# INTERMEDIATE INPUTS AND TECHNICAL CHANGE IN THE U.S. LUMBER AND WOOD PRODUCTS INDUSTRY[1]

by

David N. Bengston and Anne Strees[2]

August 1984

Staff Paper Series Number 43

---

[1] Research supported by the Department of Forest Resources, the Agricultural Experiment Station, University of Minnesota, and the USDA Forest Service and Cooperative State Research Service. Published as Paper No. 1957 of the Scientific Journal Series for the Minnesota Agricultural Experiment Station.

[2] The authors are Graduate Research Assistant, Department of Forest Resources, College of Forestry, University of Minnesota, St. Paul, MN 55108, and Economist, USDA Forest Service, Policy Analysis Staff, P.O. Box 2417, Washington, D.C. 20013. The authors thank Hans Gregersen, Willis Peterson, and Vernon Ruttan for helpful comments and suggestions during the course of this research.

Abstract

This paper examines the estimation of technical change in the U.S. lumber and wood products industry. Previous studies along these lines have assumed an industry production function in which output is measured as value-added, and therefore intermediate inputs are not treated symetrically with capital and labor inputs. The exclusion of intermediate inputs for the production process in industry level productivity studies places unnecessary restrictions on the production process, producer behavior and the nature of technical change. It is shown that the estimated rate of technical change based on a value-added model of production is necessarily greater than the rate derived from a model that treats all inputs symetrically. The practical significance of this upward bias is examined by calculating indexes of technical change for the lumber and wood products industry based on value-added and gross output production functions. It is concluded that the gross output model is more appropriate for analyzing productivity and technical change in the lumber and wood products industry.

# Intermediate Inputs and Technical Change in the Lumber and Wood Products Industry

## Introduction

Technical change in primary resource using industries can be a major factor affecting the utilization and value of those resources. Technical change enables less expensive or relatively abundant resources to be substituted for expensive or scarce resources. A current example in the forest products industry is the substitution of structural particleboard -- made primarily with low value aspen -- for softwood plywood. Since technical change redefines and expands resources, its analysis and estimation may be of interest to policymakers and resource managers.

The analysis of technical change in the forest products industry is a relatively recent area of empirical research. Manning and Thornburn (1971) estimate the rate of Hicks-neutral technical change in the Canadian pulp and paper industry using a model developed by Solow (1957). The same model was applied to the U.S. lumber and wood products industry (SIC 24) by Robinson (1975). Using a cost function approach developed by Binswanger (1974), Stier (1980b) examined factor substitution and technical change in the U.S. lumber industry (SIC 242). Three factors of production were included in this model: capital, labor and sawlogs. A two factor cost function model was used to examine the nature of technical change in ten U.S. forest products industries (Stier, 1980a). Greber and White (1982) analyzed non-neutral technical change in lumber and wood products using a model developed by Sato (1970).

The Manning and Thornburn, Robinson, and Greber and White studies were based on models originally developed to analyze technical change in the aggregate U.S. economy. With the exception of Stier (1980b), all of the forest products studies mentioned in the preceeding paragraph postulate a two factor industry production function in which output (measured as value-added) is a function only of capital and labor, and thus intermediate inputs are not treated symetrically with capital and labor inputs. The exclusion of intermediate inputs from the production process in industry level productivity studies has come under increasing criticism in recent years. It has been shown (Berndt and Christensen, 1973; Gollop, 1979) that the value-added model of production places unnecessary restrictions on the production process, producer behavior and the nature of technical change when applied to an individual industry. Furthermore, Gollop has shown that the rate of industry technical change obtained from a value-added model is greater than the rate derived from a model that treats all inputs symetrically. Hence, the rates of technical change estimated in previous studies by may be biased upward if the restrictions implied by the value-added model are inappropriate.

This paper will examine the analysis of technical change at the industry level -- specifically, the U.S. lumber and wood products industry -- with special attention focused on the role of intermediate inputs. The restrictions introduced by the value-added model will be discussed, and the upward bias in the index of technical change will be demonstrated. The practical significance of this bias will be shown by reformulating the Robinson study using a gross output model which includes an explicit measure of intermediate input.

## Restrictions of the Value-Added Model

Intermediate inputs are defined as purchases of goods and services by one firm or industry from another. Examples include raw materials (including wood) and fuel. When the production accounts of all industries are aggregated at the national level, inter-industry flows of intermediate inputs cancel out: the intermediate input of one industry is the output of some other industry. Therefore, the final output of an entire economy is produced only by the combination of primary inputs (capital and labor), given some technology (National Research Council, 1979).

