1988

# Impact of new technology on timber harvesting costs: Evaluation methods and literature

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PAPER #88-5031

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Written for presentation at the 1988
International Summer Meeting of the
AMERICAN SOCIETY of AGRICULTURAL ENGINEERS

Rushmore Plaza Civic Center
Rapid City, SD
June 26-29, 1988

**SUMMARY:**

Different economic means of evaluating the impacts of new technology on timber harvesting costs are discussed. Recent economic evaluation literature is reviewed and preliminary estimates of returns to harvesting research are made.

**KEYWORDS:** TIMBER HARVESTING, ECONOMICS, COSTS, RESEARCH EVALUATION, RESEARCH RETURNS



American Society of Agricultural Engineers

St. Joseph, MI 49085-9659

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## INTRODUCTION

Timber harvesting and transport are crucial components of the cost of delivered wood to forest products processing facilities. In fact, harvesting and delivering wood often costs more than the entire costs of growing wood until harvest. As such, timber harvesting research and development are important. Additionally, research in this area is worthwhile because efficiency gains, cost improvements, and environmental benefits due to timber harvesting research can be realized in a very short time period, rather than the decades-long wait required for research investments in timber growing.

This paper provides an overview of the means of measuring the impact of new technology on timber harvesting costs. In recent years, there have been many efforts to increase research for developing better harvesting equipment and methods. In conjunction with these efforts, greater demands have been made for research efficiency and accountability (Silversides et al. 1988); several studies have therefore been completed to measure the impacts of timber harvesting research and development. These studies, other means of evaluating timber harvesting research, and suggestions for future evaluations are discussed.

## EVALUATION METHODS

Various methods could be used to evaluate the impacts of new technology on timber harvesting costs. Research evaluation studies have been classed as *ex ante* for on-going or proposed research, and *ex post* for work that has been completed. Most research evaluations have been *ex post*--determining the returns to prior research investments--especially in timber harvesting. The ultimate aim in studying research, however, is *ex ante*, i.e., to guide in decisions concerning present or future projects (Shumway 1981). In a sense, this type of evaluation is similar to capital budgeting, where capital (research dollars) is allocated where it will have the greatest returns (cost savings).

One method that has been used to evaluate returns to harvesting research involves the analysis of time-series data on logging costs. In this approach, logging costs are determined for an extended time period and one estimates if these costs have increased or decreased in real terms. Costs can be compared at different points in time or more elegantly by the use of trend line regression analysis.

A second approach to evaluating returns to logging research and development is the use of cross-sectional data for a number of different firms at a point in time. In this type of analysis, production and cost data are collected for many different firms. From these data, total or average costs may be estimated by technology class for different output levels. The economic impact of new technology may then be assessed by comparing any cost savings that are realized by use of more efficient equipment technologies.

These first two types of timber harvesting research ex post evaluation methods may be classed as consumer-producer surplus methods. These methods are commonly used in agricultural economics research (Norton and Davis 1981). Economic surplus methods treat research as a means of decreasing the marginal costs of production, i.e., shifting the supply function down and to the right. Then benefits and costs and average rates of return to research are estimated.

Another type of evaluation performed often in the agricultural literature uses aggregate industry production functions, which can be used to estimate marginal rates of return. Marginal rates are useful in allocating resources among competing uses, e.g., research funds among competing projects (Norton and Davis 1981). Marginal rates of return can also be used to evaluate resources used to produce a particular commodity, e.g., the level of funding used to develop new or improved timber harvesting technology. To date, this approach has not been used to estimate returns to timber harvesting research and development, but should be a logical next step.

## EVALUATION LITERATURE

The preceding section briefly described the principal methods used to evaluate returns to development of new technologies, whether in agricultural, forestry, or other sectors. In this section, we will summarize the principal timber harvesting research evaluations that have been made, and extend them to estimate some approximations of returns to timber harvesting research. All of these studies were ex post economic surplus evaluations. Three used time-series data and two used cross-sectional data.

### Logging Cost Trends

Three studies have been published that have estimated the trends in logging costs. These estimates of the trends themselves are valuable, because they indicate whether logging costs are increasing or decreasing in real terms (taking out the effect of inflation). If they are decreasing, these cost savings can be attributed to improved use of capital (equipment technology) or labor. Increasing costs, of course, would represent the converse.

