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Abstract

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by

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This study examines technological change in four forest industries through several means and discusses probable future changes. The industries considered were: logging camps and contractors (SIC 2411); sawmills and planing mills, general (SIC 2421); pulpmills (SIC 2611); and papermills, except building paper (SIC 2621). Qualitative indicators of technological change were compared, consisting of time series data on consumption, prices, capital employment, number of establishments, and several of their ratios. Secondly, five econometric models were applied to measure technological change between the years 1958 and 1976. The models used were: 1) arithmetic; 2) geometric; 3) Cobb-Douglas; 4) constant elasticity of substitution; and 5) Johansen. Only the results of the first four models are reported. Several of the models also provide information such as capital to labor price movements, elasticities, and economies of scale. Finally, descriptions of past and probable future technologies were covered. Alternative projections of one of the indexes of technological change (geometric), based

on GNP and time, were made to 2030.

Technological change in the four forest industries over the 19 years have been modest. Between 1958 and 1976, the average annual increase in the geometric index was only 1.9 percent. Results of the four models are as follows:

	Arithmetic	Geometric	Cobb-Douglas	CES
	-------average annual increase---------			
Logging camps and contractors	3.4	3.1	3.8	3.3
Sawmills and planing mills, general	1.8	1.8	0.9	---
Pulpmills	2.5	2.4	2.3	---
Papermills, except building paper	0.7	0.4	2.4	---

These figures represent average annual changes in total factor productivity, or alternatively, shifts in an industry's production function.

Output has increased in all four of the industries: sawmilling the least, 20 percent, and logging the most, 150 percent. Capital also increased, with logging doubling its investment and sawmilling growing only 13 percent. Employment declined slightly in logging and papermaking, falling by one-third in sawmilling, and increasing 10 percent in pulping. Annual productivity increases, the most common measure of progress, were above or near the average for all manufacturing. Logging productivity was far above the national average for all manufacturing (2.7 percent), at 5 percent, sawmilling slightly above average at 3 percent, and pulping and papermaking only slightly below the national average at 2.6 percent. The number of establishments in each of the industries has been fairly constant in all cases except sawmilling, which has experienced a decline of almost 50 percent.

Regional shifts in the industries have occurred. In logging, the South gained while the Pacific Coast lost establishments. Sawmilling establishments declined in all regions. In pulping and papermaking, there has been a general shift to the South.

Research and development in the forest industries is not great. For both lumber and paper, funds for R&D as a percent of net sales in manufacturing companies performing R&D is less than one percent, compared to greater than three percent for all manufacturing. Universities, government, and manufacturers of equipment for the industries do perform R&D that affects the forest industries, however.

Changes in raw materials have also probably occurred. Reliable data are not readily available, but logs have most likely become smaller.

An additional factor may be that the entire forest products industry has concentrated on advancement in other areas, such as plywood, particleboard, and fiberboard.

Technological change has accounted for about 60 percent of the increases in per employee productivity for three of the industries. Additional capital per employee produced the remainder. Papermaking differed, with greater capital intensity producing 72 percent of the growth, with technological change accounting for 28 percent.

In the future, no great deviations from past trends are expected. New capital expenditures per employee less than the average for all manufacturing in logging and sawmilling (21 percent less, and 40 percent less, respectively, than the $2300 in 1976 for all manufacturing), should bring their labor productivities down somewhat, although they will still probably remain above average. Per employee expenditures in pulping are more than 5 times the national average for manufacturing, and almost twice as large in papermaking, yet their labor productivities will probably not increase greatly, based on capital requirements and probable future technologies.

Technological change trends are expected to vary only slightly from the past. Logging, which advanced technologically 3.1 percent per year, should continue at about the same rate. Sawmilling and planing, which progressed at 1.8 percent per year in the past, should be able to improve slightly on its performance. Pulping, at 2.4 percent in the past, will probably be lower, perhaps as much as 0.5 percent per year in the long run. Papermaking, which increased technologically at a very low 0.4 percent yearly, will probably not be able to improve at a much greater rate.

ACKNOWLEDGEMENTS

The impetus for this study developed during my work with Dr. Robert S. Manthy on his book, "Natural Resource Commodities - A Century of Statistics." The trends presented in that book led me to investigate the role technological change plays in the extraction of natural resources from the environment over time. To Dr. Manthy go my thanks for whetting my interest in this subject.

The U.S. Forest Service funded my project while I was in graduate school. The Forest Products Laboratory, Madison, Wisconsin, graciously allowed me to complete this dissertation while I was in their employ. I am also grateful to Dr. Robert N. Stone, my project leader, who provided valuable guidance, and who also insisted on completion.

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INTRODUCTION

Over time, changes in the technologies employed by industry affect our need for raw materials. In the forest industries, alteration in production processes and products produced will influence the quantities of timber cut from our Nation's forest lands. To prepare for our future timber requirements, then, it is important to evaluate technological change in the forest industries.

The problem

In general, economic theory includes as the main factors of production land, labor, and capital. Technology has not received equal treatment by economists in developing theory. This force which controls the manner and combination of the other factors of production has too often been assumed away under the characterization "ceteris paribus."

Economists have been becoming aware that exclusion of technology as a factor of production is resulting in discrepancies between theory and actual fact. The theory has clearly become deficient for many of the applications to which it has become necessary to extend it.

This has occured because technology is a difficult factor to include in theory. Also, technologically induced change is becoming more and more prevalent today. Advances in electronics, chemistry, metallurgy, and other sciences are producing continuing changes in our society. In fact, change has become engineered into our system.

Business and government have become more aware of the relationship between technology and productivity. Increased productivity is viewed as the solution to improving resource use, reducing inflationary pressures, and increasing our standard of living.[1] Hence, technological change in the manufacturing sector is regarded as an important issue.

In 1974, Congress mandated in the Resources Planning Act that the Forest Service periodically assess the Nation's need for renewable resources, and our ability to meet them. One of our major resources is timber; the United States consumed 13 billion cubic feet of timber products in 1976.[2]

Timber demand is expected to rise substantially in the future, to 27.8 billion cubic feet of roundwood consumption in 2020.[3] In assessing this future, it is

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[1]Gilbert P. Dempsey. 1973. Toward growth in productivity. Forest Products Journal 23(4):12-14.

[2]Robert Phelps. 1977. The demand and price situation for forest products 1976-77. Forest Service Misc. Pub. No. 1357. Washington, D.C.: U.S. Government Printing Office.

[3]U.S. Forest Service. 1977. The nation's renewable resources--an assessment, 1975. Forest Resource Rep. No. 21, Washington, D.C.: U.S. Government Printing Office.

imperative to consider the role changing technology will play in determining the quantities of roundwood that will be necessary to satisfy the demand for final wood products. For example, due to changing technology, in the future we can expect that more board feet of lumber will be obtained from each cubic foot of sawlog than was possible in the past. Improvements in pulping will extract a higher percentage of wood fiber from a cord of roundwood.

Objective of the Study

The objective of this study is to project historical patterns of technological change in the U.S. forest products industries based upon an evaluation of past performance and likely future developments. The projections will cover the years 1990-2030. Its purpose is to build a basis for the U.S. Forest Service to better evaluate the effects of technological change on the Nation's wood requirements.

Framework for Analysis

Technological change can be variously measured, evaluated, and indicated by several approaches. First, there is the consideration of the changes in processes in manufacturing. This is simply a descriptive process. Second, there are the economic trends that evidence technological change. These are the more qualitative indicators such as time trends in prices, consumption, employment, capital and capital per employee, output and output per employee, etc. These trends are evaluated by their changes through time, and by comparison with other time series. Finally, there is the measurement of technological change through the use of mathematical models.

A major problem in attempting to analyze and evaluate technological change is the fact that there exist no suitable units in which it can be measured. The approach most often employed by economists has been to construct an index of technological change, which is usually based on a model involving value added or gross output in manufacturing, and employed capital and labor. This method allows a quantification of the trend of technological change, without identifying an absolute level. One year is arbitrarily picked as the base, and an index or other measure constructed from that point. Such an approach will be utilized in this study; five models employing different configurations of the variables and different assumptions are used to measure technological change in the forest industries. The models are the: (1) arithmetic index, (2) geometric index, (3) Cobb-Douglas function, (4) constant elasticity function, and (5) Johansen index.

The purpose in employing more than one model is to compare their results, due to their differing constraints and assumptions, and not to compare the models directly. The differences and similarities of the models will be compared only in terms of the measures of technological change which they produce, in an effort to understand the causes and consequences of increased productivity.

The geometric model will be used for two projections, one based on time, the other on GNP. By far the largest portion of the literature on technological change is devoted to problems of measurement rather than explanation.[4] To avoid this limitation, all three of the above approaches will be utilized in this study.

Scope of the Study

Because of the vast number and diversity of firms and plants comprising the forest industries, the study must be focused on only a few aggregate industries to remain manageable. The majority of data utilized in this study are from the various Census of Manufactures, and the industries included conform to the Standard Industrial Classification scheme. They are logging camps and contractors (SIC 2411), sawmills and planing mills, general (SIC 2421), pulpmills (SIC 2611), and papermills, except building paper (SIC 2621). The time frame covered is the period 1958-1976, although some data series start in 1950.

These industries comprise major segments of the U.S. economy. Logging and sawmilling employed 1.3 percent of

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[4] D.W. Jorgenson and Z. Griliches. 1967. The explanation of productivity change. Review of Economic Studies 34:249-283.

the employees, paid 1.0 percent of the payroll, and produced 1.1 percent of the value added in the U.S. in 1972. The importance of pulpmills and papermills is only slightly smaller, with this industry responsible for 0.7 percent of employment, 0.9 percent of payroll, and 0.9 percent of value added in 1972.

Definitions and Relationships

Technology and technological change suffer from many definitions and interpretations. Technology as used in this study is defined as the inputs required to produce a given output.[5] In economic terms, technology determines the shape of the production function. In this sense, the state of technology is the social pool of knowledge of the industrial arts available at a given point in time.[6] It defines the complete set of possibilities society possesses to produce goods and services. Technological change involves the creation of a new set (which includes the old one) of production alternatives.[7]

The actual technologies employed at any point in time

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[5]National Science Foundation. 1976. Technological innovation and Federal government policy. Office of National R&D Assessment. NSF 76-9.

[6]Edwin Mansfield. 1971. Technological change: An introduction to a vital area of modern economics. New York: W.W. Norton & Co.

[7]Irwin Feller. 1972. Production isoquants and the analysis of technological and technical change. Quarterly Journal of Economics 86:154-161.

are techniques. When the method of producing a specific output is altered, it must be defined as a change in technique. Technical change is thus defined as a change in production method out of the existing set of alternatives. Strictly speaking then, the changes in production functions examined in this study are due to changes in technique. However, because the improvements included in these measures are all-encompassing, including better health of workers, improved managerial skills, changes in the quality of inputs, and greater capital accumulations, we shall allow these events to reside under the broader, more general term of changes in technology.

Conversion measures can be applied to all levels of the production process, from harvesting in the forest stand to final use such as lumber in housing. Along each step in the process, the raw material is transformed into a product, which in turn becomes the raw material for the next step.

Advances in technology can be expected to improve utilization, the result of techniques that allow more output from a given input. Changes may also result in additional knowledge about techniques that allow a wider range of factor substitution.[8] Changes in technology can also create new resources, by utilizing materials that were not previously acceptable.

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[8] Nathan Rosenburg. 1976. Perspectives on Technology. New York: Cambridge University Press.

II. METHODS OF INDICATING AND MEASURING TECHNOLOGICAL CHANGE

There are several methods of indicating or measuring technological change. Besides an historical examination, economic data series can be useful in evaluating progress in an industry. Also, econometric models exist that allow a measurement of technological change. The basis for these methods will be discussed in the following section with the economic data series or qualitative indicators first, followed by the econometric models.

Qualitative Indicators

The real price trend for the output of an industry can partially reflect the changes in technology that have occurred. Certainly, price is the result of the interaction of demand and supply; however, if in the face of expanding consumption, the real price remains constant, then we may be sure that changes are occurring that affect supply. These changes may be structural, political, economic, or technological. Indications of the first three factors will aid in evaluating possible changes in the latter cause. Additionally, direct evaluation of new technologies occurring in an industry may be made.

<u>Consumption and Price</u>

Consumption and price are the only data observable at any point in time from the interaction of economic demand and supply. Series of these two products of market elements, taken together, give an indication of those market forces.

A recently completed study of raw materials in the United States has reported that virtually all natural resource commodities have experienced horizontal or declining real price trends, in spite of a fifteenfold increase in consumption.[2]

With expanding populations, demand can be expected to shift outward. If no shifts occur in an inelastic supply, prices will rise. However, if with increasing consumption, price does not rise, there is an indication of a shifting supply curve. The reasons for the shifts may then be investigated for indications of technical change.

<u>Employment, Capital, and Output</u>

Labor and capital are the two basic factors of production in any productive process. Time series of the quantities used by an industry give evidence of changes in the production of output. Certainly, given an adjustable

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[2]Robert Manthy. 1978. Natural resource commodities--a century of statistics. Baltimore: John Hopkins University Press, published for Resources for the Future.

productive process, changes will be made in the amounts of capital and labor used in response to their changing relative prices, without any differences in the level of technology employed. Price series for the two factors are also necessary. However, while the adaptability of the technological productive process employed varies between industries, in few, if any, is it perfectly adjustable. There are imperfections in any firm or industry, compared to its theoretical counterpart. This fact will lessen the importance of changing relative prices versus that of new technology; for resources employed, adjustments in the capital/labor ratio will be made during periods of capital growth or replacement in the industry.

The comparison of the three time series of capital, labor, and output will provide indications of change in the underlying economic factors involved in the productive process.

Per Employee Data

The partial productivity measure of output per employee is one of the most commonly used indicators of progress in an industry. It is one of the measures used by the Bureau of Labor Statistics to trace changes in technology.[10] It is a partial measure, however, because

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[10]U.S. Department of Labor. Bureau of Labor Statistics. 1974. Technological change and manpower trends in six industries. Bulletin 1817. Washington, D.C.: U.S. Government Printing Office.

it excludes changes in the other factors of production. Such exclusion forces the assumption that all changes in production are the result of changes in the quality of labor. It is not a measure of efficiency, however, for a high labor productivity can be produced as inefficiently as a low one.[11] Such measures need to be related to the process of change of which they are a product. It remains a useful measure, however, if one is mindful of its shortcomings.

Capital per employee data provide an indication of changes in the relative amounts of the factors of input used. It is an indication of the capital intensity of the industry. Taken into consideration, it allows more realistic interpretation of output per employee data.

Utilization Rates

Utilization rates give the amount of resource that is converted into a product. For this reason, they are also sometimes called conversion factors. Examples would be the board feet of lumber produced per cubic feet of sawlog, or the cords of roundwood required to produce a ton of pulp. Direct comparison of utilization rates through time gives a reliable and valid measure of technological change, ceteris paribus.

[11] W.E.G. Salter. 1969. Productivity and Technical Change. Cambridge: The University Press. 2nd edition.

Establishment Data

A trend toward increasing size has tended to reduce the number of firms in American industries. Technological changes based on economies of scale have favored the trend toward fewer firms, lessening competition. Conversely, large firms may need to compete nationwide, and do not enjoy the benefits of local market monopolies.

If a technological trend favoring economies of scale reduces the number of establishments in an industry, ceteris paribus, then the time trend of this number will indicate the trend of technological change. Of course, there are many factors that can favor or retard such a tendency. Unregulated competition, risk taking, individual firm research and development, and many other factors favor growth of some individual firms at the expense of others. Government regulation, transportation limits, resource characteristics, and other factors can limit firm size.

The amount of capital and number of persons employed per firm, over time, can also indicate technological change, in addition to other economic influence.

Models

Of the mathematical models available, five were considered earlier.[12] Because of the difficulty of describing an absolute level of technology or techniques

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[12]The following section is based in part on Lester B. Lave. 1970. Technological Change: Its Conception and Measurement. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

in use, it is necessary to resort to describing its effects.[13] For this reason, all models use a base year and construct an index of measure from that reference point.

Arithmetic

The arithmetic index is a simple and direct measure of technological change. Kendrick used this index to develop time trends of total factor productivity for the national economy and its major sectors, including manufacturing, transportation, mining, agriculture, and government.[14]

The index is based on the equation

$$Y_o = W_oL + i_oK \qquad (1)$$

where W_o is the average wage at time zero, L and K are labor and capital, respectively, and i_o is the average return to capital at time zero. Calculations for the weights W_o and i_o are shown in Appendix B.

Implicit in national incoming accounting, equation (1) states that the output of an industry is the sum of the products of rent to capital plus wages to labor. The index is constructed by evaluation of the percentage changes in the components between periods. C_o is introduced to account for changes in efficiency.

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[13] Edwin Mansfield. 1968. Industrial Research and Technological Innovation. New York: W.W. Norton and Co., Inc.

[14] John W. Kendrick. 1961. Productivity Trends in the United States. Princeton, N.J.: Princeton University Press.

$$\frac{Y_1}{Y_o} = C_o \left(W_o \frac{L_1}{L_o} + i_o \frac{K_1}{K_o} \right) \qquad (2)$$

The series for C_o, $C_1, \ldots, C_n$ is a measure of technological change. In effect, equation (2) shows the percentage growth in output as a weighted sum of the percentage increases in labor and capital. The weights have the effect of producing what the output of period 1 would have been using the productive efficiency of period 0. Since the output in period 1 is generally greater, C_i is a measure of the increase in productivity.

However, this productivity increase, C_i, is not composed entirely of technological change. Increases may also result from changes in scale of output, changes in utilization of capacity, and changes in the quality of inputs and outputs.

The changing weights used in this study are an attempt to compensate for the effect of changing relative prices of the two inputs, capital and labor. For any period, the estimate of C_i employs the weights of the relative prices of the preceding period, i.e., for C_3 the weights are the relative prices in period 2 (W_2 and i_2). This method necessarily makes the assumption that the relative prices are indicative of the marginal productivities of the inputs. Such a condition is only attained under perfect competition in an industry.

A second and rather important implicit assumption in this method is that the weights, W and i, are changed only by technological change. This is clearly at odds with neo-classical theory, which holds that the equilibrium between marginal productivities and prices will be disturbed only through demand and price shifts. Changes in the demand or supply of a factor will change the price, and consumers will adjust their use of the factor until the marginal productivity again equals the price. Such a condition must hold for the long-run equilibrium. In the short run, however, the assumption that the weights are changed through technological change may not be unreasonable. To allow for the long-run adjustments, the weights are recalculated yearly.

An example will serve to illustrate how the arithmetic index is calculated. Equation (3) is solved for C_o:

$$C_o = \frac{Y_1/Y_o}{W_o\left(\frac{L_1}{L_o}\right) + i_o\left(\frac{K_1}{K_o}\right)} \qquad (3)$$

To calculate the arithmetic index for logging camps and contractors, for the year 1961 (C_3), the data are taken from Table C1 in Appendix C, and the weights are taken from Table B1 in Appendix B (an example of how the weights are calculated is included in Appendix B):

$$C_3 = \frac{455.9/425.9}{.5881\left(\frac{71.4}{73.1}\right) + .4119\left(\frac{442.6}{439.5}\right)}$$

$$= 1.082$$

Each yearly calculation produces a figure somewhere near the value one; it is a year-to-year measure and is not cumulative. The indexes presented in Appendix Tables C1 through C4 have been converted to cumulative indexes, however, to make them more comparable to the geometric index which is described below.

Although they are constructed differently, the arithmetic and geometric indexes yield almost identical results. For this reason, and others given in the next section, only the results of the geometric index will be discussed for the four forest industries. The results of the arithmetic index calculations are presented in Appendix C.

<u>Geometric</u>

The geometric method constructs a cumulative index of technological change using increases in output unexplained by increases in capital per employee. The necessary assumptions for this method include constant returns to scale, a perfectly competitive economy, capital and labor are paid their marginal products, and that technological change is neutral (marginal rates of substitution remain the same).

This method, developed by Solow,[15] makes use of the following equation:

$$\frac{\Delta A}{A} = \frac{\Delta Q}{Q} - W_k \frac{\Delta K}{K} - W_l \frac{\Delta L}{L} \qquad (4)$$

where Q, K, and L are output, capital, and labor, and W_k and W_l are the elasticities of output with respect to capital and labor. Gross capital is used, rather than net of depreciation. Annual depreciation and annual replacement are not necessarily the same, and the use of gross estimates circumvents that accounting problem, but makes necessary the assumption that assets are replaced fully when they are retired.[16]

The equation can also be written in a "per labor" form:

$$\frac{\Delta A}{A} = \frac{\Delta y}{y} - W_k \frac{\Delta k}{k} \qquad (5)$$

where y and k are Q/L and K/L, respectively. This equation has the straight-forward interpretation that technological change is responsible for any changes in output unaccounted for by variations in the amount of capital per employee.

