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Title: THE EFFICIENCY OF THE PARTICLEBOARD INDUSTRY OF OREGON

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This study consists of an evaluation of economic efficiency in the particleboard industry of Oregon between 1958 and 1970. Measures of efficiency included aggregate capital and labor use in the production process, relative economies of scale, and relative technological efficiencies of individual particleboard plants.

The rapid growth of the industry in terms of production, technological changes, and a trend toward larger plant operations raised the question of whether the industry was efficiently using capital and labor inputs in its production of particleboard. The measurement of input efficiency is important because it indicates to industry managers the extent to which inputs are contributing to an optimum least-cost condition.

The aggregate production function, utilizing the Cobb-Douglas model which expresses the relationship between output and production inputs, was used as the analytical framework for evaluating input efficiency.

Cross-section and time series data were used to determine three indicators of production input efficiency: estimated elasticity of production for each input, estimated mean marginal productivity for each input, and returns to scale in the production process. Economies of scale and individual plant efficiency were then further analyzed to determine if operating efficiencies differed between plants.

Empirical results of production function analysis indicated constant returns to scale for capital and labor from 1958 to 1970, implying that output increased in direct relationship to increases in all inputs. Inefficiencies existed in the input market as capital and labor were not paid proportionate to their contribution to production from 1962 to 1970.

Economies of scale results indicated that plants with outputs exceeding 80 million square feet annually were operating at relatively lower average costs than were plants with less annual output. This implied that plants with smaller outputs were relatively less efficient in their scale of operation and that economies of large scale might be effective in lowering average cost.

Relative technological differences between individual plants implied that larger plants were more efficient in their use of capital and labor production inputs between 1960 and 1970. It was hypothesized that large scale marketing and distribution systems associated with the larger plants were conducive to near-capacity levels of production, thus permitting relatively more efficient use of production inputs.

The evaluation of particleboard industry efficiency indicated that the industry was technically efficient in its use of production inputs in the production process. The criterion for this judgement was the condition of constant returns to scale, the implication being that inputs were contributing proportionately to output. However, the economic evaluation of production input use indicated that both capital and labor were contributing more to output (value of marginal product) than they were receiving for their services. Consequently, the point of optimum least-cost was not being utilized by the industry. The practical implication would be to increase the use of capital and labor through plant expansion or new facility construction so as to equate cost and input contribution to production.

Economic Efficiency of the Particleboard Industry of Oregon

by

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CHAPTER I

INTRODUCTION TO ECONOMIC EFFICIENCY EVALUATION

This study presents an economic evaluation of production input use and relative plant efficiency in the particleboard industry of Oregon. As the industry continues to increase in size, operating technologies become more expensive and complex, and producers are faced with increasing competition from other producing areas, the need for economic information to aid decision makers concerned with minimum operating costs mounts. This study applied economic theory to the particleboard industry to measure efficiency of capital and labor production inputs and analyzed the relative efficiency performance of individual plants.

Objective

The objective of this study was to analyze and evaluate the efficiency of capital and labor in the particleboard industry of Oregon between 1958 and 1970. The analysis utilized a production function approach incorporating both cross-section and time series data. In addition, an analysis was performed to determine the efficiency of input resource allocation by individual plants.

Issues of Concern

The major concerns in the study were: (1) The manner in which capital and labor were employed and compensated relative to their contribution to production; (2) The extent to which differences existed in the allocation of capital and labor among different sized plants within the industry.

Resource Input Efficiency

Efficiency of resource input use in production is important in a social context because of the basic economic criterion that consumers prefer more goods to less within a constraint of limited resources. In order to minimize the possibility of undue waste of these resources, the production process must be organized in such a way that input resource allocation contributes optimally to desired social and private goals. The organization of production in a market economy requires: (1) An understanding of how resources are allocated among specific industries. The price system tends to direct resources to those industries where consumer demand is strong enough to make production profitable and simultaneously deprives unprofitable industries of scarce resources. (2) An identification of which specific firms should do the producing in each industry, and (3) An understanding of what combination of resource inputs, within given technological constraints, each plant within an industry should employ. In a competitive market economy, those plants which do the producing are those which are willing, and should be able, to employ the most economically efficient techniques of production.

Economic efficiency is largely dependent upon two factors: (1) available technology, that is, the alternative combinations of resource inputs that will produce the desired output, and (2) the prices at which the needed resource inputs can be obtained. The combination of resource inputs which are most efficient economically depends not only upon engineering data provided by available technology, but also upon the relative worth of resource inputs as measured by their market prices. Thus, a technique requiring a low level of physical inputs to produce a given output may be inefficient economically if the required inputs are priced highly in the market place.

Theory of Production Economics

The theory of production economics provides economists with the analysis criterion by which given amounts of technical knowledge, production effort, and resource inputs can be combined within the framework of a production function. The production function quantitatively relates production output with resource inputs; providing decision makers with data by which to judge the contribution of respective inputs to production output. This provides one of two sets of information needed for choice and decision making. The second set is price data which provide economic criteria for decision makers, permitting them to evaluate the cost of the input. The two sets of information provide decision makers with a criterion base to guide them in the allocation of inputs: an input's contribution to production is equal to its cost. This point is the efficiently optimum or least cost condition of production input use.

The production function provides three indicators of economic efficiency. The efficiency indicators related to individual production inputs are estimated production elasticities and estimated mean marginal productivities. The efficiency indicator related to all production inputs under study is returns to scale in the production process.

Although production theory is generally associated with analysis and decision making at the firm level, it has been used in several studies of industries (Lomax, 1950; Komiya, 1957; Hildebrand and Liu, 1965). The application of production theory in forest products is an appropriate undertaking, since a literature search reveals but few references of this nature for forest products and none for the particleboard industry of Oregon (Mead, 1966; Dobie, 1968).

Economic Status of Oregon's Particleboard Industry

The particleboard industry of Oregon plays an important role in the overall forest products industry of the state since it is dependent upon wood residues from lumber and plywood processing as its principle source of raw material. The abundance of these residues, which once were disposed of as waste in wigwam burners, has been a factor in the rapid growth of an industry that contributes to the state's economy by providing jobs, income, and export sales to other regions in the United States. In 1970, the latest year in which complete census data were available, the value of Oregon's particleboard shipments was $70.8 million. The major share of these shipments was sold outside Oregon. Employment in the industry in 1970 totaled 1363 workers. An important contribution of the particleboard industry to resource conservation is the fact that the production of particleboard is accomplished without having to rely upon the harvesting of any additional timber beyond that required for lumber and plywood production.

The particleboard industry of Oregon has experienced a period of rapid growth since its inception in 1955. It has grown from an initial size of five plants with a production of 12.2 million square feet (3/4-inch basis) in 1955 to 14 plants with a combined production of 737.8 million square feet in 1970. This growth has established Oregon as the leading state in the production of particleboard, a position it has held over California, the second largest producer, since 1958.