At the level of an individual firm or industry, however, intermediate inputs are relevant and must be included in the production function. In some industries -- including lumber and wood products -- intermediate inputs represent a larger proportion of the value of output than capital and labor inputs. The data presented in Table 1 indicates that the value share of intermediate inputs has averaged about .55 in the U.S. lumber and wood products industry.

The most general way to include intermediate inputs is to specify an unrestricted industry production function

$$Q = f(K, L, X, t), \qquad (1)$$

where Q is the gross output of the industry, K, L and X are capital, labor and intermediate inputs respectively, and t represents time. Each of these variables except t is an aggregation of specific outputs or inputs. This model of production is referred to as a gross output model.

Alternatively, a value-added industry production function can be written as

(2) $$V = g\ (K, L, t),$$

where V is the value-added by the industry, defined as gross output less intermediate inputs. Implicit in the value-added model is the assumption that the function g is separable from X, i.e., we can write

(3) $$Q = f[g\ (K,L,t),X]$$

This is termed value-added separability. Note that both the gross output model and the value-added model include a measure of intermediate inputs. The difference lies in the way in which intermediate inputs are treated.

Value-added separability implies restrictions on the production process, producer behavior and technical change. With regard to the production process, separability implies that the marginal rate of substitution between capital and labor be independent of the level of intermediate input (Denny and Fuss, 1977). Alternatively, Berndt and Christensen (1973) have shown that value-added separability requires that the Allen partial elasticities of substitution between a factor in the sub-function g and intermediate input be equal for all factors in g (i.e., $\sigma_{kx} = \sigma_{lx}$).

This restriction, then, would effectively rule out the possibility of economies of scale with regard to the intermediate input, an assumption which may be inappropriate. Recent energy innovations in the lumber and wood products industries have most likely resulted in significant economies of scale with respect to fossil fuels -- the primary energy intermediate input over time. In these industries there has been an increasing substitution of wood residues for fossil fuels as an energy source. A firm's stock of internally generated wood residues is directly related to production level. If this source of energy is insufficient to cover needs, additional energy, in the form of wood residues and fossil fuels, must be purchased -- a charge to intermediate input.

The implied restrictions on the production process in the value-added model also leave much to be desired in terms of intuitive appeal, as emphasized by Domar: "a production function is supposed to explain a production process, such as the making of potato chips from potatoes (and other ingredients), labor, and capital. It must take some ingenuity to make potato chips without potatoes," (1967, p. 471).

The value-added model restricts producers from equating the price of intermediate inputs to their value of marginal product (VMP), as required for profit maximization. It is implicitly assumed that the ratio of intermediate inputs to output remains constant, regardless of the price of intermediate inputs. Gollop (1979) provides a compelling intuitive illustration of the restrictions on producer behavior implied by value-added separability:

> A supermarket manager can choose to have his own employee display frozen ice cream products in the frozen foods cabinet or he may contract with the raw materials supplier to have its delivery person display the product. The former is a direct labor cost to the supermarket; the latter is an expense related to intermediate input. Presumably, the store manager makes this choice such that the ratio of marginal products equals the corresponding ratio of factor prices. Imposing value-added separability unnecessarily restricts the production function describing the supermarket's operation, the characterization of the manager's rational behavior, and the necessary conditions for producer equilibrium, (pp. 321-2).

The characterization of technical change is also limited by the value-added model. Hulten (1978) has pointed out that the value-added approach assigns all measured technical progress to capital and labor inputs. Technical change is allowed to affect output only through the function g, and thus intermediate inputs are ruled out as a source of productivity growth. This is a particularly restrictive assumption for some of the lumber and wood products industries where technical change is often embodied in new products which enter into the production process as production inputs, i.e., intermediate inputs. For example, technological changes in forest management -- intensive silvicultural practices, genetic improvements, etc. -- or timber harvesting methods would be manifested in the timber resource.

In a wood resource using industry, the assumption that technical change has not affected the efficiency of intermediate input use is likely to be inappropriate. Several studies have found sawlogs to be the only natural resource commodity exhibiting increasing economic scarcity over the period from 1870 to 1973 (Ruttan and Callaham, 1962; Barnett and Morse, 1963; Manthy, 1977).

In light of this information, one might expect based on induced innovation theory (Binswanger and Ruttan, 1978) that at least some technical change in lumber and wood products has had the effect of conserving the relatively expensive stumpage input. In fact, Stier (1980) found a slight log-saving bias in technical change in the lumber industry (SIC 242). Stier's estimate of this bias is conservative if the declining quality of sawlogs is understated by a log scale. Spelter (1980) has found that saw log overruns have been increasing overtime as average log diameters decline. This suggests that the Stier estimates are in fact biased downward.

