employees per crew (including owner) by product, technology class, and survey period. As expected, the number of employees was the lowest for technology class A and gradually increased with the technology described, except for technology class D (forwarder-supplemental loader), which employed more workers in 1987 than any other class excluding technology class H (longwood-grapple skidding).

Table 4.—*Breakdown of firms, production, and assets by harvesting system technology class for southern pulpwood producers, 1979 and 1987*[a,b]

Technology class	1979				1987			
	Number of operations[c]		Production per week		Number of operations[c]		Production per week	
	N	*Percent*	*Cords*	*Percent*	*N*	*Percent*	*Cords*	*Percent*
Shortwood								
A. Manual bobtail	987	10.8	20,813	3.2	120	2.7	3,233	0.4
B. Semimanual bigstick	4,429	48.7	124,777	19.1	957	21.7	26,365	3.4
C. Manual/skidder	925	10.2	35,806	5.5	340	7.7	13,655	1.7
D. Forwarder	362	4.0	27,269	4.2	91	2.1	7,858	1.0
E. Cable skidder	451	5.0	36,334	5.5	142	3.2	8,494	1.1
F. Grapple skidder	98	1.1	25,763	3.9	88	2.0	16,189	2.1
Total (shortwood)	7,252	79.7	270,763	41.3	1,738	39.5	75,794	9.6
Longwood								
G. Cable skidder	1,061	11.7	154,222	23.5	1,070	24.3	155,290	19.7
H. Grapple skidder	787	8.6	229,958	35.1	1,595	36.2	556,233	70.7
Total (longwood)	1,848	20.3	384,180	58.7	2,665	60.5	711,523	90.4
Total (all classes)	9,100	100.0	654,943	100.0	4,403	100.0	787,317	100.0

[a]*Those respondents producing 50 percent or more of their total production in pulpwood. Breakdowns are by technology class and primary product.*

[b]*Columns may not add due to rounding.*

[c]*An operation or firm may have more than one crew.*

Table 5.—*Average number of employees per crew by harvesting system technology class, 1979 and 1987*

Technology class	Survey	N	Mean	Min	Max	S.D.	F[a]	df	t ratio
Shortwood									
A. Manual bobtail	1979:	429	2.25	1.00	9.00	1.07			
	1987:	11	2.31	1.00	5.00	1.12	1.10	438	0.18
B. Semimanual bigstick	1979:	1,923	2.75	1.00	21.00	1.15			
	1987:	79	2.88	1.00	6.00	0.93	1.53	2,000	0.99
C. Manual/skidder	1979:	402	3.13	1.00	9.00	1.34			
	1987:	28	3.38	1.00	6.00	1.13	1.41	428	0.96
D. Forwarder	1979:	155	5.34	1.00	18.00	2.51			
	1987:	16	5.84	2.00	13.00	2.93	1.36	169	0.75
E. Cable skidder	1979:	191	4.54	1.00	11.00	1.82			
	1987:	19	4.47	1.00	10.00	1.80	1.02	208	0.16
F. Grapple skidder	1979:	27	5.96	2.00	14.00	3.21			
	1987:	13	5.27	1.75	13.00	2.56	1.57	38	0.67
Total (shortwood)	1979:	3,127	3.02	1.00	21.00	1.58			
	1987:	166	3.34	1.00	13.00	1.63	1.06	3,291	2.54**
Longwood									
G. Cable skidder	1979:	383	5.94	1.00	20.00	3.00			
	1987:	97	4.70	2.00	13.00	1.88	2.55*	235	5.06*
H. Grapple skidder	1979:	170	8.76	1.00	24.00	4.17			
	1987:	200	7.69	1.33	20.50	3.50	1.42*	331	2.65*
Total (longwood)	1979:	553	7.14	1.00	24.00	3.81			
	1987:	297	6.49	1.33	20.50	3.30	1.33*	683	2.59*
Total (all classes)	1979:	3,680	3.85	1.00	24.00	2.77			
	1987:	463	5.25	1.00	20.50	3.16	1.30*	554	9.10*

[a]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*

Generally speaking, there was only a slight increase in the average number of employees per crew for both shortwood and longwood systems separately between 1979 and 1987. Although no statistical difference could be discerned for any particular shortwood class, all shortwood classes combined increased significantly from 3.02 to 3.34 employees per crew over the time period.

For each longwood system (technology classes G and H), there were significant declines in the average number of employees. For all longwood classes combined, values declined significantly from 7.14 to 6.49 employees per crew. However, for all classes combined, the number of employees per crew increased significantly from 3.85 to 5.25 employees per crew.

Assets per crew.—Table 6 gives summary statistics and t-tests for the average value of assets per crew (capitalization level) by technology class and primary product for each survey period. As with employees, asset value was lowest for technology classes A and B, and highest for technology class H. The average value of assets for technology class H (longwood-grapple skidding) was above $300,000.

Table 6.—*Average assets per crew (in $1,000) by harvesting system technology class, 1979 and 1987*[a]

Technology class	Survey	N	Mean	Min	Max	S.D.	F[b]	df	t ratio
Shortwood									
A. Manual bobtail	1979:	429	11.18	1.00	47.96	5.28			
	1987:	11	24.42	12.98	63.67	15.85	9.01*	10	2.77*
B. Semimanual bigstick	1979:	1,923	13.86	1.00	137.06	7.14			
	1987:	79	18.22	14.26	34.32	5.57	1.64*	88	6.73*
C. Manual/skidder	1979:	402	44.47	9.83	132.07	19.77			
	1987:	28	73.22	28.78	307.23	72.28	13.37*	27	2.10**
D. Forwarder	1979:	155	83.90	23.91	303.00	43.58			
	1987:	16	96.50	41.60	197.16	39.49	1.22	169	1.11
E. Cable skidder	1979:	191	133.74	47.90	378.51	51.66			
	1987:	19	124.67	56.88	243.39	49.22	1.10	208	0.73
F. Grapple skidder	1979:	27	268.10	69.53	623.32	147.40			
	1987:	13	218.93	52.58	512.56	107.23	1.89	38	1.07
Total (shortwood)	1979:	3,127	31.80	1.00	623.32	49.47			
	1987:	166	52.32	12.98	512.56	67.50	1.86*	174	3.86*
Longwood									
G. Cable skidder	1979:	383	195.29	62.73	466.70	91.99			
	1987:	97	147.24	59.46	903.21	62.14	2.19*	215	6.11*
H. Grapple skidder	1979:	170	338.81	125.62	696.54	119.27			
	1987:	200	314.29	108.42	1,009.26	134.32	1.27	368	1.84***
Total (longwood)	1979:	553	256.41	62.73	696.54	126.29			
	1987:	297	247.24	59.46	1,009.26	138.02	1.19	848	0.97
Total (all classes)	1979:	3,680	77.41	1.00	696.54	115.56			
	1987:	463	170.30	12.98	1,009.26	149.68	1.68*	533	12.88*

[a]*Indexed to 1988 dollars.*
[b]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

Shortwood systems overall showed a significant increase between surveys in the amount of assets employed by each crew. Mixed results, however, were found for each shortwood subclass. Technology classes A, B, and C had significantly higher assets per crew in 1987 than in 1979. Average assets were also higher for technology class D, but not statistically significant. Technology classes E and F had lower average assets in 1987 than in 1979 but these values were not significant.

All longwood classes combined showed no significant change in the average value of assets per crew between surveys. There was a large significant decline in assets for technology class G and a small significant decline in technology class H. The lack of real change in the total longwood category indicates movement into technology class H over time. Finally, total average assets per crew for all classes combined increased significantly from $77,410 to $170,300 per crew, a 120-percent increase between surveys.

Number of crews.—An indication of scale in the industry is the number of crews operated by each firm. Table 7 gives summary statistics and t-tests for the average number of crews by technology class and primary product for each survey period. One crew per firm remained standard practice for most shortwood classes. There was no significant change between survey periods for technology classes A through D and F. Technology class F had a substantial point estimate increase from 1.47 to 1.84 crews, but this was not statistically significant. Furthermore, there was no significant change for all shortwood classes combined. Longwood classes G and H had small but insignificant increases in the number of crews. Overall, it appears that the structure of pulpwood harvesting systems with respect to the number of crews operated by each firm did not change substantially between 1979 and 1987.

In summary, results of characteristics of firm size (employees per crew, assets per crew, number of crews) between surveys were mixed. The number of employees per crew rose by 11 percent for all shortwood classes combined and declined by 9 percent for all longwood classes combined. However, for all classes combined,

Table 7.—*Average number of crews per operator by harvesting system technology class, 1979 and 1987*

Technology class	Survey	N	Mean	Min	Max	S.D.	F[a]	df	t ratio
Shortwood									
A. Manual bobtail	1979:	429	1.01	1.00	3.00	0.13			
	1987:	11	1.00	1.00	1.00	0	——[b]	438	0.25
B. Semimanual bigstick	1979:	1,923	1.02	1.00	9.00	0.27			
	1987:	79	1.05	1.00	4.00	0.36	1.78*	81	0.73
C. Manual/skidder	1979:	402	1.08	1.00	5.00	0.46			
	1987:	28	1.06	1.00	2.00	0.24	3.67*	42	0.39
D. Forwarder	1979:	155	1.09	1.00	3.00	0.39			
	1987:	16	1.00	1.00	1.00	0	——[b]	169	0.92
E. Cable skidder	1979:	191	1.16	1.00	6.00	0.78			
	1987:	19	1.01	1.00	2.00	0.08	95.1*	207	2.53**
F. Grapple skidder	1979:	27	1.47	1.00	5.00	1.13			
	1987:	13	1.84	1.00	12.00	2.21	3.82*	15	0.57
Total (shortwood)	1979:	3,127	1.05	1.00	9.00	0.44			
	1987:	166	1.08	1.00	12.00	0.60	1.86*	175	0.64
Longwood									
G. Cable skidder	1979:	383	1.03	1.00	3.00	0.18			
	1987:	97	1.09	1.00	8.00	0.53	8.67*	101	1.10
H. Grapple skidder	1979:	170	1.19	1.00	5.00	0.52			
	1987:	200	1.22	1.00	13.00	0.91	3.06*	324	0.40
Total (longwood)	1979:	553	1.10	1.00	5.00	0.38			
	1987:	297	1.17	1.00	13.00	0.78	4.21*	373	1.46
Total (all classes)	1979:	3,680	1.06	1.00	9.00	0.43			
	1987:	463	1.13	1.00	13.00	0.72	2.80*	504	2.05**

[a]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

[b]*Cannot be computed.*

* *Significant to the 0.01 level.*

** *Significant to the 0.05 level.*

employees per crew increased 36 percent. Asset value per crew rose by 65 percent for shortwood classes but declined by 4 percent for longwood classes. However, for all classes combined, assets per crew rose 120 percent. Both the number of employees and value of assets declined in technology classes G and H over the study period, while these characteristics actually increased for all classes combined. Thus, although individual classes did not grow in scale, the population as a whole did grow because of population movements between classes and the relative increase in longwood systems.

Average Production

Tables 8 through 10 outline production characteristics of southern pulpwood harvesting systems. Three characteristics were measured: weekly production per crew, weekly production per $10,000 in asset value, and weekly production per employee.