The future growth and stability of Oregon's particleboard industry depends upon a number of factors. These include competition for residues with the pulp and paper industry and with hardboard and insulationboard producers; transportation cost differentials with respect to other producing regions located in closer proximity to major markets; and growth and stability of the housing and furniture industries. Other factors include competition for residues among existing and potential particleboard plants, continued favorable pricing of production inputs for particleboard, and healthy conditions in Oregon's industries which supply residues for particleboard production. Furthermore, realization of future growth potential depends upon increased per capita consumption and favorable economic conditions. In addition, particleboard must be produced efficiently: first, to assure growth of market shares in competition with wood and non-wood products, and second, to provide an adequate level of earnings to encourage continued investment in increased plant capacity and new production technology. This study was undertaken to aid industry people in making those decisions conducive to the future growth and stability of the industry in Oregon.

Plan of Study

Chapter II presents an overview of the particleboard industry in a national context reviewing plant capacity, production processes, particleboard use, and plant capacity utilization.

Chapter III analyzes some of the historic reasons for the establishment of the particleboard industry in Oregon and reviews changes that occurred between 1955 and 1970 relative to production and the use of capital, labor, wood, and resin adhesive inputs. A comparison is also presented between the particleboard industry and the major forest products industries, softwood lumber and plywood.

Chapter IV discusses the methodology underlying production function analyses and the information derived from production function analysis which can be used to measure economic efficiency of resource use.

Chapter V analyzes the technical-economic relations between particleboard output and production inputs when a single factor input is used.

Chapter VI presents the analysis of aggregate production function analyses for the particleboard industry of Oregon between 1958 and 1970, utilizing both cross-section and time series data. Also discussed are efficiency comparisons for capital and labor inputs from 1962 to 1970, years in which relevant particleboard price data were available.

Chapter VII presents a discussion of economies of scale for the particleboard industry and derives an estimated long run average cost curve for the period 1955 to 1970. Also discussed are factors that may have led to the occurrence of economies of scale.

Chapter VIII is concerned with the derivation of total and technical economic efficiencies for individual particleboard plants.

Chapter IX discusses the results of the study and presents suggestions for additional research investigation.

CHAPTER II

CHARACTERISTICS OF THE UNITED STATES PARTICLEBOARD INDUSTRY

Regional Structure of Industry

Particleboard, which was first produced commercially in the United States in 1945, has experienced sustained growth over the past two decades principally due to two factors: (1) the ingenuity of industry personnel in production and marketing methodology, and (2) the availability of large amounts of low cost wood residues as by-products from the conventional conversion of logs to lumber and plywood.

In recent years a wide variety of particleboard panel products has been developed. Several methods of manufacture are used and many types of resin adhesives are available for bonding the individual particles together under various operating conditions. Control of particle geometry and particle distribution within the mat matrix contributes to a wide range of particleboard physical and surface properties. It is now possible to specifically engineer certain properties into board products so that particleboard can fulfill specific end use requirements.

During 1955, 25 plants in the United States were producing particleboard, 12 in the South, 7 in the West, and 6 in the North as shown in Table 2.1. By the end of 1970, the total number of plants

Table 2. 1. Number of particleboard plants in the United States, by region, 1955-1970.

Year	Total no.	Plants starting production	Plants ceasing production	Total no.	Plants starting production	Plants ceasing production
	All regions			North		
1955	25	11	0	6	2	0
1956	36	11	4	8	1	1
1957	43	7	1	8	2	0
1958	49	2	0	10	0	0
1959	51	5	3	10	1	1
1960	53	2	2	10	1	1
1961	53	1	3	10	0	1
1962	51	0	1	9	0	0
1963	50	3	1	9	1	1
1964	52	7	1	9	2	0
1965	58	3	6	11	1	3
1966	55	6	3	9	2	0
1967	55	2	2	11	2	0
1968	59	5	1	10	0	1
1969	63	4	0	11	1	0
1970	67	-	-	12	-	-
	South			West		
1955	12	7	0	7	2	0
1956	19	5	1	9	5	2
1957	23	3	1	12	2	0
1958	25	1	0	14	1	0
1959	26	2	0	15	2	2
1960	28	0	1	15	1	0
1961	27	0	2	16	1	0
1962	25	0	0	17	0	1
1963	25	1	0	16	1	0
1964	26	1	1	17	4	0
1965	26	1	1	21	2	2
1966	25	4	0	21	0	3
1967	25	0	0	19	0	2
1968	28	3	0	21	2	0
1969	30	2	0	22	1	0
1970	32	-	-	23	-	-

Source: Data collected from annual issues of Timberman and Forest Industries trade publications.

had increased to 67--32 in the South, 23 in the West, and 12 in the North. Industry expansion was concentrated in two periods: 1955-1958 and 1965-1970. During the first period, 29 new plants were constructed, primarily in the South and West. During this period, total plant capacity increased three-fold. Following this initial period of rapid growth, the industry entered a period of slow expansion in which the number of plants ceasing production nearly equalled the number constructed.

The period 1965-1970 was another expansive era in new plant construction. Twenty-seven plants were added during this period which increased plant capacity three times what it had been in 1965.

Particleboard plant capacity, traditionally the amount of 3/4-inch panel that can be produced with continuous shifts in 300 operating days, increased approximately 2.9 billion square feet (3/4-inch basis) between 1955 and 1970. Capacity increased nearly 20-, 15-, and 23-fold in the West, South, and North respectively. Two-thirds of the increase in particleboard plant capacity from 1955 to 1970 came from new plants, the balance from expansion of existing plants.

During the first period of extensive plant construction, 1955-1958, new plant capacity was concentrated in the South, with smaller amounts in the West and North. During the following six-year period of slow growth, most of the new plant capacity was added in the West. However, much of the capacity increase during this period for each of the three regions came from existing plant expansions.

During the period 1965-1970, nearly two-thirds of capacity increases was from new plants and the balance from expansion of existing ones. Contributing to the large scale capacity increases were several new Western mills that produced from 60 to 100 million square feet per year.

Prior to 1962, plant capacity in the South was roughly the same as in the West and was increasing at approximately the same rate. Most of the capacity increases from 1962 to 1970 have been in the West, although gains have been substantial in the South and somewhat less in the North. Plant capacity distribution by region at the end of 1955 and 1970 is shown in the following list:

Region	1955 Capacity		1970 Capacity	
	MM sq. ft. 3/4-inch basis	%	MM sq. ft. 3/4-inch basis	%
North	19	11	438	15
South	75	46	1152	40
West	70	43	1379	45
Total U. S.	164	100	2969	100

The average capacity of particleboard plants that began production after 1955 was 19 million square feet per year. During the period 1955-1958 average plant size was 7.6 million square feet. From 1959-1965, the capacity of a typical new particleboard plant had increased to 25 million square feet and from 1966-1970, average capacity was 36 million square feet.