Dennis and Remington (1987) estimated the trends in harvest costs in New Hampshire from 1964 to 1983. Logging costs were based on stumpage and roadside price data derived from the New Hampshire Forest Market Report, which is published annually by the Cooperative Extension Service at the University of New Hampshire. Cubbage et al. (1988a) estimated trends in southern forest harvesting equipment and logging costs. They derived logging costs from stumpage prices and

Table 1. Average Nominal and Real Southern Logging Costs 1967 to 1984

| Year | Difference between stumpage and mill prices for southern pine (logging costs) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Timber Mart-South | | | | Louisiana Market Report | | | |
| | Pulpwood ($/CD) | | Sawtimber ($/MBF) | | Pulpwood ($/CD) | | Sawtimber ($/MBF) | |
| | nominal | real | nominal | real | nominal | real | nominal | real |
| 1967 | - | | - | | 11.90 | 11.90 | 21.70 | 21.70 |
| 1968 | - | | - | | 12.35 | 11.76 | 22.90 | 21.81 |
| 1969 | - | | - | | 13.10 | 11.81 | 22.10 | 19.93 |
| 1970 | - | | - | | 13.05 | 11.16 | 22.00 | 18.81 |
| 1971 | - | | - | | - | - | 24.90 | 20.14 |
| 1972 | - | | - | | 14.50 | 11.20 | 26.80 | 20.70 |
| 1973 | - | | - | | 17.30 | 12.55 | 31.00 | 22.48 |
| 1974 | - | | - | | 22.25 | 14.79 | 33.70 | 22.40 |
| 1975 | - | | - | | 22.85 | 13.84 | 36.00 | 21.80 |
| 1976 | 22.80 | 22.80 | 41.20 | 41.20 | 23.75 | 13.52 | 36.90 | 21.00 |
| 1977 | 22.80 | 21.37 | 41.60 | 38.99 | 24.55 | 13.09 | 40.90 | 21.81 |
| 1978 | 23.20 | 20.26 | 38.30 | 33.45 | 26.75 | 13.30 | 44.90 | 22.32 |
| 1979 | 25.30 | 20.29 | 35.90 | 28.79 | 29.65 | 13.53 | 40.30 | 18.39 |
| 1980 | 28.40 | 20.90 | 45.80 | 33.70 | 31.15 | 13.04 | 41.40 | 17.34 |
| 1981 | 28.40 | 19.05 | 40.30 | 27.03 | 31.55 | 12.04 | 59.40 | 22.67 |
| 1982 | 29.20 | 18.41 | 42.80 | 26.98 | 32.65 | 11.71 | 62.90 | 22.57 |
| 1983 | 31.40 | 19.05 | 50.80 | 30.82 | 32.75 | 11.31 | 65.60 | 22.65 |
| 1984 | 32.90 | 19.25 | 57.50 | 33.64 | 25.15 | 8.37 | 68.50 | 22.81 |

Source: Adapted from Cubbage et al. 1988a.

delivered-to-mill prices as reported by Timber Mart-South and the Louisiana Market Report. Additionally, Hassler et al. (1981) examined the trends in pulpwood logging costs in the North Central states during the 1970s.

The South.--Cubbage et al. (1988a) estimated logging cost trends for southern pine pulpwood and sawtimber based on the Timber-Mart and Louisiana price series. They found that forest harvesting equipment prices increased at rates similar to the general inflation rate, as measured by the GNP deflator, and were slightly less than the inflation rate of manufacturing inputs, as measured by the Producer Price Index for industrial goods. The costs of logging increased considerably less than the costs of equipment or inflation. Timber Mart-South logging cost trends increased at 4.9% and 3.3% annually for pulpwood and sawtimber, respectively, from 1976 to 1984. Louisiana price increases were 2.2% and 8.7% per year from 1967 to 1984. Trend-line inflation rates for these periods varied from 7.2% to 8.3%. Thus substantial real cost savings were achieved over this period.

We estimated the benefits of these cost reductions by determining the real price trends for logging costs and multiplying the annual percent savings in logging costs by the annual production to obtain an approximate gross annual cost savings. These savings could be further partitioned into producer surplus and consumer surplus components, although we will not do so here. Table 1 summarizes the published nominal logging cost data and the real logging cost data that we computed.

For the South-wide data, the gross annual cost savings may be approximated as shown in Table 2. For the Louisiana price series data, the regression trends in harvesting were not statistically different than zero, so no cost savings should be attributed to research. The South-wide derived cost data based on Timber Mart-South, however, showed very substantial annual percentage decreases in logging costs. When multiplied by the price per unit and the total number of units, huge benefits could be attributed to equipment research, development, and adoption. Pulpwood harvesting cost savings amounted to about $22 million and sawtimber savings to $35 million.