Production per Crew.—Table 8 gives summary statistics and t-tests for weekly pulpwood production per crew (measured in cords). Weekly production ranged from about 27 cords

Table 8.—*Average production in cords per week per crew by harvesting system technology class, 1979 and 1987*

Technology class	Survey	N	Mean	Min	Max	S.D.	F[a]	df	t ratio
Shortwood									
A. Manual bobtail	1979:	429	20.84	10.00	78.00	11.26			
	1987:	11	26.88	10.00	70.00	15.14	1.81	438	1.74***
B. Semimanual bigstick	1979:	1,923	27.03	10.00	125.00	14.85			
	1987:	79	26.80	10.00	75.00	10.74	1.91*	90	0.18
C. Manual/skidder	1979:	402	36.26	10.00	210.00	24.48			
	1987:	28	38.77	10.00	75.00	17.59	1.93	428	0.53
D. Forwarder	1979:	155	70.17	10.00	200.00	40.21			
	1987:	16	86.05	15.00	156.00	46.96	1.36	169	1.48
E. Cable skidder	1979:	191	69.36	10.00	200.00	40.20			
	1987:	19	59.83	10.00	140.00	33.21	1.47	208	1.00
F. Grapple skidder	1979:	27	189.28	10.00	380.00	109.49			
	1987:	13	160.50	25.00	400.00	139.91	1.63	38	0.71
Total (shortwood)	1979:	3,127	34.36	10.00	380.00	33.05			
	1987:	166	41.70	10.00	400.00	48.02	2.11*	173	1.95***
Longwood									
G. Cable skidder	1979:	383	143.14	10.00	429.00	98.98			
	1987:	97	127.82	15.00	500.00	97.31	1.03	478	1.37
H. Grapple skidder	1979:	170	254.85	10.00	650.00	114.99			
	1987:	200	294.69	12.00	1,000.00	185.24	2.60*	338	2.52**
Total (longwood)	1979:	553	190.72	10.00	650.00	119.59			
	1987:	297	227.71	12.00	1,000.00	176.14	2.17*	446	3.24*
Total (all classes)	1979:	3,680	66.11	10.00	650.00	87.92			
	1987:	463	154.29	10.00	1,000.00	167.19	3.62*	495	11.16*

[a]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

per week for shortwood technology classes A and B to nearly 300 cords per week for longwood technology class H (1987 survey).

Most of the shortwood classes (A through F) did not change significantly in weekly production from 1979 to 1987. Significant increases were found only in technology class A. However, average total shortwood production increased significantly between surveys, from 34 to 42 cords per week, a 21-percent increase.

Significant increases were evident in longwood technology class H. Average weekly production declined in technology class G, but this was not significant. For all longwood classes combined, average weekly production rose significantly from 191 to 228 cords per week, a 19-percent increase.

Production per Assets.—Table 9 outlines summary statistics and t-tests for weekly production per $10,000 in asset value. Average production per amount invested was generally highest for classes with smaller systems, and steadily declined with increasing capitalization levels. Longwood technology class H, however, had higher production per assets than technology classes F and G.

Table 9.—*Average production in cords per week per $10,000 in assets by harvesting system technology class, 1979 and 1987*

Technology class	Survey	N	Mean	Min	Max	S.D.	F[a]	df	t ratio
Shortwood									
A. Manual bobtail	1979:	429	20.12	2.09	180.00	12.92			
	1987:	11	13.58	4.38	53.92	11.50	1.26	438	1.66***
B. Semimanual bigstick	1979:	1,923	20.58	2.99	169.81	11.33			
	1987:	79	15.10	5.66	39.74	5.51	4.23*	107	8.16*
C. Manual/skidder	1979:	402	8.45	1.54	47.71	4.81			
	1987:	28	7.38	1.24	17.17	3.94	1.49	428	1.15
D. Forwarder	1979:	155	9.08	1.46	28.86	4.90			
	1987:	16	9.23	3.57	24.69	4.64	1.11	169	0.12
E. Cable skidder	1979:	191	5.21	0.74	13.93	2.54			
	1987:	19	4.95	0.74	9.99	2.19	1.35	208	0.43
F. Grapple skidder	1979:	27	8.10	1.31	24.45	5.88			
	1987:	13	6.35	2.85	14.35	3.97	2.19	38	0.97
Total (shortwood)	1979:	3,127	17.27	0.74	180.00	11.71			
	1987:	166	11.91	0.74	53.92	6.77	2.99*	221	9.48*
Longwood									
G. Cable skidder	1979:	383	7.08	0.71	16.01	3.04			
	1987:	97	8.30	0.80	22.99	4.43	2.12*	119	2.56*
H. Grapple skidder	1979:	170	7.64	0.46	21.66	2.97			
	1987:	200	9.25	0.98	21.13	4.08	1.89*	359	4.38*
Total (longwood)	1979:	553	7.32	0.46	21.66	3.02			
	1987:	297	8.87	0.80	22.99	4.24	1.97*	460	5.58*
Total (all classes)	1979:	3,680	15.25	0.46	180.00	11.28			
	1987:	463	10.07	0.74	53.92	5.58	4.08*	1,025	16.22*

[a]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

Weekly production declined from 1979 to 1987 for most shortwood classes, especially technology classes A and B, when measured on a per asset basis. However, this was not out of line with results obtained from increasing total asset levels (i.e., diminishing marginal returns), remembering that asset value for technology class A had risen substantially (table 6). Changes in other shortwood technology classes were insignificant. Average weekly production decreased for all shortwood classes combined by 31 percent from 1979 to 1987.

For each longwood class (G and H), there was a substantial increase in average weekly production. Production per assets rose 17 percent for technology class G and 26 percent for technology class H between surveys, although the capitalization level had not changed substantially for the H class. Average weekly production increased for all longwood classes combined by 21 percent from 1979 to 1987. For all classes combined, average production per assets fell 34 percent due to the increased capitalization level for all systems combined.

Production per employee.—Summary statistics and t-tests for average weekly production per employee are given in table 10. Production ranged from about 10 cords per week for technology classes A and B (shortwood) to more than 38 cords per week in 1987 for technology

Table 10.—*Average production in cords per week per employee by harvesting system technology class, 1979 and 1987*

Technology class	Survey	N	Mean	Min	Max	S.D.	F[a]	df	t ratio
Shortwood									
A. Manual bobtail	1979:	429	10.36	3.00	40.00	5.58			
	1987:	11	12.39	6.00	25.00	5.70	1.04	438	1.19
B. Semimanual bigstick	1979:	1,923	10.29	0.71	56.00	4.76			
	1987:	79	10.06	3.33	30.00	4.81	1.02	2,000	0.40
C. Manual/skidder	1979:	402	11.88	2.50	56.00	6.17			
	1987:	28	12.04	3.33	21.00	4.64	1.77	428	0.14
D. Forwarder	1979:	155	13.42	3.57	41.67	5.91			
	1987:	16	15.23	6.00	32.50	7.08	1.42	169	1.11
E. Cable skidder	1979:	191	15.77	2.40	120.00	10.35			
	1987:	19	14.14	2.43	25.00	5.98	2.99*	30	1.04
F. Grapple skidder	1979:	27	33.27	5.00	76.00	17.33			
	1987:	13	27.28	11.20	79.33	18.71	1.17	38	0.97
Total (shortwood)	1979:	3,127	11.31	0.71	120.00	6.64			
	1987:	166	12.08	2.43	79.33	7.55	1.29*	178	1.29
Longwood									
G. Cable skidder	1979:	383	23.69	1.82	60.00	10.39			
	1987:	97	26.48	3.00	66.67	15.19	2.14*	119	1.71***
H. Grapple skidder	1979:	170	31.49	2.00	79.80	13.44			
	1987:	200	38.49	4.42	163.25	19.02	2.00*	357	4.13*
Total (longwood)	1979:	553	27.01	1.82	79.80	12.40			
	1987:	297	33.67	3.00	163.25	18.54	2.24*	442	5.56*
Total (all classes)	1979:	3,680	14.50	0.71	120.00	10.31			
	1987:	463	25.15	2.43	163.25	18.49	3.22*	498	12.16*

[a]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

* *Significant to the 0.01 level.*
*** *Significant to the 0.10 level.*

class H (longwood). None of the shortwood subclasses changed significantly in average weekly production per employee from 1979 to 1987. For all shortwood classes combined, the change also was small.

Longwood systems had relatively large increases in the reported weekly production per employee. Longwood technology class G increased by about 3 cords per week, while technology class H rose by more than 6 cords per week per employee. Both were significant. For all longwood classes combined, weekly production rose significantly—by 25 percent, from 27 to 34 cords per week. For all systems combined, production per employee increased by 73 percent, from 15 to 25 cords per week. Once again, this was largely a result of population movements between system classes.

Average Cost

Table 11 gives t-tests and summary statistics for short-run average costs per cord by technology class, product, and survey period. Both arithmetic and production-weighted averages were calculated. Figure 1 illustrates average costs per cord by technology class and survey period using the production-weighted average cost. T-tests were based on arithmetic means.

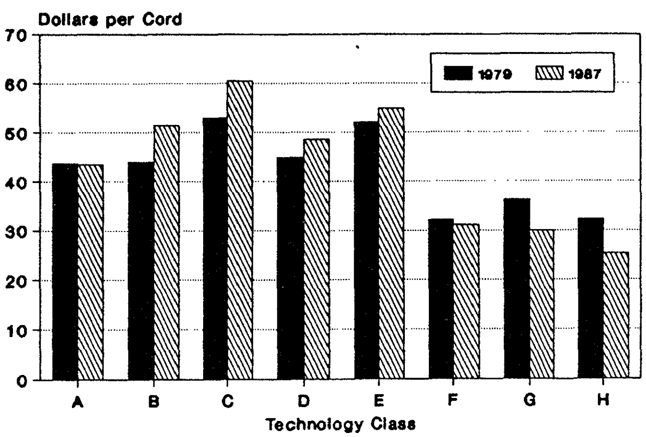

Figure 1.—*Average costs per cord by harvesting system technology class, 1979 and 1987.*

Shortwood systems B through D, and F had higher average costs per cord in 1987 than in 1979, although only the costs for technology class B were statistically significant. Only technology classes A and E had lower arithmetic average costs in 1987 than in 1979, but changes were not significant. The production-weighted average cost for technology class E however, was still higher. For technology class F, the production-weighted average cost was lower but insignificant. For all shortwood pulpwood combined, arithmetic average costs increased significantly from $50.93 to $56.75 per cord, an 11-percent increase. For the production-weighted average cost, the increase was only 8 percent.

These average cost figures were higher than the reported margins between stumpage and delivered softwood pulpwood prices (table 3). Calculated average costs, however, may not have represented actual costs to the producer in the short run. One possible reason for this was that labor was calculated as a fixed and not a variable cost, and at full employment. This would have tended to overestimate average cost somewhat at low production levels, especially for technology classes A and B, where the largest proportion of average cost was attributable to labor. Another reason was that producers may not be explicitly accounting for depreciation and other opportunity costs in all equipment reported in the survey. According to economic theory, in the short run, firms will operate as long as they can cover their variable costs. It should be noted that average cost estimates were most sensitive to reported weekly production, equipment spread, and number of employees. Finally, smaller shortwood systems may have received a premium for harvesting smaller tracts, tracts without particularly high timber volumes, or tracts with difficult terrain. The range between minimum and maximum average costs in table 11 shows that there were owners operating within a "profitable" range as defined by the harvest margin in table 3. Clearly, however, there seemed to have been pressure on these producers to find ways to decrease cost levels.