Plants discontinuing production have generally been small capacity mills. Average size of the 28 discontinued plants from 1955 through 1970 was 10 million square feet and many of these produced less than two million feet annually.

Plants in the West have consistently been larger capacity mills than those in the South and North. In 1970, average capacity of Western plants was 60 million square feet as compared to 36 million in the South and 37 million in the North.

Extrusion Process

In 1970, only eight particleboard plants used the extrusion process, a process in which the particle-resin mixture is forced by pressure through a die composed of rigidly mounted steel platens to form the pressed board. Only one extrusion plant has been constructed since 1965. Extruded particleboard, principally used as furniture corestock, is subsequently faced with veneer, vinyl, or other materials for decorating effects. Each of the existing extrusion plants are captive operations owned by furniture companies'and account for approximately two percent of total particleboard production.

Platen Process

The so-called platen process, where resin coated wood particles are deposited as mats on movable cauls and then pressed into panels in a single to multi-platen press, is used almost exclusively in new plants. Mat-formed panels are generally adaptable to a wider variety of end uses than are those produced by the extrusion process. The platen process also lends itself to the production of special grades and board densities and to rigid quality controls.

In recent years an increasing number of plants have been selling cut-to-size pieces and partially manufactured parts. In 1970, at least 47 plants had cut-up facilities and 30 of these shipped only cut-to-size products (U. S. Industrial Outlook, 1972).

Particleboard Use

In 1955, 15 percent of installed capacity was in captive plants that furnished particleboard for further processing in other plants owned by the same firm. Plants with 21 percent of installed capacity were partially captive, selling on the open market surplus production not utilized by other plants of the same firm. The balance of the plants (64 percent of total capacity) sold their entire production on the open market. By 1970, capacity of captive plants had declined to five percent and partially captive plants to 17 percent of the industry, leaving 78 percent of industry capacity for distribution on the open market (U. S. Industrial Outlook, 1972).

In response to increased demand for particleboard, particularly for use as furniture corestock and as underlayment in residential construction, production increased 15-fold between 1955 and 1970. This was an average increase of nearly 20 percent per year. In 1970, regional production by grade was:

Grade	Total U. S. production	West		North & South	
	MM sq. ft.	MM sq. ft.	%	MM sq. ft.	%
Floor underlayment	601	268	44. 6	333	55. 4
Industrial corestock	1131	618	54. 6	513	45. 4
Extruded	32	-	-	32	100. 0

Source: U. S. Industrial Outlook, U. S. Dept. of Commerce, 1972

Since 1967 there has been a decided shift in the type of particleboard produced in the three regions. In 1967, the West produced 88 percent of the floor underlayment and 60 percent of the industrial corestock. The South and North produced the balance of these categories. By 1970, a more balanced production pattern of corestock and underlayment developed between the regions. The West produced 45 percent of the floor underlayment while the South and North produced 55 percent. Corestock had dropped slightly, with the West producing 55 percent of industrial corestock and the South-North regions providing the balance. Bureau of Census figures give some indication of the use of particleboard corestock in wood furniture, exclusive of upholstered furniture, and in metal dinette furniture:

Year	Corestock used (MM sq. ft.)		Total U. S. Production	
	Wood furniture	Dinette	MM sq. ft.	% Total
1958	49. 5	16. 4	250	26. 4
1963	112. 7	38. 8	496	30. 5
1967	154. 5	55. 9	1115	18. 5

Source: Bureau of Census, Census of Manufacturers, 1967

A study conducted by the U. S. Forest Service of single family housing in the United States inspected by the Federal Housing Authority in 1959, 1962, and 1968 indicates the increased usage of particleboard in residential housing construction:

Year	No. houses inspected	Ave. house size (M sq. ft.)	Particleboard used/house (sq. ft.)	Particleboard used/sq. ft. floor area (sq. ft.)
1959	289,075	1086	50	.04
1962	176,327	1197	70	.06
1968	136,333	1392	180	.12

Source: Wood Products used in Single-family Houses, U. S. D. A. U. S. Forest Service Bulletin no. 452, 1969

Particleboard use per housing unit averaged 180 square feet (3/4-inch basis) in 1968. This was more than 2.5 times the 70 square feet used in 1962. The increased usage was largely the result of substituting particleboard for other materials and the increase in average house size. Particleboard use was highest in the Southwest (352 square feet per house) and lowest in Florida (49 square feet). The study indicated that particleboard usage had increased per housing unit in each of the eight regions observed between 1962 and 1968.

Average particleboard use as floor underlayment in 1968 was 131 square feet. This was 100 square feet more than was used in 1962 and 117 square feet more than in 1959. Practically all of the increase was due to the greater use of particleboard underlayment under tile, resilient flooring, carpeting, and to the increase in house size.

Use of particleboard in millwork and trim also increased between 1962 and 1968. Particleboard used in these applications went into cabinets, kitchen countertop underlayment, and a small amount into wall paneling.

Increase in per capita consumption has increased 18-fold between 1955 and 1970. Per capita consumption in 1955 was .20 square feet and by 1970 had increased to 3.54 square feet per year.

Capacity Utilization

Production has increased more rapidly than industry capacity in recent years. Prior to 1963, production output ranged from 48 to 69 percent of designed plant capacity. Since 1963, production has averaged above 70 percent of plant capacity except in the North where production averaged 44 percent of capacity (Figure 2. 1).

The rate of capacity use in the particleboard industry is lower than for many other industries because particleboard estimates generally assume continuous three-shift operations. However, many plants normally only operate one or two shifts per day so that under-utilization of capacity exists according to industry standards.

Excess capacity in the 1959-1965 period was evidently a primary cause for the slower rate of expansion during this time span. Recent improvements in utilizing plant capacity because of increased particleboard consumption have apparently aroused renewed interest