Many recent technological advances in forest products have had the effect of increasing lumber and plywood recovery per unit of cubic log input (Haygreen and Bowyer, 1982, p. 442), so it is likely that the wood-saving bias will increase in the future. Therefore, restricting technical change from affecting the efficiency of intermediate input use in the forest products industry is highly questionable.

Upward Bias of the Value-Added Model

It has been shown that value-added separability implies a number of restrictions which may not be appropriate, particularly in the lumber and wood products industry. This section demonstrates that the rate of technical change based on a value-added model of production is necessarily larger than the rate obtained from a gross output model, given consistent data.

The following relationship, based on a value-added model of production, was used by Robinson for measuring neutral technical change:

$$(4) \qquad (\dot{A}/A)^* = (\dot{V}/V) - v_k^* (\dot{K}/K) - v_l^* (\dot{L}/L),$$

where A measures cumulative shifts in the production function over time, V is net output or quantity of value-added, K is capital input, L is labor input, $v_k*$ is capital's share of income, $v_l*$ is labor's share of income, and the dots indicate time derivatives. Note that $v_k* = (p_k K/q*V)$, where $p_k$ is the price of capital inputs and q* is the price of net output, and $v_l* = (p_l L/q*V)$, where $p_l$ is the price of labor inputs. See Robinson (1975, pp. 149-50) for the derivation of this relationship.

An analogous relationship for measuring neutral technical change based on a gross output model is

$$(5) \qquad (\dot{A}/A) = (\dot{Q}/Q) - v_k(\dot{K}/K) - v_l(\dot{L}/L) - v_x(\dot{X}/X),$$

where Q is gross output of the industry, X is intermediate input, and $v_x$ is intermediate input's share of income. Note that $v_x = (p_x X/qQ)$, where $p_x$ is the price of intermediate input and q is the price of output, and $v_k$, $v_l$ are defined analogously to $v_x$. See Appendix A for the derivation of this expression.

Proof that the industry rate of neutral technical change derived from the value-added production function is greater than the corresponding rate derived from the gross output model follows from a comparison of $(\dot{A}/A)$ and $(\dot{A}/A)*$. Following Gollop's (1979) reasoning for a more general case, the definition of the value of an industry's net output or value-added is

$$(6) \qquad q*V = qQ - p_x X.$$

Totally differentiating (6) with respect to time, dividing both sides by $q^*V$ and simplifying yields

$$(7) \qquad (\dot{V}/V) = (qQ/q^*V)\,(\dot{Q}/Q) - (p_x X/q^*V)\,(\dot{X}/X).$$

Substituting (7) into (4), we get:

$$(8) \qquad (\dot{A}/A)^* = (qQ/q^*V)\,(\dot{Q}/Q) - (p_x X/q^*V)\,(\dot{X}/X) - (p_k K/q^*V)\,(\dot{K}/K) - (p_1 L/q^*V)\,(\dot{L}/L).$$

Note that if we multiply (8) by $(q^*V/qQ)$, we obtain (5). Therefore,

$$(9) \qquad (\dot{A}/A)^* = (qQ/q^*V)\,(\dot{A}/A) = (qQ/(qQ - p_x X))\,(\dot{A}/A).$$

Since the ratio of value of gross output to the value of net output must be greater than one, i.e.,

$$(qQ/(qQ - p_x X)) > 1,$$

it follows that $(\dot{A}/A)^* > (\dot{A}/A)$. Therefore, the rate of technical change estimated from the value-added model is greater than the corresponding rate estimated from the gross output model. Notice that $(\dot{A}/A)$ is equal to $(\dot{A}/A)^*$ less an amount proportional to the industry's share of intermediate input purchases in its total factor payments:

$$(10) \qquad (\dot{A}/A) = (1 - (p_x X/qQ))\,(\dot{A}/A)^* = (\dot{A}/A)^* - v_x\,(\dot{A}/A)^*.$$

Thus, the larger the income share of intermediate inputs in an industry, the larger the gap between the two measures of technical change will be. When the prices of intermediate inputs such as stumpage and energy are rising, an index of technical change based on the value-added model will rise relative to an index based on the gross output model.

## An Empirical Example

What is the practical significance of the upward bias in an index of technical change introduced by the value-added model? In order to address this question, Robinson's index was recalculated and compared to an index based on the gross output model. These indexes were obtained by first calculating $(\dot{A}/A)$ and $(\dot{A}/A)^*$, and then setting A(1) equal to one and evaluating the expression

$$A(t+1) = A(t)\,[1 + (\dot{A}/A)], \qquad t = 1, 2, \ldots, T$$

for the index based on the gross output model, and

$$A(t+1) = A(t)\,[1 + (\dot{A}/A)^*], \qquad t = 1, 2, \ldots, T$$

for the index based on the value-added model.