These total cost savings (benefits) can be compared with harvesting research expenditures. Research expenditures are hard to quantify accurately, but some estimates can be made. In 1984, the U.S. Forest Service spent approximately $2 million on harvesting research. Forest Service research has been estimated to comprise about one-third of the total forestry sector research, so total annual U.S. harvesting research efforts might be at least $6 million (Hodges and Harris 1988). Assuming that even one-half of this could be attributed to the South, total annual expenditures might be $3 million. It has also been estimated that the approximate lag for harvesting research and development to adoption is 7 to 10 years (Office of Technology Assessment 1983).

Using the above figures, one could estimate total benefits of $57 million, versus the costs of $3 million. With the 10-year lag, this could be used to calculate a simple internal rate of return of 34% per

Table 2. Estimates of Gross Annual Southern Pine Timber Harvesting Cost Savings

| Data Series | Real Price Trend Annual Change | Per Unit Logging Cost | Approximate Annual Harvest | Gross Annual Cost Savings |
|---|---|---|---|---|
| | percent | 1984 dollars | cords/MBF | 1984 dollars |
| Timber Mart-South: | | | | |
| Pulpwood | -2.10 | $ 32.90/cord | 32,000,000[1] | 22,109,000[3] |
| Sawtimber | -3.29 | $ 57.50/MBF | 18,500,000[2] | 35,100,000 |
| Louisiana Market Report | | | | |
| Pulpwood | -0.43 | $ 25.15/cord | 3,400,000[1] | [4] |
| Sawtimber | +0.28 | $ 68.50/MBF | 2,000,000[2] | [4] |

[1] From American Pulpwood Association (1987): 1984 Wood fiber deliveries for shortwood, longwood, and whole tree chips, based on 1986 amounts for some sources as a percent of total.

[2] From U.S.D.A. Forest Service (1982, p. 427): 1977 annual southern sawtimber removals.

[3] Real annual price change in decimal form x per unit logging costs x annual harvest.

[4] Annual percentage changes for price trends not statistically significant, so no cost savings calculated.

year. The net present value of the research investments, at a 10% discount rate, would be $19 million per year, and the discounted benefit:cost ratio 7.3:1.

New Hampshire.--Dennis and Remington (1987) determined the average harvesting cost for sawtimber, pulpwood, and fuelwood in New Hampshire from 1964 to 1983 (Table 3). The authors found that during that period, real harvesting costs for sawtimber decreased at an average annual rate of 1.2%, while real stumpage prices increased. Real pulpwood harvesting costs declined at a 0.8% average annual rate during this period. Fuelwood harvesting costs increased 3.2% per year.

Estimates of timber harvesting cost savings may also be made, as with the southern data. In this case, annual New Hampshire softwood plus hardwood sawtimber harvests in 1972 were approximately 191,000 MBF, and pulpwood harvests were about 250,000 cords (Kingsley 1976). Recent fuelwood consumption has been estimated at 375,000 cords per year (Dennis and Remington 1987). Average 1983 logging prices were $48.58 per MBF for sawtimber; $24.83 per cord for pulpwood; and $41.50 per cord for fuelwood. Thus the net logging cost savings (increases) were about $111,000 per year for sawtimber, $50,000 per year for pulpwood, and ($500,000) per year for fuelwood. The net benefits of decreases in New Hampshire conventional products' logging costs thus would be more than offset by the increase in fuelwood logging costs. One cannot reasonably calculate a benefit:cost ratio for logging innovation in New Hampshire alone, since it does not have its own harvesting research program, and produces only a fraction of the national wood supply.

Minnesota.--Hassler et al. (1981) computed harvesting equipment price trends and also derived an index of pulpwood logging costs in the Lake States (Minnesota, Wisconsin, and Michigan) during the 1970s. They found that harvesting equipment purchase and operating prices had increased substantially--even greater than the inflation rate. However, real logging costs declined significantly during this period. Using their index data, we estimated that Lake States real logging price declines in the 1970s averaged -1.17% per year for hardwoods and -0.62% per year for softwoods.

Pulpwood production in the Lake States during this period averaged about 1,370,000 cords of softwood and 2,860,000 cords of hardwoods (Blyth and Hahn 1978). Logging costs were about $30 per cord for softwoods and $25 per cord for hardwoods in 1979 (Ulrich 1987). This would translate into annual cost savings of about $532,000 for softwood logging and $444,000 for hardwood logging. Total regional share of research costs would again be largely conjecture, but should be much less than the $975,000 in total annual benefits.