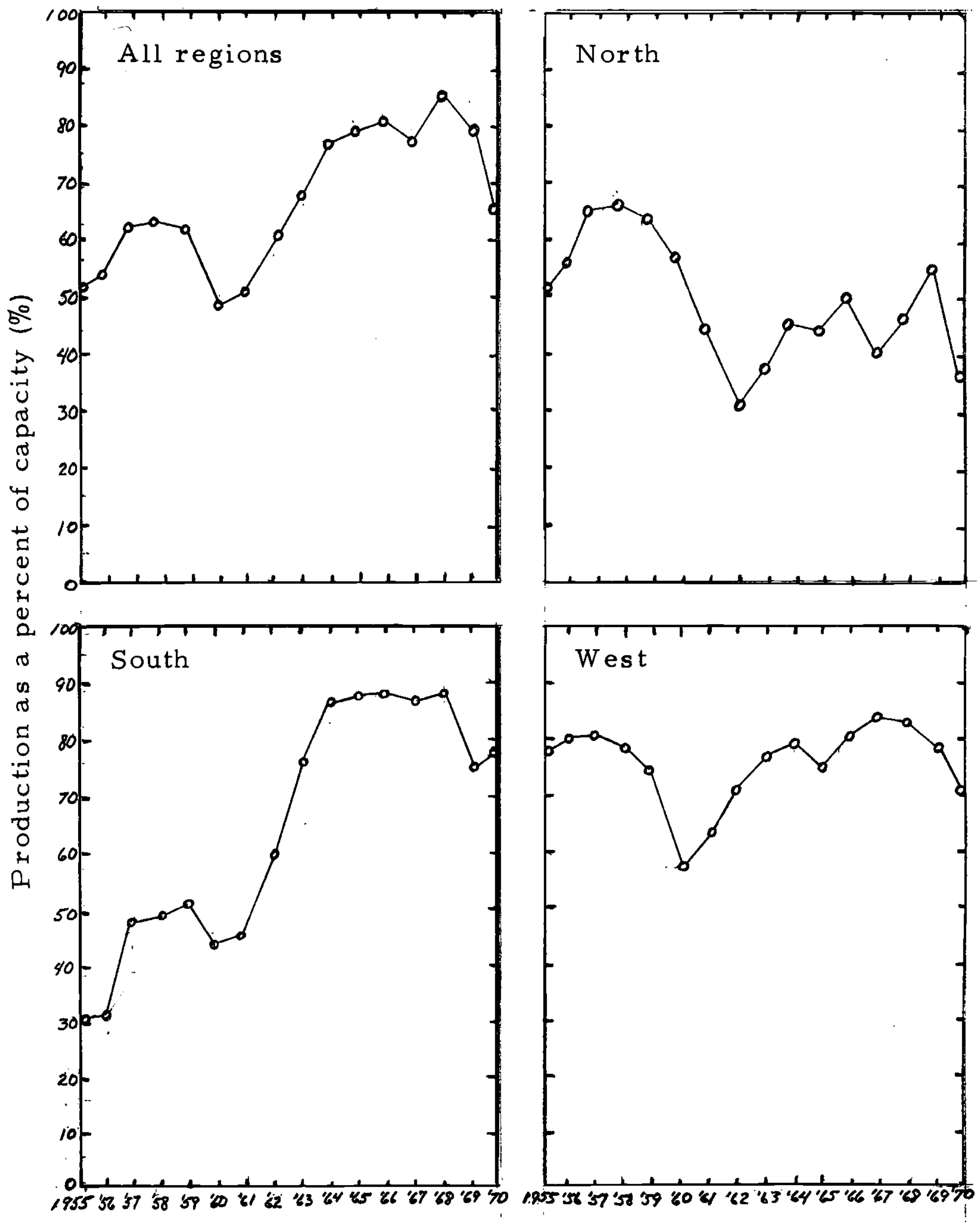

Figure 2. 1. Utilization of the particleboard industry, by region, 1955-1970.

in new plant construction and expansion of existing mills. Increased construction in new plant facilities created an over-capacity situation that was augmented by reduced particleboard consumption between 1968 and 1970.

Residue Utilization

Except for two plants in the North, new plants built since 1961 use residues of other forest products industries. Since these residues are more easily broken into small particles than cut into flakes, the portion of flake-type particleboard as a percentage of the industry's total output has declined. Production of layered boards with fine particles on the surface and coarse material in the center has increased.

Most particleboard producers have continually sought to reduce losses of wood in manufacturing operations. Much of the fine wood formerly screened out and destroyed is now used. Reuse of the plant's own residues from trimming and defective panels has become commonplace. A number of plants also use sander dust from particleboard surfacing operations. Reuse of waste and sander dust can approximate savings of 10 to 16 percent in basic wood raw material requirements.

It is estimated that approximately 80 cubic feet of solid wood or the equivalent amount of residues is required to produce 1000 square feet of particleboard (3/4-inch basis). Based on this value, the estimated use of wood raw material for particleboard production increased from 9 million cubic feet (157,500 tons) in 1955 to 142 million cubic feet (2,485,000 tons) in 1970. Approximately 88 percent of the raw material used in 1970 was residues, roundwood comprising the balance of requirements. In 1970, softwoods comprised 90 percent of the residues used but only a negligible portion of the roundwood. In the West, practically all raw material used in particleboard manufacture consisted of softwood residues (Forest Industries, November, 1971).

This chapter presented a general review of the particleboard industry in a national context with emphasis on industry size, production processes, product use, and raw material. The following chapter will be concerned with the particleboard industry in Oregon. Factors leading to the establishment and growth of the industry are discussed, as well as the industry's use of production resources and its comparative size in relation to the softwood lumber and plywood industries.

CHAPTER III

PARTICLEBOARD INDUSTRY IN OREGON

The purpose of this chapter is to present insights into the particleboard industry of Oregon and the part the Oregon segment plays in the national particleboard industry. Reference was made to why Oregon became the leading state in the production of particleboard and the changes that have occurred between 1955 and 1970 in particleboard production and in the use of production inputs of capital, labor, wood, and resin adhesives. In addition, a comparison was made between the particleboard industry of Oregon and Oregon's two leading forest products industries, softwood lumber and plywood, in order to obtain a perspective of particleboard growth trends relative to lumber and plywood.

Factors Contributing to Establishment and Growth of Industry

The economic justification for the establishment of the particleboard industry in Oregon is complex but understandable. The abundance of low cost wood residues and resin technology, an outgrowth of advances made in the softwood plywood industry, were inducements. However, factors such as labor and distribution costs and proximity to markets would seem to have favored the Southern region as an area with the greatest potential for accelerated growth. Operating personnel and engineering technology were certainly not unique to Oregon. The Southern Region had 12 plants operating in 1955 whose personnel had developed considerable expertise in particleboard production methods. Of the five original plants constructed in Oregon in 1955, three of these used the services of a Virginia engineering firm.

Although many of the major forest products corporations were located in, or at least had operating facilities located in Oregon, their size or presence did not appear to be a strong argument for the establishment of this infant industry. Several of the initial plants established in Oregon were relatively small and not part of a large scale forest products complex. This is not to say that an integrated forest products complex did not play an important role in the later expansion of the industry, which has since become the case.

A consideration of these factors would seem to indicate that two features have been important in establishing Oregon as a major producer of particleboard. Initially, it must be assumed that the abundance, type, and concentration of wood residues was a major contributing factor. The entrepreneurs of the initial plants, who had the foresight to envision a giant in the making, saw raw material type and quantity as a major constituent for production success. An adequate supply of raw material did not come easily to the early independent particleboard plants as testified to by some of the principals involved with these operations. In personal interviews, they reported the difficulties encountered in convincing sawmill and planing mill managers on the feasibility of installing truck loading facilities and other equipment in order to supply raw material residues.