A meaningful comparison requires that the data employed in each index are consistent. Robinson's data are flawed in several respects (see, pp. 151-52), so data on capital and labor inputs reported in Greber and White (1982) were used. Unpublished data collected by the Bureau of Economic Analysis (1974) on intermediate input, value added and gross output (SIC 24) were also used. This is the same intermediate input data used by Gollop and Jorgenson (1980) in their mammoth study of U.S. productivity growth by industry. The complete data set is presented in Table 1.

The calculated indexes are shown in Table 2 and Figure 1. It is clear that the large income share of intermediate inputs in the lumber and wood products industry creates a significant gap between the two measures of productivity. This gap widens when the importance of intermediate inputs in production is rising.

Note in Figure 1 that the value-added index A(t)* exhibits a sawtooth pattern -- peaks and valleys are more pronounced than in the gross output index A(t). A similar pattern was observed by Solow (1957, p. 316). The value-added index thus exagerates both increases and decreases in total factor productivity due to its treatment of intermediate inputs.

## Concluding Remarks

Much of the early empirical analysis of productivity and technical change was done at the economy-wide level, and thus it was reasonable to work with a value-added model of production. The application of this same approach to individual industries or sectors has been common (e.g., Lydall, 1968; Doutriaux and Zind, 1976; Lianos, 1976; Batavia, 1979), often due to a lack of data on intermediate inputs. But the restrictive assumptions of the value-added model have come under increasing attack in recent years.

These assumptions are particularly suspect in a wood resource using industry. As noted recently by the National Research Council (1979),

> ... when the price of some materials rise sharply, as occurred recently for wood and more dramatically for coal and oil, industries that use these materials substitute cheaper materials if possible or they cut down on their use by reducing waste (which often involves substituting capital or labor). The probable result of these economizing actions

> is that the ratio of the value of intermediate inputs to gross output changes (p. 141).

In wood using industries, rising real stumpage prices have induced producers to reduce intermediate input relative to output by utilizing as materials or fuel residuals that were formerly discarded, and by adopting new production technologies that reduce wood requirements (Myers and Nakamura, 1979). Thus, the assumptions of the value-added model are clearly violated: the ratio of intermediate input to output is not constant, and technical change does affect the efficiency of intermediate input utilization. It is therefore concluded that the gross output approach is more appropriate for analyzing productivity and technical change in the lumber and wood products industry.

Table 1. Data series for the U.S. Lumber and Wood Products Industry, (SIC 24), 1951-1973 (all dollar amounts in millions of 1958 dollars).

| Year | K[a/] | $\dot{K}/K$ | L[b/] | $\dot{L}/L$ | X[c/] | $\dot{X}/X$ |
|---|---|---|---|---|---|---|
| 1951 | 5,297.25 | | 842 | | 3,589 | |
| 1952 | 5,468.99 | .0324 | 783 | -.0701 | 3,620 | .0086 |
| 1953 | 5,555.67 | .0158 | 751 | -.0409 | 3,773 | .0423 |
| 1954 | 5,657.06 | .0182 | 683 | -.0905 | 3,719 | -.0143 |
| 1955 | 5,817.23 | .0283 | 719 | .0527 | 4,228 | .1369 |
| 1956 | 6,072.51 | .0439 | 706 | -.0181 | 4,227 | -.0002 |
| 1957 | 6,060.24 | -.0020 | 631 | -.1062 | 3,983 | -.0577 |
| 1958 | 6,198.63 | .0228 | 583 | -.0761 | 4,360 | .0947 |
| 1959 | 6,231.67 | .0053 | 623 | .0686 | 4,784 | .0972 |
| 1960 | 6,401.80 | .0273 | 601 | -.0353 | 4,832 | .0100 |
| 1961 | 6,451.67 | .0078 | 557 | -.0732 | 4,891 | .0121 |
| 1962 | 6,531.77 | .0124 | 566 | .0162 | 5,321 | .0879 |
| 1963 | 6,652.68 | .0185 | 567 | .0018 | 5,558 | .0445 |
| 1964 | 6,728.57 | .0114 | 582 | .0265 | 5,361 | -.0354 |
| 1965 | 6,817.62 | .0132 | 595 | .0223 | 5,429 | .0127 |
| 1966 | 7,014.41 | .0289 | 603 | .0134 | 5,313 | -.0217 |
| 1967 | 7,071.61 | .0082 | 581 | -.0365 | 5,500 | .0352 |
| 1968 | 7,110.31 | .0055 | 587 | .0103 | 5,463 | -.0067 |
| 1969 | 7,292.76 | .0257 | 588 | .0017 | 5,492 | .0055 |
| 1970 | 7,435.53 | .0196 | 559 | -.0493 | 5,633 | .0257 |
| 1971 | 7,497.84 | .0084 | 573 | .0250 | 5,560 | -.0130 |
| 1972 | 7,610.20 | .0150 | 603 | .0523 | 6,673 | .2002 |
| 1973 | 7,588.11 | -.0029 | 623 | .0332 | 6,434 | -.0358 |

[a/] Capital input. Source: Greber and White, 1982.