In this model, factor changes are combined geometrically (weighted by elasticities of output with respect to each factor) rather than arithmetically

[15] Robert M. Solow. 1957. Technical change and the aggregate production function. Review of Economics and Statistics 39:323-333.

[16] Warren Hogan. 1958. Technical progress and production functions. Review of Economics and Statistics 40:407-413.

(weighted by prices). The geometric name is derived from the weights, which, if the function is defined as Q=f(K,L), means the elasticity of output with respect to labor is the partial derivative $(\delta Q/\delta L)(L/Q)$. Another difference from the arithmetic model is that capital is adjusted for the capacity utilized, as an attempt to include the flow of capital, rather than the stock.

The capital utilization rate is calculated according to the Wharton School Econometrics Unit, as discussed by Phillips.[17] This method adjusts for idle capacity by charting quarterly output data and selecting peaks by inspection. Each peak was defined as 100 percent capacity, and a straight line from peak to peak was used to describe the capacity utilized in the intervening years. The average annual capacity utilized was then multiplied by the capital series to obtain an estimate for capital in use. The capacity utilization rates are included in Appendix A.

An example will show how the geometric index is calculated. Equation (6) is multiplied by A to yield:

$$\Delta A = A \left(\frac{\Delta y}{y} - W_k \frac{\Delta k}{k}\right) \qquad (6)$$

The index for logging camps and contractors, for 1959, is calculated from the data in Table 3. The

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[17] Almarin Phillips. 1963. An appraisal of measures of capacity. American Economic Review 53(2):275-292.

residual for that year results from the two years between 1958 and 1959:

$$-.050 = 1.000\left(\frac{5453-5445}{5445}\right) - .416\left(\frac{5649-5025}{5025}\right)$$

Since the index (A) for 1959 was arbitrarily set at one, each residual is then added to the previous year's index to produce the cumulative result (1.000 - .050 = .950, the index for 1959; the residual for 1960 is .077, which yields the index .950 + .077 = 1.027).

Capital's share in income, W_k, is calculated by subtracting the payroll from value added, and dividing the result by value added. The weight for calculating the residual for the change between 1958-59 comes from data for 1958: (390.4-288.0)/390.4 = .416. This data is from Appendix Tables B1-B4.

A similarity in the two models is the fact that the indexes of technological change are calculated as residuals. This practice led Abramovitz to declare them "some sort of measure of our ignorance."[18]

Cobb-Douglas

The Cobb-Douglas has been one of the most popular aggregate production functions ever since its introduction in 1928.[19] Its success has no doubt been

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[18] Moses Abramovitz. 1956. Resource and output trends in the United States since 1870. American Economic Review 46(2):5-23.

[19] C.E. Ferguson. 1969. Microeconomic thecry. Homewood, Ill. Richard D. Darwin, Inc.

due to several factors: its ease of explanation, its plausible form (constant return to scale, diminishing returns to a factor), and its ease of estimation by standard regression techniques.

The Cobb-Douglas production function is given by the form:

$$Q = A K^{B} L^{1-B} \qquad (7)$$

This function is homogeneous of degree one and has an elasticity of substitution of unity, since the exponents sum to one. A less restrictive form of this function is to remove the constraint that the exponents sum to unity:

$$Q = AK^{b}L^{c} \qquad (8)$$

While not strictly a Cobb-Douglas, fitting such a function by regression will provide an estimate of the returns to scale for the industry, as indicated by the sum of the exponents. A sum greater than one indicates economies of scale; less than one, diseconomies of scale.[20] If we assume competition in factor markets and that entrepreneurs minimize costs, then the ratio of the price of capital, P_K, to the wage rate, w, will be the same as the ratio of the marginal product of capital to the marginal product of labor:[21]

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[20] Murray Brown and John S. de Cani. 1962. Technological changes in the United States, 1950-1960. Productivity Measurement Review 29:26-39.

[21] Ibid.

$$\frac{P_k}{w} = \frac{bL}{cK} \qquad (9)$$

From this relation we see that an increase in b relative to c implies a labor-saving technological change, and a decrease in b relative to c implies a labor-using technological change.

A further modification of the classical Cobb-Douglas function also allows an estimate of the trend in technological change. Addition of a time variable will indicate the rate of change:

$$Q = AK^bL^ct^d \qquad (10)$$

This form of the Cobb-Douglas function has been used to identify "technological epochs," during which there was no nonneutral technological change.[22]

Constant Elasticity of Substitution

The constant elasticity of substitution (CES) function is more general, and it includes the Cobb-Douglas as a special case. It was developed because the assumption of unitary elasticity of substitution was felt to be unduly restrictive.[23] The function is expressed as:

$$V = A\left(dK^{-p} + (1 - d)\ L^{-p} \right)^{-1/p} \qquad (11a)$$

where V is value added, K and L are capital and labor, A is a (neutral) efficiency parameter, p is a substitution

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[22] Murray Brown and Joel Popkin. 1962. A measure of technological change and returns to scale. The Review of Economics and Statistics 44:402-411.

[23] K.J. Arrow, H.B. Chenery, B.S. Minhaus, and R.M. Solow. 1961. Capital-labor substitution and economic efficiency. Review of Economics and Statistics 43:255-248.

parameter ($1/(1 + p) = s$, the elasticity of substitution), and d is a distribution parameter.

The addition of a time parameter allows estimation of technical change:

$$V = A(1)^t \left(dK^{-p} + (1 - d) \ L^{-p}\right)^{-1/p} \tag{11b}$$

The CES function was derived from an observed relationship between wages and labor productivity:

$$\log\left(\frac{V}{L}\right) = \log a + b \log W + e \tag{12}$$

The coefficient b is taken as an estimate of the elasticity of substitution.

The function is developed by showing the reverse of the implications of the standard theory of production: that a particular relation between value added per unit labor and wages determines the production function.

The original method for estimating this equation involved a piecemeal process, calculating one or two coefficients at a time. To avoid the simultaneous equation bias this method introduces, the entire equation (11b), save one coefficient, was estimated at one time using nonlinear regression. The elasticity of substitution (and therefore p) was estimated separately, using equation (12).

It is necessary to make the usual assumptions for this model to hold; those of constant returns to scale and competitive labor markets. One additional assumption is that the prices of products and material inputs do not vary systematically with the wage level. A weak test of this assumption was performed by Arrow, *et. al.*, and the assumption was not rejected.[24] This test was not performed for the data used in this study.

The generality and adaptability of the function has been demonstrated by its use to measure the influence of technological change on employment,[25] and to study the distribution of income between capital and labor.[26]

Johansen Index

The reliability of the results from any mathematical model depend greatly on the quality of the data available. The data series principly employed in all of the above models are value added, labor, and capital. Of these three, the capital series is of the poorest quality. Accounting problems involving use of historical or replacement cost, depreciation methods, and taxation elements make estimation of capital series difficult.

Johansen derived a model which does not use a capital series in estimating technological change.[27] Its aim is

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[24] *Ibid*.

[25] Murray Brown and John S. de Cani. 1963. A measure of technological employment. Review of Economics and Statistics 45:386-394.

[26] Murray Brown and John S. de Cani. 1963. Technological change and the distribution of income. International Economic Review 4(3):289-309.

[27] Leif Johansen. 1961. A method for separating the effects of capital accumulation and shifts in production functions upon growth in labor productivity. Economic Journal 71:775-782.

to avoid use of the poor quality data series.

The equation is:

$$\log\left(\frac{a_2}{a_1}\right) = (\log w)\ B + e \tag{13}$$

where a is labor productivity, B is capital's share in value added, w is the relative increase in wages between periods 1 and 2, and e is the log of the average increase in productivity. A necessary assumption to perform the computation by regression techniques is that e is not correlated with B.

The model is derived from a Cobb-Douglas formulation, on the assumptions that firms minimize costs, and that relative shares of capital and labor are constant, with the result that the proportional increase in total wages paid between two periods is equal to the proportional change in total return to capital:

$$\frac{W_2L_2}{W_1L_1} = \frac{R_2K_2}{R_1K_1} \tag{14}$$

where W is wages, L is labor, R is rate of return to capital, and K is capital. If managers consider W and R as given, then to minimize costs they make adjustments in the capital to labor ratio. This leads to

$$\frac{K_2/L_2}{K_1/L_1} = \frac{W_2/W_1}{R_2/R_1} = w \tag{15}$$

where w is taken to be the relative increase in wages.

The above mathematical models are all dependent upon simplifying assumptions, necessary to handle an otherwise unmanageably complex reality, or to release the analysis from otherwise crippling lacks of information. The differing assumptions and forms of modeling can produce striking differences in results. Further, the models generally produce only one type of information; the time trend of technological advance. This time trend is usually calculated as the "residual" increase in value added from one period to another, unexplained by increases in capital or labor. This residual time trend, while useful for increasing our knowledge of the changes in an industry, needs to be corroborated with additional indicators of technological change to be properly interpreted.

III. EVIDENCE OF PAST TRENDS

The trends of technological change in the U.S. forest industries will be presented first by a brief history of the major machinery and process changes that have occurred, followed by the information that can be extracted from the series on prices, production, capital, employment, etc. Lastly, four models will be employed to measure technological change. These various types of evidence of technological change will be presented for four forest industries, classified by the Census of Manufactures as (a) logging camps and contractors (Standard Industrial Classification 2411), (b) sawmills and planing mills, general (SIC 2421), (c) pulpmills (SIC 2611), (d) papermills, except building paper (SIC 2621).

No correction is made in this study for improvements in the quality of labor. Improved health and education presumably increase the productivity of workers, and this will bias the quantitative measures of technological change upward. For example, Denison estimated that 23 percent of the growth rate in the United States from 1929 to 1957 was due to education. He further projected the contribution of education to the growth rate for 1960-1980 would be 19 percent.[28] To the extent that better education is not

[28] Edward F. Denison. 1962. The Sources of Economic Growth in the United States and the Alternatives Before Us. Committee for Economic Development, Supplementary Paper No. 13.

reflected in the price of labor, the measures will overstate technological change.

A second factor affecting productivity and hence of concern in estimating technological change is management. Improvements in management are presumed to have accumulated over time. In a recent survey of chief executive and industrial relations offices, 65 percent of the respondents rated "more effective management" as very important in improving productivity. The percentages for other factors rated as very important in influencing productivity were: Capital investment, 27 percent; improved technology, 35 percent; and human relations, 36 percent.[29] Productivity in the survey was defined in a broad sense of overall efficiency, effectiveness, and performance of the organization. The importance attached to management in the survey is taken to be an indication of both past progress in this area, and of potential for future improvement. However, due to the difficulty of quantifying the effects of management on productivity, this factor is not explicitly considered in the quantitative measures.

A third concern is factor quality. Changes in the quality of logs are not corrected for in the indexes; however, some indication will be given through the use of supplemental data.

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[29] Mildred Katzell. 1975. Productivity: The measure and the myth. American Management Association survey report.

Logging Camps and Contractors (SIC 2411)

Firms in this industry are primarily engaged in cutting timber and in producing rough, round, hewn, or riven primary forest or wood raw materials.[30]

Logging and woods operations connected with pulpmills, sawmills, etc., and not separately reported are included in these other industries.

Examples of technological change in this industry are mainly of new machinery. A major productivity increase occurred with the adoption of the power chainsaw. This development, adopted in the 1940's and 1950's, will probably have little effect on the indexes.

Another method of cutting developed soon after the power saw: the hydraulic shear. This means of cutting results in lower stumps, although it is generally limited to smaller sized timber (usually less than 24 inches, although one model can handle trees up to 36 inches). One problem involved with shears is the compressing and tearing of fibers up to 10 inches from the cut. The major advantage of this method, of course, is its speed. Timber up to 14 inches is cut in 3 to 6 seconds, where a manually operated power saw takes 30 to 90 seconds.[31]

Other new machines have been developed to perform a

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[30]Executive Office of the President, Office of Management and Budget. 1972. Standard Industrial Classification Manual. GPO. Washington, D.C.

[31]Steve Conway. 1973. Timber cutting practices. San Francisco: Miller Freeman Publications, Inc.

greater number of operations. There are feller-bunchers, which raise productivity by reducing the amount of time necessary to choke a full load for skidding. A further development is the Buschcombine, which fells, limbs, bucks, and forwards the load to a trailer. These types of machinery find limited use in the Pacific Northwest and Rocky Mountains. The terrain and timber size limit their use to the South, Lake States, and Northeast.

Wheeled skidders are possibly the second-most major development after the chain saw. These machines move with twice the speed of crawler tractors, although their loads are generally smaller. New models of these skidders are being adapted to operate on rougher and wetter terrains than their predecessors.[32]

A new method of logging, which also has entailed the development of suitable equipment, is whole-tree harvesting. Its advantages are that there are fewer pieces to skid for a given amount of wood, and any bucking can be done by machine in a timber yard. Opportunities for bucking for highest value are improved.

A related development to whole-tree harvesting is chipping in the woods. This allows more complete utilization of the total material in the stand.[33] Development of a bark/chip separator is necessary for

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[32] Forest Industries. 1967. Logging handbook No. 4. San Francisco, Calif. Miller Freeman Publications, Inc.

[33] Ibid.

greater use of this method, however.

There are other indicators of technological change in any industry, some of which are given in Table 1 for logging camps and contractors. Comparison of yearly new capital expenditures with the year-to-year change in gross fixed assets reveals little similarity. This serves to point out that the quality of the capital data series is probably low. The capital series is poor because of changes that are difficult to adjust for, such as tax laws, depreciation methods, etc.

New capital expenditures rose at about 5.6 percent yearly, on the average, over the 19 years covered, while U.S. domestic production of industrial roundwood grew by only 1.8 percent per year.[34] A rate of capital investment in an industry greater than the rate of its market expansion indicates either capital replacement of labor, technological change, or both.

The number of establishments in this industry, as estimated by the Bureau of the Census, has remained fairly constant, as shown in Table 2. Except for the peak year of 1967, the number has stayed near 13,000 establishments. The real value added by each has also increased about 85 percent. The number of employees, however, has remained the same, except for a low in 1967. That year showed an increase in the number of establishments, but a decrease in the

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[34] Robert B. Phelps. 1977. op. cit.

Table 1.--Some indicators of technological change in logging camps and contractors.

Year	New Capital Expenditures (Mill 1958 $)	Change in Gross Fixed Assets[1] (Mill 1958 $)	Total Gross Fixed Assets (Mill 1958 $)	All Employees (Thou)
1958	68.4		388.7	71.7
1959	71.1	49.1	437.8	75.8
1960	80.5	1.7	439.5	73.1
1961	60.2	3.1	442.6	71.4
1962	59.4	48.4	491.0	69.3
1963	95.3	36.6	527.6	73.1
1964	75.2	39.5	567.1	70.1
1965	113.6	18.8	585.9	73.7
1966	109.1	-9.6	576.3	72.5
1967	89.5	20.8	597.1	70.6
1968	86.5	37.4	634.5	69.9
1969	102.5	65.4	699.9	73.8
1970	63.4	-117.7	582.1	76.1
1971	105.4	3.2	585.3	68.3
1972	99.4	151.5	736.8	80.0
1973	90.6	21.0	757.8	85.9
1974	136.9	-63.2	694.6	75.5
1975	164.2	48.7	743.2	67.2
1976	129.2	34.3	777.6	71.5

[1]Calculated from total gross fixed assets.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 2.--Number of establishments and per establishment data for logging camps and contractors.

Year	Number of Establishments	Per Establishment: Capital[1] (Thou. $)	Per Establishment: Employees	Per Establishment: Value Added[2] (Thou. $)
1958	12828	30.3	6	30.4
1963	13588	38.8	5	37.9
1967	16334	36.6	4	39.3
1972	13238	55.7	6	56.3

[1]Gross value of fixed assets, 1958 dollars.
[2]Value added by manufacture, 1958 dollars.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

capital and employees in each establishment. These smaller, but more numerous operations managed to maintain the growth in value added for the industry, however.

The geometric index (Table 3) increased at a rate of 2.32 percent compounded annually.

Real value added per employee increased from $5,445 in 1958 to $13,665 in 1976, a 151 percent change. At the same time, real capital per employee increased by 109 percent. The corresponding annually compounded increases are 4.96 percent and 3.95 percent, respectively, while output per unit of capital grew at an annual compounded rate of 1.19 percent. The share of capital in income increased by 52 percent from 41.6 percent to 63.3 percent. This latter measure is also an estimate of the elasticity of capital with respect to output.

The last column of Table 3 is the real value added per employee net of technological change. The increase in capital intensity accounts for 41.2 percent of the increase in per employee productivity. Technological change is responsible for the majority of the gain, or 58.8 percent. This indicates that during the time period covered, technological change has had a substantial impact on the timber harvesting industry.

The growth in output per unit of capital was greater for the last half of the period than for the first half, as shown in Table 4.

Table 3.--Geometric index of technological change in industry SIC 2411.

Logging Camps and Contractors

Year	Real Value Added[1] Per Employee	Capital[2] Share	Real Capital[3] Per Employee	Geometric Index of Technological Change	Corrected[4] Real Value Added Per Employee
1958	5445	.416	5025	1.000	5445
1959	5453	.433	5649	.950	5740
1960	5827	.436	5543	1.027	5674
1961	6385	.449	5492	1.126	5671
1962	6739	.461	6667	1.086	6205
1963	7037	.459	6915	1.113	6323
1964	7689	.465	7710	1.153	6669
1965	8102	.514	7537	1.217	6657
1966	8343	.527	7393	1.256	6643
1967	9097	.513	7654	1.328	6850
1968	9235	.528	8678	1.275	7243
1969	8535	.528	9114	1.172	7282
1970	9546	.546	6900	1.419	6727
1971	9133	.529	8133	1.278	7146
1972	9312	.550	8906	1.248	7462
1973	9760	.625	8636	1.312	7439
1974	12238	.632	8059	1.608	7611
1975	13323	.612	9213	1.606	8296
1976	13665	.633	10495	1.547	8833

[1]Deflated value added by manufacture, divided by number of all employees.
[2]Value added by manufacture minus all employees payroll, divided by value added.
[3]Deflated gross value of fixed assets, divided by number of all employees.
[4]Real value added per employee, divided by the geometric index of technological change.

Table 3.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 4.--Annual growth rates in productivity, 1958-1967, and 1968-1976 for logging camps and contractors.

Year	Output per unit of labor	Output per unit of capital
1958-1967	5.26	0.69
1968-1976	4.45	2.38

This increase in capital productivity, coupled with a decline in labor productivity, is evidence of a substitution of capital for labor in latter period, in terms of the rate at which each factor increased output.

Kaiser and Guttenburg calculated output per manhour for U.S. sawmills as increasing at an average annual rate of 3.2 percent between 1954 and 1967. This was in contrast to the 1.2 percent rate for the first half of the century.[35] They also found the greatest increase in the South, with 3.4 percent, while the West experienced 2.9 percent, and the North lowest at 2.3 percent.

The sum of the exponents in an unrestricted Cobb-Douglas production function (the exponents are not forced to sum to 1) give an indication of returns to scale for an industry. For logging camps and contractors, the unrestricted Cobb-Douglas function is:

$$\log Y = 0.7948 + \underset{(.1612)}{1.1896} \log K - \underset{(.5974)}{0.3688} \log L \quad R^2=0.782$$

[35] H.F. Kaiser and Sam Guttenburg. 1970. Gains in labor productivity by the lumber industry. Southern Lumberman 221:15, 18.

The sum of the labor and capital coefficients is 0.8208; a figure less than one indicates the industry is operating at diseconomics of scale (the numbers in parenthesis are standard errors).

A negative exponent is unexpected in a Cobb-Douglas equation; its literal meaning is that production could be increased by decreasing the labor input. In a Cobb-Douglas function, the coefficients will not turn out "right," i.e., both positive and less than one unless the indexed trend of value added lies between those for capital and labor.[36]

Introduction of a time factor into the function will give an estimate of the change in output due to time, and hence, an indication of technological change.

Table 5 shows the time trend in the Cobb-Douglas coefficients. Regressions were fitted on the data for the first 10 years and also on successive periods consisting of additions of 2 years, i.e., 10, 12, 14, 16, 18, and finally 19 years. Unfortunately, the only coefficients with acceptable standard errors are those for the time variable. This series of coefficients show an increasing trend, which would suggest that the rate of technological change was increasing in the seventies. This is also indicated by the geometric index where the greatest

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[36] E.H. Phelps Brown. 1957. The meaning of the fitted Cobb-Douglas production function. Quarterly Journal of Economics 71:546-560.

Table 5.--Three-factor Cobb-Douglas function ($Y = AK^bL^cT^d$) for logging camps and contractors.