Despite the initial apathy on the part of raw material suppliers, they soon came to realize the potential of the particleboard industry as an outlet for their residues, particularly planer shavings. Planer shavings, being a thin flake-like particle, required little additional milling for acceptance as the basic constituent of particleboard.

The concentration of log processing mills west of the Cascades, utilizing predominately one species, Douglas-fir, also was important from the standpoint of plant location and future growth. Douglas-fir has been favored by the users of particleboard due to its dimensional stability, machining characteristics, and physical properties. Particleboard produced from Douglas-fir is also less abrasive during machining due to somewhat lower resin requirements for its manufacture.

As previously mentioned, two major uses of particleboard have been furniture corestock and floor underlayment in residential housing construction. Consequently, demand for a substantial portion of particleboard follows closely the demand for softwood lumber in housing construction. The supply of raw material for Oregon's particleboard industry, being principally a residual of softwood log conversion, is therefore a function of demand for softwood lumber. As might be expected, available residues for particleboard fluctuate with lumber production and may present a serious supply problem in localized areas at particular points in time.

The concentration of lumber processing west of the Cascades also contributed to reduced raw material transportation costs and has been another factor favorable to Oregon's particleboard industry.

The second feature that favored the establishment and growth of Oregon's particleboard industry was resin technology made available through the research efforts conducted for the softwood plywood industry. Much of the technology of bonding Douglas-fir with urea formaldehyde resins had been developed; consequently it was a matter of adapting these resins to the smaller particles, plus adjusting for the longer assembly times between resin application and mat consolidation in the press.

It may be hypothesized that the concentration and quantity of low cost raw material residues plus resin technology made possible the establishment of large-sized plants that were able to capture anticipated economies of scale and associated lower production costs. These plants, by incorporating capital intensive equipment, utilizing the latest production technology, and not faced with raw material constraints, have been able to remain competitive in spite of unfavorable distribution and labor cost differentials with respect to other competing regions.

Industry Capacity and Utilization

Oregon's particleboard industry (Table 3. 1) began in 1955 with the establishment of five plants having a combined capacity of 38 million square feet (3/4-inch basis). In 1957, four additional plants were added, increasing industry capacity to 73. 5 million square feet. During 1955-1960, industry capacity increased 400 percent and the number of plants and average capacity per plant doubled. During this period, 85 percent of the additional capacity came from new plants, the balance from expansion of existing plants.

During the five-year period 1961-1965, industry capacity again doubled and operating plants increased to 13. Average capacity per plant increased to 30. 9 million square feet which was twice the average plant capacity in 1960. New plants accounted for 75 percent of the increase, the balance from expansion of existing mills. Six plants discontinued production during this period, a capacity loss of 33 million square feet. These were small capacity plants, having only 8. 2 percent of the industry capacity which prevailed in 1965.

Industry capacity again doubled during 1966-1970 with a net gain of one new plant. During this period, 38 percent of increased capacity was from new plant construction, the balance from expansion of existing ones. By 1970, average plant capacity had increased to 58. 2 million square feet, a 770 percent increase over 1955.

Table 3.1. Oregon particleboard industry capacity, production, and capacity utilization, 1955-1970 (million square feet, 3/4-inch basis).

Year	Total no. plants	Plants starting production	Plants ceasing production	Industrial capacity	Capacity gains & losses during year: Total	Gains: Total	Gains: New plants	Gains: Existing plants	Losses	Production for year	Production as % capacity	Ave. capacity/plant
1955	5	5	0	38.0	38.0	38.0	38.0	0	0	12.2	32	7.6
1956	4	0	1	31.3	- 6.7	0	0	0	6.7	16.1	51	7.8
1957	8	4	0	73.5	42.2	42.2	42.2	0	0	20.9	28	9.2
1958	9	1	0	99.0	25.5	25.5	4.0	21.5	0	46.3	47	11.0
1959	8	0	1	94.0	- 5.0	1.0	0	1.0	6.0	75.6	80	11.8
1960	10	3	1	149.0	55.0	65.0	65.0	0	10.0	72.3	49	14.9
1961	9	0	1	144.0	- 5.0	0	0	0	5.0	85.9	60	16.0
1962	10	2	1	167.3	23.3	30.0	12.0	18.0	6.7	125.1	74	16.7
1963	10	1	1	171.3	4.0	8.0	8.0	0	4.0	145.4	85	17.1
1964	10	1	1	242.3	71.0	83.0	18.0	65.0	12.0	207.7	86	24.2
1965	13	4	1	402.3	160.0	165.0	150.0	15.0	5.0	286.3	71	30.9
1966	14	2	1	560.3	158.0	182.0	132.0	50.0	24.0	478.3	85	40.0
1967	14	0	0	660.3	100.0	100.0	0	100.0	0	539.6	82	47.2
1968	15	1	0	764.3	104.0	104.0	24.0	80.0	0	613.3	80	50.9
1969	15	0	0	784.3	20.0	20.0	0	20.0	0	707.9	93	52.3
1970	14	0	1	815.3	31.0	55.0	0	55.0	24.0	739.6	91	58.2

Source: Personal interviews, annual issues of Timberman and Forest Industries trade publications, and U. S. Dept. of Commerce Bulletin M24SF, annual issues.

During 1966-1970, production as a percentage of industry capacity averaged 86 percent, the highest period of capacity utilization for Oregon's industry since its start in 1955. This was 12 percent greater than the national average for the same period of time.

From 1955-1970, the industry experienced a 60-fold increase in production, production doubling on the average every three years. This was an average increase of 40 percent per year.

During 1966-1970, Oregon's production of particleboard averaged 44 percent of United States production. However, the per-year percentage of total United States production declined from 48 percent in 1966 to 42 percent in 1970.

Capital Value

Capital value for the particleboard industry increased 21-fold during 1955-1970, an average annual increase of 58 percent. This followed closely the increase in industry capacity as is shown in Table 3.2.

The annual increases in capital value were greatest during the period 1955-1960, 81 percent, decreased to 55 percent during 1960-1965, and exhibited a further decline to 37 percent for 1965-1970. This trend is similar to increases in industry capacity during each of the respective time periods.

Capital value increases per plant averaged 39 percent during

Table 3.2. Capital value and industry capacity for the particleboard industry of Oregon from 1955 to 1970.

Year	Capital value (million $)	Percent change/year	Average capital value/year/plant (million $)	Percent change/year	Increase in value (million $)	Industry capacity (million sq. ft.)	Percent change/year
1955	1.96		.39			38.0	
1960	8.02	81	.80	41	6.06	149.0	78
1965	22.25	55	1.71	43	14.23	402.3	54
1970	40.86	37	2.89	34	18.61	815.3	41
Ave.		58		39			58

1955-1970. Increases in capital value per plant remained relatively constant through 1965, but declined to an annual increase of 34 percent for 1966-1970.