## Cross-Sectional Logging Cost Analyses

In addition to the prior time-series analyses, at least two cross-sectional studies have been performed that measure the effects of logging equipment innovation and adoption. Cubbage et al. (1988b) measured the impacts of innovation in southern pulpwood logging, and

Table 3. Average Harvesting Cost for Sawtimber, Pulpwood, and Fuelwood in New Hampshire, 1964-83

| Year | Sawtimber[1/] Nominal | Sawtimber[1/] Real | Pulpwood[2/] Nominal | Pulpwood[2/] Real | Fuelwood Nominal | Fuelwood Real |
|---|---|---|---|---|---|---|
| | ---- dollars per mbf ---- | | ------------------ dollars per cord ------------------ | | | |
| 1964 | 20.31 | 20.31 | 9.17 | 9.17 | - | - |
| 1965 | 20.50 | 19.96 | 9.17 | 8.93 | - | - |
| 1966 | 20.46 | 19.23 | 9.50 | 8.93 | - | - |
| 1967 | 19.92 | 18.25 | 10.00 | 9.16 | - | - |
| 1968 | 19.32 | 16.86 | 10.00 | 8.72 | - | - |
| 1969 | 19.15 | 15.82 | 12.00 | 9.91 | - | - |
| 1970 | 19.11 | 14.97 | 12.00 | 9.40 | - | - |
| 1971 | 19.16 | 14.20 | 12.00 | 8.89 | - | - |
| 1972 | 18.52 | 13.10 | 12.50 | 8.85 | - | - |
| 1973 | 21.76 | 14.46 | 12.50 | 8.31 | 15.00 | 15.00 |
| 1974 | 21.17 | 12.89 | 13.67 | 8.33 | 16.00 | 14.67 |
| 1975 | 27.08 | 15.02 | 15.00 | 8.32 | 23.50 | 19.62 |
| 1976 | 30.14 | 15.71 | 15.50 | 8.08 | 23.00 | 18.05 |
| 1977 | 31.70 | 15.49 | 17.33 | 8.47 | 20.50 | 15.07 |
| 1978 | 33.40 | 15.21 | 17.00 | 7.74 | 39.00 | 26.73 |
| 1979 | 36.47 | 15.25 | 22.17 | 9.27 | 41.50 | 26.11 |
| 1980 | 42.18 | 16.18 | 22.00 | 8.44 | 41.50 | 23.96 |
| 1981 | 44.66 | 15.62 | 24.17 | 8.45 | 41.50 | 21.84 |
| 1982 | 45.90 | 15.08 | 24.00 | 7.89 | 41.50 | 20.53 |
| 1983 | 48.58 | 15.37 | 24.83 | 7.85 | 41.50 | 19.76 |

Source: Adapted from Dennis and Remington 1987.

[1/] Weighted average of low-, medium-, and high-quality sawtimber classes.

[2/] Northern counties in New Hampshire--costs of hardwood, spruce fir, and other softwood.

Herrick (1982) examined whole-tree chipping as a logging innovation in the North. Each of these provides insights about research benefits.

Southern Pulpwood Logging.--Cubbage et al. (1988b) obtained cross-sectional data on southern pulpwood logging firms from a 1979 American Pulpwood Association pulpwood producer's census (Weaver et al. 1981). The survey data collected information from pulpwood loggers regarding their age, education levels, number of employees, equipment spreads, and other characteristics. Data from the survey represented over 4,000 pulpwood loggers throughout the South, with mechanization levels ranging from simple manual systems to modern grapple skidder systems.

Based on the equipment spread, number of employees, and weekly production rate reported, average logging costs per cord were estimated for each firm. Firms were grouped by technology class in order to estimate the effects of differing mechanization levels; average cost curves were then estimated for each technology class.

These calculations provided the basis for comparing productivity and average costs of different harvesting systems at one point in time. As the older, more manual systems were replaced by newer, more mechanized systems, one could estimate the possible cost savings attributable to timber harvesting equipment research and adoption. This method is somewhat harder to use to derive annual cost savings estimates from than time-series analyses, but approximations can be made.