For longwood classes, the reverse appeared true. Both longwood classes had lower average costs between survey periods, although only results from technology class H (longwood-grapple skidding) were statistically significant. Technology class H had the lowest estimated average costs of all systems at $31.52 per cord. The production-weighted average cost was lower at $25.36 per cord. For all pulpwood classes combined, the production-weighted average cost per cord was $28.80 per cord in 1987. This was very close to the estimated harvesting margin of $30.49 per cord given in table 3 for 1987. The estimated harvesting margin (table 3) and production-weighted average cost (table 11) were slightly higher for the 1979 data, $36.51 and

Table 11.—*Average costs per cord (in dollars) by harvesting system technology class, 1979 and 1987*[a]

Technology class	Survey	N	Mean	Mean[b]	Min	Max	S.D.[c]	F[d]	df	t ratio
Shortwood										
A. Manual bobtail	1979:	429	47.79	43.74	17.60	103.89	16.35			
	1987:	11	47.55	43.48	25.57	68.07	14.92	1.20	438	0.05
B. Semimanual bigstick	1979:	1,923	48.63	43.96	20.28	388.00	16.92			
	1987:	79	55.13	51.44	24.68	117.98	17.07	1.02	2,000	3.35*
C. Manual/skidder	1979:	402	60.67	52.91	23.27	171.37	20.23			
	1987:	28	66.05	60.53	38.82	151.27	26.55	1.72	428	1.33
D. Forwarder	1979:	155	51.29	44.83	20.88	122.50	17.93			
	1987:	16	54.28	48.61	31.40	90.92	15.72	1.30	169	0.64
E. Cable skidder	1979:	191	62.80	52.04	24.91	272.72	30.99			
	1987:	19	60.77	54.90	34.26	215.79	23.91	1.68	208	0.28
F. Grapple skidder	1979:	27	39.76	32.18	17.72	124.04	22.59			
	1987:	13	46.94	31.10	15.75	70.61	21.72	1.08	38	0.95
Total (shortwood)	1979:	3,127	50.93	45.37	17.60	388.00	19.31			
	1987:	166	56.75	48.89	15.75	215.79	20.43	1.12	3,291	3.77*
Longwood										
G. Cable skidder	1979:	383	45.89	36.29	20.93	320.77	29.78			
	1987:	97	44.10	29.96	15.67	216.97	33.88	1.29	478	0.51
H. Grapple skidder	1979:	170	36.88	32.32	15.56	395.60	26.07			
	1987:	200	31.52	25.36	12.94	169.94	21.01	1.54*	323	2.19**
Total (longwood)	1979:	553	42.05	34.03	15.56	395.60	28.60			
	1987:	297	36.56	26.40	12.94	216.97	27.57	1.08	848	2.70*
Total (all classes)	1979:	3,680	49.13	38.73	15.56	395.60	21.82			
	1987:	463	44.53	28.80	12.94	216.97	26.88	1.52*	541	4.16*

[a]*Indexed to 1988 dollars.*
[b]*Production-weighted average.*
[c]*Based on arithmetic average.*
[d]*Folded form of the F statistic used to test the hypothesis that the population variances are equal. If the hypothesis is rejected at the 0.01 level of confidence, then an unequal variance t-test procedure is used. The degrees of freedom are similarly calculated based on the test chosen.*

* *Significant to the 0.01 level. Based on arithmetic average.*
** *Significant to the 0.05 level. Based on arithmetic average.*

$38.73 per cord, respectively. The estimated harvesting margin in 1979 (table 3) was relatively close, however, to the production-weighted average cost for longwood producers in 1979 (table 11) at $36.51 and $34.03 per cord, respectively.

For all longwood classes combined, there was a significant decline in arithmetic average cost from $42.05 to $36.56 per cord, a 13-percent decrease. The production-weighted average cost declined from $34.03 to $26.40 per cord, a 22-percent decrease. However, even the arithmetic averages were higher than the derived harvesting profit margin, suggesting that pressure was also being placed on many longwood operators, particularly cable skidder operators, to lower costs. This pressure was likely being caused by the cheaper longwood-grapple skidder operations.

In real terms, the estimated harvesting margin declined by $6.02 per cord (table 3). This decrease may be attributed largely to two effects: (1) the large decline in average longwood system costs, and (2) the high percentage of the total pulpwood harvesting population shifting to longwood production.

These conclusions were reinforced by the results presented in table 4. In 1979, shortwood producers made up 80 percent of total operations and produced 41 percent of total pulpwood volume. In 1987, this segment made up about 40 percent of operations and produced only about 10 percent of total volume. The largest population shift was found in technology class H (longwood-grapple skidding)—from 9 percent to 36 percent of the total number of operators. This class produced 71 percent of the total pulpwood volume in 1987, compared to only 35 percent in 1979.

Cost Functions

Average cost functions for each harvesting system technology class are summarized in tables 12 and 13. As mentioned earlier, we used two functional forms for average cost: the logarithmic and quadratic. Dummy variables were used to separate survey periods. This provided a method for analyzing both intercept and slope shifts in the average cost functions.

Both functional forms generally had quite favorable summary statistics; all regressions were significant as were t statistics for the primary production variable (and squared quadratic terms). Coefficients of determination (R^2) ranged from 0.24 to 0.70. These R^2 values indicate that although the regressions were statistically significant, much variation in the average costs was not attributable to average production alone. Many factors determine harvesting costs.

Although R^2 values are not directly comparable between these two transformations of the data, overall analysis of R^2 values and residual plots indicated that the logarithmic functional form generally provided the best results for low production levels. The logarithmic formulation provided for average costs that decrease throughout the range of output (fig. 2). Economic theory, however, suggests that cost functions should be U-shaped. The logarithmic function suggests, for example, that technology class A provided the lowest average cost at all production levels, and therefore, all production should have originated from this technology class. The quadratic cost functions summarized in table 13 and illustrated in figure 3 provide a more theoretically accepted model of cost behavior. However, these forms also had limitations and could not model well the extremely high average costs associated with low production levels. They did, using the available information contained in the data, provide a theoretical minimum cost level and illustrated why technology class A was not necessarily the desired class to maximize profits.

The cost functions represented in figures 2 and 3 should be interpreted as long run due to the cross-sectional nature of the data. They roughly represented the cost envelope for firms of different size and composition within a technology class. The distinction is important because it means that not every firm size would have been able to reach the minimum average cost by simply increasing (decreasing) output level. For example, long-run minimum average cost for technology class A could have been reached at about 60 cords per week (in 1979), but only with the optimum firm size and labor/capital composition. Technology class F (grapple skidder) had, by far, the largest economies of scale of any shortwood class.

Changes in average cost functions (i.e., technology) between 1979 and 1987 were evaluated through the use of a joint F test that tested if the dummy intercept and slope shifters were equal to zero. The results showed that all technology

Table 12.—Logarithmic average cost functions by harvesting system technology class[a]

Technology class	Regression equation	R^2	F[b]	df	F[c]
Shortwood					
A. Manual bobtail	lnAC=4.8637-0.3603lnWP-0.2075D+0.0896DlnWP (-12.4)* (-0.86) (1.21)	0.28	56.24*	436	2.52***
B. Semimanual bigstick	lnAC=4.9794-0.3602lnWP+0.4561D-0.0973DlnWP (-33.9)* (4.31)* (-3.02)*	0.43	495.4*	1,998	64.12*
C. Manual/skidder	lnAC=5.3546-0.3792lnWP-0.1182D+0.0674DlnWP (-18.7)* (-0.72) (1.49)	0.50	141.1*	426	16.38*
D. Forwarder	lnAC=5.3912-0.3702lnWP-0.0290D+0.0406DlnWP (-11.7)* (-0.09) (0.59)	0.50	56.45*	167	6.52*
E. Cable skidder	lnAC=5.8249-0.4374lnWP-0.5937D+0.1379DlnWP (-14.3)* (-2.02)** (1.92)***	0.52	75.41*	206	2.25***
F. Grapple skidder	lnAC=5.5799-0.4020lnWP+0.2773D-0.0569DlnWP (-4.72)* (0.50) (-0.53)	0.67	23.89*	36	0.14
Total (shortwood)	lnAC=4.5870-0.2168lnWP+0.2455D-0.0291DlnWP (-26.9)* (3.84)* (-1.64)	0.24	348.0*	3,289	68.59*
Longwood					
G. Cable skidder	lnAC=5.5121-0.3816lnWP+0.6352D-0.1770DlnWP (-17.5)* (4.39)* (-5.91)*	0.70	362.5*	476	59.68*
H. Grapple skidder	lnAC=5.5076-0.3685lnWP+0.1274D-0.0509DlnWP (-8.30)* (0.46) (-1.00)	0.53	135.5*	366	14.72*
Total (longwood)	lnAC=5.4203-0.3577lnWP+0.1832D-0.0654DlnWP (-18.1)* (1.44) (-2.68)*	0.61	445.6*	846	38.73*
Total (all classes)	lnAC=4.5524-0.1999lnWP+0.7168D-0.1614DlnWP (-37.3)* (18.7)* (-19.1)*	0.55	1,681*	4,139	183.4*

[a]*Average cost using market-based depreciation, 1988 input costs. lnAC = natural log of harvest cost in dollars per cord; lnWP = natural log of harvest system production per week; D = dummy variable for 1987 survey.*
[b]*Test for overall regression significance.*
[c]*Test for structural change between 1979 and 1987.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

classes except technology class F had significantly different cost curves in 1987 than they did in 1979 for both logarithmic and quadratic functions (tables 12 and 13). However, results of t-tests for individual intercept and slope shifters were mixed, with some significant and some not.

Logarithmic results.—Results of the logarithmic form for technology classes A through D indicated that average costs had increased over the entire range of output from 1979 to 1987 (table 12). For technology class E, average costs declined for production levels below 80 cords per week and increased above this level. Technology class G had lower costs for all production levels above 30 cords per week. Technology class H had lower harvesting costs over the entire range of output from 1979 and 1987.

For all shortwood classes combined, costs were higher in 1987 than in 1979 for all production

Table 13.—*Quadratic average cost functions by harvesting system technology class*[a]

Technology class	Regression equation	R^2	F[b]	df	F[c]
Shortwood					
A. Manual bobtail	AC=68.24-1.2806WP+0.0107WP²-6.2327D+0.5848DWP-0.0066DWP² (-7.75)* (4.85)* (-0.78) (1.23) (-1.03)	0.28	34.16*	434	2.74**
B. Semimanual bigstick	AC=68.60-0.9556WP+0.0056WP²+19.689D-0.6815DWP+0.0069DWP² (-20.6)* (12.8)* (4.94)* (-3.01)* (2.37)**	0.38	239.6*	1,996	32.91*
C. Manual/skidder	AC=80.53-0.7196WP+0.0025WP²+35.433D-1.4494DWP+0.0159DWP² (-11.9)* (7.81)* (4.11)* (-3.73)* (3.96)*	0.45	68.69*	424	14.88*
D. Forwarder	AC=82.76-0.6484WP+0.0021WP²+10.079D-0.1222DWP+0.0008DWP² (-8.05)* (5.95)* (0.82) (-0.43) (0.57)	0.48	30.33*	165	6.01*
E. Cable skidder	AC=99.38-0.7614WP+0.0022WP²+5.0588D-0.4104DWP+0.0034DWP² (-6.93)* (4.39)* (0.40) (-1.23) (1.77)***	0.45	33.05*	204	3.04**
F. Grapple skidder	AC=61.45-0.2037WP+0.0003WP²+20.866D-0.1796DWP+0.0003DWP² (-1.84)*** (1.31) (1.40) (-1.24) (1.00)	0.62	11.02*	34	0.99
Total (shortwood)	AC=54.98-0.1915WP+0.0003WP²+8.2911D-0.0176DWP-0.0001DWP² (-15.5)* (8.99)* (6.54)* (-0.70) (-0.83)	0.24	207.26*	3,287	41.85*
Longwood					
G. Cable skidder	AC=67.28-0.2533WP+0.0004WP²+1.4737D-0.0794DWP+0.0001DWP² (-8.06)* (6.00)* (0.34) (-1.85)*** (1.47)	0.45	76.33*	474	16.60*
H. Grapple skidder	AC=53.69-0.1031WP+0.0001WP²-7.4434D+0.0233DWP-0.00004DWP² (-2.86)* (1.99)** (-1.97)** (1.42) (-1.35)	0.33	36.30*	364	6.46*
Total (longwood)	AC=57.44-0.1357WP+0.0001WP²-10.032D+0.0447DWP-0.0001DWP² (-7.77)* (5.14)* (-3.44)* (2.36)** (-2.71)*	0.35	92.43*	844	16.12*
Total (all classes)	AC=52.87-0.1135WP+0.0001WP²+0.1072D-0.0013DWP-0.00003DWP² (-19.4)* (10.3)* (0.12) (-0.19) (-2.77)*	0.44	646.6*	4,137	34.37*

[a] *Average cost using market-based depreciation, 1988 input costs. AC = harvest cost in dollars per cord; WP = harvest system production per week; D = dummy variable for 1987 survey.*
[b] *Test for overall regression significance.*
[c] *Test for structural change between 1979 and 1987.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

levels (fig. 4). This was consistent with the cost comparisons presented in table 11. For all longwood classes combined, the 1987 cost curve survey was below the 1979 curve (fig. 5). As might be expected, there were significant changes in the average cost function for all classes combined (fig. 6). However, average costs in 1987 were higher at low production levels but quickly fell below the 1979 cost curve after about 80 cords per week.