[b/] Labor input, thousands of full-time equivalent employees.
Source: National Income and Products Accounts of the United States, 1929,1974 (reported in Greber and White, 1982).

[c/] Cost of materials. Source: Bureau of Economic Analysis (1974).

Table 1. (continued)

| Year | $Q^{\underline{d}/}$ | $\dot{Q}/Q$ | $V^{\underline{e}/}$ | $\dot{V}/V$ |
|---|---|---|---|---|
| 1951 | 6,948 | | 3,460 | |
| 1952 | 6,962 | .0020 | 3,438 | -.0064 |
| 1953 | 7,040 | .0112 | 3,333 | -.0305 |
| 1954 | 6,711 | -.0467 | 3,031 | -.0906 |
| 1955 | 7,659 | .1412 | 3,478 | .1475 |
| 1956 | 7,717 | .0076 | 3,544 | .0190 |
| 1957 | 7,178 | -.0698 | 3,231 | -.0883 |
| 1958 | 7,525 | .0483 | 3,165 | -.0204 |
| 1959 | 8,215 | .0917 | 3,415 | .0790 |
| 1960 | 8,043 | -.0209 | 3,157 | -.0755 |
| 1961 | 8,001 | -.0052 | 3,031 | -.0399 |
| 1962 | 8,432 | .0539 | 2,992 | -.0129 |
| 1963 | 9,520 | .1290 | 3,952 | .3209 |
| 1964 | 10,010 | .0515 | 4,746 | .2009 |
| 1965 | 10,190 | .0180 | 4,865 | .0251 |
| 1966 | 10,223 | .0032 | 5,048 | .0376 |
| 1967 | 10,779 | .0544 | 5,450 | .0796 |
| 1968 | 11,046 | .0248 | 5,800 | .0642 |
| 1969 | 10,758 | -.0261 | 5,445 | -.0612 |
| 1970 | 11,030 | .0253 | 5,567 | .0224 |
| 1971 | 11,017 | -.0012 | 5,593 | .0047 |
| 1972 | 13,132 | .1920 | 6,682 | .1947 |
| 1973 | 12,702 | -.0327 | 6,483 | -.0298 |

d/ Value of production. Source: Bureau of Economic Analysis (1974).

e/ Value-added. Source: Bureau of Economic Analysis (1974).

Table 1. (continued).

| Year | $v_k$ | $v_1$ | $v_x$ | $v_k$* | $v_1$* |
|---|---|---|---|---|---|
| 1951 | .1766 | .3227 | .5007 | .3536 | .6464 |
| 1952 | .1548 | .3312 | .5140 | .3184 | .6816 |
| 1953 | .1548 | .3255 | .5197 | .3222 | .6778 |
| 1954 | .1336 | .3292 | .5372 | .2887 | .7113 |
| 1955 | .1434 | .3123 | .5443 | .3146 | .6854 |
| 1956 | .1465 | .3132 | .5403 | .3187 | .6813 |
| 1957 | .1261 | .3216 | .5523 | .2816 | .7184 |
| 1958 | .1171 | .3107 | .5722 | .2613 | .7387 |
| 1959 | .1189 | .3046 | .5765 | .2807 | .7193 |
| 1960 | .1017 | .3155 | .5828 | .2437 | .7563 |
| 1961 | .1052 | .3153 | .5795 | .2502 | .7498 |
| 1962 | .1063 | .3153 | .5784 | .2494 | .7506 |
| 1963 | .1266 | .3164 | .5570 | .3287 | .6713 |
| 1964 | .1425 | .3018 | .5557 | .3091 | .6909 |
| 1965 | .1292 | .3070 | .5638 | .2840 | .7160 |
| 1966 | .1288 | .3139 | .5573 | .2910 | .7090 |
| 1967 | .1373 | .3069 | .5558 | .3093 | .6907 |
| 1968 | .1631 | .2963 | .5406 | .3551 | .6449 |
| 1969 | .1643 | .2912 | .5445 | .3606 | .6394 |
| 1970 | .1307 | .3211 | .5482 | .2892 | .7108 |
| 1971 | .1333 | .3124 | .5543 | .2990 | .7010 |
| 1972 | .1825 | .2621 | .5554 | .4106 | .5894 |
| 1973 | .2014 | .2471 | .5515 | .4490 | .5510 |

Definitions provided within the text.