Period	log A	b	c	d	b + c	R^2
1958-1967	3.3510	0.4756 (.3458)	-0.0603 (.9313)	0.1287 (.7704)	0.4153	0.902
1958-1969	4.8054	.4020 (.2523)	- .2979 (.7664)	.1375* (.0647)	.1041	.921
1958-1971	1.8395	.1143 (.2301)	.7806 (.5955)	.2219* (.0533)	.8949	.908
1958-1973	1.2627	.1194 (.2024)	.9082* (.3483)	.2223 (.0487)	1.0276	.939
1958-1975	3.0267	.0626 (.3266)	.5596 (.5200)	.2812* (.0774)	.6222	.870
1958-1976	2.8567	.3185 (.3168)	.2461 (.5273)	.2405* (.0796)	.5646	.865

*Significant at the 10 percent level.

increases occur in 1970 and 1974. The coefficient corresponds to a yearly rate of increase of 3.8 percent, which is a somewhat larger increase than the geometric index.

The relationship of the capital and labor exponents suggests the type of technological change that occurred. A rise in b relative to c denotes a labor-saving technical change, while a fall in b relative to c is evidence of a labor-using technical change.

Except for a dip in the second period, the labor coefficient was rising, and the capital coefficient falling, through 1973. This indicates that technological changes during this period tended to be of a labor-using type, suggesting new technologies adopted required relatively more labor than capital. This trend was reversed in the last two periods, however.

The sum of the exponents for the capital and labor variables is a measure of returns to scale for the industry. While highly variable, returns to scale have generally been less than one. Unfortunately, only one coefficient for one period is significant for these two variables; hence, these estimates of returns to scale are not reliable. The full equation, however, is relatively good at explaining the variation in the observed output levels, as evidenced by the R-squares.

Unlike the Cobb-Douglas function which assumes the elasticity of substitution to equal unity, the CES function allows its estimation. For logging camps and contractors, fitting equation (11b) by least squares yields:

$$V = 2.6536\ (1.0334)^t \left(.3075\ K^{.3542} + .6925\ L^{.3542}\right)^{.2823}$$

The elasticity of substitution, estimated by equation (12) is 1.548 (the standard error is .0952). This suggests it has been relatively easy to replace labor with capital in the logging industry. This is verified by the trends in labor and capital presented above.

The technological change parameter indicates that this factor has been advancing at the rate of 3.3 percent yearly. This is close to the rate estimated by the geometric index.

Sawmills and Planing Mills, General (SIC 2421)

Past technological changes in the sawmilling and planing industry have consisted of refinements to systems in general use before 1958. One of the major adjustments has been to process logs in a continuous flow, requiring little manual handling. Another has been the shift from ponding to cold-decking of logs, with transport accomplished with large-capacity, log-loading tractors.

The move toward cold-decking logs has also allowed better log sorting systems. The logs are sorted first for product (veneer, sawlogs, pulp) and for sawlogs, sorted further by size. Sawmilling runs of logs of all one size are then made at greater speeds, due to less need for adjustment.

Chipping of slabs and edges has reduced waste disposal problems and added salable chips. Debarking has also increased, with the bark often being burned for energy or sold for mulch.

Edger saws with thin blades and carbide-tipped teeth have reduced saw-kerf waste by one-third.

Improvements have also been made in sorting, stacking, and packaging of lumber. The main effort has been to replace hand labor with automated machines.

These innovations have required major investments by sawmill and planing mills. Capital expenditures in 1972 were $1,842 per employee, considerably higher than for all manufacturing ($1,335). These investments supported a rising output per employee hour at an average annual rate of 2.7 percent from 1958 to 1975.[37] From 1971 to 1976, however, the annual average percent change was only 0.4 percent.[38]

Other indications of technological change add insight into the sawmilling and planing industry. The trend in new capital expenditures, shown in Table 6, averages a compounded increase of 3.1 percent annually. This is in contrast to the rate of decrease in total employees, (-1.95 percent) and the growth in domestic lumber production of only .43 percent compounded annually.[39]

Table 7 shows the number of establishments in this industry, as estimated by the Bureau of the Census, has experienced a dramatic decline, on the order of 48 percent. Further, the contraction in the number of establishments has been quite steady. In contrast, capital per establishment has greatly expanded between 1958 and 1972, by 145 percent. Capital in the industry has not been augmented greatly; the expansion has been due to the decline in the

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[37] John Duke and Clyde Huffstutler. 1977. Productivity in sawmills increases as labor input declines substantially. Monthly Labor Review. April.

[38] Arthur S. Herman. 1977. Productivity reports. Monthly Labor Review. October.

[39] Robert P. Phelps. 1977. op. cit.

Table 6.--Some indicators of technological change in sawmills and planing mills, general

Year	New Capital Expenditures (Mill 1958 $)	Change in Gross Fixed Assets[1] (Mill 1958 $)	Total Gross Fixed Assets (Mill 1958 $)	All Employees (Thou)
1958	129.4		1633.7	245.9
1959	127.0	180.7	1814.4	252.2
1960	152.1	-182.8	1631.6	240.6
1961	103.8	-153.3	1478.2	214.3
1962	123.9	70.6	1548.8	209.8
1963	165.1	63.4	1612.2	207.4
1964	144.0	97.3	1709.5	199.0
1965	160.7	-57.2	1652.3	201.6
1966	148.4	-21.5	1630.8	195.0
1967	114.2	-25.8	1605.0	180.5
1968	147.7	26.3	1631.3	175.8
1969	171.1	50.2	1681.5	177.7
1970	145.5	-69.0	1612.5	173.8
1971	169.1	-12.2	1600.3	169.7
1972	215.4	468.0	2068.3	166.6
1973	253.0	22.4	2090.7	173.7
1974	331.2	-147.1	1943.6	186.0
1975	230.8	-101.0	1842.6	159.7
1976	231.9	4.5	1847.1	169.1

[1]Calculated from total gross fixed assets.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 7.--Number of establishments and per establishment data for sawmills and planing mills, general

Year	Number of Establishments	Per Establishment: Capital[1] (Thou. $)	Per Establishment: Employees	Per Establishment: Value Added[2] (Thou. $)
1958	15637	104.5	16	76.5
1963	12189	132.3	17	110.8
1967	10271	156.3	18	135.6
1972	8071	256.3	21	202.2

[1] Gross value of fixed assets, 1958 dollars.
[2] Value added by manufacture, 1958 dollars.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

number of establishments and the survivors expanding to take their place in production. This will also be indicated by the Cobb-Douglas estimate that the industry has been operating under rather large diseconomies of scale.

While the amount of capital in each establishment has been growing rapidly, the number of employees in each has been growing only slightly. The average mill employs five more in 1972 than it did 14 years previously. This is less than a one-third increase. At the same time, output per establishment has increased by 164 percent.

Improvements in processing technology in sawmilling and planing should generally be reflected in the amount of raw material required to produce a given output. Figures 1 and 2 show the trend in cubic feet of sawlogs required to produce 1,000 board feet of lumber, softwood and hardwood, International $^1/4$-inch scale.

The North was the only region showing a decline in the raw material requirements for production of 1,000 board feet of softwood lumber. The South had a slightly rising trend and the Pacific Coast and Rocky Mountain regions had level trends (Figure 1).

There are two forces which would tend to offset a decline in raw material requirements per unit of output in this industry. One is a decline in the quality of the logs used, manifested by smaller diameter environmental and economic considerations requiring use of lesser quality

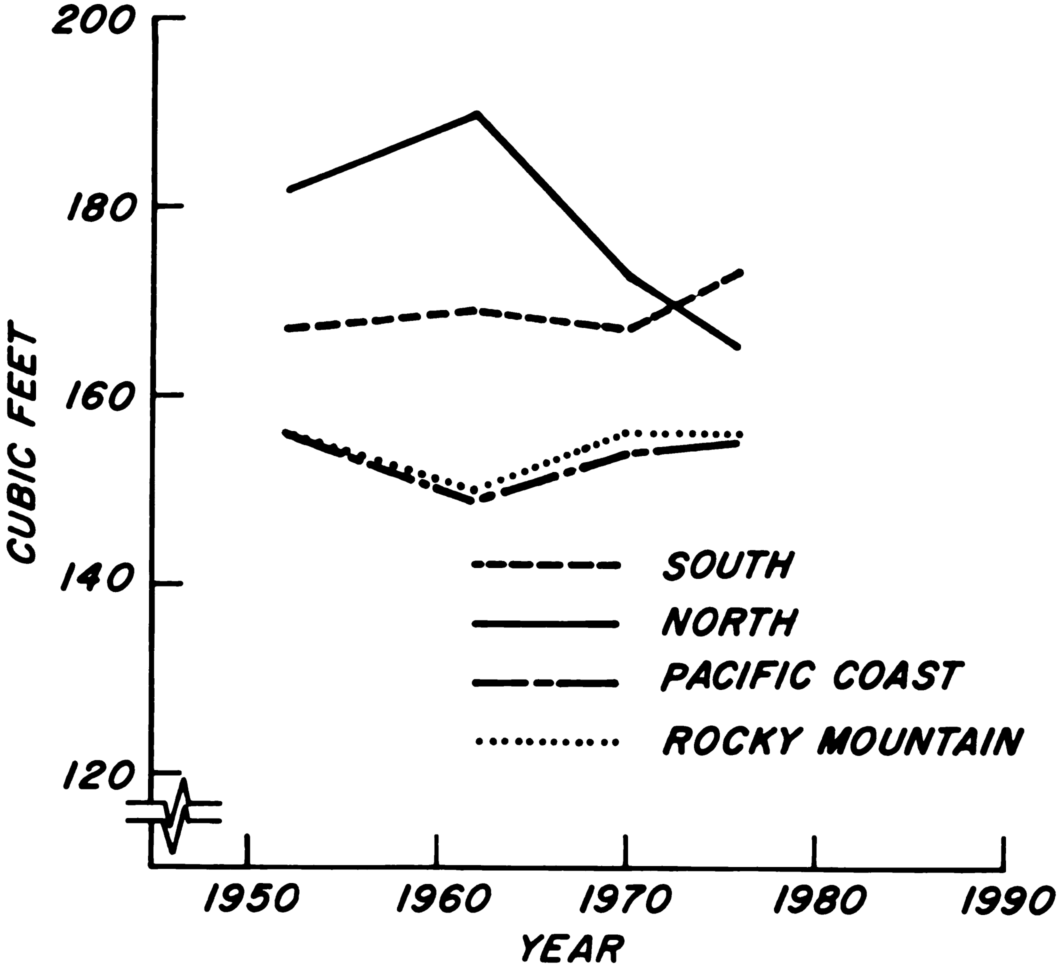

Figure 1. Cubic feet per thousand board feet International 1/4 scale: softwood sawlogs, 1952-1976.

Sources:

1952 - Forest Service. 1958. Timber Resources for America's Future. USDA Forest Resource Report No. 14. Washington, D.C.: U.S. Government Printing Office.

1962 - Forest Service. 1965. Timber Trends in the United States. USDA Forest Resource Report No. 17. Washington, D.C.: U.S. Government Printing Office.

1970, 1976 - Unpublished Forest Service data.

materials that would otherwise be left in the woods. The other is the development of new technologies that allow utilization of smaller material for sawlogs. An example would be the chipping headrig, which can turn very small logs into studs, and the slabs and edgings into chips. Increased use of such technologies would result in an upward trend in the raw material requirements per unit of output.

Figure 2 shows the raw material requirements to produce 1,000 board feet of hardwood lumber. For this resource, the trends have been much more sharply upward, relative to those for softwoods. The trend for all regions except the North turned upward sharply in 1962, and the latter also turned upward in 1970. These upward trends mean that it now takes more cubic feet of hardwood sawlogs to produce a 1,000 board feet of lumber than it did in the past. (The datum point for the Pacific Coast, 1976 is considered a poor estimate. In addition, the amount of hardwood production in this region is very small, 3 percent of the national total in 1976.)

These increasing trends for hardwood are probably the result of a decline in the quality of the resource (more defects, sweep, crook, knots, etc.) and smaller sizes, not offset by yield-increasing advances in technology.

The national trends in this area are shown in Figure 3. Overall, the trend for softwoods has been slowly upward, and that for hardwoods more sharply upward since 1962. Advances

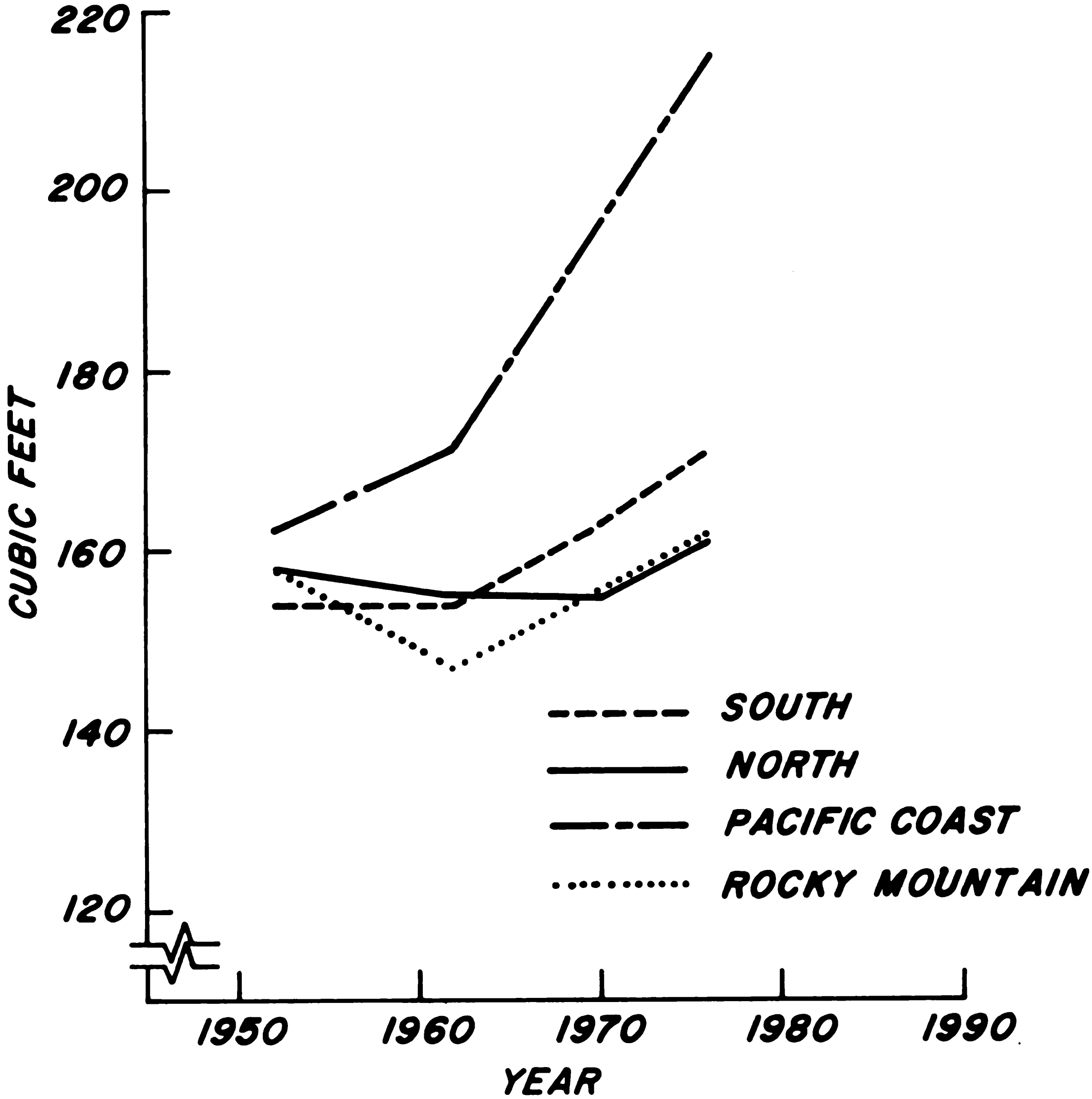

Figure 2. Cubic feet per thousand board feet International 1/4 scale: hardwood sawlogs 1952-1976.

Sources:

1952 - Forest Service. 1958. Timber Resources for America's Future. USDA Forest Resource Report No. 14. Washington, D.C.: U.S. Government Printing Office.
1962 - Forest Service. 1965. Timber Trends in the United States. USDA Forest Resource Report No. 17. Washington, D.C.: U.S. Government Printing Office.
1970, 1976 - Unpublished Forest Service data.

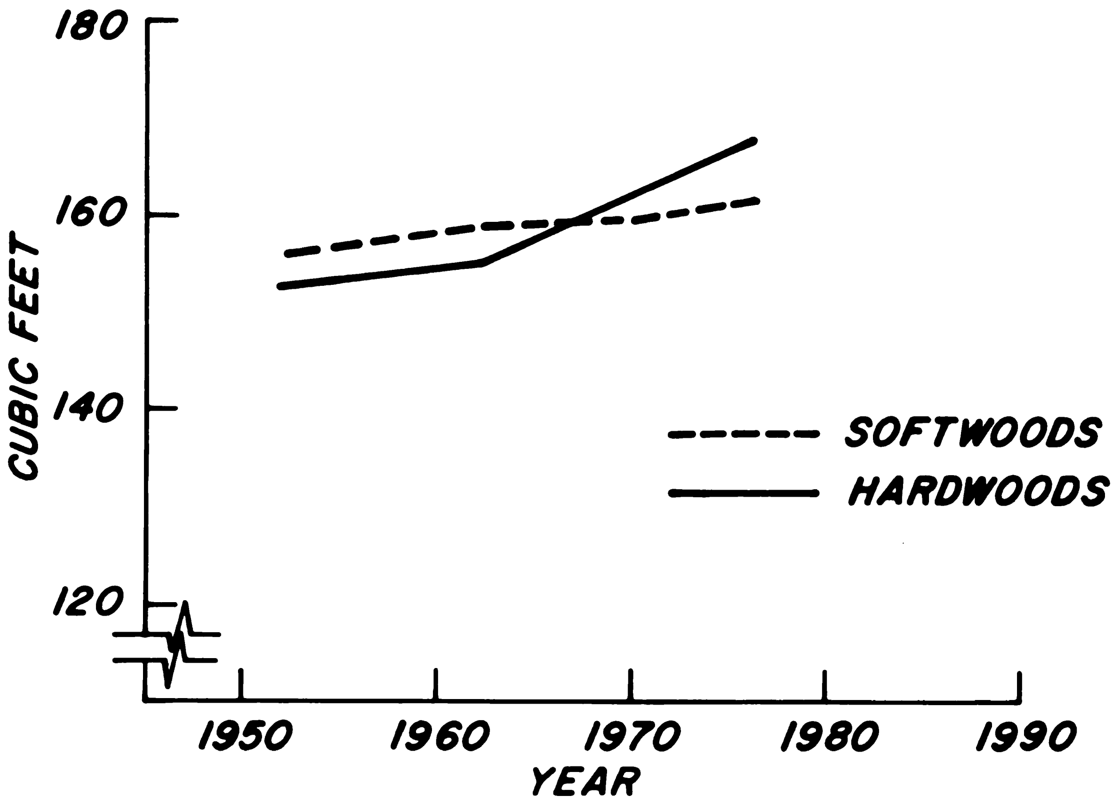

Figure 3. Cubic feet per thousand board feet International 1/4 scale: sawlogs, U.S. totals. 1952-1976.

Source:

Figures 1 and 2, weighted by regional sawlog removals, 1952, 1962, 1970, and 1976.

in sawmilling and planing technologies may have slowed what would have otherwise been a more rapidly rising trend.

The geometric index shows additional details, such as that the output per employee increased 75 percent over the period studied (Table 8), an average annual compounded increase of 1.7 percent.

The last column in Table 8 gives the trend in per employee productivity due only to capital increases. This series is net of technological change. The capital deepening in this industry is responsible for only 35.2 percent of the increase in per employee productivity. The major portion of the increase, 64.8 percent is due to technological improvements. Real capital per employee peaked in 1972, just before the housing recession. It then fell by 23 percent in just 2 years. Had the housing recession not occurred, there would have presumably been no interruption in the rate of capital investment per employee. Investment per employee has since apparently resumed its normal upward trend of about 2.9 percent per year.

The share of capital in income also peaked in 1973, just one year after the investment per employee high. However, the overall trend in this estimate of output elasticity with respect to capital has been upward.