The analysis indicated good correlation between capital value and industry capacity increases for either industry-wide or per plant comparisons.

Labor

Production per man hour and employment have both shown marked increases over the period 1955-1970 as shown in Table 3.3.

Employees per plant doubled each five years from 1955 to 1970. Much of the early increase in employment was due to increases in shift requirements as plants increased from one to three shift operation. Later increases in employment have been due to installation of secondary operations such as cut-to-size and prefinishing plus increased labor requirements for auxiliary operations such as processing and raw material handling. As plant size increased, these operations became more complex and many times were not conducive to labor saving equipment.

Production per man hour, the standard measure of productivity in our industrial society, has approximately doubled from 1955 to 1970 in spite of rapid increases in labor employment. Average wage also doubled during this time period, indicating that wages have increased in proportion to productivity.

Table 3. 3. Employment and productivity for particleboard industry of Oregon between 1955 and 1970.

Year	No. plants	Total employees	Employees/ plant	Annual production (MM sq. ft.)	Productivity/ M. H.	Ave. wage ($)	Ave. labor cost/ M sq. ft. ($)
1955	5	47	10	12.2	103	1.80	16.67
1960	10	200	20	72.3	151	1.94	12.84
1965	13	637	49	290.2	187	2.73	14.61
1970	14	1363	98	737.8	226	3.44	15.20

For 1960-1970, average labor costs per thousand square feet (3/4-inch basis) increased approximately 18 percent, an annual increase of 1.8 percent. During this same period production per man hour increased 49.6 percent or an average of five percent per year. Productivity therefore increased at a greater rate than did labor costs per thousand square feet.

Raw Materials

In addition to capital and labor, wood and resin adhesives are two necessary inputs for the manufacture of particleboard. As previously discussed, availability, type, and concentration of wood residues from conventional log conversion have been major factors in the success of Oregon's particleboard industry. Accurate insight into the use of residues by the industry is difficult since not all plants use the same type of wood raw material. However, an idea of the demand and supply situation may be obtained if the assumption is made that only planer shavings are used by the industry. Supply of planer shavings, a residual from lumber surfacing, is largely dependent upon lumber production and the percentage of lumber surfaced. An estimation of planer shavings production, requirements, and cost are shown in Table 3.4.

Planer shavings residues increased approximately one cubic foot per thousand board feet of lumber produced during the period 1963 to

Table 3.4. Planer shavings supply for particleboard industry of Oregon from 1955 to 1970.

Year	Oregon softwood lumber production (MM bd. ft.)	Shavings production (O. D. tons)	Oregon particleboard production (MM sq. ft.)	Required shavings (tons)	% shavings utilized	Average shavings cost/ton ($)	Ave. cost/ M sq. ft. ($)
1955	9719	2,243,000	12.2	18,300	.8	6.95	10.42
1960	7549	2,046,000	72.3	108,450	5.3	7.00	10.50
1965	8441	2,338,000	290.2	435,300	18.6	8.20	12.30
1970	7395	1,650,000	737,8	1,106,700	67.1	7.20	10.80

1967 (Forest Industries, November, 1971). This indicated that annual fluctuations in shavings supply was primarily due to variations in lumber production and not to lumber surfacing practices.

The cost per oven dry ton of residues used in particleboard production remained relatively constant between 1955 and 1970, following to some degree the increased residue demand resulting from increases in industry capacity. The excess supply of residuals such as planer shavings, lack of competition for planer shavings from competing industries such as pulp and paper, hardboard, and insulationboard, and increased public pressures to reduce air pollution have undoubtedly contributed to wood residue price stability.

Resin Adhesives

Resin costs are a major component of particleboard production cost and are the only major operating expenses that have shown a steady decrease since 1955. Urea formaldehyde resin, the predominant adhesive used in particleboard manufacture, has as a principle ingredient urea. Nationally, urea has experienced a rapid rate of utilization, primarily in agricultural fertilizers. Figure 3. 1 shows the increased use of urea in agriculture, a 900 percent increase from 1955 to 1970. There has also been a significant increase in the use of urea formaldehyde resins, both in particleboard and plywood manufacture, which has also contributed to the use of urea. This increased