Table 2. Residuals and indexes of technical change for the gross output and value-added models (definitions provided within the text).

| Year | $\dot{A}/A$ | $(\dot{A}/A)*$ | A(t) | A(t)* |
|---|---|---|---|---|
| 1951 | | | 1.0000 | 1.0000 |
| | .0158 | .0311 | | |
| 1952 | | | 1.0158 | 1.0311 |
| | .0001 | -.0079 | | |
| 1953 | | | 1.0159 | 1.0311 |
| | -.0117 | -.0315 | | |
| 1954 | | | 1.0040 | .9908 |
| | .0462 | .1025 | | |
| 1955 | | | 1.0504 | 1.0924 |
| | .0069 | .0173 | | |
| 1956 | | | 1.0576 | 1.1113 |
| | -.0035 | -.0117 | | |
| 1957 | | | 1.0539 | 1.0983 |
| | .0151 | .0299 | | |
| 1958 | | | 1.0698 | 1.1311 |
| | .0141 | .0282 | | |
| 1959 | | | 1.0849 | 1.1630 |
| | -.0184 | -.0555 | | |
| 1960 | | | 1.0649 | 1.0985 |
| | .0100 | .0130 | | |
| 1961 | | | 1.0755 | 1.1128 |
| | -.0034 | -.0282 | | |
| 1962 | | | 1.0718 | 1.0814 |
| | .1013 | .3136 | | |
| 1963 | | | 1.1804 | 1.4205 |
| | .0615 | .1791 | | |
| 1964 | | | 1.2530 | 1.6749 |
| | .0023 | .0054 | | |
| 1965 | | | 1.2559 | 1.6839 |
| | .0074 | .0197 | | |
| 1966 | | | 1.2652 | 1.7171 |
| | .0449 | .1023 | | |
| 1967 | | | 1.3220 | 1.8928 |
| | .0164 | .0556 | | |
| 1968 | | | 1.3437 | 1.9980 |
| | -.0337 | -.0716 | | |
| 1969 | | | 1.2984 | 1.8549 |
| | .0245 | .0518 | | |
| 1970 | | | 1.3302 | 1.9510 |
| | -.0029 | -.0153 | | |
| 1971 | | | 1.3263 | 1.9211 |
| | .0644 | .1577 | | |
| 1972 | | | 1.4117 | 2.2241 |
| | -.0206 | -.0494 | | |
| 1973 | | | 1.3826 | 2.1142 |