Table 8.--Geometric index of technological change in industry SIC 2421

Sawmills and Planing Mills, General

Year	Real Value Added[1] Per Employee	Capital[2] Share	Real Capital[3] Per Employee	Geometric Index of Technological change	Corrected[4] Real Value Added Per Employee
1958	4863	.355	6159	1.000	4863
1959	5543	.432	7036	1.089	5090
1960	5357	.374	6252	1.104	4852
1961	5885	.381	6112	1.211	4860
1962	6371	.416	6947	1.241	5134
1963	6511	.410	7447	1.233	5281
1964	7343	.405	8187	1.320	5563
1965	6887	.399	7770	1.279	5385
1966	7133	.440	7777	1.314	5428
1967	7717	.432	8047	1.381	5588
1968	8301	.509	8871	1.412	5879
1969	7757	.501	9094	1.334	5815
1970	7981	.414	8369	1.403	5689
1971	8538	.497	8949	1.444	5913
1972	9794	.562	12005	1.421	6892
1973	9476	.629	11784	1.399	6773
1974	7751	.551	9154	1.357	5712
1975	7720	.462	9611	1.326	5822
1976	8527	.550	10541	1.386	6152

[1] Deflated value added by manufacture, divided by number of all employees.
[2] Value added by manufacture minus all employees payroll, divided by value added.
[3] Deflated gross value of fixed assets, divided by number of all employees.
[4] Real value added per employee, divided by the geometric index of technological change.

Table 8.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 9 shows some rather surprising results of applying the partial measures of capital and labor productivity to the sawmilling and planing industry. Productivity shows a tremendous decline in the last half of the period; in fact the capital measure becomes negative. This decline in capital productivity is possibly a reflection of added equipment for pollution control.

Table 9.--Annual growth rates in productivity, 1958-1967, and 1968-1976, for sawmills and planing mills.

Years	Output per unit of labor Pct.	Output per unit of capital Pct.
1958-1967	4.73	1.72
1968-1976	.30	-1.50

The unrestricted Cobb-Douglas function for this industry is given by:

$$\log Y = 4.5275 + \underset{(.1079)}{.4990} \log K - \underset{(.0896)}{.1841} \log L \quad R^2 = .678$$

The sum of the coefficients equals .3149; this is much less than one, and indicates the industry has been operating under diseconomies of scale.

The addition of a time variable into the unrestricted Cobb-Douglas yields an indication of technological change. Table 10 shows the time trend of the fitted parameters. The standard error of the labor coefficient is always larger than the coefficient; hence, it cannot be considered statistically significant. However, the series would

Table 10.--Three-factor Cobb-Douglas function ($Y=AK^bL^cT^d$) for sawmills and planing mills, general.

Period	log A	b	c	d	b + c	R^2
1958-1967	3.5381	0.4968* (.0961)	-0.0135 (.1793)	0.0645* (.0257)	0.4833	0.923
1958-1969	3.5587	.4209* (.1190)	.0840 (.2023)	.0712* (.0328)	.5049	.834
1958-1971	3.6386	.4289* (.1075)	.0589 (.1750)	.0686* (.0295)	.4878	.844
1958-1973	3.6170	.4456* (.0549)	.0408 (.1492)	.0662* (.0259)	.4864	.934
1958-1975	2.7746	.4856* (.1088)	.1433 (.2508)	.0632 (.0437)	.6289	.734
1958-1976	2.9787	.4648* (.1084)	.1350 (.2534)	.0588 (.0440)	.5998	.712

*Significant at the 10 percent level.

indicate labor was becoming more important in the productive process.

The A term, changes in which represent a change in neutral technology, remains relatively stable until the last few years, when it declines. This relates well to the c term, in which changes indicate changes in nonneutral technology. This parameter rises considerable in the last 2 years, relative to the other subperiods. The d parameter, an indicator of the rate of change in neutral technology, remains about the same throughout the period. The result of this factor yields only about a 0.9 percent yearly increase in neutral technological change. This estimate is much lower than the geometric index; however, the coefficients are not statistically acceptable in the last periods, although they are in the first four.

The sums of the labor and capital coefficients are all less than one, meaning the industry has been operating under diseconomies of scale. The figures have been generally approaching unity, however, which suggests that the forces causing the diseconomies may be lessening. Changes in the size and quality of sawlogs may also be involved.

The CES equation for sawmills and planing mills, estimated by nonlinear regression, is:

$$V = 1.1375\ (.9989)^{t} \left(.8360\ K^{.1314} + .164\ L^{.1314}\right)^{7.6104}$$

The equation yields the result that the output (real value added) of this industry can be estimated fairly closely by using just capital data. The elasticity of substitution of capital for labor is calculated as 1.1513 (standard error = .0747), which suggests it has not been as easy to substitute capital for labor in this industry as it has been for some of the other forest industries.

Ferguson found that for eleven cases in the lumber industry (SIC 26), the elasticity was greater than zero for eight, between 0 and 1 for two, and greater than one for one case. His data consisted of the Census years 1947, 1954, and 1958.[40]

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[40] C.E. Ferguson. 1963. Cross-section production functions and the elasticity of substitution in American manufacturing industry. Review of Economics and Statistics 45:305-313.

The time parameter, the measure of technological change, signals no advance. With the figure lying so close to one, however, it is difficult for the model to differentiate the small difference. Hence, it is viewed as not being very different from the other measures.

Pulpmills (SIC 2611)

This industry is defined as establishments engaged in manufacturing pulp from wood or from other materials. Included are logging camps operated by pulpmills but not separately reported.

One indication of technological change in this industry would be the use of fewer cords of wood per ton of pulp produced. Table 11 presents the trends in cords of wood consumed per ton of pulp produced for the various pulping processes.

In aggregate, pulping shows little progress in the reduction of cords of wood required to produce a ton of pulp. There was virtually no change between 1920 and 1970. Since then, there has been about a 6 percent improvement.

The reason for this lack of improvement in pulping lies primarily with the sulfate process, which has been steadily increasing its share in woodpulp production to 69 percent of the total. No stable improvement in terms of output per unit input has been made in this process since 1940. Instead, changes in this process have been

Table 11.--Pulpwood consumption per ton of pulp produced, by process, 1920-1976.
(Cords)

Year	Total	Dissolving and special alpha	Sulfite	Sulfate	Groundwood
1920	1.60	[1]	2.02	2.10	[2]
1930	1.55	[1]	2.00	1.78	[2]
1940	1.53	[1]	1.90	1.59	[2]
1950	1.59	[1]	2.30	1.70	[2]
1960	1.59	1.96	2.29	1.68	0.94
1965	1.57	2.23	1.96	1.72	.93
1970	1.60	2.14	2.15	1.72	.98
1974	1.54	2.30	2.14	1.68	.94
1976	1.51	2.24	1.81	1.65	1.02

[1] Included in sulfite/sulfate.
[2] Included in "other".

Sources:

David B. McKeever. 1977. Woodpulp mills in the United States in 1974 U.S.D.A. Forest Service Resource Report FPL - 1.

American Paper Institute. 1977. Statistics of paper and paperboard.

Table 11.--(cont'd.)

Year	Soda	Semichemical	Defibrated/esploded	Other[3]
1920	1.99	---	---	1.00
1930	1.79	[2]	---	.93
1940	1.84	[2]	[2]	.88
1950	1.95	[2]	[2]	.91
1960	----	1.04	0.97	----
1965	----	1.06	1.20	----
1970	----	1.03	1.38	----
1974	----	1.02	.83	----
1976	[1]	.95	.79	----

[3]Includes groundwood, semichemical, defibrated/exploded, screenings, and unspecified pulpwood types.

in improvements in the quality of the paper produced from the woodpulp. This has entailed generally more bleaching and refining. These changes have been to the detriment of the output of pulp per cord of wood, and have offset any yield-increasing improvements.

The slight improvement in the aggregate yield has been due to the introduction of new, and growth of older, higher yielding processes, such as semichemical, and defibrated/exploded pulps. These are not the type of pulps used for high-quality, bleached and coated papers, however, and they have not replaced the major process of sulfate pulping.

Some other indicators of technological change are presented in Table 12. New capital expenditures show the decline in the industry actually started about 1970, and this indicator didn't pick up again until 1975. Total gross fixed assets also show the slump the industry experienced in 1972-1974. Overall, employment in the pulpmill industry has remained fairly stable, with the exception of the 1972-1974 period.

Table 13 shows the number of establishments in this industry has remained constant except for a drop in the early 1960's. This decline was offset by the increases in capital, employees, and output per establishment. Given the tremendous investment required per establishment, a sudden change in the number of establishments in the

Table 12.--Some indicators of technological change in pulpmills

Year	New Capital Expenditures (Mill 1958 $)	Change in Gross Fixed Assets[1] (Mill 1958 $)	Total Gross Fixed Assets (Mill 1958 $)	All Employees (Thou)
1958	43.0		654.8	14.2
1959	89.9	65.3	720.1	14.5
1960	34.2	-18.4	701.7	14.5
1961	47.5	-54.2	647.5	13.6
1962	32.5	176.3	823.8	13.9
1963	37.2	24.8	848.6	15.1
1964	63.0	50.3	899.0	15.3
1965	104.4	19.9	918.9	14.8
1966	102.8	114.7	1033.6	15.9
1967	107.0	22.3	1055.9	15.1
1968	65.5	17.8	1073.7	15.4
1969	107.8	17.4	1091.1	14.9
1970	93.5	121.7	1212.8	15.6
1971	98.5	-20.8	1192.0	14.5
1972	95.8	-340.5	851.5	10.6
1973	80.1	34.3	885.8	10.8
1974	82.1	20.0	905.8	12.0
1975	156.3	112.9	1018.7	13.1
1976	190.5	227.3	1246.0	15.7

[1] Calculated from total gross fixed assets.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 13.--Number of establishments and per establishment data for pulpmills

		Per Establishment		
Year	Number of Establishments	Capital[1] (Mill $)	Employees	Value Added[2] (Mill $)
1958	59	11.10	241	3.32
1963	45	18.86	336	7.22
1967	61	17.31	248	5.62
1972	60	14.19	177	4.71

[1]Gross value of fixed assets, 1958 dollars.
[2]Value added by manufacture, 1958 dollars.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

industry would not be expected. In addition, the Census does not report separately pulpmills associated with paper mills. For example, the American Paper Institute reports 279 wood pulpmills in 1972.[41]

The geometric index of technological change for pulpmills (Table 14) advances at the compounded rate of 1.3 percent per year. Pulpmills have the highest real value added per employee of the four industries studied. This real output per man has grown from $13,803 to $22,313 in 19 years, an annually compounded rate of 2.6 percent. In contrast, the corrected real value added per employee (net of technological change), rose only 1.2 percent compounded annually. Of the productivity increase per employee, 42 percent is due to capital deepening, while the remainder, 58.0 percent, is accounted for by technological change.

This is also the most highly capitalized (in per employee terms) of the four industries. In 1976, real capital per employee in pulpmills was roughly 7.5 times higher than either logging camps and contractors or sawmills and planing mills, and about twice as high as paper mills. This investment per man grew at an annually compounded rate of 3 percent over the period studied. Both of these indicators had peaked in earlier years; real output per employee in 1974, and real capital per employee in 1971.

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[41] American Paper Institute. 1977. Statistics of paper and paperboard.

Table 14.--Geometric index of technological change in industry SIC 2611

Pulpmills

Year	Real Value Added[1] Per Employee	Capital[2] Share	Real Capital[3] Per Employee	Geometric Index of Technological Change	Corrected[4] Real Value Added Per Employee
1958	13803	.618	45652	1.000	13803
1959	15510	.613	48666	1.083	14321
1960	13957	.553	46115	1.015	13751
1961	15305	.552	46371	1.108	13813
1962	15196	.522	57668	.967	15715
1963	21515	.637	55694	1.400	15368
1964	22712	.657	57345	1.437	15805
1965	24016	.676	59603	1.469	16349
1966	23566	.661	63900	1.401	16821
1967	22718	.624	67619	1.327	17120
1968	24118	.624	67629	1.388	17376
1969	24976	.606	71321	1.390	17968
1970	28113	.656	76031	1.475	19060
1971	23244	.574	81302	1.257	18492
1972	26685	.590	78641	1.424	18739
1973	28392	.639	80626	1.473	19275
1974	30652	.791	72767	1.615	18980
1975	22733	.767	63999	1.451	15667
1976	22313	.733	76426	1.284	17378

[1]Deflated value added by manufacture, divided by number of all employees.
[2]Value added by manufacture minus all employees payroll, divided by value added.
[3]Deflated gross value of fixed assets, divided by number of all employees.
[4]Real value added per employee, divided by the geometric index of technological change.

Table 14.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

The share of capital in income trend roughly follows the trend of real capital per employee. This would be expected, unless there are significant changes in the price ratio between capital and labor and in the elasticity of substitution.

Table 15 shows a dramatic reversal in the two partial productivity measures presented. Both measures are negative in the last period because of a decline in output in the industry (5.7 percent), while capital increased 16 percent and labor increased 2 percent.

The unrestricted Cobb-Douglas function for the pulpmill industry, 1958-1976, is:

$$Y = 1.445 + \underset{(.1643)}{1.1015} \log K - \underset{(.2772)}{.1208} \log L \qquad R^2 = .752$$

The sum of the coefficients is very nearly one, suggesting that the industry has been operating under neither economies nor diseconomies of scale.

The addition of time into the equation results in an indicator for technological change. Table 16 shows the results of fitting such an unrestricted Cobb-Douglas function for various periods. Unfortunately, the standard errors are usually large relative to the coefficients; thus, their reliability is in question. However, the R-squares are high; while none of the individual coefficients may be reliable, taken as a whole, the equations do explain major portions of the variations observed in the data.

Table 15.--Annual growth rates in productivity, 1958-1967, and 1968-1976, for pulpmills.

Year	Output per unit of labor	Output per unit of capital
1958-1967	5.11 percent	0.82 percent
1968-1976	-.86 percent	-2.28 percent

Table 16.--Three-factor Cobb-Douglas function($Y = AK^bL^cT^d$) for pulpmills.

Period	log A	b	c	d	b + c	R^2
1958-1967	-4.2449	0.2678 (.5347)	2.9150* (1.3248)	0.1470 (.0940)	3.1828	0.904
1958-1969	-4.1390	.3582 (.4112)	2.6545* (1.0502)	.1410 (.0821)	3.0127	.920
1958-1971	-4.4670	.3118 (.2828)	2.8909* (.7392)	.1435* (.0702)	3.2027	.932
1958-1973	.0874	.5220 (.3639)	.6536* (.3842)	.1746* (.0918)	1.1756	.859
1958-1975	.0140	.5916* (.3166)	.5144 (.3685)	.1615* (.0763)	1.1060	.834
1958-1976	.5517	.5566 (.3425)	.4081 (.3946)	.1464* (.0823)	.9647	.795

*Significant at the 10 percent level.

Changes in log A represent change in neutral technology. This term in the function fitted to the pulpmill industry data remains at a low level until 1973, when it takes a tremendous jump (the figures are in logs). The occurrence is reversed for the labor coefficient, changes in which reflect changes in nonneutral technological change. The level of nonneutral technological change dropped dramatically after 1971. In contrast, the rate of neutral technological change (d) increased after 1973, but only slightly; the estimate for the entire 19-year period is equivalent to an annual increase of 2.3 percent. This estimate is much higher than the geometric index for pulpmills.

Up to 1971 the equations show large economies of scale (b + c) for the industry. However, there was little entry by new firms. The industry is an oligopoly and maintains price control in wood buying. Competition for stumpage is lessening this practice, however.[42] High capital requirements and other barriers probably prevented other firms from entering the industry to take advantage of the economies of scale.

Between 1971 and 1972, the industry experienced a large drop in capital, on the order of 29 percent, while labor

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[42] Sam Guttenberg. 1970. Economics of southern pine pulpwood pricing. Forest Products Journal 20(4):15-18.

decreased by 27 percent, and value added fell by only 16 percent (Appendix Table C3). The years 1971 and 1972 were poor for the industry, and firms had to adjust. Output in 1976 had not yet returned to its 1970 level. Because of these changes, after 1971, the large economies of scale dropped closer to unity. The fitted CES function for pulpmills is:

$$V = .3567\ (.9958)^{t}\ \left(.99K^{.4140} + .01\ L^{.4140}\right)^{2.4155}$$

Estimated by equation (10), the elasticity of substitution is 1.7065 (standard error = .2325). This is an indication that it has been easy for the pulp industry to replace labor with capital, verified by the near doubling of capital while the number of employees has remained about the same, Appendix C3.

The technological change parameter is less than one, suggesting there has been negative progress in the pulping industry. Given the results of the other measures, this can be discounted. The confidence interval estimated for this parameter places the upper limit at about 2.7 percent, and the estimates of the other models fall into this range. With the rate so close to one, it is difficult for the model to statistically differentiate the small deviation.

Recently Lothner constructed an index of technology for the various pulping processes.[43] The index also indicates the Minnesota and Wisconsin industries' ability to use hardwoods in pulping. Lothner's applied technology index rises about 25 percent from 1949 to 1969. His index is based on a set theory derivation as proposed by Scott, which is an alternate method of estimating technological change.[44]

Paper Mills, Except Building Paper (SIC 2621)

There are basically three types of papermaking machines in use today. The oldest type is the cylinder paper machine, which although in many mills, is gradually being phased out. While the cylinder machine has the advantage of being able to build papers of greater thicknesses, it is a relatively slow process.

A much faster machine is the Fourdrinier, which can be run at speeds greater than 2,000 ft./min., and hence produce more tons per day. In this machine the slurry is drained through a moving belt, sometimes using vacuum to increase the amount of water removed.

The third machine, the Yankee machine, differs from the Fourdrinier only in the drying section. This type consists of a very large (up to 15 ft. in diameter)

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[43] David C. Lothner. 1974. The Minnesota and Wisconsin Pulpwood Markets: An Econometric Study of Past Changes and the Future Outlook for Forest Resource Planning. Ph.D. dissertation. University of Minnesota.

[44] J.R. Scott, Jr. 1964. The measurement of technology. Journal of Farm Economics 46(3):657-661.

single drum for drying, rather than many small drying drums of similar diameters.

The paper formation process can be arbitrarily broken down into five segments: stock preparation, web formation, wet pressing, drying, and finishing.[45] Technical improvements have occurred in all these segments, but the majority have been in the class of "fine tuning."

The trend in papermaking has clearly been toward larger and faster papermaking machines. Twenty years ago, a "big" machine had a width of 200 inches and a lineal speed of about 1,000 feet per minute. Today, many machines have widths twice as great and speeds in excess of 2,000 feet per minute, with some (producing lighter weight papers) with speeds of up to 5,000 feet per minute.

Due mostly to the large capital investment involved, new techniques and innovations have been accepted slowly and cautiously. One change that has been accepted is the switch from brass or bronze wire forming belts to plastic belts. These are longer lasting than the metal belts, which have a useful life of 7 to 21 days, are easier to install, and experience less downtime, thus producing

[45] John G. Strange. 1977. The Paper Industry: A clinical study. Appleton, Wis.: Graphic Communications Center, Inc.

more tons of paper.

Some qualitative indicators of technological change, such as new capital expenditures, are shown in Table 17. Yearly capital expenditures increase by 105 percent from 1958 to 1976. The average yearly increase is 6.9 percent of total gross fixed assets.

The number of establishments and per establishment data for this industry are shown in Table 18. The number of paper mills has been fairly constant from 1958 to 1972. The amount of capital and output per establishment, however, have grown by 5.2 percent and 2.7 percent compounded annually. The number of employees, after increasing in 1963, fell to about the same level in 1972 as it was in 1958.

Table 19 shows that the geometric index increased only 12 percent, virtually all of it in the last 5 years.

Real value added per employee increased by over $7,000, or by 62 percent, while capital per employee increased by 105 percent. These increases are reflected in the value added per unit capital, which fell from .603 in 1958 to .476 in 1976 on a per-employee, real-dollar basis. The corrected real value added per employee increased by only 1.96 percent, compounded annually. Increased capital provided 71.6 percent of the increase in productivity, by far the largest proportion among the four industries studied. Technological change accounted

Table 17.--Some indicators of technological change in paper mills, except building paper.

Year	New Capital Expenditures (Mill 1958 $)	Change in Gross Fixed Assets[1] (Mill 1958 $)	Total Gross Fixed Assets (Mill 1958 $)	All Employees (Thou)
1958	258.8		2672.7	131.3
1959	209.9	450.3	3123.0	134.8
1960	239.6	197.5	3320.5	136.7
1961	275.8	90.8	3411.3	132.4
1962	266.2	372.1	3783.4	132.3
1963	222.8	179.2	3962.6	129.8
1964	279.7	209.3	4171.9	129.6
1965	461.6	447.5	4619.4	132.6
1966	521.8	569.0	5188.5	135.0
1967	510.8	72.9	5261.4	140.0
1968	414.4	271.4	5532.9	139.3
1969	451.0	78.2	5611.1	141.9
1970	387.1	-3.1	5608.0	138.3
1971	272.2	-49.1	5558.9	132.0
1972	261.4	62.4	5621.3	129.9
1973	343.2	12.2	5633.5	131.2
1974	437.7	-328.8	5304.7	130.4
1975	442.1	-232.1	5072.5	120.9
1976	530.2	179.1	5251.6	127.5

[1]Calculated from total gross fixed assets.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 18.--Number of establishments and per establishment data for paper mills, except building paper.