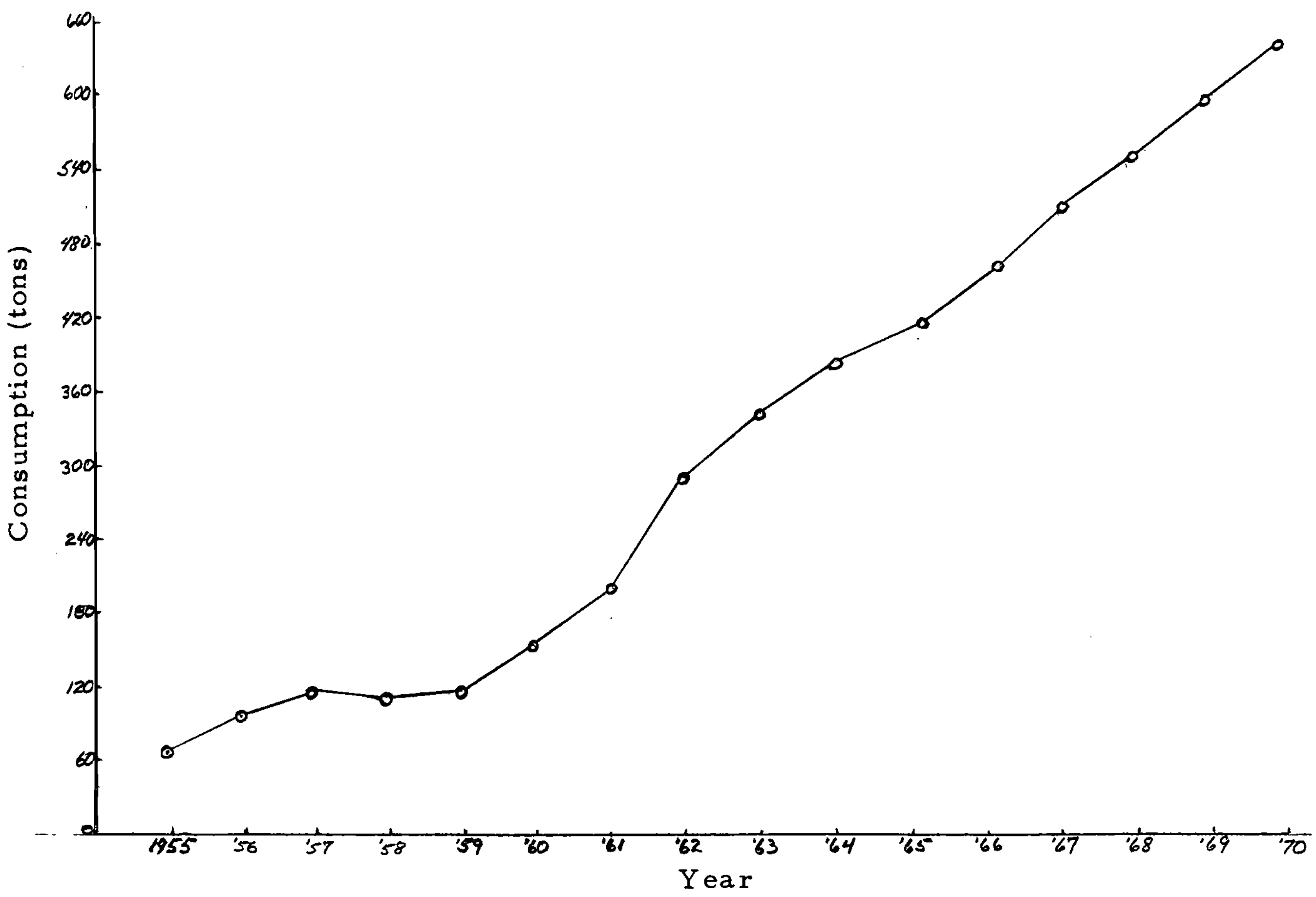

Figure 3. 1. Urea consumption in agriculture, 1955-1970.
Source: U. S. D. A. Statistical Bulletin 472, p. 34.

use has substantially reduced the price of urea which in turn has reduced prices for urea formaldehyde resin.

Table 3.5 shows the estimated use of urea formaldehyde resins in Oregon's particleboard industry between 1955 and 1970.

Table 3.5. Usage of urea formaldehyde resin in the particleboard industry of Oregon between 1955 and 1970.

Year	Particleboard production (MM sq. ft.)	Urea formaldehyde resin (lbs.)	Wood used (OD tons)	Resin used (%)	Resin cost/ MM sq. ft. ($)
1955	12.2	2,537,600	18,300	6.9	37.44
1960	72.3	14,821,500	108,450	6.8	29.72
1965	290.2	49,243,600	435,300	5.7	19.78
1970	739.6	122,034,000	1,106,700	5.5	14.02

The cost of urea formaldehyde resin was $.18 per pound in 1955 but by 1970, the price had declined to $.085 per pound, an average price decrease per year of 3.2 percent. Resin treatment of wood particles decreased 20.3 percent from 1955 to 1970. This can be largely attributed to increases in resin efficiency, and to improvements in operating equipment and technology.

In summary, a number of factors have contributed to the reduction of resin costs per thousand square feet, amounting to 63 percent between 1955 and 1970, an average cost saving of 4.2 percent per year. This was a major accomplishment when one recognizes that resin costs account for 20 to 25 percent of particleboard production costs.

Comparison with Other Forest Products Industries in Oregon

Examination of the absolute values for the particleboard industry is important but a perspective of industry size and growth trends is not fully understood unless one compares it with other forest products industries within Oregon.

Two forest products industries, softwood lumber and softwood plywood, both of which supply raw material residues for the particleboard industry, are used as a basis for comparison (Table 3.6).

Particleboard

United States per capita consumption of particleboard increased at an annual rate of 18.8 percent for 1960-1970, but for the period 1966-1970, average annual increase had declined to 15.2 percent.

Direct comparisons between lumber and particleboard are difficult due to differences in standard measurement. For comparisons between plywood and particleboard, the task is somewhat easier since each uses square foot measurement as a standard. With this as a basis and disregarding thickness differences, per capita consumption of particleboard was four percent of per capita consumption of softwood plywood in 1960, increasing to 12 percent in 1970.

Oregon's production of particleboard, million square feet 3/4-inch basis, had an average annual increase of 30.7 percent for

Table 3.6. Comparison of softwood lumber, softwood plywood, and particleboard for Oregon, 1960-1970 (in terms of Oregon production and value of shipments, and U.S. per capita consumption).

Year	U.S. per capita consumption	Percent change	Oregon production	Percent change	Value of shipments	Percent change
			Softwood lumber			
	(board ft.)		(million bd. ft.)		(million $)	
1960	148		7549		702	
1961	143	3.4	7366	- 2.4	594	-15.4
1962	144	.7	7712	4.7	679	14.3
1963	146	1.4	7818	1.4	710	4.6
1964	153	4.8	8476	8.4	774	9.0
1965	151	-1.3	8441	- .4	643	-16.9
1966	147	-2.6	8233	- 2.5	644	.2
1967	138	-6.1	7077	-14.0	576	-10.6
1968	149	8.0	7367	4.1	737	27.9
1969	139	-6.7	6817	-7.5	781	5.9
1970	131	-5.7	7395	8.5	627	-19.7
			Softwood plywood			
	(sq. ft. 3/8" basis)		(million sq. ft. 3/8"-basis)		(million $)	
1960	42.9		5160		322.5	
1961	46.2	7.7	5680	10.1	354.7	10.0
1962	49.9	8.0	6329	11.4	362.3	2.2
1963	54.7	9.6	6795	7.4	443.4	22.4
1964	59.5	8.8	7742	13.9	475.0	7.1
1965	64.2	7.9	8018	3.6	513.0	8.0
1966	64.6	.6	7865	- 1.9	484.0	- 5.7
1967	64.4	- .3	7392	- 6.0	446.9	- 7.7
1968	71.9	11.7	8304	12.3	605.8	35.6
1969	67.0	-6.8	7239	-12.4	575.6	- 5.0
1970	69.5	3.7	7240	0	490.6	-14.8

(Continued on next page)

Table 3.6. (Continued)

Year	U.S. per capita consumption	Percent change	Oregon production	Percent change	Value of shipments	Percent change
			Particleboard			
	(sq. ft.)		(million sq. ft. 3/4"-basis)		(million $)	
1960	1.5		72.3		8.4	
1961	1.8	20.0	108.3	49.7	9.5	13.1
1962	2.2	22.2	125.1	15.5	12.2	27.4
1963	2.6	18.2	146.1	16.8	11.6	- 4.9
1964	3.3	26.9	207.7	42.1	14.1	21.5
1965	4.1	24.2	290.2	39.7	28.6	102.8
1966	5.5	26.8	480.3	65.5	42.8	49.7
1967	5.6	1.8	504.7	5.1	43.8	.2
1968	7.1	26.8	610.3	20.9	60.4	37.9
1969	8.4	18.3	709.9	16.3	83.2	37.7
1970	8.6	2.4	737.8	3.9	65.4	-21.4
Ave.		18.8		30.7		26.4

Source: Industrial Forestry Association, Portland, Oregon, Annual issues, demand and price situation for forest products, U.S.D.A. #1086. Oregon Economic Statistics, 1972.