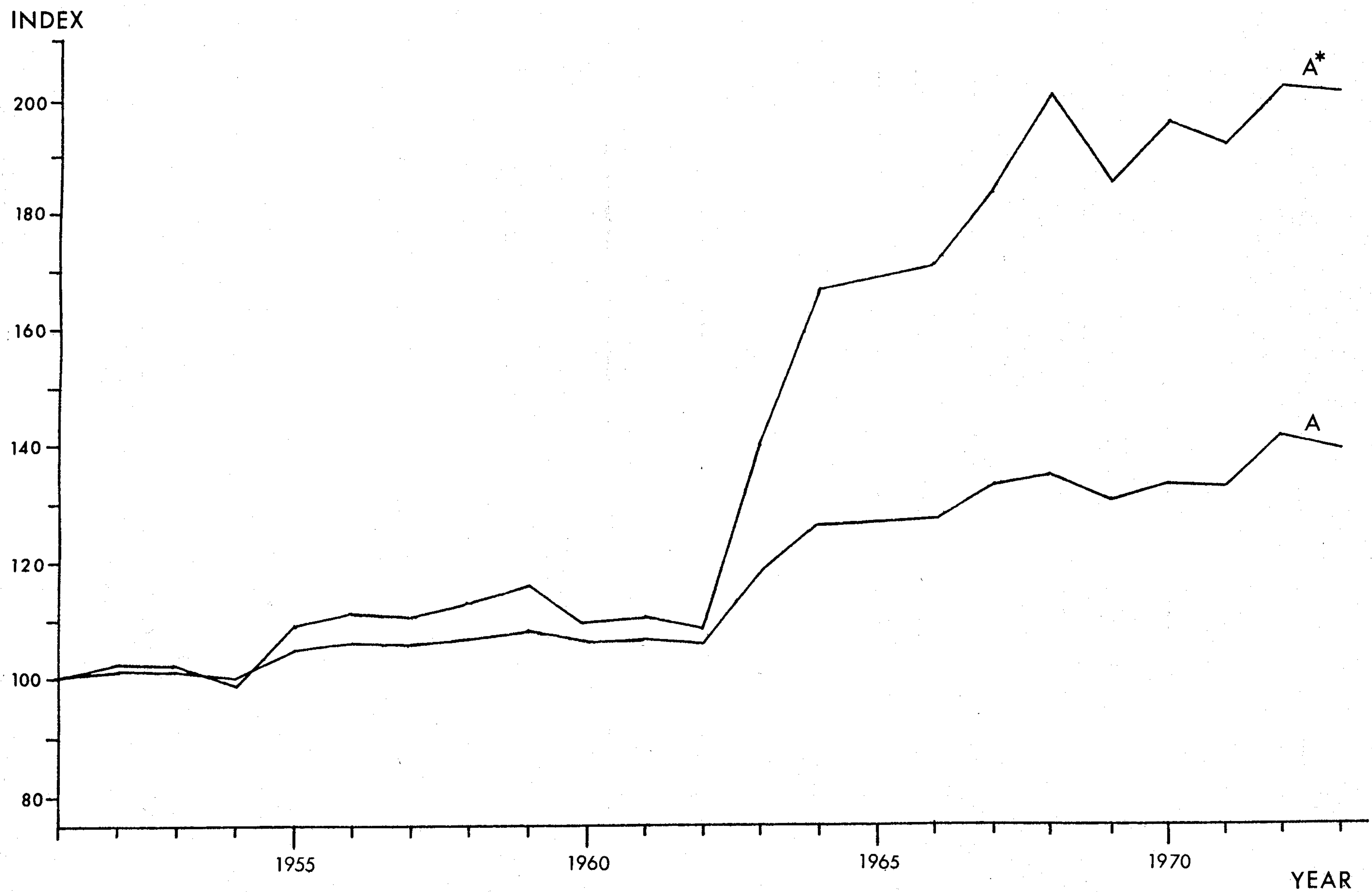


Figure 1. Indexes of technical change for the U.S. lumber and wood products industry based on value added (A*) and gross output (A) models of production, 1951-1973, (1951=100).

## Appendix A

Derivation of the relationship used to estimate the rate of neutral technical change based on a gross output production function is presented in this appendix. This approach is an extension of Solow's (1957) "residual" method, in which changes in productivity are attributed to changes in output which are not explained by changes in inputs. The extension is the explicit inclusion of intermediate inputs, in addition to capital and labor.

The unrestricted industry production function can be written as

$$Q = f(K, L, X, t), \tag{1}$$

where Q is gross output of the industry, K, L and X are capital, labor and intermediate inputs respectively and t is time. If technical change is assumed to be neutral, the production function takes the form

$$Q = A(t)f\ (K, L, X), \tag{2}$$

where A(t) measures the cumulative shifts in the production function due to technical change over time. Totally differentiating (2) with respect to time, dividing both sides by Q and simplifying yields

$$(\dot{Q}/Q) = (\dot{A}/A) + A(\partial f/\partial K)\ (\dot{K}/Q) + A(\partial f/\partial L)\ (\dot{L}/Q) + A(\partial f/\partial X)\ (\dot{X}/Q), \tag{3}$$

where the dots indicate time derivatives. Since $(\partial Q/\partial K) = A(\partial f/\partial K)$, $(\partial Q/\partial L) = A(\partial f/\partial L)$ and $(\partial Q/\partial X) = A(\partial f/\partial X)$, equation (3) may be written as

$$(\dot{Q}/Q) = (\dot{A}/A) + (\partial Q/\partial K)\ (K/Q)\ (\dot{K}/K) + (\partial Q/\partial L)\ (L/Q)\ (\dot{L}/L) + (\partial Q/\partial X)\ (X/Q)\ (\dot{X}/X). \tag{4}$$

If factors of production are paid their marginal products and the production function is assumed to be homogeneous of degree one in inputs, then

(5) $\sigma_k = (\partial Q/\partial K)\ (K/Q) = v_k$

(6) $\sigma_l = (\partial Q/\partial L)\ (L/Q) = v_l$

(7) $\sigma_x = (\partial Q/\partial X)\ (X/Q) = v_x$

(8) $v_k + v_l + v_x = 1$

where $\sigma_k$, $\sigma_l$ and $\sigma_x$ are the elasticities of output with respect to capital, labor and intermediate input respectively, and $v_k$, $v_l$ and $v_x$ are the respective value shares of inputs. Substituting (5), (6) and (7) into (4) and rearranging terms we obtain

$$(9) \qquad (\dot{A}/A) = (\dot{Q}/Q) - v_k\ (\dot{K}/K) - v_l\ (\dot{L}/L) - v_x\ (\dot{X}/X)$$

This expression can be calculated using discrete approximations of the time derivatives. The index of technical change is then obtained by setting A(1) equal to one and evaluating the expression

$$(10) \qquad A(t+1) = A(t)\ [1 + (\dot{A}(t)/A(t))], \qquad t = 1, 2, \ldots, T$$

Literature Cited

Barnett, Harold J. and Chandler Morse. 1963. Scarcity and Growth: The Economics of Natural Resource Availability. Baltimore: The Johns Hopkins Press for Resources for the Future.