First, one can simply compare average production, costs, employees, and assets among technology classes (Table 4). This provides an initial aggregate measurement of inputs, outputs, and average costs for technology classes. If average costs are less (or greater) for more modern equipment, this indicates the possible cost savings (price increases) that will be incurred as loggers adopt new technology. One problem with these comparisons is determining probable shifts in equipment adoption. For example, bobtail systems appeared to have very low average costs, but were probably being used less each year because manual in-woods labor was becoming scarcer. Recently completed surveys of the logging work force have indicated that bobtail trucks constitute a very small proportion of the current southern logging force. While they constituted about 65% of the operations and 35% of production in 1979, preliminary estimates suggest they comprise less than 5% of the pulpwood production in the South now.

One can use these shifts in technologies to estimate approximate cost savings. Assuming the reported 1979 southern pulpwood harvesting production level of 179,000 cords per week, the total cost improvement might be computed as shown in Table 5 if the approximate shifts were made from manual systems to longwood grapple skidder systems. This should provide a conservative estimate of cost savings, because South-wide production levels also have increased considerably. Table 5 cost savings are based on yearly production of only about 8 million cords; 1984 annual production was actually about 32 million cords, as noted in Table 2.

Table 4. Production, Average Costs, Capital, and Assets for Responding Southern Pulpwood Producers, 1979

| Technology Class | Number of Operations | | Production Total Per Week | | Total Employees | | Total Assets | | Average Cost Per Cord |
|---|---|---|---|---|---|---|---|---|---|
| | number | percent | cords | percent | number | percent | $1980 | percent | $1980 |
| Shortwood | | | | | | | | | |
| A. Manual bobtail | 445 | 12.2 | 9,300 | 5.2 | 1,157 | 7.9 | 1,686,550 | 1.1 | 27.16 |
| B. Semimanual bigstick | 1,938 | 53.0 | 52,520 | 29.4 | 6.008 | 41.3 | 11,087,298 | 7.1 | 28.05 |
| C. Manual/skidder | 360 | 9.8 | 13,356 | 7.5 | 1,368 | 9.4 | 10,608,480 | 6.8 | 36.77 |
| D. Forwarder | 149 | 4.1 | 10,445 | 5.8 | 939 | 6.4 | 7,328,565 | 4.7 | 31.62 |
| E. Cable skidder | 193 | 5.3 | 13,838 | 36.80 | 1,119 | 7.7 | 20,813,892 | 13.3 | 36.80 |
| F. Grapple skidder | 26 | 0.7 | 3,728 | 24.46 | 161 | 1.1 | 5,186,454 | 3.3 | 24.46 |
| Total (shortwood) | 3,111 | 85.0 | 103,187 | 29.68 | 10,752 | 73.8 | 56,711,239 | 36.3 | 29.68 |
| Longwood | | | | | | | | | |
| G. Cable skidder | 382 | 10.4 | 42,937 | 24.0 | 2,368 | 16.3 | 57,630,812 | 36.8 | 28.90 |
| H. Grapple skidder | 166 | 4.5 | 32,719 | 18.3 | 1,444 | 9.9 | 42,182,260 | 26.9 | 25.69 |
| Total (Longwood) | 548 | 14.9 | 75,656 | 42.3 | 3,812 | 26.2 | 99,813,072 | 63.7 | 26.98 |
| Total (all classes) | 3,659 | 100.0 | 178,843 | 100.0 | 14,564 | 100.0 | 156,524,311 | 100.0 | 27.68 |

Source: Cubbage et al. 1988b

Table 5. Cross-Sectional Estimation of Southern Timber Harvesting Aggregate Cost Savings

| Technology Class | Production Per Week | | Average Costs | Total Cost Per Week | | Weekly Cost Savings[2] |
|---|---|---|---|---|---|---|
| | 1979 | 1987[1] | | 1979 | 1987 | |
| | --- cords per week ---- | | $1980/cord | --------- $1980 ------------ | | $1980 |
| Shortwood | | | | | | |
| A. Manual bobtail | 9,300 | 1,000 | 27.16 | 252,588 | 27,160 | +225,428 |
| B. Bigstick | 52,520 | 8,850 | 28.05 | 1,473,186 | 248,243 | +1,224,943 |
| C. Manual/skidder | 13,356 | 4,000 | 36.77 | 491,100 | 147,080 | +344,020 |
| D. Forwarder | 10,445 | 8,000 | 31.62 | 330,271 | 252,960 | +77,311 |
| E. Cable skidder | 13,838 | 8,000 | 36.80 | 509,238 | 294,400 | +214,838 |
| F. Grapple skidder | 3,728 | 4,000 | 24.46 | 91,187 | 97,840 | -6,653 |
| Total (shortwood) | 103,187 | 33,850 | 29.68 | - | - | - |
| Longwood | | | | | | |
| G. Cable skidder | 42,937 | 40,000 | 28.90 | 1,240,879 | 1,156,000 | +84,879 |
| H. Grapple skidder | 32,719 | 104,993 | 25.69 | 840,551 | 2,697,270 | -1,856,719 |
| Total (longwood) | 75,656 | 144,993 | 26.98 | - | - | - |
| Total (all classes) | 178,843 | 178,843 | 27.68 | 5,229,000 | 4,920,953 | +308,047 |