Quadratic results.—Results of the quadratic average cost functions (table 13) indicated that all technology classes, except for technology class F, had significantly different cost curves in 1987 than in 1979. Generally speaking, cost intercepts were higher and slopes were steeper for shortwood systems, while the reverse was true for longwood systems.

Average costs increased for all shortwood classes combined as indicated by the significant intercept shift. Figure 7 shows, however, that at extremely high shortwood production levels, average costs in 1987 could fall below 1979 levels. This result was unlikely to occur for most firms in practice considering average production levels. Average costs significantly decreased for all longwood classes combined (fig. 8) and indicated that theoretical minimum average cost could be achieved at higher production levels. For all classes combined, average costs declined

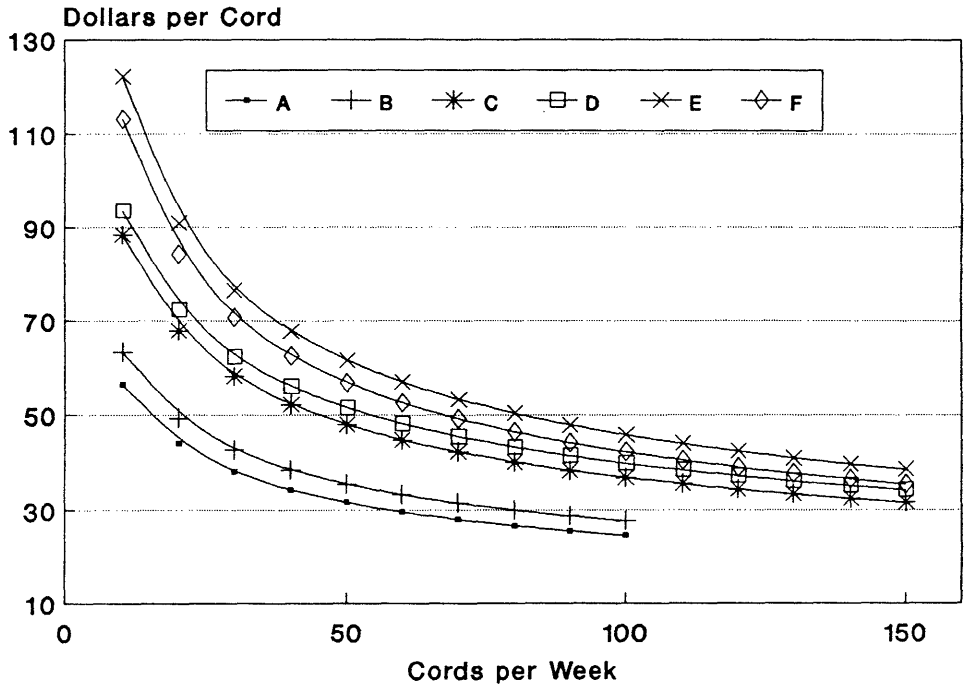

Figure 2.—*Logarithmic average cost curves by harvesting system technology class, 1979.*

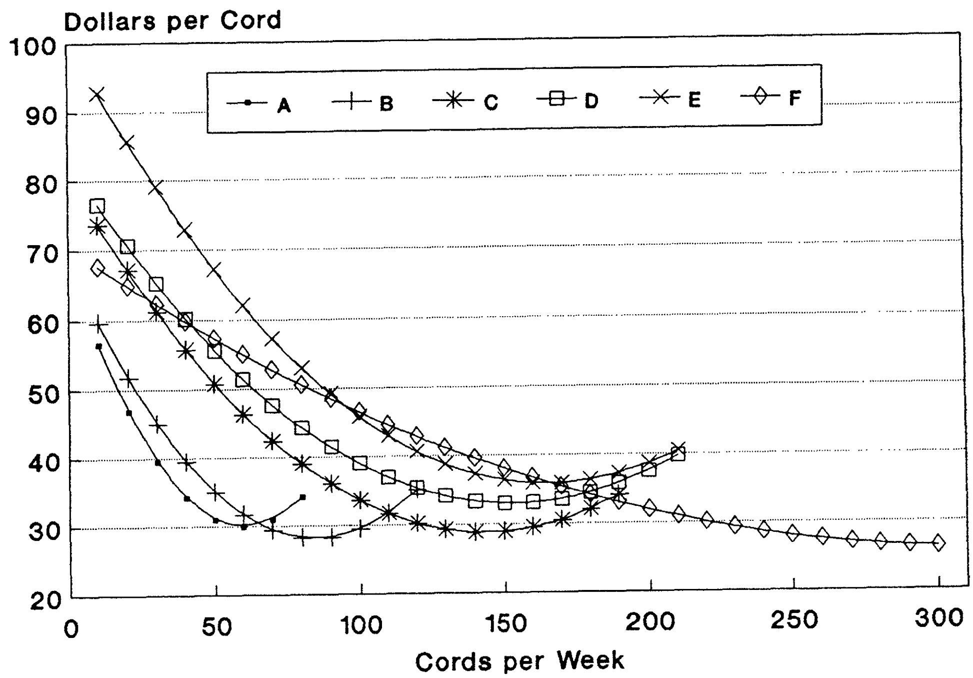

Figure 3.—*Quadratic average cost curves by harvesting system technology class, 1979.*

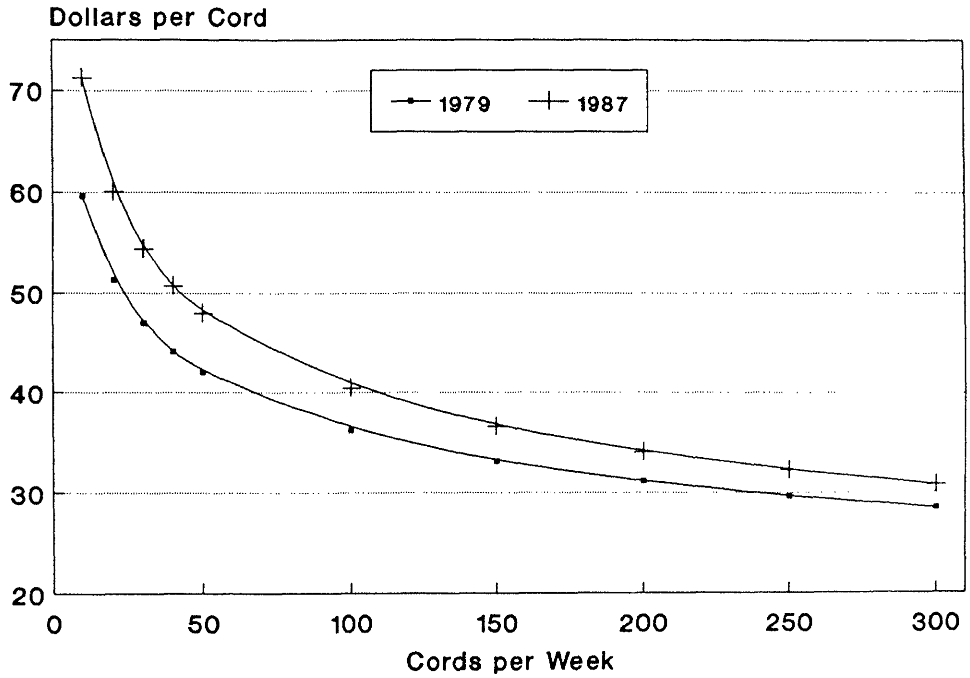

Figure 4.—*Logarithmic average cost curves for all shortwood classes combined, 1979 and 1987.*

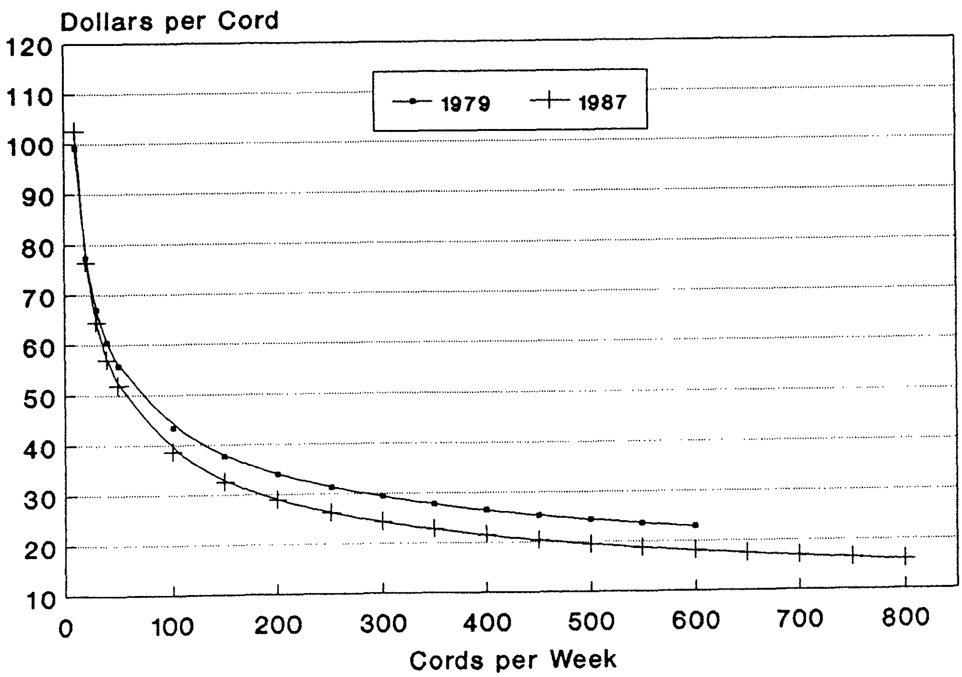

Figure 5.—*Logarithmic average cost curves for all longwood classes combined, 1979 and 1987.*

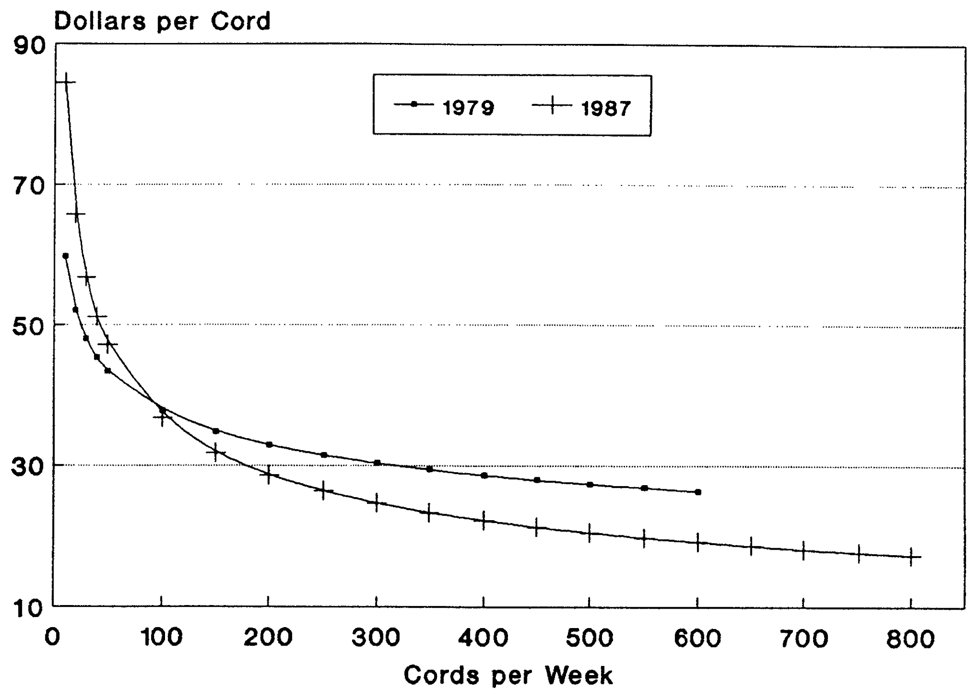

Figure 6.—*Logarithmic average cost curves for all classes combined, 1979 and 1987.*