Batavia, Bala. 1979. The estimation of biased technical efficiency in the U.S. textile industry, 1949-1974. Southern Economic Journal 45(4):1091-1103.

Berndt, Ernst and Laurits R. Christensen. 1973. The internal structure of functional relationships: separability, substitution, and aggregation. The Review of Economic Studies 40(3):403-410.

Binswanger, Hans P. 1974. The measurement of technical change with many factors of production. American Economic Review 64(6):964-76. December.

Binswanger, Hans P. and Vernon W. Ruttan (eds.). 1978. Induced Innovation: Technology, Institutions, and Development. Baltimore: The Johns Hopkins University Press.

Bureau of Economic Analysis. 1974. Gross national product by industry, work file 1205-04-06. Washington, D.C.: U.S. Department of Commerce.

Denny, Michael and Melvyn Fuss. 1977. The use of approximation analysis to test for separability and the existence of consistent aggregates. American Economic Review 67(3):404-18. June.

Domar, E. D. 1967. Comment. in M. Brown (ed.), Theory and Empirical Analysis of Production. National Bureau of Economic Research. pp. 471-72.

Doutriaux, J. and R. G. Zind. 1976. Factor input efficiency and technological bias with application to U.S. agriculture. Review of Economics and Statistics 58(3):380-82. August.

Gollop, Frank M. 1979. Accounting for intermediate input: the link between sectoral and aggregate measures of productivity growth. In: Measurement and Interpretation of Productivity. Panel to Review Productivity Statistics, National Research Council. Washington, D.C.: National Academy of Sciences. pp. 318-333.

Gollop, Frank M. and Dale W. Jorgenson. 1980. U.S. productivity growth by industry, 1947-73. pp. 17-124 in: J. W. Kendrick and B. N. Vacarra (eds.), New Developments in Productivity Measurement and Analysis. National Bureau of Economic Research, Studies in Income and Wealth, Vol. 44. Chicago: University of Chicago Press.

Greber, Brian J. and David E. White. 1982. Technical change and productivity growth in the lumber and wood products industry. Forest Science 28(1):135-147.

Haygreen, John G. and Jim L. Bowyer. 1982. Forest Products and Wood Science. Ames, Iowa: Iowa State University Press.

Hulten, Charles R. 1978. Growth accounting with intermediate inputs. Review of Economic Studies 45(3):511-518. October.

Lianos, T. P. 1976. Factor augmentation in Greek manufacturing, 1958-1969. European Economic Review 8(1):15-31. June.

Lydall, H. F. 1968. Technical progress in Australian manufacturing. The Economic Journal 78(312):807-826. December.

Manning, G. H. 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.

Manthy, Robert S. 1977. Scarcity, renewability, and forest policy. Journal of Forestry 75(4):201-205. April.

Myers, John G. and Leonard Nakamura. 1979. Data adequacy for productivity analysis: a case study of the primary paper industry. In: Measurement and Interpretation of Productivity. Panel to Review Productivity Statistics, National Research Council. Washington, D.C.: National Academy of Sciences. pp. 391-422.

National Research Council. 1979. Measurement and Interpretation of Productivity. Panel to Review Productivity Statistics. Washington, D.C.: National Academy of Sciences.

Robinson, Vernon L. 1975. An estimate of technological progress in the lumber and wood-products industry. Forest Science 21(2):149-154.

Ruttan, V. W. and J. C. Callaham. 1962. Resource inputs and output growth: Comparisons between agriculture and forestry. Forest Science 8(1):68-82. March.

Sato, Ryuzo. 1970. The estimation of biased technical progress and the production function. International Economic Review 11(2):179-208. June.

Solow, Robert M. 1957. Technical change and the aggregate production function. Review of Economics and Statistics 39(3):312-320. August.

Spelter, H. 1980. Trends in softwood sawmill overruns and their impact on stumpage prices. Forest Products Journal 30(9):21-24.

Stier, J. C. 1980a. Estimating the production technology in the U.S. forest products industries. Forest Science 26(3):471-482.

Stier, J. C. 1980b. Technical adaptation to resource scarcity in the U.S. lumber industry. Western Journal of Agricultural Economics. 5(2):165-75. December.