Source: Adapted from Cubbage et al. 1988b

[1] 1987 distributions based on author's estimates

[2] Based on shifts among technology classes. Approximate yearly total savings would be: 44 operating weeks per year x total weekly savings ($308,047) = $13,554,068

As table 5 indicates, total research benefits of the shift from shortwood systems to longwood grapple skidder systems probably exceeded $13.5 million in 1980 dollars (or $17 million in 1984 dollars) per year by 1987. These benefits could be compared with the previously estimated southern harvesting expenditures of $3 million (Hodges and Harris 1988) to arrive at a discounted benefit:cost ratio of 2.2:1 at a 10% discount rate for the 10-year investment span. The net present value of research expenditures at a 10% discount rate would be $3.6 million, and the simple internal rate of return would be 19%.

The above calculations are rather crude first-order estimations of the returns to timber harvesting research in the South. But they do indicate the type of analyses that can be performed with cross-sectional data, either by us or by other interested researchers. As new pulpwood producer survey data become available, more exact evaluations of southern pulpwood harvesting returns should be possible.

Northern Whole-Tree Chipping.--Herrick (1982) estimated the benefits of whole-tree chipping as a logging innovation in northern U.S. forests. He estimated two supply schedules for pulpwood production and quantities--one with and one without adoption of whole-tree chipping technology. One schedule reflected the output of hardwood pulpwood (including whole-tree chips) harvested in the Northeast in 1979. The other showed what would have resulted if this pulpwood would have been harvested with the mix of production methods that existed five years earlier (preinnovation).

By measuring the downward shift of the supply function, Herrick estimated that the gross annual benefit of research and technology adoption amounted to a 2 percent cost reduction spread across the entire hardwood pulpwood supply system. This benefit was measured as the difference between the two supply schedules--translating into a gross annual research benefit of $2,435,000.

Herrick did not estimate regional research costs, but based on the analysis by Hodges and Harris (1988), one can safely assume they are far less than the benefit. If the Northeast had a proportional share of the national whole-tree chipping harvesting research in the 1960s and 1970s, total expenditures would equal $500,000 or less. With a 10-year lag, these expenditures and Herrick's benefits would yield a discounted (10%) benefit:cost ratio of 1.9:1, and a simple internal rate of return of 17%.

## CONCLUSION

This paper has presented a brief discussion of the means of and literature on evaluating the impact of new technology on timber harvesting costs. Based on recent literature, it also makes some relatively unsophisticated calculations to estimate approximate research benefits--i.e., the total logging cost savings generated by new equipment adoption.

The two principal sources for evaluating equipment development and adoption efforts consist of a time-series and cross-sectional data on southern logging costs. Using these data sets, we estimated that simple internal rates of return could vary from about 19% to 34%, and benefit: cost ratios from about 2:1 to 7:1. These returns are obviously excellent. The returns to whole-tree chipping in the Northeast were similar. Large conventional logging cost savings also occurred in New Hampshire and the Lake States, but calculating rates of return for such small geographic areas is difficult. Fuelwood harvest costs increased in New Hampshire, but it is a minor product nationally, and often is harvested by amateurs and part-timers.

The accuracies of the preceding estimates of returns to harvesting equipment research are extremely hard to verify, but their large size does at least indicate the potential for substantial payoffs. A small decrease in per unit harvesting costs, spread over a large annual cut, can yield large cost savings. It may be that some of the cost savings estimated here are not attributable to equipment technology research, development, and adoption alone. Labor skills may also be improving, and market forces also create pressure for reduced costs. However, few logger training programs exist, so it probably is safe to attribute most of the gains to new equipment technology.

The estimates derived here are very simple first-order approximations of the returns to harvesting equipment research. More sophisticated econometric analyses should be the next step required for credible economic evaluations of the returns to harvesting research.

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