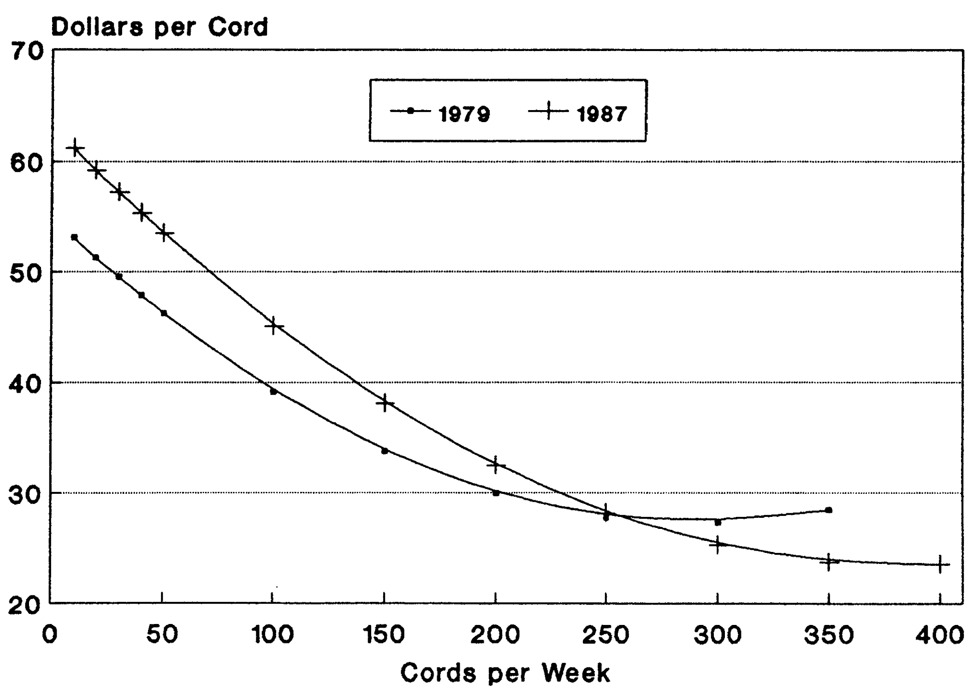

Figure 7.—*Quadratic average cost curves for all shortwood classes combined, 1979 and 1987.*

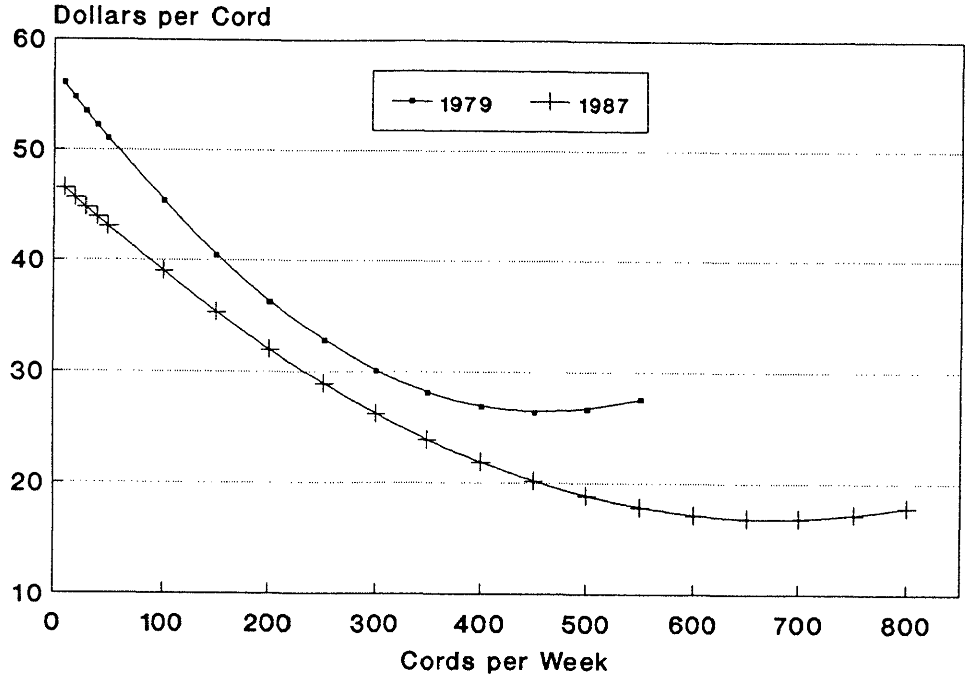

Figure 8.—*Quadratic average cost curves for all longwood classes combined, 1979 and 1987.*

after about 150 cords per week, showing that theoretical minimum average cost could be achieved at higher production levels (fig. 9).

Figures 10, 11, and 12 illustrate the relationship between logarithmic and quadratic cost functions for all shortwood classes (fig. 10), all longwood classes (fig. 11), and all classes combined (fig. 12). Note that the logarithmic curves were nonincreasing in output, but were able to characterize the high average costs associated with low output levels. Again, this resulted from the rather inflexible specifications of these functions.

Production Functions

Production function results of Cobb-Douglas and linear functional forms are given in tables 14 and 15. Overall, summary statistics were favorable. All regressions were significant. R^2 values ranged from 0.34 to 0.81 for the linear form and from 0.33 to 0.66 for the Cobb-Douglas form. Generally speaking, crew asset and employee values were significant in explaining output variability. Results of the joint F-test for structural (i.e., technological) change showed that almost all production functions had shifted from 1979 to 1987 except for technology classes C, D, and E using the Cobb-Douglas form and technology classes D, E, and F using the linear form. As in the preceding discussion of cost functions, results of individual t-tests for dummy intercept and slope shifters were mixed.

Cobb-Douglas results.—As stated previously, primary regression coefficients in the Cobb-Douglas form are partial output elasticities (table 14). The closer either is to 1.0 (or 0.0), the greater (lesser) its contribution to total production. Virtually all partial output elasticities fell between 0 and 1, a result consistent with diminishing marginal returns to factor usage. Except for technology classes E and F, partial output elasticities for labor were higher for the shortwood technology classes than for the longwood classes, implying the labor-intensive nature of shortwood classes. In a Cobb-Douglas formulation where the sum of the partial output elasticities is restricted to equal one, the same elasticities are also the relative output shares. Therefore, we can assess the relative intensity of labor in each system. For example, the labor partial output elasticity coefficient was 0.64 for

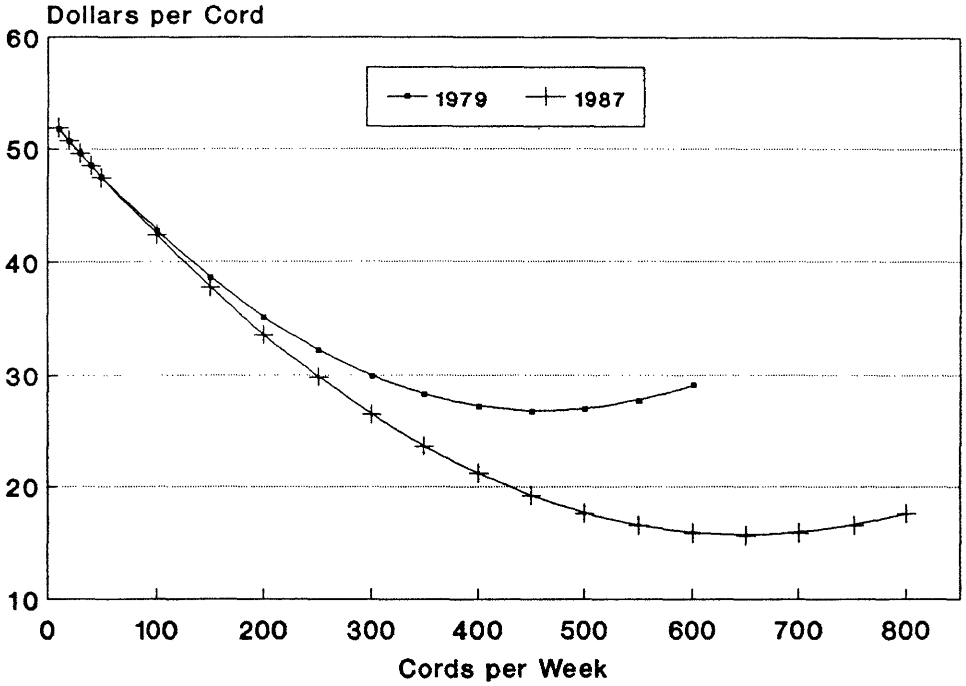

Figure 9.—*Quadratic average cost curves for all classes combined, 1979 and 1987.*

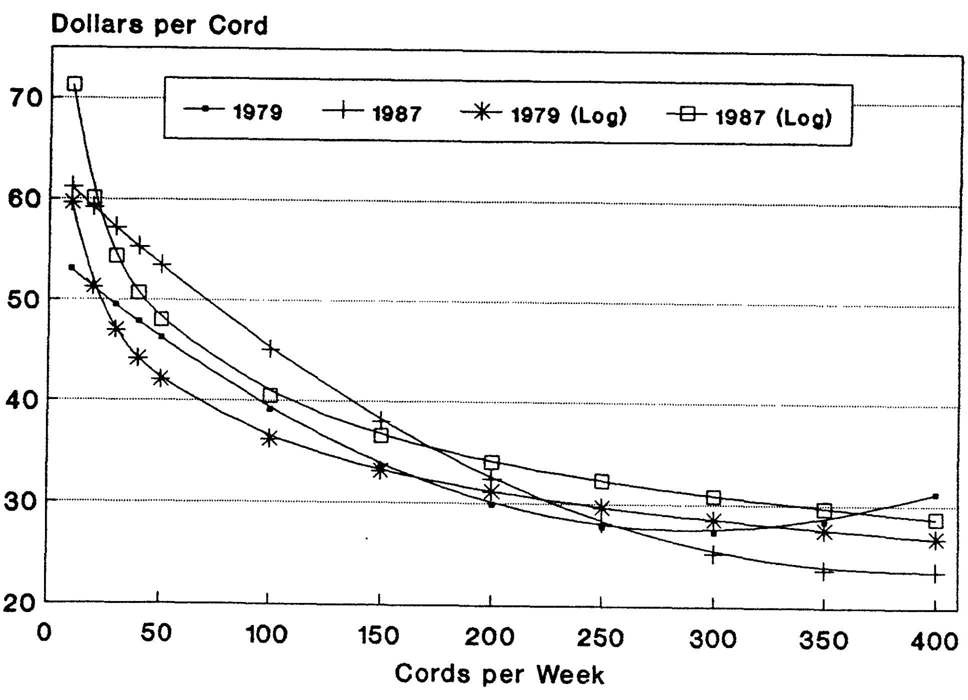

Figure 10.—*Logarithmic and quadratic average cost curves for all shortwood classes combined, 1979 and 1987.*