Year	Number of Establishments	Per Establishment: Capital[1] (Mill $)	Employees	Value Added[2] (Mill $)
1958	354	7.55	371	4.36
1963	325	12.19	399	5.57
1967	354	14.86	395	6.04
1972	349	16.11	372	6.50

[1]Gross value of fixed assets, 1958 dollars.
[2]Value added by manufacture, 1958 dollars.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part I, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 19.--Geometric index of technological change in industry SIC 2621

Paper Mills, Except Building Paper

Year	Real Value Added[1] Per Employee	Capital[2] Share	Real Capital[3] Per Employee	Geometric Index of Technological Change	Corrected[4] Real Value Added Per Employee
1958	11749	.520	19501	1.000	11749
1959	13456	.568	22658	1.061	12682
1960	13435	.563	23489	1.039	12931
1961	13754	.561	25250	1.020	13484
1962	13997	.549	27825	.981	14268
1963	13939	.527	30162	.930	14988
1964	14666	.535	31643	.957	15325
1965	14940	.534	34210	.932	16030
1966	16058	.552	38087	.946	16975
1967	15265	.524	36755	.916	16665
1968	15815	.522	38845	.922	17153
1969	16195	.519	38870	.946	17119
1970	15691	.509	39090	.912	17205
1971	15742	.490	41439	.885	17788
1972	17467	.505	42798	.978	17860
1973	19455	.550	42122	1.100	17686
1974	20347	.617	39663	1.178	17273
1975	17240	.580	35831	1.085	15889
1976	19045	.595	40036	1.122	16974

[1]Deflated value added by manufacture, divided by number of all employees.
[2]Value added by manufacture minus all employees payroll, divided by value added.
[3]Deflated gross value of fixed assets, divided by number of all employees.
[4]Real value added per employee, divided by the geometric index of technological change.

Table 19.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

for only 28.4 percent of the increase.

The trend in capital's share in income is only weakly upward at the rate of 3 percent over the 19-year period. There has been little change in the elasticity of output with respect to capital.

As shown in Table 20, the growth in output per unit labor slowed in the second decade covered in this study, while the output per unit of capital reversed itself from negative to positive growth. Such a reversal occurred because of the decline in the amount of capital in the industry after a doubling in the first decade. At the same time, total labor employed in paper mills remained fairly constant. These trends mean that the industry may have been capitalizing at a rate faster than its markets were growing.

The unrestricted Cobb-Douglas function for paper mills, 1958-1976, is fitted as:

$$Y = 5.4382 + \underset{(.0687)}{.5033} \log K - \underset{(.4411)}{.4151} \log L \qquad R^2 = .771$$

The sum of the exponents is very nearly zero, suggesting there are large diseconomies of scale of operation in this industry.

Addition of a time variable allows estimation of the shift of the production function through time, and hence the estimation of technological change.

Table 20.--Annual growth rates in productivity, 1958-1967, and 1968-1976, in paper mills.

Year	Output per unit of labor	Output per unit of capital
1958-1967	2.65	-3.45
1968-1976	2.09	1.68

Table 21 shows that, like the pulpmill industry, major changes occurred between 1971 and 1973. Like its companion industry, the changes occurred in neutral technology (log A) which took a major jump, and in nonneutral technological change (c) which experienced a major decline.

Table 21.--Three-factor Cobb-Douglas function ($Y = AK^bL^cT^d$) for paper mills, except building paper.

Period	log A	b	c	d	b + c	R^2
1958-1967	-0.2832	0.2275 (.1671)	1.2025* (.4566)	0.0413 (.0504)	1.4300	0.943
1958-1969	- .1639	.2165 (.1432)	1.1958* (.3504)	.0439 (.0436)	1.4123	.965
1958-1971	- .2315	.2073 (.1301)	1.2253* (.2946)	.0426 (.0403)	1.4326	.966
1958-1973	3.0543	.3157 (.2916)	.3739 (.5819)	.0399 (.0920)	.6896	.854
1958-1975	4.1553	.1358 (.2991)	.4314 (.7285)	.1086 (.0899)	.5672	.792
1958-1976	3.9259	-.0058 (.0066)	.7040 (.4319)	.1501* (.0196)	.6982	.806

*Significant at the 10 percent level.

However, the time coefficient, d, which indicates the rate of neutral technological change, begins to increase in 1975. The final value, that for the entire 19 years, yields an annual rate of increase of 2.4 percent. This is too high when compared with either the arithmetic or geometric indexes. A more reasonable rate is about 0.7 percent per year, which would obtain from the coefficients of the periods ending in 1973 and before.

Economies of scale in the industry change from 1.4 to about half this value after 1971. This timing follows the other changes in the series of equations.

Like most of the other industries, few of the coefficients are statistically significant. Nevertheless, the R squares are sufficiently high; meaning that while few of the individual coefficients are reliable, the equations on the whole explain the variation observed in the data fairly well.

The CES equation for paper mills is:

$$V = 1.0000\ (1.0198)^t \left(.0047\ K^{.2221} + .9953\ L^{.2221}\right)^{4.5027}$$

The elasticity of substitution used in estimating this equation was 1.2855 (standard error = .1224). Such a level of elasticity suggests it has been possible to replace labor with capital with relative ease.

The technological change parameter places this factor of growth at about 2 percent per year. While a slow rate, it is still about five times the geometric index rate.

A Comparison

Table 22 summarizes the percent of technological change for each of the industries, estimated by each model. There is close agreement between the arithmetic and geometric measures. For this reason, only the results of the geometric index were discussed, as stated earlier. The geometric model was chosen over the arithmetic because the assumptions required for the former were judged less restrictive. In particular, the assumption for the arithmetic that prices are changed only in the short run by technology shifts is a difficult one to make, since there have been no studies performed that would indicate this. In addition, weighting by the elasticities of labor and capital with respect to output, as in the geometric model, provides additional information on the industries through the estimation of those elasticities.

Table 22.--Annual increase in technological change, by industry and method of measurement.

Industry	Arithmetic[1]	Geometric[1]	Cobb-Douglas	CES
	Percent			
Logging	3.4	3.1	3.8	3.3
Sawmilling & Planing	1.8	1.8	0.9	[2]
Pulping	2.5	2.4	2.3	[2]
Papermaking	0.7	0.4	2.4	2.0

[1]Linear regression trend.
[2]Less than zero.

For the projections that follow in the next chapter, the geometric index is used for several reasons, rather than the arithmetic (for the reasons given above), the Cobb-Douglas, or the constant elasticity of substitution. Both the Cobb-Douglas and the CES models are fitted through regression techniques. Hence, both are limited by the number of data points in excess of the number of parameters estimated, i.e., the degrees of freedom. There are only 19 data points available, and with three or more parameters estimated, the degrees of freedom become somewhat lower than desired. The geometric index does not suffer from this limitation, and so is judged the most suitable for the projections and overall use.

Other studies

The four industries included in this study have also been evaluated as aggregates. The Bureau of Census classifies the two industries, logging camps and contractors, and sawmills and planing mills, general, into the two-digit industries are also included in this classication.[46] Pulpmills and paper mills, except building paper, are included in SIC 26, Paper and Allied Products.[47]

Robinson constructed a geometric index of technological change for the lumber and wood products industry (SIC 24). He found that the level of technology had advanced at an average rate of 1.75 percent per year bewteen 1949 and 1970.[48] Using the translog function, another method of calculating technological change, Gollop and Jorgenson found the average annual rate of growth to be 1.77 percent for 1960-1966, and 1.02 percent

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[46] The 1972 classification, in addition to these two industries, includes the following in SIC 24A: Hardwood Dimension and Flooring (SIC 2426), and Special Product Sawmills, n.e.c. (SIC 2429). Other subgroups are Millwork, Plywood, and Structural Wood Members, n.e.c. (SIC 24B), Wooden Containers and Miscelleneous Wood Products (SIC 24C), and Wood Buildings and Mobile Homes (SIC 24D).

[47] SIC 26A, in addition to the two above-named, includes the four-digit industries Paperboard Mills (SIC 2631), and Building Paper and Building Board Mills (SIC 2661). Other subgroups are Converted Paper and Paperboard Products, except Containers and Boxes (SIC 26B), and Paperboard Containers and Boxes (SIC 26C).

[48] V.L. Robinson. 1975. An estimate of technological progress in the lumber and wood products industry. Forest Science 22(2):149-154.

for 1966-1973 in the lumber and wood products (except furniture) industry. The average annual rate of growth for the paper and allied products industry (SIC 26), for the same two periods are .0124 percent and .0094 percent, respectively.[49] Massell used a geometric index to estimate the average percentage rate of technical change to be 3.77 for lumber and wood products, and 2.34 for pulp, paper and products for the period 1946-1957.[50]

A Canadian study employing the geometric index of technological change found a 50 percent increase in that country's pulp and paper products industry, with only a 8 percent increase in the wood products industry.[51] The period covered was the years 1940 to 1960. The figures correspond to average annual rates of change of 2.4 percent and 0.4 percent, respectively.

A study of American manufacturing estimated the partial elasticity of substitution of capital for labor to be 2.54 for lumber and wood products, and 0.37 for

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[49] F.M. Gollop and D.W. Jorgenson. 1977. U.S. productivity growth by industry 1947-1973. Univ. of Wisconsin--Madison, Social Systems Research Institute Workshop Series No. 7712.

[50] B.F. Massell. 1961. A dissagregated view of technical change. Journal of Political Economy 69(6):547-557.

[51] G.H. Manning and G. Thornburn. 1971. Capital deepening and technological change: The Canadian pulp and paper industry 1940-1960. Canadian Journal of Forest Research 1:159-166.

pulp, paper, and allied products.[52] The former is higher than either of the partial elasticities estimated for the logging or sawmilling industries in this study, and the latter figure is much lower than the elasticities of substitution estimated for pulpmilling and papermaking.

For comparison with the general economy, Massell estimated the rate of technological change (with a geometric model) to be 2.54 percent per year in United States manufacturing from 1919 to 1955.[53]

Schmookler included papermaking as one of the industries in his study on inventive activity and economic growth.[54] While the years covered by his study (1837-1957) do not overlap with those covered by this study, the information he presents is of interest. The data on the annual number of patents show that the inventive activity in papermaking peaked during the late 1920's and early 1930's. There were 898 patents in 1931 versus 653 in 1957.

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[52] D.B. Humphrey and J.R. Moroney. 1975. Substitution among capital, labor, and natural resource products in American manufacturing. Journal of Political Economy 83(1):57-82.

[53] B.F. Massell. 1960. Capital formation and technological change in United States manufacturing. Review of Economics and Statistics 42:182-188.

[54] Jacob Schmookler. 1966. Invention and Economic Growth. Cambridge: Harvard University Press.

In a second study covering the same time period, Schmookler traced the number of patents in a number of specialized categories.[55] For woodsawing machines, the apparent inventive activity peaked in the 1870's and 1880's.

A final illustration of technological change in the forest industries is contained in Figure 4. This figure is a comparison of the trends in inputs and outputs for the entire forest products industry (SIC 24 and 26). In 1950, 115 cubic feet of industrial roundwood were required to produce one ton of product. By 1976, only 93 cubic feet were required, a reduction of 19 percent. A factor that may be important involved in producing this reduction is a changing product mix. The proportion of woodpulp has increased from 18.3 percent to 38.6 percent, while lumber has declined from 57.3 percent in 1950, to 32.8 percent in 1976 (measured in tons). Another factor is the increased use of mill residue for pulp chips. Figure 4 is unadjusted for these changes. In this way, however, it reflects the overall progress in providing for wood consumption with less raw material.

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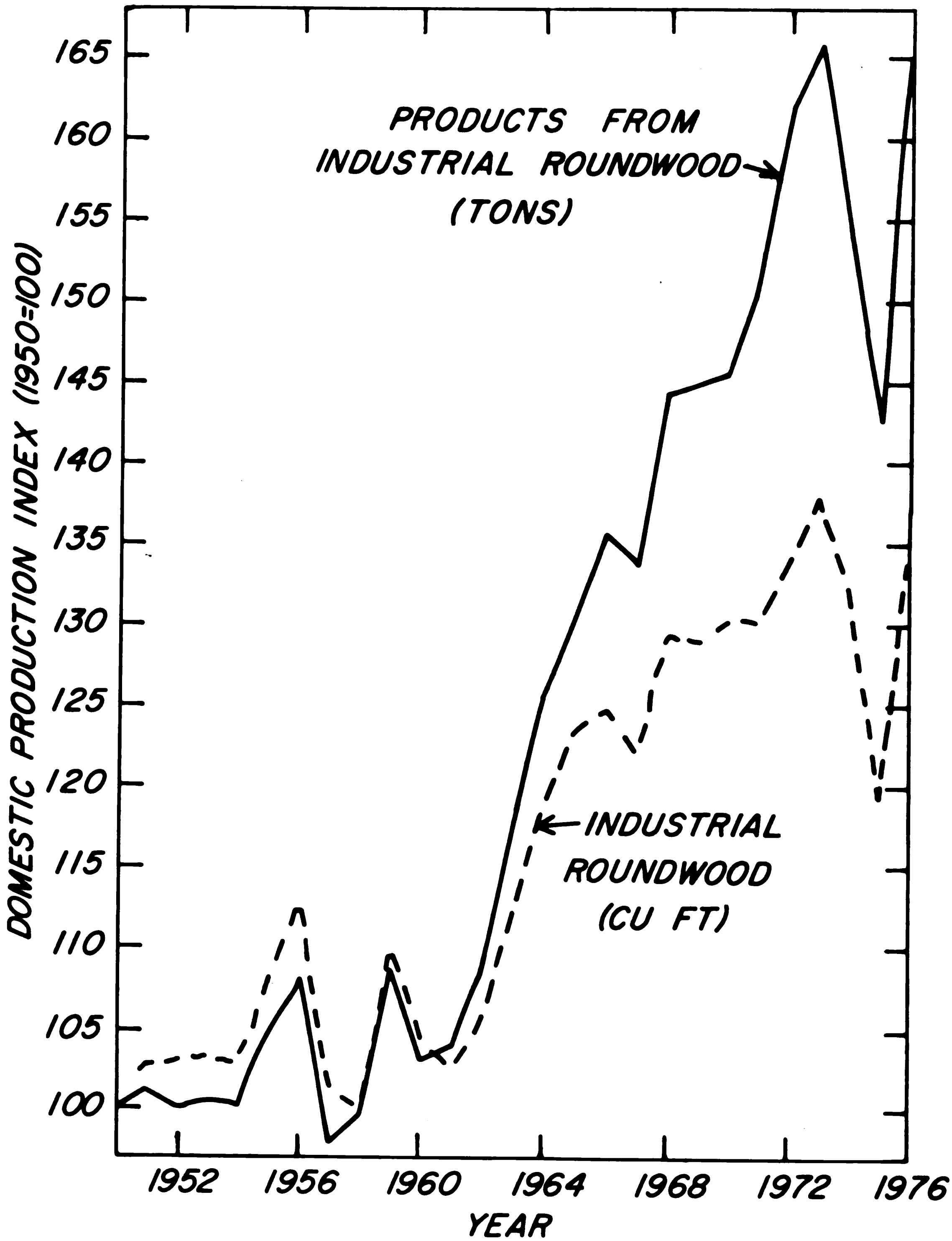
[55] Jacob Schmookler. 1972. Patents, Invention, and Economic Change. Cambridge: Harvard University Press.

Figure 4. Input and output rates of growth for industrial roundwood.

Source: Robert B. Phelps. 1977. The demand and price situation for forest products 1976-77. USDA Forest Service Miscellaneous Pub. No. 1357. Washington, D.C.: U.S. Government Printing Office.


PRODUCTS FROM
INDUSTRIAL ROUNDWOOD
(TONS)
INDUSTRIAL
ROUNDWOOD
(CU FT)
DOMESTIC PRODUCTION INDEX (1950=100)
165
160
155
150
145
140
135
130
125
120
115
110
105
100
1952
1956
1960
1964
1968
1972
1976
YEAR

IV. PROJECTIONS AND PROBABLE TECHNOLOGIES

Any static equilibrium projection model must have an exogenous variable to provide the "driving force," to produce change. For the purposes of this study there appear to be two suitable exogenous variables: gross national product and time. Projections of the geometric index of technological change based on GNP and time are presented in this chapter, for each of the four industries included in this study. These are followed by a discussion of products and processes the industries may adopt in the future.

In the projections, the industries maintain their respective positions with respect to the rate of technological change; i.e., logging camps and contractors is the most rapidly advancing of the four industries, while paper mills are the least rapid. These relationships hold for both the time and GNP projections.

The rates of increase in the geometric index, for the two projection methods are given below.

Industry	Annual rate of increase	Percent of GNP log (billions)
Logging camps and contractors (SIC 2411)	.03079	0.817904
Sawmills and planing mills, general (SIC 2421)	.01837	.540279

Industry	Annual rate of increase	Percent of GNP log(billions)
Pulpmills (SIC 2611)	.02375	.703027
Papermills, except building paper (SIC 2621)	.00424	.0807496

Factors Influencing Change

There are many factors that affect the rate of technological progress. These can be divided into two broad areas. First, there are changes in the rewards and benefits from particular kinds of technological advance. These are the demand factors that stimulate or retard efforts to achieve advances. Second, there are changes and differences in the stock of materials and components, and in knowledge about them and processes. These factors constitute the supply side for technological advance.[56] Technological change is in many respects simply another commodity produced by the economic system, and subject to economic forces.

The projections for each of the industries are dependent upon certain assumptions. Given the past rapid growth in capital for each of the industries (doubling, or nearly so, for all but sawmilling), future technological advance will depend on the availability of investment funds.

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[56] R.R. Nelson, M.J. Peck, and E.D. Kalachek. 1967. Technology, Economic Growth, and Public Policy. Washington, D.C.: The Brookings Institution.

A second factor influencing technological change is the structure of the industries. In terms of number of firms in the industry, the sawmilling industry has been the only one that has seen significant changes. It is probable that the rate of decline in the number of firms is this industry will slow and perhaps stop in the future. Fewer firms are likely to mean economies of scale and the possibility of increased profitability and hence a source of capital for increased technological change. It is then possible that the rate of future technological change will be greater than that of the past. The evaluation of available technologies reveals that such opportunities are extant.

A third factor involved in technological change is price trends. The trends for both inputs (raw materials especially energy, capital, and labor) and outputs (logs, lumber, pulp, and paper) will be important. A rising price trend for one or more inputs should stimulate new technologies for reducing the amount required, or for allowing substitution of a cheaper input.

A fourth influence on the rate of technological change is government policy. Tax policy, such as investment credit and depreciation, play a role in the amount of new capital a firm or industry is willing to invest. A second area where government policy is important is in the amount of research and development government is willing to fund, in both Federal research organizations and in universities. A third area where government actions will specifically influence technological change in the forest products industries is in Federal timber sales. Changes in timber supply security would alter the performance of affected firms.[57]

One final influence important to consider (although the list could be greatly expanded), is the rate of technological advance in the rest of the economy. There are two aspects here; one is the rate of advance in competing industries, the other is the development of technologies that can be adapted for uses in the forest industries. There is evidence that the rate of technological advance in the U.S. economy is declining, or at least the average rates of social return on progress-generating activities is declining.[58,59] This general decline will surely influence the rate of technological change in the forest industries, and could indicate that the several projections, since the are based on

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[57]William R. Bentley. 1970. Technological change in the forest industries--a problem analysis. The University of Wisconsin Forestry Research Notes, No. 151.

[58]Michael Boretsky. 1975. Trends in U.S. technology: A political economist's view. American Scientist 63(1): 70-82.

[59]William Fellner. 1970. Trends in the activities generating technological progress. American Economic Review 60(1):1-29.

past performances, are too high.

Rapid changes that lower prices, improve quality, or add entirely new products in competing industries will increase pressure on the forest industries to adopt equally innovative changes or lose their markets. In the past, the lumber industry has not been particularly successful in preserving and expanding its market. New technologies evaluated in this study offer some hope that this trend can be reversed.

Often, technologies that develop in other industries are adopted by the forest industries. An example in the future will be cutting of lumber by laser. Other adoptions are not so straightforward, but are equally dependent on advances in other scientific fields. For example, the development of plastic webs for papermaking was dependent on advances in the plastics industry.

As covered earlier in this study, the forest industries have achieved only modest gains in technological advances and manufacturing productivity. An analysis of some of the factors affecting technological change in the industries is covered in another section of this chapter.