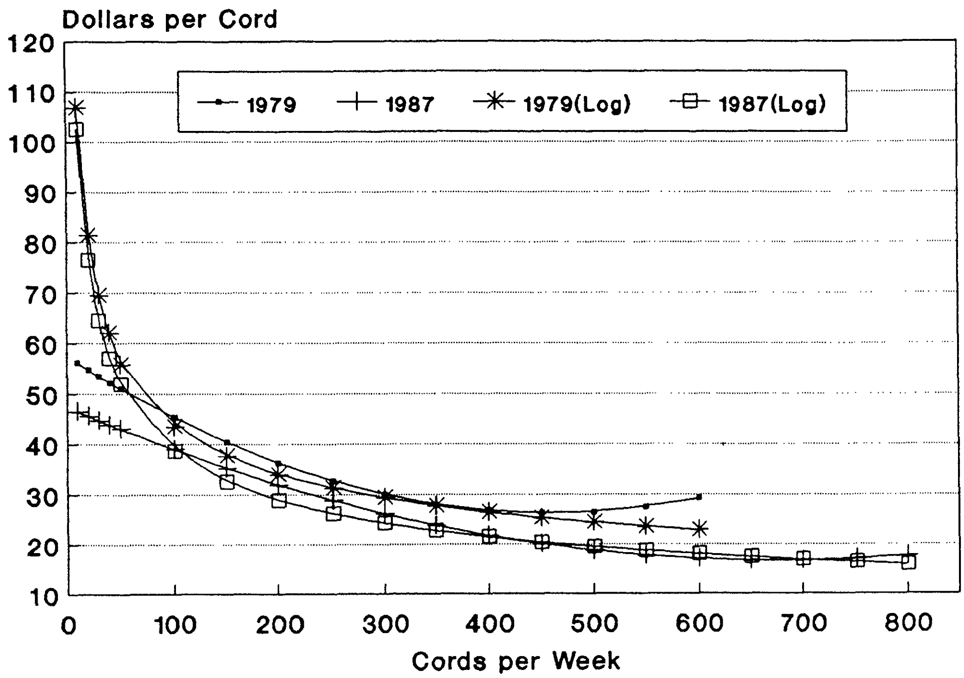

Figure 11.—*Logarithmic and quadratic average cost curves for all longwood classes combined, 1979 and 1987.*

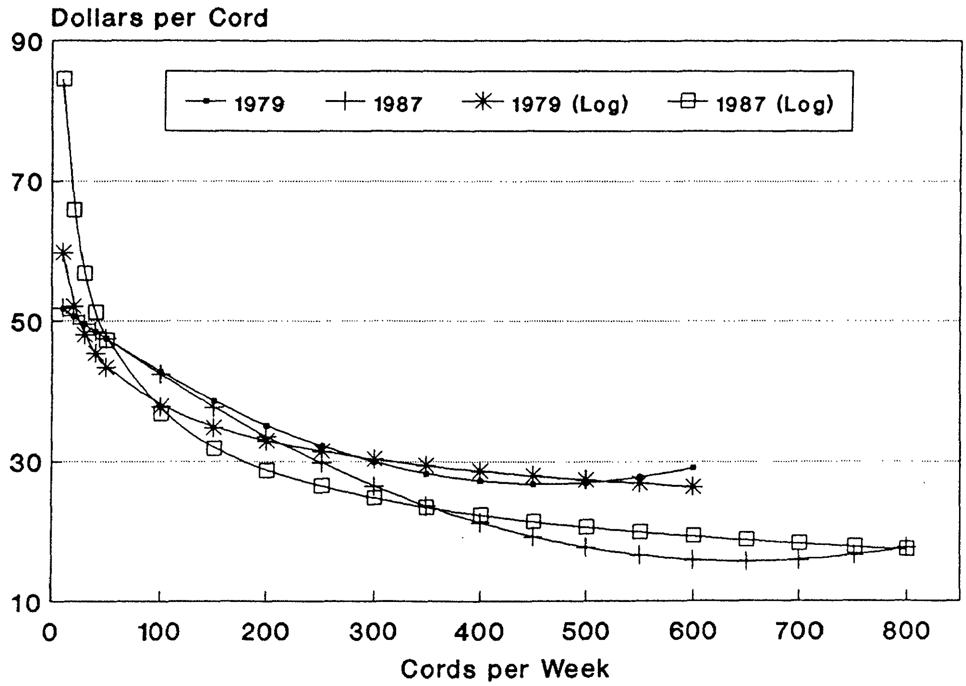

Figure 12.—*Logarithmic and quadratic average cost curves for all classes combined, 1979 and 1987.*

Table 14.—*Cobb-Douglas production functions by harvesting system technology class*[a]

Technology class	Regression equation	R^2	F[b]	df	F[c]
Shortwood					
A. Manual bobtail	lnWP=1.951+0.2858lnAST+0.4184lnEMP+0.2647D-0.2060DlnAST+0.4660DlnEMP	0.44	67.46*	434	2.83**
	(4.97)* (10.3)* (0.67) (-1.44) (2.86)*				
B. Semimanual bigstick	lnWP=1.893+0.2675lnAST+0.6300lnEMP-0.4570D+0.2489DlnAST-0.3314DlnEMP	0.34	201.7*	1,996	12.42*
	(7.59)* (27.0)* (-1.65)*** (2.46)** (-4.86)*				
C. Manual/skidder	lnWP=1.069+0.4490lnAST+0.6447lnEMP+0.6460D-0.1304DlnAST-0.1561DlnEMP	0.44	66.15*	424	1.69
	(6.71)* (11.7)* (1.73)*** (-1.28) (-1.36)				
D. Forwarder	lnWP=1.645+0.2695lnAST+0.8082lnEMP-1.2750D+0.3009DlnAST+0.0153DlnEMP	0.58	45.93*	165	0.93
	(3.32)* (9.49)* (-1.50) (1.49) (0.08)				
E. Cable skidder	lnWP=0.702+0.5391lnAST+0.5269lnEMP+2.6819D-0.7563DlnAST+0.5785DlnEMP	0.39	26.34*	204	2.05
	(3.29)* (3.52)* (2.42)** (-2.43)** (1.74)***				
F. Grapple skidder	lnWP=0.035+0.8430lnAST+0.2023lnEMP-13.525D+3.2456DlnAST-2.4618DlnEMP	0.68	14.35*	34	3.95**
	(1.26) (0.37) (-2.88)* (2.85)* (-2.39)**				
Total (shortwood)	lnWP=1.820+0.2829lnAST+0.6427lnEMP-0.2009D+0.0866DlnAST-0.1303DlnEMP	0.54	786.4*	3,287	8.90*
	(24.6)* (33.8)* (-2.55)* (3.17)* (-2.74)*				
Longwood					
G. Cable skidder	lnWP=-0.32+0.8366lnAST+0.4277lnEMP-0.2438D+0.1080DlnAST-0.1012DlnEMP	0.48	86.22*	474	2.35**
	(6.44)* (3.49)* (-0.30) (0.52) (-0.49)				
H. Grapple skidder	lnWP=0.710+0.7191lnAST+0.2695lnEMP+1.2018D-0.3678DlnAST+0.5398DlnEMP	0.48	66.66*	364	7.09*
	(3.22)* (1.63) (1.03) (-1.47) (2.80)*				
Total (longwood)	lnWP=-0.37+0.8855lnAST+0.3138lnEMP+0.7783D-0.2273DlnAST+0.3489DlnEMP	0.59	245.3*	844	11.04*
	(8.86)* (3.24)* (1.51) (-1.80)*** (2.73)*				
Total (all classes)	lnWP=1.508+0.3934lnAST+0.6642lnEMP-0.6978D+0.1717DlnAST+0.0282DlnEMP	0.81	342.6*	4,137	65.94*
	(38.3)* (31.7)* (-12.3)* (8.68)* (0.68)				

[a] *ln = natural log; WP = harvest system weekly cord production; AST = crew assets in thousands of 1988 dollars; EMP = number of employees per crew; D = dummy variable for 1987 survey.*
[b] *Test for overall regression significance.*
[c] *Test for structural change between 1979 and 1987.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

all shortwood systems combined, while it was only 0.31 for all longwood systems combined. The capital partial output elasticity was only 0.28 for shortwood systems but was 0.89 for longwood systems. These results clearly show the magnitude of importance of capital in the mechanized systems and labor in the manual systems.

Although the all-shortwood-combined regression showed significant t- and F-test statistics for structural change, the practical effect on output was negligible. These changes were primarily due to shifts in the labor-capital mix with increased capital and decreased labor shares. Figure 13 shows predicted output levels for increasing labor-capital input ratios. This figure indicates that there was no real effect in output for shortwood systems between 1979 and 1987. Furthermore, the function coefficient for all shortwood systems in table 16 indicates that shortwood systems had decreasing returns to scale in both survey periods, with function coefficients of 0.93 in 1979 and 0.88 in 1987. That is, as they have grown larger, they have become less efficient.

Different results occurred for longwood systems. The production function had changed noticeably from 1979 to 1987 (fig. 14). At low labor-capital input ratios, there was little difference in production functions between 1979 and 1987. But

Table 15.—*Linear production functions by harvesting system technology class*[a]

Technology class	Regression equation	R^2	F^b	df	F^c
Shortwood					
A. Manual bobtail	WP=4.322+0.5873AST+4.3690EMP-2.4094D-0.5714DAST+5.8044DEMP (7.10)* (11.5)* (-0.78) (-3.75)* (3.03)*	0.45	70.23*	434	6.20*
B. Semimanual bigstick	WP=2.104+0.4820AST+6.6083EMP+2.8253D+0.2411DAST-3.5854DEMP (7.20)* (26.9)* (0.93) (1.40) (-5.22)*	0.33	197.0*	1,996	15.01*
C. Manual/skidder	WP=-1.89+0.3010AST+7.7055EMP+7.2508D-0.1921DAST-0.1789DEMP (5.40)* (11.0)* (1.34) (-3.11)* (-0.11)	0.42	61.10*	424	3.60**
D. Forwarder	WP=-3.09+0.2131AST+10.407EMP-14.663D+0.3631DAST-2.1172DEMP (3.29)* (9.78)* (-0.82) (1.90)*** (-0.86)	0.60	47.47*	165	1.26
E. Cable skidder	WP=-4.26+0.3453AST+6.1809EMP-1.9174D-0.1982DAST+4.4698DEMP (4.21)* (3.13)* (-0.15) (-1.29) (1.10)	0.44	31.91*	204	1.05
F. Grapple skidder	WP=48.94+0.5631AST-2.5997EMP-100.15D+1.5929DAST-46.848DEMP (1.52) (-0.17) (-1.61) (1.48) (-1.01)	0.62	11.16*	34	1.75
Total (shortwood)	WP=3.673+0.3204AST+6.5842EMP+4.6847D+0.0220DAST-2.4368DEMP (20.4)* (32.0)* (3.43)* (0.53) (-5.02)*	0.40	443.2*	3,287	10.46*
Longwood					
G. Cable skidder	WP=-26.7+0.5191AST+11.497EMP-11.602D+0.0237DAST+7.0984DEMP (7.31)* (5.01)* (-0.99) (0.21) (1.78)***	0.57	125.8*	474	7.91*
H. Grapple skidder	WP=21.94+0.5333AST+6.0032EMP-78.237D+0.0092DAST+17.601DEMP (4.29)* (1.58) (-2.73)* (0.06) (3.57)*	0.55	87.98*	364	16.91*
Total (longwood)	WP=-22.9+0.5923AST+8.8433EMP-32.589D+0.0423DAST+10.699DEMP (10.9)* (4.52)* (-3.48)* (0.54) (3.51)*	0.66	330.6*	844	24.39*
Total (all classes)	WP=1.613+0.4681AST+6.6089EMP-14.1097+0.2059DAST+2.5254DEMP (41.4)* (30.0)* (-6.23)* (9.00)* (2.86)*	0.65	1,562	4,137	66.12*

[a] *WP = harvest system weekly cord production; AST = crew assets in thousands of 1988 dollars; EMP = number of employees per crew; D = dummy variable for 1987 survey.*

[b] *Test for overall regression significance.*

[c] *Test for structural change between 1979 and 1987.*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*
*** *Significant to the 0.10 level.*

for increasing levels of input, the difference widened greatly. Furthermore, table 16 shows that in 1987, longwood systems exhibited increasing returns to scale with a function coefficient of 1.32, up from 1.20 in 1979. For all longwood combined, the capital partial output elasticity fell from 1979 to 1987 while the labor partial output elasticity increased, indicating that labor was contributing more to output in 1987 than in 1979.