Because of the low past productivities, most probably the result of low rates of adoption of new technologies, opportunities for improvement are considered to be large, since new knowledge of production has been accumulating. Many of these opportunities exist in the areas of marketing, institutional arrangements, management improvement, and employee training. While these factors can play a large role in increasing productivity, they are not the concern in this chapter (although past changes of these types no doubt played a role in the trends found in the calculated indexes). The focus of this chapter will be on the technical improvements in timber harvesting and processing that have been developed. Some of these are already in use, but have not had widespread adoption. Others have yet to be tried by industry, but appear promising.

Timber Harvesting

The projections for technological change in logging camps and contractors, based on the geometric index, are below:

Year	GNP Based	Time Based
1990	1.883	1.957
2000	2.112	2.264
2010	2.353	2.572
2020	2.557	2.880
2030	2.770	3.188

If future technologies are adopted at the same rate as those in the past, other things being equal, then the geometric index of technology will be approximately 3.2 times its 1958 level in 2030. In contrast, if the adoption of new technologies depends on the growth of the U.S. economy, then the index for 50 years in the future will be somewhat lower, at 2.8.

In either case, the level of employed technology in harvesting timber will be roughly three times as great 50 years in the future as it was 20 years ago. The following discussion covers some of the developments judged probable to produce the projected levels of technology.

The process of cutting standing trees and moving them to a mill has shown a clear trend toward mechanization. This trend will certainly continue in the future. With few exceptions, one general principle has held for logging in the past - the object has been to remove the sound, clear bole of the preferred wood species. Recently, however, this general principle has begun to give way to complete tree and full tree harvesting, usually involving chipping in the woods.[60] Full tree harvesting involves taking the entire above-ground portion of the tree, while complete tree harvesting also includes the stump and a portion of the root system. There are several machines or machine systems now in use that utilize these harvesting methods.[61] These systems can reduce per cord costs by about half, while increasing output per man by more than seven times, compared to

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[60] J.L. Keays. 1975. Forest harvesting of the future. Western Forest Products Laboratory. Unnumbered report.

[61] J.R. Erickson. 1968. Mechanization in the timber-producing industry. Forest Products Journal 18(7): 21-27.

conventional systems.[62] A more recent analysis of whole tree chipping estimated a $3 savings per cord over chips from debarked roundwood.[63]

A major emphasis in the development of new timber harvesting techniques will be on reducing the wood residues left in the forest after logging operations. To a large degree, the reduction in residues will depend upon the prices of chips containing bark and foliage. These prices will in turn depend on the development of separating methods, or new pulping processes that can digest the bark and leaves. The increasing possibility of using wood for fuel may also play a major role in reducing forest residues.[64] Research in the area of bark and chip separation is continuing.[65]

New machinery will evolve the fastest in the pulpwood and chip harvesting areas, rather than in the

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[62] K.K. Neilson. 1967. The present state, problems, and outlook of mechanized tree processing in Eastern Canada. Pulp and Paper Canada 67:WR 297-WR 301.

[63] Frank E. Biltonen, J.R. Erickson, and J.R. Mattson. 1974. A preliminary economic analysis of whole-tree chipping and bark removal. Forest Products Journal 24(3):45-47.

[64] T.H. Ellis. 1975. The role of wood residue in the national energy picture. in Proceedings of the International Meeting of the Forest Products Research Society on "Wood Residue as an Energy Source," Denver, Colo.

[65] Logging research progress report, No. 45. 1974. Pulp and Paper Research Institute of Canada, Pointe Clare, Quebec.

sawlog and veneer harvesting areas, because of movement toward continuous flow harvesting techniques.

Utilization efficiency during harvesting is expected to allow the minimum tree removed to be 6 inches DBH with a 4-inch top, for second growth timber in the West. Currently (1976), the minimum tree removed in the West is 9 inches DBH with a 6-inch top. In the East, the minimum will drop from 9 inches DBH and a 7-inch top to 9-inch DBH with 0-inch top.[66] This will increase the amount of material removed per acre. This increased harvesting utilization is estimated to possibly reduce logging residues by 1.4 billion cubic feet.[67]

If past trends in real value added per employee and capital share continue, then to reach a geometric index of 3 (in 2030), it will be necessary for real capital per employee to be over $17,200 in 1958 dollars. Considering the past pattern of investment, this level should not be difficult to attain. While logging is projected to continue to be the most progressive technologically (relative to its own 1958 level), the possible improvements cited above are judged sufficient for the industry to meet the time series projection levels.

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[66] R.L. Porterfield. 1977. Utilization efficiency during harvesting--a survey of current and prospective status. Forest Products Journal 27(12):17-20.

[67] L.E. Lassen and Dwight Hair. 1970. Potential gains in wood supplies through improved technology. Journal of Forestry 68(7):404-407.

Sawmilling

The projected geometric indexes of technological change for sawmills and planing mills, general, are:

Year	GNP Based	Time Based
1990	1.717	1.720
2000	1.868	1.904
2010	2.027	2.087
2020	2.162	2.271
2030	2.302	2.455

A range of technological change projections is provided by the two bases of GNP and time. If the rate of increase will be the same as it has been in the past, then the geometric index of technology will be roughly two and one-half times its 1958 level in 2030 for sawmilling. Alternatively, if adoption of new technologies depends upon future economic activity, then the rate will be somewhat lower than in the past, and the geometric index will reach only 2.3 times the 1958 level by the year 2030. Either way, progress in the sawmilling and planing industry will continue. Promising technologies that will contribute to future progress are covered in the remainder of this section.

The process of cutting solid lumber from logs in the United States has evolved slowly since the first sawmill was built in Maine in 1624. Today, however, there are a host of new products and processes that are in development or beginning to be commercially accepted. The trend is strong toward producing wood as an "engineered" material, i.e., with prespecified qualities and properties.

These new developments can be broken into three main groups: Those sawing processes that convert more of the log into solid lumber; those that control the quality of lumber; and those that produce new products similar to or that can be called lumber.

Improvements in the sawing of logs into lumber include high-strain headsaws with narrow kerf, more accurate set works, and computer-controlled or assisted sawing decisions. By simply using currently available technologies, lumber recovery factors can be increased by over 27 percent.[68]

There are now about a dozen sawmills using the computer-controlled sawing operation called "Best Opening Face (BOF)," and approximately an additional fifty are using some type of less sophisticated computer control.[69] The BOF sawing can increase yields on an average in excess of 20 percent over conventional methods.[70] The number of mills using some degree of

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[68] H.C. Mason & Associates, 1973. Study of softwood sawlog conversion efficiency and the timber supply problems. Report to the USDA Forest Service, Forest Products Laboratory, Madison, Wis.

[69] Hiram Hallock. 1977. Precision-quality and value. Expo '77 logging-sawmilling seminar. ed. by Keith Judkins. Southern Forest Products Association.

[70] Hiram Hallock and David W. Lewis. 1971. Increasing softwood dimension yield from small logs--best opening face. USDA Forest Service Research Paper FPL 166.

computer control can be expected to increase. Systems to also control ripping and crosscutting are now under development.[71]

Technological advance can create resources out of otherwise useless material. An example of this is the shaping-lathe headrig which shows promise of being able to economically convert small, low-grade hardwoods into marketable products.[72] This machine can convert small logs into solid lumber products plus flakes for board.[73]

More exotic methods of cutting wood other than by saw are being investigated. One method showing promise involved lasers for cutting both solid wood and wood-based products. The advantage of such a method is the very thin kerf produced.[74] One company is now using a

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[71]Abigail Stern and Kent McDonald. 1978. Computer optimization of cutting yield from multiple-ripped boards. USDA Forest Service Research Paper FPL 318 (in press).

[72]Peter Koch. 1976. Key to utilization of hardwoods on pine sites: the shaping-lathe headrig. Forest Industries 103(11):48-51.

[73]Peter Koch. 1975. Shaping-lathe headrig will convert small hardwoods into pallet cants plus flakes for structural exterior flakeboard. in Proceedings of the Ninth Particleboard Symposium, Washington State University, Pullman, Wash.

[74]Curtis C. Peters and Conrad M. Banas. 1977. Cutting wood and wood-base products with a multikilowatt laser. Forest Products Journal 27(11):41-45.

laser for cutting puzzles and blocks in toy manufacture.[75]

Another area for improvement is in sawing methods. Research has shown that some sawing methods are superior to others for given log sizes.[76,77] Adoption of a differing method may require log sorting prior to breakdown, but this can also prove profitable, if there is opportunity for the conversion into more than one product.

Improvements can be expected throughout the sawmilling process. Research into new methods of drying have yielded faster curing of green lumber. Microwave kilns can dry large pieces of Douglas-fir and hemlock in only 5 to 10 hours with minimum degrade.[78]

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[75]Gordon R. Connor, Sr. 1977. The central hardwoods response. in Resource Availability and the Hardwood Forest Products Industry. W.L. Hoover and H.A. Holt, eds. Department of Forestry and Natural Resources, Purdue University.

[76]Hiram Hallock, Abigail R. Stern, and David W. Lewis. 1976. Is there a "best" sawing method? USDA Forest Service Research Paper FPL 280, 12 pp.

[77]D.W. Bousquet, and I.B. Flann. 1975. Hardwood sawmill productivity for live and around sawing. Forest Products Journal 25(7):32-37.

[78]L. Admiral Barnes, R.L. Pike, and V.N.P. Mathur. 1976. Continuous system for the drying of lumber with microwave energy. Forest Products Journal 26(5): 31-42.

There are several methods for maintaining the quality of lumber produced by a mill. One of these, of which there are already about fifteen machines in use, is high-speed machine stress rating (MSR). These machines grade lumber on the basis of its stiffness, at speeds of up to 1,000 feet per minute.[79]

Another quality-control process locates specific defects in lumber using ultrasound. This is also a computer-controlled system; it reduces waste made by inaccurate sawing decisions resulting in lower grade.[80]

The third area of technological advance lies in the area of new lumber products. These include press-lam and EGAR. Press-lam is dimension lumber from parallel-grain, rotary-cut, thick veneer laminates. The product yield from 12- to 18-inch-diameter logs averaged 60 percent.[81]

A new process of producing solid lumber is by edge gluing and ripping (EGAR). In this process, logs are live sawn, the unedged flitches are dried, ripped to the

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[79] W.L. Galligan, D.V. Snodgrass, and G.W. Crow. 1977. Machine stress rating: practical concerns for lumber producers. USDA Forest Service General Technical Report FPL 7.

[80] Kent McDonald. 1978. Lumber defect detection by ultrasonics. USDA Forest Service Research Paper FPL 311.

[81] FPL Press-Lam Research Team. 1972. FPL press-lam process: fast, efficient conversion of logs into structural products. Forest Products Journal 22(11): 11-18.

largest usable width, and edge-glued into panels up to 48 inches wide. Lumber of any feasible width can then be ripped from the panel. A product recovery of about 10 percent over conventional systems is produced by this method.[82]

Although many new innovations have been researched and developed since World War II, the sawmilling industry has been slow to accept them, and will probably remain slow, although with some improvement, into the future. Reasons cited for this situation are:

--A shortage of skilled implementation engineers who can analyze a mill operation to determine the feasibility of a new application.

--Communication with mill managers, and getting their cooperation, is difficult.

--Training operators is costly and difficult.

--There is a shortage of skilled maintenance crews.[83]

Without remedies to correct these problems, acceptance of new techniques and products will continue to be sluggish.

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[82] K.C. Compton, H. Hallock, C. Gerhards, R. Jokerst. 1977. Yield and strength of softwood dimension lumber produced by EGAR system. USDA Forest Service Research Paper 293.

[83] W. Bennett. 1978. Sawmill technology outruns industry's skill at using it. Forest Industries 105(1):28-29.

Should past trends in real value added per employee and capital's share in income continue, the sawmilling and planing industry can attain the projected geometric index of technology of 2.4 in 2030 with an investment per employee of slightly more than $19,900 (1958 dollars). This means less than a doubling of the 1976 level of real capital per employee. Since the industry achieved a near doubling in the nineteen years covered in this study, considering this past trend, the required investment should be easily attained, and probably surpassed.

Adoption of new technologies has been slow in the past, which is probably a strongly contibuting factor to the decline in the number of establishments recorded for this industry. This decline, however, suggests that the least progressive firms have been "weeded out" of the industry. As a result, the industry is composed of fewer, but larger and more progressive firms. These points, plus the promising technologies discussed above, lead to the judgement that this industry should be able to surpass the geometric projections, possibly to an index level of 3.5 to 4.

Pulping

The projections for technological change in pulpmills, based on the geometric index, are:

Year	GNP Based	Time Based
1990	1.859	1.860
2000	2.056	2.098
2010	2.263	2.335
2020	2.439	2.573
2030	2.621	2.811

Two alternative projections are provided by the different bases of GNP and time. Should the pulping industry continue to progress as it has in the past, its geometric index of technology will increase to 2.8 by 2030. On the other hand, if future progress in pulping is linked to growth in the economy, then the adoption of new technologies will be lower. This industry has been the second-most technologically progressive of the four industries. Following is a discussion of some of the probable technologies that will support future progress.

Current pulping methods are relatively old, being built from discoveries first practiced over a century ago. Even so, there are few new pulping processes under development which show promise of becoming important in the years ahead. Most research today is on aspects of "fine tuning" existing processes.

In spite of its disadvantages of odor, high costs, and high pollutant loading, the kraft process has expanded its share of pulp production. Its advantages of versatility, energy generation, and pulp strength will ensure that it will continue to be the major pulping process into the future. The kraft process may see competition from some other methods, however.

An old pulping method that may see a return to greater usage is the soda process. The addition of oxygen for pulping and bleaching has renewed soda as a viable alternative to kraft, due to its reduced pollution loading.[84,85] Research indicates higher hardwood pulping yields than that for kraft. Further improvements may be expected.[86]

Thermomechanical pulping (TMP) may expand the fastest of all the methods in the future. Its advantages are improved pulp strength and adaptability for potential chemical treatment.[87] The minimum acceptable size of a TMP mill is only about one-third that of a kraft, allowing future plants to be built more cheaply and in areas without the large wood supplies required for kraft.

Several new pulping systems are being developed.[88] Holopulping, a selective delignification, three-stage process, will retain all cellulose, hemicelluloses,

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[84]Anonymous. 1976. Where's pulping headed? A review of state of the art. Pulp & Paper 60(9):78-80, 89.

[85]A.H. Nissan, ed. 1973. Future technical needs and trends in the paper industry. Special Technical Association Publication No. 10. TAPPI.

[86]Anonymous. 1978. Funded research plan. The Institute of Paper Chemistry. Unnumbered report.

[87]John G. Strange. op. cit.

[88]J. Rauch, ed. 1976. Kline guide to the pulp and paper industry. Charles H. Kline & Co., Inc. Fairfield, N.J..

and other polysaccharides of wood. The process will yield between 65 and 80 percent compared to 45 to 50 percent for kraft. Nonsulfur pulping in Canada is expected to occur before 1990, although sulfur-based processes will still dominate.[89]

Another pulping method, hydrorefining, will have enormous impact on the industry, if it is fully developed and put in commercial operation. This method is envisioned as producing yield of up to 90 percent, by retaining almost all lignin through hydrogenation.

Other advances in this industry will involve improved bleaching with oxygen or ozone, and increased use of computers for process control.

Based on the assumption of continued past trends of real value added per employee and capital's share in income, the pulping industry will have to invest over $125,000 (1958 dollars) per employee to reach the projected geometric index level of 2.8 in 2030. This is a very high level of investment, and it is doubtful that the industry can attain it. On this assumption, it is suggested that the rate of technological progress in the

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[89] K.M. Jege and K.M. Thompson. 1975. The Canadian pulp and paper industry--threats and opportunities. 1980-1990. Unnumbered report, Pulp and Paper Research Institute of Canada.

pulping industry in the future will be less than that of the past. Because of the tremendous investment required, changes will probably be restricted to continued refinements of existing and in place production methods, rather than to additions of totally new ones. Hence, it is judged that the future level of technology in this industry will probably reach only 2.5 on the geometric index.

Papermaking

Papermaking is a very ancient process; in the United States, it is a mature industry and relatively little technological progress can be expected. The projections of geometric technological change for papermills, except building paper, are:

Year	GNP Based	Time Based
1990	1.058	1.093
2000	1.081	1.135
2010	1.104	1.178
2020	1.124	1.220
2030	1.145	1.262

The two projections of the geometric index of technological change for papermaking are significantly lower than for any of the other three forest industries. With either assumption, of the same progress as in the past through time, or of progress linked to the growth of the U.S. economy, the projections are not of very large increases in the level of technology in the papermaking industry. The methods of making paper are very old, and there possibly is not much improvement that remains to be made, in terms of efficiency per unit of capital equipment and labor. There are some new developments that may become important in the industry, however, and they are discussed in the next few paragraphs.

The two basic papermaking machines are the Fourdrinier and the cylinder, and their basic principles of operation have remained unchanged for over a century. A new sheet-forming machine was commercialized in the mid '60's, the twin-wire former. By draining the sheet from both sides, the method is more rapid, with better formation and uniformity, and improved physical properties. It also eliminates two-sidedness. These advantages will lead to an expansion of this type of paper forming in the future.

The U.S. papermaking industry had 1,210 Fourdriniers, 536 cylinder machines, 6 combination units, and 8 twin-wire formers in 1975.[90]

One problem with papermaking is the large amounts of water it requires. The furnish (fiber-containing slurry) typically consists of over 99 percent water and less than 1 percent wood fibers. Research is underway to develop processes using higher consistency forming and

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[90] J. Rauch, ed. op. cit.

also closed-loop systems.

Dry forming is a papermaking method without water. Its use has been predicted to form 2 percent of Canada's paper by 1990.[91]

Other improvements in papermaking will occur in the drying sections and in process control, using computers. These will consist of adjustments to existing systems, however, rather than radically new technologies. Emphasis for some time into the future will be on pollution control and reducing energy requirements.

Should past trends in real value added and capital's share in income continue as in the past, the industry will only have to invest $33,000 (1958 dollars) in real capital per employee to reach the projected 1.2 geometric index in the year 2030. The actual level of investment is already past this figure. The reason the geometric index of technological change in this industry has not increased much is because increases in capital per employee have not produced proportionately large increases in output per employee. Thus, the industry has been increasing its investment per man, doubling it in the nineteen years covered, but output per man has gone up only 62 percent. Similar conditions can be expected to remain true in the future, with increasing investment, but output per man lagging behind. Hence, the judgement is

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[91] K.M. Jege and K.M. Thompson. op. cit.

that the projections of little technological change will occur in this industry are accurate.

The Environment for Technological Change

Technological change does not occur in isolation. Its formation and rate of change depend on many factors--social, economic, institutional, and political.

Size class distribution

One of these factors affecting technological change is the size of the firm. Table 23 shows the size class distributions for the four industries included in this study. It is evident that the two industries dealing with solid wood tend to be small units in terms of employment. These units are also low in capital per employee, as shown earlier.

The pulp and paper industries, in contrast, tend to be much larger. Nearly half of the pulpmills have 50 or more employees, while three-fourths of the papermills have that number.

All of these forest products industries are mature, in the sense of having been in production for many years. Mature large industries tend to reduce employment through increased capital spending and thereby improving labor productivity. It is also suggested that large corporations view innovation largely in terms of cost reduction and increased labor productivity for existing,

Table 23.--Size class distribution of four forest industries in the United States 1972.

Employees	SIC 2411 Establishments	SIC 2411 Cumulative numbers*	SIC 2421 Establishments	SIC 2421 Cumulative numbers*
1-4	9,196	13,238	4,566	8,071
5-9	2,175	4,042	1,072	3,505
10-19	1,171	1,867	716	2,433
20-49	531	696	901	1,717
50-99	111	165	473	816
100-249	40	54	266	343
250-499	9	14	53	77
500-999	4	5	14	24
1,000-2,499	1	1	10	10
2,500+				

*Beginning with the largest.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Table 23.--(cont'd.)

Employees	SIC 2611		SIC 2621	
	Establish-ments	Cumulative numbers*	Establish-ments	Cumulative numbers*
1-4	21	60	27	349
5-9	1	39	13	322
10-19	3	38	14	309
20-49	7	35	31	295
50-99	6	28	33	264
100-249	5	22	80	231
250-499	10	17	56	151
500-999	6	7	68	95
1,000-2,499	1	1	26	27
2,500+			1	1

*Beginning with the largest.

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

in place processes.[92] Such a view tends to hold technical change to "fine tuning" of technologies already in use rather than adoption of radically different methods. These facts help explain why the rate of technological change is so low in the pulp and paper industries. The logging and sawmilling industries, being smaller and less capital intensive, can adopt new technologies more rapidly.

Region of operation

The region of the United States an establishment operates in may also play a role in affecting the adoption of new technologies. Tables 24 through 27 present regional data on the number of establishments, employment, and value added for the four industries in 1972 and 1958.

These data show that the number of logging operations has grown in the southern and mountain regions to the detriment of the other regions. A comparison of the percentage figures for establishments versus employment and value added, however, reveal that operations in the South tend to be small, while those in the Pacific region are larger than average.

All regions experienced a decline in the number of sawmills and planing mills between 1958 and 1972. In percentage terms, the South had the greatest decline in employment, but its share of value added remained the

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[92] Commerce Technical Advisory Board. 1976. The role of new technical enterprises in the U.S. economy. A report to the Secretary of Commerce, 15 pp.

Table 24.--Establishments, employment, and value added by region for logging camps and contractors, 1972, 1958.

Region	Establishments				Employment				Value added			
	Number		Percent		Number		Percent		Number		Percent	
	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958
					(1,000)				(Millions $)			
Northeast	1,115	1,751	8.4	13.7	6.2	7.5	7.8	10.5	77.2	31.4	6.6	8.1
North Central	1,121	1,376	8.5	10.7	4.3	5.0	5.4	7.0	48.0	19.1	4.1	4.9
South	7,698	5,718	58.2	44.7	29.1	30.3	36.4	42.4	336.5	90.7	28.9	23.4
Mountain	646	509	4.9	4.0	5.9	4.1	7.4	5.7	77.7	26.9	6.7	6.9
Pacific	2,658	3,451	20.1	27.0	34.4	24.6	43.0	34.4	624.0	219.4	53.6	56.6
Total	13,238	12,805	100.0	100.0	80.0	71.5	100.0	100.0	1,163.4	387.5	100.0	100.0

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. 1958 Census of Manufactures. Volume II, Industry Statistics. Part 1, General Summary and Major Groups 20 to 28. Washington, D.C.: U.S. Government Printing Office.

Table 25.--Establishments, employment, and value added by region for sawmills and planing mills, 1972, 1958.

Region	Establishments				Employment				Value added			
	Number		Percent		Number		Percent		Number		Percent	
	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958
					(1,000)				(Millions $)			
Northeast	1,127	2,083	14.0	13.3	9.0	13.8	5.4	5.6	119.6	73.2	4.1	6.1
North Central	1,363	2,162	16.9	13.8	9.7	13.6	5.8	5.5	132.1	60.6	4.6	5.1
South	4,248	8,781	52.6	56.2	68.8	123.6	41.3	50.3	926.1	386.6	32.1	32.3
Mountain	415	788	5.1	5.0	16.6	18.6	10.0	7.6	302.6	114.9	10.5	9.6
Pacific	918	1,822	11.4	11.7	62.4	76.1	37.5	31.0	1,425.5	559.3	49.4	46.8
Total	8,071	15,636	100.0	100.0	166.6	245.7	100.0	100.0	2,886.0	1,194.7	100.0	100.0

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. 1958 Census of Manufactures. Volume II, Industry Statistics. Part 1, General Summary and Major Groups 20-28. Washington, D.C.: U.S. Government Printing Office.

Table 26.--Establishments, employment and value added by region for pulpmills, 1972, 1958.

Region	Establishments				Employment				Value added			
	Number		Percent		Number		Percent		Number		Percent	
	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958
					(1,000)				(Millions $)			
Northeast	--	18	--	30.5	--	3.0	--	21.2	--	28.3	--	14.4
North Central	13	11	21.7	18.6	0.8	.7	7.5	4.9	18.5	6.6	6.0	3.4
South	28	15	46.7	25.4	5.3	6.5	50.0	45.9	145.4	94.6	47.4	48.2
Mountain	--	15	--	25.4	--	4.0	--	27.9	--	66.6	--	34.0
Pacific	12		20.0		4.3		40.6		139.8		45.6	
Total	60	59	100.0	100.0	10.6	14.2	100.0	100.0	306.9	196.0	100.0	100.0

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. 1958 Census of Manufactures. Volume II, Industry Statistics. Part 1, General Summary and Major Groups 20 to 28. Washington, D.C.: U.S. Government Printing Office.

Table 27.--Establishments, employment, and value added by region for paper mills, except building paper, 1972, 1958.

Region	Establishments				Employment				Value added			
	Number		Percent		Number		Percent		Number		Percent	
	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958	1972	1958
					(1,000)				(Millions $)			
Northeast	169	194	48.4	54.8	45.6	52.7	35.2	40.2	913.9	534.5	31.4	34.7
North Central	89	94	25.5	26.6	37.4	35.7	28.8	27.1	771.2	400.5	26.5	26.0
South	56	39	16.0	11.0	34.1	33.0	26.3	25.1	872.3	444.7	30.0	28.8
Mountain	1	27	0.3	7.6	12.7	10.0	9.8	7.6	351.8	163.0	12.1	10.6
Pacific	34		9.7									
Total	349	354	100.0	100.0	129.9	131.3	100.0	100.0	2909.3	1542.7	100.0	100.0

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. 1958 Census of Manufactures. Volume II, Industry Statistics.

same. This would indicate this region made the greatest gain in technological advance.

With so many establishments failing, only the most economically viable survived. This industry, then, has experienced strong pressure to accept new, more productive technologies.

Both pulpmills and paper mills have been very stable in terms of the number of establishments (the small number of pulpmills relative to paper mills is due to the fact that they are often not reported separately in the Census of Manufactures). Pulpmills have been relatively more successful in reducing their employment than paper mills.

While the data are incomplete, due to disclosure rules, it is apparent the South has gained in the number of establishments. The new plants in the South would tend to employ the latest methods, and therefore this region should be slightly more technologically advanced than the others.

Research and development

Research and development plays a major role in technological advance. The great majority of studies on the subject indicate that the rate of return from R&D is very high, usually ranging well above 20 percent.[93]

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[93]Edwin Mansfield. 1972. Contribution of R&D to economic growth in the United States. Science 175:477-486.

Yet, Table 28 shows the forest industries to be poor performers in this area. Funding for R&D in the forest industries as a percent of net sales for companies performing R&D is significantly below the average for all industries. This dismal record is sometimes defended on the basis that much of the research and development in the forest industries is done by the equipment manufacturers supplying the industry. While this is true, it also holds for many other industries. Further, the figures on the bottom of Table 28 are only for those companies performing R&D; it is probably justified to assume most companies engaged in logging and sawmilling perform no R&D. Therefore, if funding for R&D were calculated as a percent of total net sales for the industry, the figures would be even lower.

The above discussion is only for nongovernmentally performed R&D. In these industries, significant efforts are made by government and universities in research and development.

Efficiencies

The minor emphasis placed on technological advance in the forest industries is shown by another symptom other than low R&D funding. This symptom is also shown by the ratios in Table 29. The wide discrepancies between the most efficient plants and the least efficient plants show the potential for improvement in the forest

Table 28.--Funds for research and development performed by the forest industries, 1960-1975.

	1960	1965	1970	1975
Lumber, wood products, and furniture	13	13	48	68*
Paper and allied products	56	76	178	253
Total, all industries	10,509	14,197	18,062	23,540
COMPANY FINANCED				
Lumber, wood products, and furniture	11	NA	48	NA
Paper and allied products	56	76	NA	NA
FUNDS FOR R&D AS A PERCENT OF NET SALES IN MANUFACTURING COMPANIES PERFORMING R&D				
Lumber	0.6	0.4	0.5	0.4
Paper	0.7	0.8	0.8	0.7
Average, all industries	4.3	4.3	3.7	3.1

*29 of which was for furniture

Sources:

National Science Foundation. Research and development in industry, 1975. Survey of Science Resources Series, NSF 77-324. Washington, D.C.

National Science Foundation. Basic research, applied research, and development in industry, 1965. Survey of Science Resources Series, NSF 67-12. Washington, D.C.

National Science Foundation, Research and development in industry, 1960. Survey of Science Resources Series, NSF 63-7. Washington, D.C.

Table 29.--Value added and capital expenditures in the lumber and wood products industry: Ratios of "most efficient" to "least efficient" plants and to average plant, 1967.

Industry sector	Value added per production worker man-hour: "Most efficient" to "least efficient" plants	Value added per production worker man-hour: "Most efficient" to average plant	Capital expenditures per employee: "Most efficient" to "least efficient" plants	Capital expenditures per employee: "Most efficient" to average plant
	(Ratios)			
Logging camps and contractors	5.7	1.8	2.0	1.4
Sawmills and planing mills	4.1	1.7	1.6	1.2

Source:

U.S.D.L., Bureau of Labor Statistics. 1974. Technological change and manpower trends in six industries. Bulletin 1817. Washington, D.C.: U.S. Government Printing Office.

industries. Moreover, the differences between the two measures (value added and capital expenditures) show that while the average plant does not lag by a large degree in capital expenditures per employee, there is a greater difference in value added per production worker man-hour. This implies that the less efficient plants lag in the utilization of their capital, probably by investing in outdated technologies, or poorly managing that which they possess.

Prices

The real price movements of the products manufactured by an industry are both a reflection of past technological change and a factor influencing further change. A lag in productivity relative to growth in demand should, ceteris paribus, result in an increase in real price, relative to other goods. If total productivity rises faster than demand, then the real price should decline.[94]

As shown in Table 30, the wholesale price index of lumber and wood products has risen relative to that of materials and components for construction, although the relationship has been quite variable. Woodpulp and paper are compared relative to the all commodities index. Prior

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[94] V.W. Ruttan and J.C. Callahan. 1962. Resource inputs and output growth: Comparisons between agriculture and forestry. Forest Science 8(1):68-82.

Table 30.--Wholesale price indexes of selected timber products, 1950-1976.

(1967 = 100)

Year	Materials and components for construction	Lumber and wood products		Lumber		Woodpulp		Paper	
		Actual	Relative[1]	Actual	Relative[1]	Actual	Relative[2]	Actual	Relative[2]
1950	77.0	89.3	116.0	86.6	112.5	81.0	99.0	67.9	83.0
1951	84.3	97.2	115.3	93.7	111.2	96.9	106.4	76.0	83.4
1952	83.7	94.4	112.8	91.3	109.1	94.5	106.7	79.1	89.3
1953	85.1	94.3	110.8	90.5	196.3	92.4	105.7	80.1	91.6
1954	85.5	92.6	108.3	88.9	104.0	93.0	106.2	80.8	92.2
1955	88.9	97.1	109.2	94.5	106.3	95.7	109.0	82.8	94.3
1956	93.5	98.5	105.3	96.5	103.2	99.8	110.0	87.6	96.6
1957	94.0	93.5	99.5	90.9	96.7	100.7	107.9	90.5	97.0
1958	94.0	92.4	98.3	89.5	95.2	102.8	108.7	90.7	95.9
1959	96.6	98.8	102.3	96.4	99.8	102.8	108.4	91.5	96.5
1960	95.9	95.3	99.4	92.2	96.1	102.2	107.7	92.7	97.7
1961	94.6	91.0	96.2	87.4	92.4	96.9	102.5	92.9	98.3
1962	94.2	91.6	97.2	89.0	94.5	95.1	100.3	93.3	98.4
1963	94.5	93.5	98.9	91.2	96.5	93.6	99.0	93.1	98.5
1964	95.4	95.4	100.0	92.9	97.4	98.1	103.6	94.2	99.5
1965	96.2	95.9	99.7	94.0	97.7	100.1	103.6	94.6	97.9
1966	98.8	100.2	101.4	100.1	101.3	100.0	100.1	97.5	97.7
1967	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1968	104.9	113.3	108.0	117.4	111.9	100.0	97.6	102.0	99.5
1969	110.8	125.3	113.1	131.5	118.7	100.0	93.9	105.5	99.1

Table 30.--(cont'd.)

Year	Materials and components for construction	Lumber and wood products		Lumber		Woodpulp		Paper	
		Actual	Relative[1]	Actual	Relative[1]	Actual	Relative[2]	Actual	Relative[2]
1970	112.6	113.7	101.0	113.7	101.0	109.3	99.0	111.0	100.5
1971	119.7	127.0	106.1	135.5	113.2	112.0	98.3	114.1	100.2
1972	126.2	144.3	114.3	159.4	126.3	111.5	93.6	116.3	97.6
1973	136.7	177.2	129.6	205.2	150.1	128.3	95.2	121.4	90.1
1974	161.6	183.6	113.6	207.1	128.2	217.8	136.0	148.6	92.8
1975	176.4	176.8	100.2	192.5	109.1	283.4	162.0	172.9	98.9
1976	188.0	205.5	109.3	233.0	123.9	286.0	156.4	182.2	99.6

[1]Relative to the materials and components for construction index.
[2]Relative to the all-commodities index.

Sources:

Robert B. Phelps, op. cit.

The President. 1978. Economic Report of the President. Washington, D.C.: U.S. Government Printing Office.

to the last 3 years, woodpulp had remained at about the same level as the all-commodities index. The sudden increase in the last few years is possibly due to the necessity of raising prices to cover the costs of added polution control equipment.

Softwood lumber shows a more variable index than the other commodities because of swings in the housing market.

Competing materials have generally shown less of a rise in their price indexes than lumber. Aluminum siding, concrete products, building brick, and gypsum products have all declined relative to the materials and components for construction index. This difference in price behavior has no doubt led to the level consumption of lumber, while the Nation's population has been expanding.

Resources

The characteristics of the raw material base an industry utilizes also determine the direction technological change may take. However, resources cannot be defined without references to the level of technology. Technological knowledge has been defined as "information which improves man's capacity to control and to manipulate the natural environment in the fulfillment of human goals, and to make that environment more responsive to human needs."[25]

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[25] Nathan Rosenburg. 1972. Technology and American Economic Growth. New York: Harper & Row.

It is then technological knowledge which determines which materials in the environment the forest industries can utilize to satisfy the needs of our society.

Data in the area of raw material quality are virtually nonexistent for stumpage, sawlogs, or pulpwood. The general concensus is that, overall, the quality of sawlogs, at least as reflected by sawlog size, has declined. In contrast, there is no good reason to believe that pulpwood quality has changed.

Technological changes have redefined resources for the forest industries, however. Semichemical pulping has allowed the utilization of small, low-grade hardwoods for pulp. The chipping headrig has also allowed use of small material. This fact has led Irland to declare that "The major role of technological development in United States forest industry over this century has been one of resource-expanding change."[96]

The changing resource base in the forest industries is the result of two forces: One is the expansion to the physical limits of traditional resources, such as softwood sawlogs, limited by the allowable cut policies of the

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[96]Lloyd C. Irland. 1973. Resource endowment, technology, and trade: The case of U.S. timber resources. Unpublished paper presented at meeting of the Southern Economic Association and Southern Forest Economics Workers, Houston, Texas.

U.S. Forest Service; the second is the realization of the opportunity represented by huge amounts of harvesting residues. Utilization of these residues was viewed both as an untapped raw material resource and as a response to rising pressures by the public and government to lessen impacts on the environment.[97]

The difficulties of prediction are numerous, the last not being that of defining an invention or innovation. Should the high-strain bandsaw be classified as a separate innovation from an ordinary bandsaw? Or should both be included in a general class of headrigs? Prediction must be based on counting, which cannot be done without definition. Lack of consistent definition, because of evolving techniques and equipment, makes prediction difficult.[98]

Future technological change is expected to produce more output from a given amount of raw material. Projections by the U.S. Forest Service place softwood lumber yields 15 percent higher in 2000, based on 1970 yields. The increased yield for hardwoods is projected to be 5 percent. Both of the projections are based on the relative price of lumber rising at 1.5 percent per year.

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[97] Richard L. Porterfield. 1977. op. cit.

[98] S. Colum Gilfillan. 1952. The prediction of technical change. Review of Economics and Statistics 34:368-385.

Pulp yields are also expected to increase by about 7 percent over their 30-year projection period, based on relative prices rising 0.5 percent per year.[99]

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[99] U.S. Forest Service. 1973. The outlook for timber in the United States. USDA Forest Service, Forest Resource Report No. 20. Washington, D.C. U.S. Government Printing Office.

SUMMARY AND CONCLUSIONS

Technological change in the four forest industries of logging, sawmilling, pulping, and papermaking has been modest. Between 1958 and 1976, the average annual increase in the geometric index of technological change for the four industries was only 1.4 percent. Such an indicator of technological change is based on the changes in production unaccounted for by concurrent changes in labor and capital in the industry. Its interpretation is that of an index of shifts in the production function, or alternatively, that of a measure of total factor productivity. It may also be considered as an indicator of progressiveness, inasmuch as the index of technological change measures the success of the industry in producing extra output, in excess of relative changes in capital and labor. The index may also be considered an indicator of the adaptiveness or adoptiveness of an industry in utilizing the technological opportunities available.

A descriptive evaluation of possible future technology for the four industries reveals that there are both improved versions of currently employed processes and totally or radically new technologies available. The range and magnitude of new technologies varies between the industries, with the greatest opportunities apparently in the logging and sawmilling industries, and less in papermaking. Capital requirements for new technologies also varies considerably between the industries, with less investment required for new machines in logging and sawmilling than in pulping or papermaking.

One of the four econometric models measuring technological change also allowed estimation of the elasticity of substitution between labor and capital. The constant elasticity of substitution function placed the elasticities for all the industries above one, ranging from 1.2 for sawmills and planing mills, to a high of 1.7 for pulpmills. Estimates for all in the elastic range is reasonable because all have increased their levels of capital, while increasing output usually without increasing labor. Apparently the price of capital relative to that of labor has also declined, evidenced by the proxy price weights calculated for the arithmetic index (Appendix Tables B1 through B4).

The geometric technological index weights changes in labor and capital by their respective elasticities of output. An estimate for the elasticity of output with respect to capital is capital's share in income, which has been increasing for all of the industries. This parameter of the production function has increased only slightly in pulping and papermaking, but has increased fairly substantially in sawmilling and even more so in logging. An increasing elasticity of output with respect to capital means that it is becoming relatively easier to increase output through the addition of capital than of labor (the two elasticities were assumed to sum to one in the model). The declining relative price of capital (evidenced from the arithmetic model) and the additions to each industry's capital reflect this trend.

Several qualitative indicators of technological change also show varying rates of progress, although not in such an exact fashion. All of the industries have increased their output. The real value of output in logging camps and contractors grew the most (150.3 percent), while in sawmills and planing mills, general, it grew the least (20.6 percent). Real gross assets also increased, and the same industries were first and last in this ranking. Table 31 summarizes most of the qualitative indicators considered.

Employment over the nineteen year period declined in three of the industries, with sawmilling decreasing by over 30 percent. The sole industry to increase employment was pulping which climbed slightly more than 10 percent. Per employee productivity, the most commonly used measure of progress in manufacturing, grew almost uniformly in three of the industries, with increases between 60 and 75 percent for the nineteen years. Labor productivity in logging increased twice as much as the others, increasing by over 150 percent. Annual growth rates in labor productivity for pulping and papermaking ranged slightly below the national average for manufacturing of 2.7 percent, with sawmilling slightly

Table 31.--Percent change in some qualitative indicators of technological change in the forest industries, 1958-1976.

Indicator	Logging	Sawmilling	Pulping	Papermaking
		Percent		
Real output	150.3	20.6	78.7	57.4
Real capital	100.0	13.1	90.3	96.5
Employment	-0.3	-31.2	10.6	-2.9
Output/unit labor	151.0	75.3	61.6	62.1
Output/unit capital	25.2	6.6	-6.1	-19.9
Annual growth in labor productivity	5.0	3.0	2.6	2.6
Number of establishments	3.4	-48.4	1.7	-1.4
Capital/employee	108.9	71.1	67.4	105.3
New capital expenditures/ employee	89.4	160.7	300.7	111.0

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.

above and logging well above the national average of growth in labor productivity.[100]

The number of establishments in each of the industries in this group has remained fairly stable over the years, with the exception of sawmilling. In this manufacturing activity, the number of establishments as recorded by the Bureau of the Census has declined by almost one half. With such a reduction, it is probable that the least efficient and progressive plants have been the most likely to cease production. All in the group have achieved output growth by increasing in size (in capital terms), and not generally by establishment numbers.

Regional shifts have occurred, however. Some movement in logging establishments has been from the Pacific Coast to the South. Sawmilling establishments declined in all regions. In pulping and papermaking, there has also been a general shift to the South.

Research and development in the forest industries is not great. For both lumber and paper, funds for R&D as a percent of net sales in manufacturing companies performing R&D is less than one percent, compared to greater than three percent for all manufacturing. Universities, government, and manufacturers of equipment for the

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[100] J.E. Henneberger. 1978. Productivity growth below average in the household furniture industry. Monthly Labor Review 101(11):23-29.

industries do perform R&D that affects the forest industries, however.

Changes in raw materials have also probably occurred. Reliable data are not readily available, but logs have most likely become smaller.

An additional factor may be that the entire forest products industry has concentrated on advancement in other areas, such as plywood, particleboard, and fiberboard.