Finally, for all technology classes combined, there were significant shifts in the production function. The capital partial output elasticity increased, while labor did not change. Structural change in the production function indicates substantially improved productivity as shown graphically in figure 15. Two factors were at work here: first, more firms shifted into longwood production from 1979 to 1987, and second, longwood systems became more productive over time than shortwood systems. Table 16 also shows that there were increasing returns to scale in southern pulpwood harvesting in 1987 with a function coefficient of 1.26, up from 1.06 in 1979.

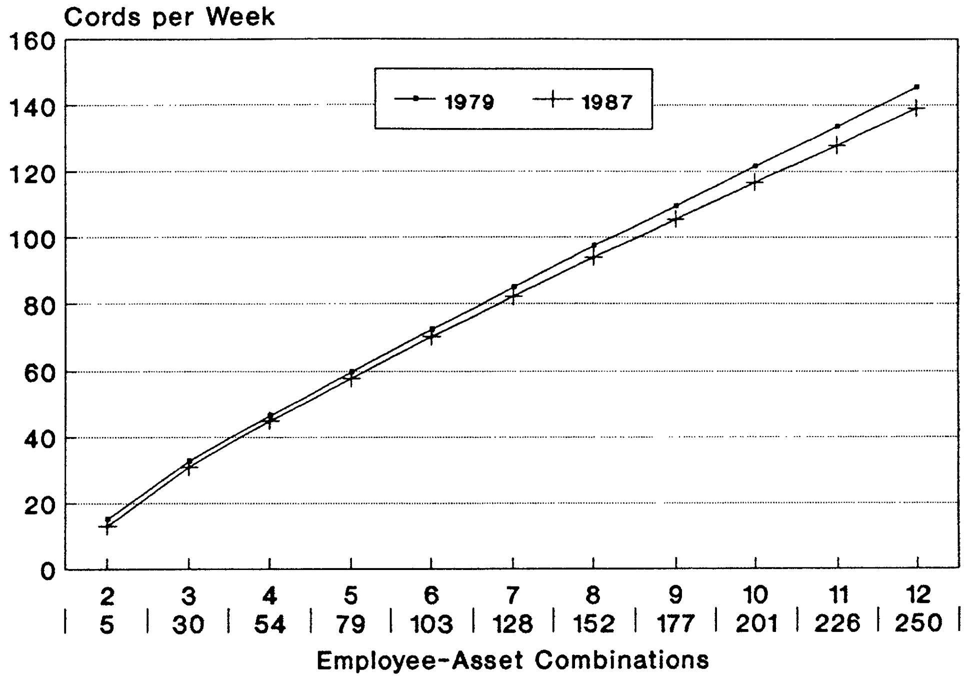

Figure 13.—*Predicted average production for alternative labor-capital input ratios for all shortwood classes combined, Cobb-Douglas production function, 1979 and 1987.*

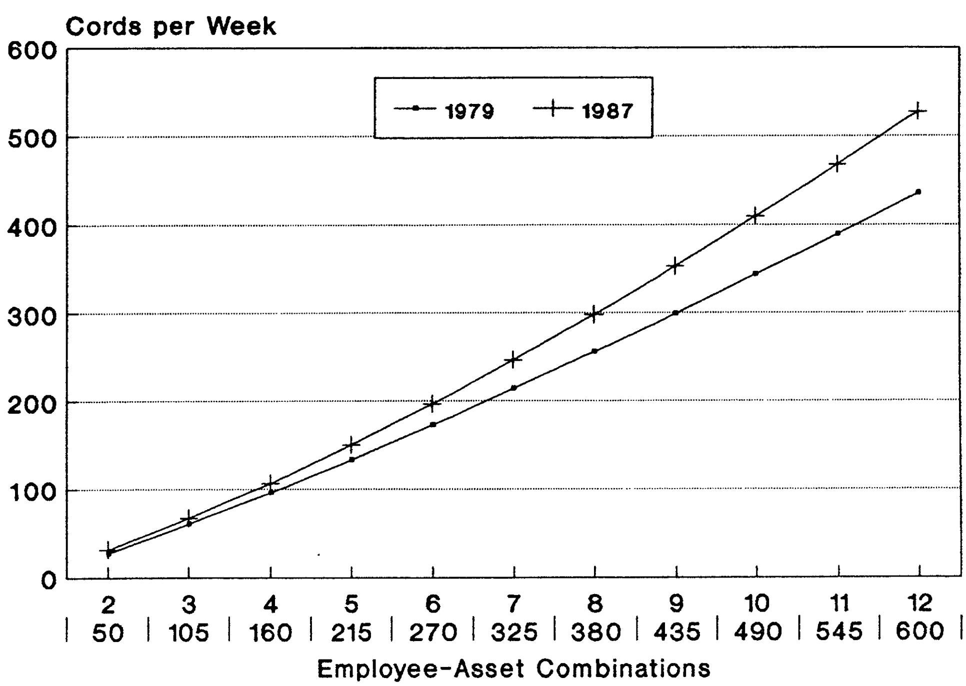

Figure 14.—*Predicted average production for alternative labor-capital input ratios for all longwood classes combined, Cobb-Douglas production function, 1979 and 1987.*

Table 16.—*Returns to scale by harvesting system technology class, 1979 and 1987*

Technology class	Function coefficient 1979	1987
<u>Shortwood</u>		
A. Manual bobtail	0.70*	0.96
B. Semimanual bigstick	0.90**	0.82**
C. Manual/skidder	1.10	0.81**
D. Forwarder	1.08	1.39**
E. Cable skidder	1.07	0.89**
F. Grapple skidder	1.05	1.83**
Total (shortwood)	0.93*	0.88*
<u>Longwood</u>		
G. Cable skidder	1.26*	1.27*
H. Grapple skidder	0.99	1.16*
Total (longwood)	1.20*	1.32*
Total (all classes)	1.06*	1.26*

* *Significant to the 0.01 level.*
** *Significant to the 0.05 level.*

Linear results.—Results from the linear production functions (table 15) were similar in explanatory power to the Cobb-Douglas ones. Structural change in the production function was significant for all but technology classes D, E, and F. As mentioned earlier, coefficients represent marginal productivities of capital (per $1,000 in assets) and labor (per employee).

The marginal productivity of labor rose substantially in both longwood systems. Results were mixed in shortwood systems. There was a slight, but insignificant increase in the marginal productivity of capital in shortwood systems. Overall, however, the marginal productivity of labor declined in shortwood systems. There was no significant change in the marginal productivity of capital in either longwood class, or for the combined longwood regression.

For all classes combined, the marginal productivity of labor rose from 6.61 cords per week in 1979 to 9.03 in 1987. The marginal productivity of capital also rose from 0.47 cords per week in 1979 to 0.67 in 1987.

Figures 16, 17, and 18 illustrate the practical effects of the shifting shortwood, longwood, and all classes-combined linear production functions for alternative labor/capital input ratios. Once again, there was little noticeable change in shortwood production from 1979 to 1987 (fig. 16). However, gains were clearly evident in longwood classes (fig. 17), and in all classes combined (fig. 18).

Aggregate productivity.—The linear and Cobb-Douglas production functions were used to calculate average annual productivity increases for each technology class (table 17). The calculations were made using 1979 and 1987 average input levels for each technology class and aggregation.

Varying productivity rates were evident in each shortwood system, depending on the technology class, production function used, and input level. Using average 1979 input data, technology class A had about a 2-percent annual productivity increase. However, the 1987 input data exhibited only productivity decreases. The other shortwood classes had more consistent results. Technology classes B, C, and E had productivity decreases, while technology classes D and F had increased productivity. For shortwood systems overall, results were consistent and indicated a very small average productivity decrease between survey periods (see also figs. 13 and 16).

For longwood systems, productivity increased substantially between 1979 and 1987. The average increase was between 1.9 and 3.1 percent per year for technology class G, between 2.6 and 3.9 percent per year for class H, and between 2.4 and 3.6 percent per year for all longwood classes combined.

For all classes combined, the results were more sensitive to the production function used and average input level because average levels of labor and capital inputs increased substantially between 1979 and 1987. In addition, along with the different input levels, the degree of increasing returns to scale capital/labor substitution affected the productivity measures. Therefore, the average annual productivity increase for all classes combined was somewhere between 1.1 and 3.7 percent per year, depending on the measure chosen.

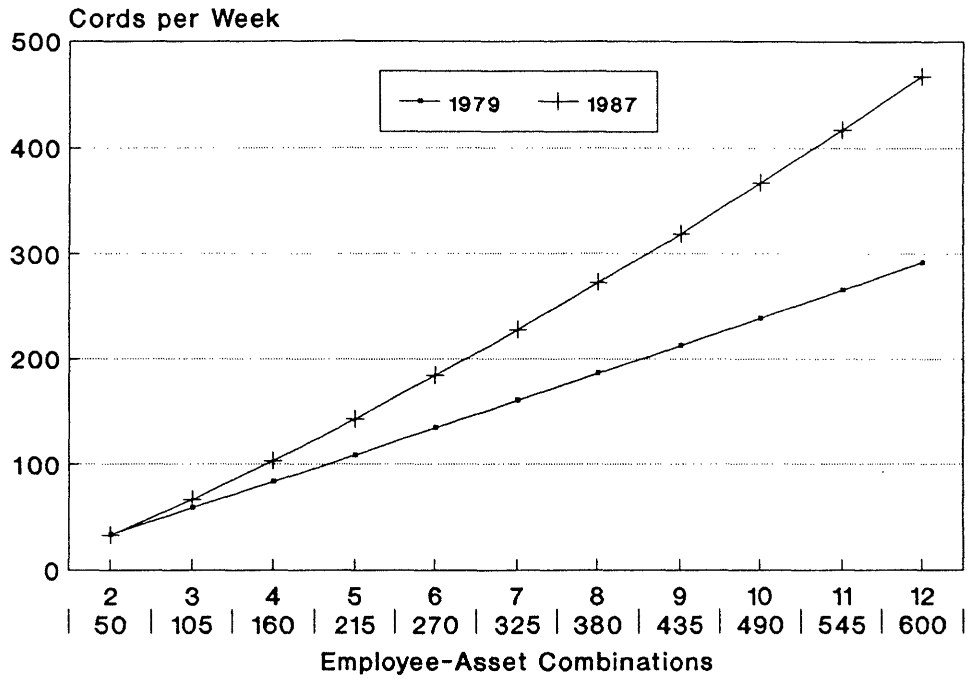

Figure 15.—*Predicted average production for alternative labor-capital input ratios for all classes combined, Cobb-Douglas production function, 1979 and 1987.*

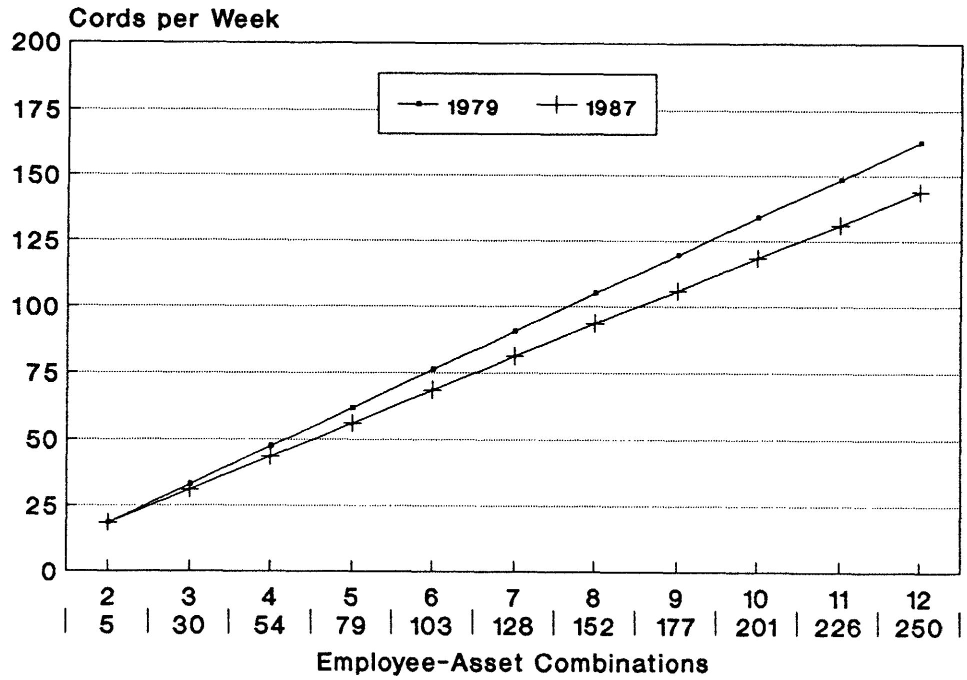

Figure 16.—*Predicted average production for alternative labor-capital input ratios for all shortwood classes combined, linear production function, 1979 and 1987.*

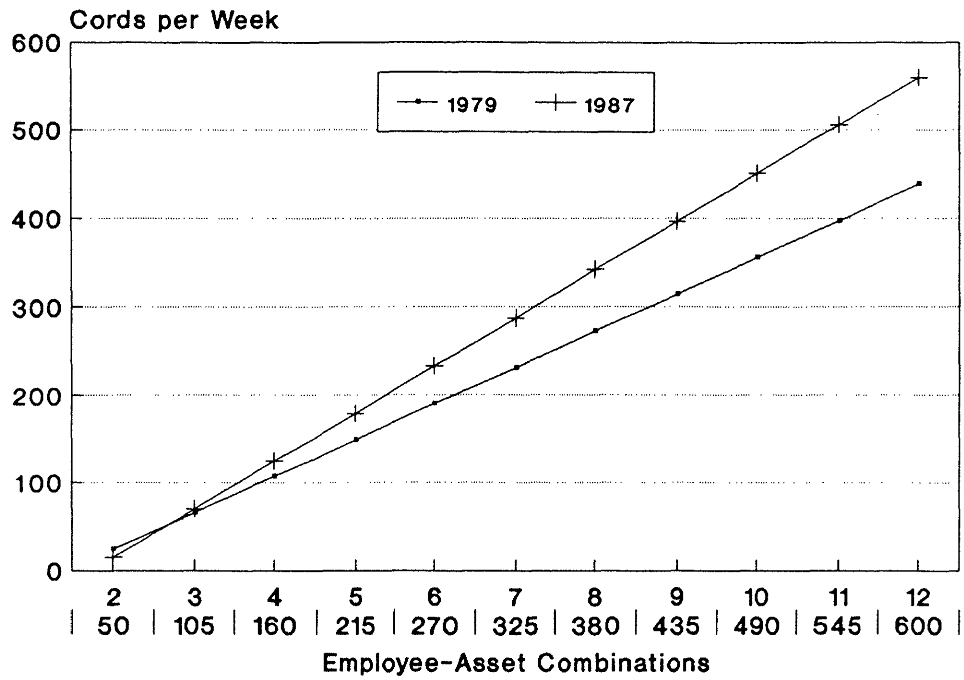

Figure 17.—*Predicted average production for alternative labor-capital input ratios for all longwood classes combined, linear production function, 1979 and 1987.*

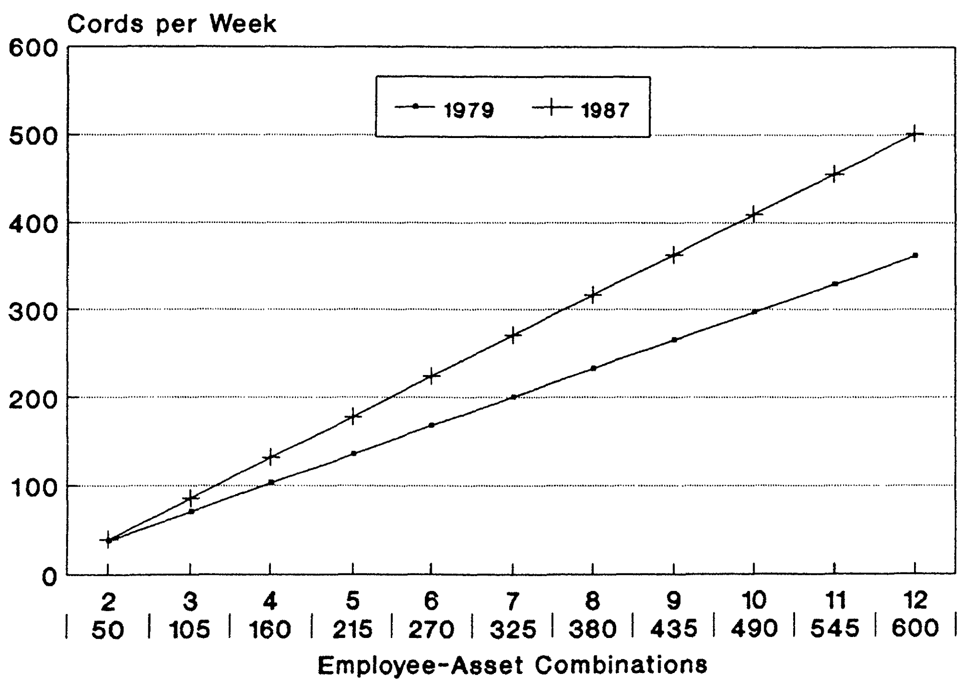

Figure 18.—*Predicted average production for alternative labor-capital input ratios for all classes combined, linear production function, 1979 to 1987.*

Table 17.—*Average annual productivity increases by harvesting system technology class, linear and log/log production functions, using average 1979 and 1987 input levels per system*

Technology class	1979 input levels Linear	Log/Log
Shortwood		
A. Manual bobtail	2.57	1.95
B. Semimanual bigstick	-1.71	-1.60
C. Manual/skidder	-0.65	-0.33
D. Forwarder	0.80	1.09
E. Cable skidder	-1.46	-1.71
F. Grapple skidder	3.23	3.15
Total (shortwood)	-0.73	-0.54
Longwood		
G. Cable skidder	3.07	1.94
H. Grapple skidder	3.87	3.23
Total (longwood)	3.56	2.82
Total (all classes)	2.28	1.14

Technology class	1987 input levels Linear	Log/Log
Shortwood		
A. Manual bobtail	-1.28	-0.04
B. Semimanual bigstick	-1.30	-1.01
C. Manual/skidder	-2.01	-1.23
D. Forwarder	1.28	1.69
E. Cable skidder	-1.25	-1.21
F. Grapple skidder	0.14	-1.52
Total (shortwood)	-0.68	-0.17
Longwood		
G. Cable skidder	3.04	1.85
H. Grapple skidder	3.18	2.58
Total (longwood)	3.27	2.44
Total (all classes)	3.69	3.25

DISCUSSION

The use of harvesting technology in the southern pulpwood industry changed dramatically from 1979 to 1987. At least two factors prompted this change: first, longwood production systems became more efficient, and second, many firms adopted new harvesting technology and methods. Longwood grapple skidder systems became dominant by 1987, accounting for 71 percent of pulpwood production. As a result, the average pulpwood harvesting costs declined significantly in real terms.

Most shortwood systems had higher costs, primarily due to increased workers' compensation rates. The productive capability of these systems, however, did not change much over the period. Although input shares shifted in favor of more capital (table 14), there was no discernible productivity increase over the period. Weekly production per cord per crew also changed little from 34 to 42 cords per week. Much of this increase could be attributed to population movements within shortwood technology classes themselves (e.g., increased grapple skidding). Furthermore, the technology of shortwood systems showed evidence of decreasing returns to scale. As a result, average costs of production rose for shortwood systems. This partly explains the mass exodus by firms from shortwood production.

Conversely, longwood systems had large efficiency gains from both cable and grapple systems. Grapple skidder feller-buncher systems had the lowest average cost production of all technology classes. Aggregate average costs of longwood production declined because of a shifting cost function and movements along the cost function. Weekly longwood production per crew rose from 191 to 228 cords per week, while longwood capitalization levels remained unchanged over the period, and the number of employees per crew rose by only one-half of a person, on average. Longwood systems over the study period characterized a constant to increasing returns to scale technology.

As a result of the shifts to higher mechanization levels, average output per crew rose from 66 cords to 154 cords per week for the industry. The number of operations declined more than 50 percent from 9,100 in 1979 to 4,403 in 1987. Average assets per crew rose from $77,410 to $170,300. Average cost per cord declined almost $6 over the period.

Estimates of shortwood average costs were generally much higher than the estimated harvesting margin perhaps because of three factors. First, shortwood systems may have not been accounting for all opportunity costs of equipment and employees in the short run, especially considering the assumption of full employment (i.e., 40 hours per week). Second, these systems may have received a premium for harvesting smaller tracts or more inaccessible tracts. Third, in the short run, firms will operate as long as they can cover variable costs (i.e., wages, fuel, oil, etc.). These three reasons may help to explain why the difference between the production-weighted average costs for all classes combined between 1979 and 1987 was nearly $10 per cord (table 11) while the estimated harvesting margin difference was only $6.02 (table 3). The difference implies that while average harvesting costs declined $9.93, only $6.02 of this savings showed up in the market price for logging. Other cost factors we did not measure could have made up some of the difference, and profits could have increased.

In 1979, 80 percent of firms were shortwood producers, but in 1987 only 40 percent of firms were shortwood producers. If many firms were operating under a long-run loss, this would account for much of the difference. The longwood class, whose estimated production-weighted average cost was close to the estimated harvesting margin, placed economic pressure on less efficient systems. The most efficient systems set the price in a competitive market. The 1979 survey probably captured an industry in transition, not equilibrium. There is no reason to believe that the 1987 survey captured an equilibrium situation either, especially given the high average cost estimates for shortwood systems. We can expect further shifts into longwood and grapple skidder systems, although some manual systems will be needed to harvest specific tract types.

CONCLUSIONS

The southern pulpwood harvesting industry experienced a substantial change in productivity and costs from 1979 to 1987. The industry shifted from harvesting a slight majority of its timber in shortwood to the dominant mechanized longwood harvesting systems. This change in industry structure was caused by decreasing efficiency and increasing costs for shortwood systems (scale diseconomies) and increasing efficiency and decreasing average costs for highly mechanized longwood systems (scale economies). Average industry harvesting costs declined significantly during this period because of production shifts to longwood systems and efficiency gains in those systems.

Although published aggregate industry harvesting costs for other countries are unavailable, there is no question that timber harvesting costs in the U.S. South are among the lowest in the world, and perhaps the lowest. Harvesting equipment innovations and system configurations led to substantial decreases in harvesting costs in the 1980's. These cost decreases surely helped keep delivered-to-mill wood fiber costs at reasonable levels, and probably helped contribute to the competitiveness of the southern forest industry. Maintaining or increasing these harvest cost reductions will be more challenging in the future. Probably many of the least efficient logging firms were forced out of business in the 1980's, so further reductions from this source will dwindle. Also, increased demands for environmental protection may place increased constraints on loggers' operating freedom, thus impeding productivity gains. Continued innovations in equipment, labor training, and management will continue to determine the productivity of the logging industry in the 1990's.

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The Southern U.S. pulpwood harvesting industry experienced substantial changes in productivity and logging costs from 1979 to 1987. This research measures physical and economic changes in southern timber harvesting and the degree of industry shifting between different levels of harvesting mechanization.

KEY WORDS: Economics, pulpwood, logging costs.