Technological change has accounted for about 60 percent of the increases in per employee productivity for three of the industries, while additional capital per employee produced the remainder. Papermaking differed, with greater capital intensity producing 72 percent of the growth, with technological change accounting for 28 percent.

Capital per employee increased in all of the industries, however this factor change did not produce equal results among the four industries. Logging augmented their investment per man the most, and also succeeded in leading the group in most of the qualitative measures of technological change, especially growth in labor productivity and the change in real output. Yet in papermaking, an increase in capital per employee of almost the same proportions resulted in low growth in labor productivity and the geometric index of technological change. Growth in the ratio which measures the rate of investment per man was highest in pulping. This fact coupled with the others, suggests that it has been easier, and less expensive in terms of capital, to produce technological change in logging than in any of the other three industries in the group.

The two industries producing solid wood products, logging and sawmilling, improved their output per unit of capital ratios, while the two fiber industries, pulping and papermaking, suffered declines in their output per unit capital input ratios. In general, growth in an industry's capital investments will lead to expansions in its productivity. All of the industries have expanded their expenditures per employee, as shown in Table 32.

Three of the forest industries in this group were ahead of the national average in new capital investment per employee in 1958, and in the cases of the two fiber-based industries, much ahead. Sawmilling was only slightly behind in 1958, but had fallen proportionately further behind by 1976. By 1976, logging camps and contractors had also fallen behind in new capital invested per man. In contrast, pulping and papermaking were still well ahead of the national average, and for the former, more than five times as much was invested per employee as in the average U.S. manufacturing industry. Yet, technological change (measured by the geometric index) was not spectacular, and growth in per employee productivity was slightly below the national average.

Table 32.--New capital expenditures per employee in four forest industries and all manufacturing, 1958 and 1976.

Industry	New Capital Expenditures Per Employee	
	1958	1976
Logging camps and contractors	954	1,807
Sawmills and planing mills, general	526	1,371
Pulpmills	3,028	12,134
Papermills, except building paper	1,971	4,158
All manufacturing	620	2,300

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

In the future, trends will probably not vary much from what they were in the past, with a few exceptions. New capital expenditures per employee of less than the national average should bring the growth in labor productivity down somewhat in logging and sawmilling. However, evidence examined above suggest that it is easier to produce technological change (shifting the production function) in these two industries than in pulping and papermaking, at least in terms of investment per man. While there is no hard and fast evidence yet to suggest it, the decline in the number of sawmills may slow in the future. Distances economical to transport logs will tend to limit the area from which the average mill can draw raw materials and hence its size. Improved processing technologies can compensate for the trend to smaller logs.

While new capital investment per man has been high in pulping and papermaking, advances in technological change have not been as great per dollar. Alternatively, it has been difficult to increase total factor productivity in these two industries. In terms of the geometric index, pulping will probably not be able to retain its past rate of 2.4 percent annually. Should past trends in capital share and real output per employee continue, capital requirements will probably be too great to maintain pulpings past rate of technological improvement. If the industry continues to invest as it has in the past, productivity could fall even lower. Technological change in papermaking will probably remain low, as it has in the past.

APPENDICES

APPENDIX A

GEOMETRIC INDEX UTILIZATION RATES

Table A1.--Percent capacity utilized, lumber production, 1958-1976, by quarter.

Year	Quarter I	Quarter II	Quarter III	Quarter IV	Average
1958	81.0	92.1	100.0	97.7	92.7
1959	96.1	100.0	100.0	95.2	97.8
1960	91.8	100.0	95.1	81.8	92.2
1961	79.9	93.4	93.8	87.3	88.6
1962	83.8	99.2	100.0	93.5	94.1
1963	89.9	98.2	100.0	95.0	95.8
1964	93.8	98.0	100.0	89.4	95.3
1965	88.8	95.8	100.0	94.7	94.8
1966	92.8	100.0	94.8	84.5	93.0
1967	87.1	93.6	92.0	89.2	90.5
1968	89.7	100.0	98.9	93.6	95.6
1969	95.2	100.0	96.1	92.9	96.1
1970	89.9	93.1	91.9	86.0	90.2
1971	91.3	100.0	96.6	91.5	94.9
1972	93.0	100.0	98.8	95.0	96.7
1973	97.1	100.0	100.0	94.6	97.9
1974	91.0	100.0	88.9	70.3	87.6
1975	69.3	87.7	90.7	85.6	83.3
1976	92.1	96.1	100.0	97.6	96.5

Note: The above capacity utilization figures were used as a proxy for logging camps and contractors.

Table A2.--Percent capacity utilized, woodpulp production, 1958-1976, by quarter.

Year	Quarter I	Quarter II	Quarter III	Quarter IV	Average
1958	99.0	97.1	100.0	100.0	99.0
1959	100.0	100.0	96.3	95.6	98.0
1960	100.0	96.7	92.5	91.9	95.3
1961	94.0	100.0	95.4	100.0	97.4
1962	100.0	100.0	94.4	94.8	97.3
1963	98.8	100.0	97.6	100.0	99.1
1964	100.0	100.0	94.8	95.4	97.6
1965	96.8	96.5	95.1	95.7	96.0
1966	97.3	100.0	97.3	98.4	98.3
1967	99.5	100.0	93.2	94.1	96.7
1968	100.0	100.0	94.4	93.4	97.0
1969	93.9	100.0	96.9	98.9	97.4
1970	99.3	100.0	95.3	96.5	97.8
1971	98.9	100.0	96.6	100.0	98.9
1972	99.0	100.0	95.7	96.9	97.9
1973	99.0	100.0	97.1	97.2	98.3
1974	97.3	100.0	95.2	93.1	96.4
1975	83.2	76.6	81.9	89.3	82.3
1976	97.1	100.0	93.2	94.8	96.3

Table A3.--Percent capacity utilized, paper production, 1958-1976, by quarter.

Year	Quarter I	Quarter II	Quarter III	Quarter IV	Average
1958	94.8	94.9	93.4	100.0	95.8
1959	100.0	100.0	94.2	96.8	97.8
1960	100.0	100.0	91.8	94.9	96.7
1961	97.5	100.0	94.6	100.0	98.0
1962	100.0	100.0	93.0	96.3	97.3
1963	100.0	100.0	95.0	100.0	98.8
1964	100.0	100.0	95.0	98.3	98.3
1965	100.0	100.0	95.0	97.8	98.2
1966	100.0	100.0	97.1	99.4	99.1
1967	100.0	98.6	93.3	99.3	97.8
1968	100.0	100.0	94.3	96.9	97.8
1969	100.0	99.1	95.7	98.2	98.3
1970	100.0	99.0	92.1	94.6	96.4
1971	100.0	99.1	94.3	100.0	98.4
1972	100.0	100.0	95.7	100.0	98.9
1973	100.0	100.0	95.1	97.4	98.1
1974	98.8	100.0	95.2	96.1	97.5
1975	82.8	79.2	85.5	94.0	85.4
1976	99.2	100.0	93.7	95.8	97.2

APPENDIX B

ARITHMETIC INDEX WEIGHT CALCULATIONS

The weights for the arithmetic index were calculated using the following formulas:

$$\text{Labor weight} = \frac{\text{payroll/employment index}}{(\text{payroll/employment index}) + ((\text{value added} - \text{payroll})/\text{capital index}))}$$

Capital weight = 1 - labor weight.

Below is an example for logging camps and contractors, for 1959, taken from Table B1:

$$\text{Labor weight} = \frac{250.5/105.7}{(250.5/105.7) + ((442.0 - 250.5)/113.2)}$$

$$= .5837$$

$$\text{Capital weight} = 1 - .5837$$

$$= .4163$$

Table B1.--Arithmetic index weight calculations, industry SIC 2411.

Year	Value added[1]	Payroll[2]	Capital[3] (Index)	Labor[4] (Index)	Labor Weight	Capital Weight
1958	390.4	228.0	100.0	100.0	.5840	.4160
1959	442.0	250.5	113.2	105.7	.5834	.4166
1960	439.3	247.6	112.7	102.0	.5881	.4119
1961	449.0	247.2	112.8	99.6	.5811	.4189
1962	463.0	249.4	125.7	96.7	.6030	.3970
1963	520.5	281.8	136.2	102.0	.6119	.3881
1964	556.5	297.8	148.4	97.8	.6361	.3639
1965	619.7	301.3	156.9	102.8	.5910	.4090
1966	655.9	310.3	161.2	101.1	.5886	.4114
1967	695.1	338.8	174.2	98.5	.6272	.3728
1968	791.5	373.3	194.2	97.5	.6400	.3600
1969	854.2	403.4	230.7	102.9	.6673	.3327
1970	893.9	406.2	208.2	106.1	.6203	.3797
1971	857.4	403.6	224.6	95.3	.6771	.3229
1972	1163.4	523.9	299.5	111.6	.6874	.3126
1973	1607.8	602.8	332.0	119.8	.6244	.3756
1974	1835.9	675.2	361.6	105.3	.6664	.3336
1975	1713.1	664.1	440.4	93.7	.7484	.2516
1976	2172.9	797.7	476.3	99.7	.7348	.2652

[1] Value added by manufacture, millions of dollars.
[2] Payroll, all employees, millions of dollars.
[3] Gross value of fixed assets, indexed at 1958=100.
[4] All employees, number, indexed at 1958=100.

Table B1.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C.: U.S. Government Printing Office.

Table B2.--Arithmetic index weight calculations, industry SIC 2421.

Year	Value added[1]	Payroll[2]	Capital[3] (Index)	Labor[4] (Index)	Labor Weight	Capital Weight
1958	1195.8	770.9	100.0	100.0	.6447	.3553
1959	1505.7	855.4	113.5	102.6	.5928	.4072
1960	1327.8	831.2	102.8	97.8	.6374	.3626
1961	1231.5	762.3	93.6	87.1	.6356	.3644
1962	1329.2	775.8	98.7	85.3	.6185	.3814
1963	1376.1	811.6	103.1	84.3	.6374	.3626
1964	1516.8	902.2	110.6	80.9	.6674	.3326
1965	1458.2	876.9	108.7	82.0	.6667	.3333
1966	1555.7	871.5	110.0	79.3	.6386	.3614
1967	1556.4	884.6	111.8	73.4	.6673	.3327
1968	1914.2	940.3	117.3	71.5	.6131	.3869
1969	2025.3	1011.5	126.6	72.3	.6361	.3639
1970	1762.2	1032.8	128.3	70.7	.7199	.2801
1971	2193.6	1103.2	134.5	69.0	.6635	.3365
1972	2906.0	1272.2	180.3	67.8	.6745	.3255
1973	3773.7	1400.7	189.5	70.6	.6130	.3870
1974	3336.1	1499.2	196.5	75.6	.6796	.3204
1975	2651.8	1427.4	212.3	64.9	.7921	.2079
1976	3753.7	1687.7	222.5	68.8	.7255	.2745

[1]Value added by manufacture, millions of dollars.
[2]Payroll, all employees, millions of dollars.
[3]Gross value of fixed assets, indexed at 1958=100.
[4]All employees, number, indexed at 1958=100.

Table B2.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Sruvey of Manufactures. Washington, D.C.: U.S. Government Printing Office.

Table B3.--Arithmetic index weight calculations, industry SIC 2611.

Year	Value added[1]	Payroll[2]	Capital[3] (Index)	Labor[4] (Index)	Labor Weight	Capital Weight
1958	196.0	74.8	100.0	100.0	.3816	.6184
1959	224.9	87.1	112.4	102.1	.4103	.5897
1960	201.2	89.9	110.3	102.1	.4659	.5341
1961	196.2	87.9	102.2	95.8	.4642	.5358
1962	195.4	93.4	131.0	97.9	.5506	.4494
1963	295.8	107.4	135.4	106.3	.4206	.5794
1964	331.6	113.6	145.1	107.7	.4124	.5876
1965	346.1	112.3	150.9	104.2	.4101	.5899
1966	364.5	123.5	173.9	112.0	.4432	.5568
1967	333.7	125.6	183.5	106.3	.5102	.4898
1968	361.3	136.0	192.7	108.5	.5175	.4825
1969	362.0	142.6	204.9	104.9	.5594	.4406
1970	466.3	160.2	240.8	109.9	.5342	.4658
1971	367.2	156.3	249.9	102.1	.6446	.3554
1972	306.8	125.7	185.2	74.6	.6326	.3674
1973	382.7	138.2	200.4	76.1	.5982	.4018
1974	779.3	163.2	228.5	84.5	.4174	.5826
1975	821.0	191.4	292.8	92.3	.4911	.5089
1976	974.6	260.5	374.5	110.6	.5527	.4473

[1] Value added by manufacture, millions of dollars.
[2] Payroll, all employees, millions of dollars.
[3] Gross value of fixed assets, indexed at 1958=100.
[4] All employees, number, indexed at 1958=100.

Table B3.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

Table B4.--Arithmetic index weight calculations, industry SIC 2621.

Year	Value added[1]	Payroll[2]	Capital[3] (Index)	Labor[4] (Index)	Labor Weight	Capital Weight
1958	1542.7	741.0	100.0	100.0	.4803	.5197
1959	1829.9	790.2	119.4	102.7	.4692	.5308
1960	1877.0	820.3	127.8	104.1	.4880	.5120
1961	1865.2	818.0	132.0	100.8	.5055	.4945
1962	1904.9	859.9	147.4	100.8	.5462	.4538
1963	1857.2	877.9	154.9	98.9	.5842	.4158
1964	1974.0	917.6	165.0	98.7	.5922	.4078
1965	2066.2	963.3	185.8	101.0	.6164	.3836
1966	2330.3	1043.3	213.9	102.8	.6278	.3722
1967	2356.3	1120.7	224.0	106.6	.6558	.3442
1968	2477.5	1184.5	243.2	106.1	.6775	.3225
1969	2673.0	1285.5	258.2	108.1	.6888	.3112
1970	2655.7	1305.2	272.8	105.3	.7145	.2855
1971	2614.0	1334.0	285.6	100.5	.7475	.2525
1972	2909.3	1439.6	299.5	98.9	.7478	.2522
1973	3416.4	1537.6	312.2	99.9	.7188	.2812
1974	4346.9	1666.2	327.9	99.3	.6723	.3277
1975	3973.2	1668.0	357.2	92.1	.7373	.2627
1976	4877.8	1976.7	386.7	97.1	.7303	.2693

[1] Value added by manufacture, millions of dollars.
[2] Payroll, all employees, millions of dollars.
[3] Gross value of fixed assets, indexed at 1958=100.
[4] All employees, number, indexed at 1958=100.

Table B4.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

APPENDIX C

ARITHMETIC INDEXES OF TECHNOLOGICAL CHANGE

Table C1.--Arithmetic index of technological change in industry SIC 2411

Constant Prices

Year	Real Capital[1] (Millions $)	Labor[2] (thousands)	Real Value Added[3] (Millions $)	Arithmetic Index
1958	388.7	71.7	390.4	1.000
1959	437.8	75.8	413.4	.975
1960	439.5	73.1	425.9	1.027
1961	442.6	71.4	455.9	1.109
1962	491.0	69.3	467.0	1.102
1963	527.6	73.1	514.4	1.138
1964	567.1	70.1	539.0	1.179
1965	585.9	73.7	597.1	1.239
1966	576.3	72.5	604.8	1.269
1967	597.1	70.6	642.3	1.329
1968	634.5	69.9	645.5	1.313
1969	699.9	73.8	629.9	1.221
1970	582.1	76.1	726.4	1.423
1971	585.3	68.3	623.8	1.326
1972	736.8	80.0	745.0	1.314
1973	757.8	85.9	838.4	1.380
1974	694.6	75.5	923.9	1.612
1975	743.2	67.2	895.3	1.611
1976	777.6	71.5	977.0	1.644

[1]Gross value of fixed assets, deflated.
[2]All employees, number, deflated.
[3]Value added by manufacture, deflated.

Table C1.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

Table C2.--Arithmetic index of technological change in industry SIC 2421

Constant Prices

Year	Real Capital[1] (Millions $)	Labor[2] (thousands)	Real Value Added[3] (Millions $)	Rebased Arithmetic Index
1958	1633.7	245.9	1195.8	1.000
1959	1814.4	252.2	1397.9	1.107
1960	1631.6	240.6	1288.9	1.095
1961	1478.2	214.3	1261.1	1.187
1962	1548.8	209.8	1336.7	1.239
1963	1612.2	207.4	1350.4	1.239
1964	1709.5	199.0	1461.3	1.322
1965	1652.3	201.6	1388.4	1.276
1966	1630.8	195.0	1391.0	1.304
1967	1605.0	180.5	1393.0	1.360
1968	1631.3	175.8	1459.3	1.418
1969	1681.5	177.7	1378.4	1.345
1970	1612.5	173.8	1387.1	1.381
1971	1600.3	169.7	1448.9	1.444
1972	2068.3	166.6	1631.7	1.471
1973	2090.7	173.7	1645.9	1.448
1974	1943.6	186.0	1441.7	1.300
1975	1842.6	159.7	1232.9	1.267
1976	1847.1	169.1	1441.9	1.387

[1] Gross value of fixed assets, deflated.
[2] All employees, number, deflated.
[3] Value added by manufacture, deflated.

Table C2. (cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

Table C3.--Arithmetic index of technological change industry SIC 2611

Constant Prices

Year	Real Capital[1] (Millions $)	Labor[2] (Thousands)	Real Value Added[3] (Millions $)	Arithmetic Index
1958	654.8	14.2	196.0	1.000
1959	720.1	14.5	224.9	1.073
1960	701.7	14.5	202.4	.987
1961	647.5	13.6	208.1	1.093
1962	823.8	13.9	211.2	.962
1963	848.6	15.1	324.9	1.416
1964	899.0	15.3	347.5	1.442
1965	918.9	14.8	355.4	1.462
1966	1033.6	15.9	374.7	1.415
1967	1055.9	15.1	343.0	1.335
1968	1073.7	15.4	371.4	1.398
1969	1091.1	14.9	372.1	1.403
1970	1212.8	15.6	438.6	1.489
1971	1192.0	14.5	337.0	1.288
1972	851.5	10.6	282.9	1.450
1973	885.8	10.8	306.6	1.501
1974	905.8	12.0	367.8	1.633
1975	1018.7	13.1	297.8	1.361
1976	1246.0	15.7	350.3	1.332

[1]Gross value of fixed assets, deflated.
[2]All employees, number, deflated.
[3]Value added by manufacture, deflated.

Table C3.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

Table C4.--Arithmetic index of technological change in industry SIC 2621

Constant Prices

Year	Real Capital[1] (Millions $)	Labor[2] (Thousands)	Real Value Added[3] (Millions $)	Rebased Arithmetic Index
1958	2672.7	131.3	1542.7	1.000
1959	3123.0	134.8	1813.9	1.069
1960	3320.5	136.7	1836.5	1.042
1961	3411.3	132.4	1821.0	1.034
1962	3783.4	132.3	1851.8	.998
1963	3962.6	129.8	1809.3	.963
1964	4171.9	129.6	1900.7	.991
1965	4619.4	132.6	1981.0	.974
1966	5188.5	135.0	2167.8	1.004
1967	5261.4	140.0	2137.2	.964
1968	5532.9	139.3	2203.0	.977
1969	5611.1	141.9	2298.0	1.003
1970	5608.0	138.3	2170.0	.962
1971	5558.9	132.0	2077.9	.951
1972	5621.3	129.9	2268.9	1.049
1973	5633.5	131.2	2552.5	1.166
1974	5304.7	130.4	2653.2	1.236
1975	5072.5	120.9	2084.3	1.071
1976	5251.6	127.5	2428.2	1.184

[1]Gross value of fixed assets, deflated.
[2]All employees, number, deflated.
[3]Value added by manufacture, deflated.

Table C4.--(cont'd.)

Source:

Bureau of the Census. 1972 Census of Manufactures. Volume II, Industry Statistics. Part 1, SIC Major Groups 20-26. Washington, D.C.: U.S. Government Printing Office.

Bureau of the Census. Various Annual Survey of Manufactures. Washington, D.C., U.S. Government Printing Office.

APPENDIX D

STRICT COBB-DOUGLAS PRODUCTION FUNCTIONS

Strict Cobb-Douglas production functions for the forest industries:

Logging camps and contractors

$$\log Y = -1.1619 + 1.1868 \log K - \underset{(.1567)}{.1868} \log L \qquad R^2 = .771$$

Sawmills and planing mills, general

$$\log Y = 3.4068 + .8991 \log K + \underset{(.0835)}{.1009} \log L \qquad R^2 = .634$$

Pulpmills

$$\log Y = -1.5087 + 1.1046 \log K - \underset{(.1536)}{.1046} \log L \qquad R^2 = .741$$

Paper mills, except building paper

$$\log Y = 4.6416 + .5037 \log K + \underset{(.0752)}{.4962} \log L \qquad R^2 = .769$$

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