1960-1970, but the average increase decreased to 22.3 percent during 1966-1970. In 1960, Oregon's production of particleboard, per million square feet, was only one percent that of the State's softwood plywood production. By 1970, this proportion had increased to 12 percent even though plywood production had increased 40 percent during the decade.

Oregon's particleboard industry shipments had an average annual increase in value of 26.4 percent for the period 1960-1970, but this decreased to an average annual increase of 20.8 percent during 1966-1970. In 1960, value of particleboard shipments was 2.6 percent the value of shipments for softwood plywood. In 1970, the percentage had increased to 13 percent. Value of plywood shipments had also increased 52 percent during the period.

Average annual value of shipments for particleboard remained relatively constant, averaging $100 per thousand square feet for both the 1960-1970 and 1966-1970 time periods.

For 1966-1970, Oregon's average annual increase in production of particleboard decreased at a faster rate than did the average per capita consumption of particleboard, indicating that the additional consumption requirements were being supplied by other regions.

Softwood Lumber

The average per capita consumption of softwood lumber in the United States has remained relatively constant between 1960 and 1970.

However, for 1966-1970, there was an average decline in annual per capita consumption of softwood lumber amounting to 2.5 percent for the United States.

There was little average annual change in the production of softwood lumber in Oregon from 1960 to 1970; however, for the period 1966-1970, production declined in Oregon an average of 2.3 percent.

Value of shipments for softwood lumber exhibited little change from 1960 to 1970 and only increased slightly over the latter five years of the period. For the period 1960-1970, value of shipments averaged $80 per thousand board feet, increasing to $90 per thousand from 1966 to 1970.

In general, the softwood lumber industry of Oregon has shown little growth for the period 1960-1970 in either production or value of shipments, following closely the static condition in average per capita consumption of lumber for the United States.

Softwood Plywood

The average per capita consumption of softwood plywood increased five percent in the United States for the period 1960-1970, but the increase had declined to 1.8 percent during 1966-1970.

Production of softwood plywood in Oregon exhibited an average increase of 3.8 percent per year for 1960-1970, but during 1966-1970, the increase had declined to an average of 1.6 percent per year.

Value of shipments was characterized by an average annual increase of 5.2 percent for 1960-1970. For 1966-1970, the average annual increase had declined to 1.6 percent per year. Value of shipments, per thousand square feet 3/8-inch basis, remained steady for both comparative time periods at $70 per thousand.

The softwood plywood industry of Oregon experienced a relatively slow growth rate in both production and value of shipments for the period 1960-1970. In fact, average annual production did not keep up with average per capita consumption for the United States, indicating that the South was supplying the consumption deficit. Indications are that average annual value of shipments per thousand square feet remained relatively steady for the period 1960-1970.

Particleboard Production by Grade

The major portion of Oregon's particleboard production prior to 1968 was residential housing floor underlayment, averaging 62.9 percent of total production annually from 1962 to 1968. Underlayment is a standard commodity item, readily adaptable to high speed production, and is undoubtedly the reason Oregon producers favored this product. Underlayment is commonly produced in two thicknesses, 3/8-inch and 5/8-inch, and the standard size is 4 feet x 8 feet, a size dictated by the construction industry.

In 1968, the product mix from Oregon's particleboard industry shifted from predominately underlayment to other products such as panel corestock and other specialty items which have more stringent quality standards and demand a higher price in the market place.

It may be hypothesized that this shift in product grade was necessitated by competition from other regions, particularly the South where an additional 292 million square feet of capacity was added in 1968, chiefly orientated to underlayment production. This added production potential, located in close proximity to major underlayment markets, placed Oregon producers in a precarious marketing situation and forced them to look to other markets. The logical move was to shift product orientation to corestock and specialty items, products which are potentially capable of higher monetary gains to producers, and the markets which may be more advantageously located in respect to Oregon. Table 3.7 shows production grade trends for Oregon particleboard producers from 1962 to 1970.

During 1962-1967, estimated average annual price of particleboard produced in Oregon was $86.54 per thousand square feet. For the period 1968-1970, the average annual price increased to $101.33, a 17 percent increase reflecting the shift in product mix to a higher percentage of corestock production.

For the period 1968-1970, production grade averaged 63.2 percent per year for corestock and products other than underlayment,

Table 3.7. Production and product trends for the particleboard industry of Oregon from 1962 to 1970.

Year	Total U.S. production (MM sq. ft.)	Oregon production (MM sq. ft.)	% of total	Underlayment production (MM sq. ft.)	% Oregon production	Other production (MM sq. ft.)	Value of shipments (MM $)	Ave. price/M ($)
1962	407	125.1	30.7	81.6	65.2	43.5	12.2	97.52
1963	496	146.1	29.4	81.5	55.8	64.6	11.6	79.40
1964	638	207.7	32.6	111.5	53.7	96.2	14.1	67.88
1965	803	290.2	32.4	211.0	72.7	79.2	28.6	98.55
1966	997	480.3	48.2	337.6	70.3	142.7	42.8	89.11
1967	1115	504.7	45.3	301.8	59.8	202.9	43.8	86.78
1968	1425	610.3	42.8	293.5	48.1	316.8	60.4	98.15
1969	1716	707.9	41.4	242.1	34.1	467.8	83.2	117.20
1970	1764	737.8	41.8	207.3	28.1	530.5	65.4	88.64

Source: U.S. Department of Commerce Bulletin M24SF, Annual Issues.

a reversal from the previous six years when the average was 62.9 percent underlayment production. The particleboard industry of Oregon had changed its orientation from commodity item production to a specialty item approach with emphasis upon corestock. This required that the industry maintain a high degree of production and processing flexibility to meet the changing demands of the market place.

The establishment of Oregon as the leading state in the production of particleboard was primarily the result of an abundant low cost supply of wood residues, which were concentrated in a relatively small geographic area and available resin technology. This supply source favored the concentration of large capacity plants utilizing expensive production equipment not conducive to small capacity particleboard plants due to the high initial capital requirements. The production output of these large capacity plants tended to offset increased labor costs incurred by the particleboard industry between 1955 and 1970, and in combination with relatively stable wood costs and a substantial reduction in resin costs, permitted the industry to experience a reduction in its cost of production.

When the particleboard industry of Oregon was faced with competition from the Southern Pine Region in production of underlayment, a relatively low priced commodity item, the industry was able to shift its productive talents to a larger proportion of corestock and specialty items, products which are potentially capable of higher monetary gains to producers.

The particleboard industry of Oregon, although an infant by the quantitative standards of softwood lumber and plywood industries, exhibited substantial growth increases in the three categories analyzed: per capita consumption, production, and value of shipments relative to the lumber and plywood industries. This indicated the ability of the particleboard industry to capture a substantial portion of the United States market despite competition from established products, and perhaps even more important, indicated the economic contribution an industry, predicted on utilizing wood residues from primary conversion industries, could make to a state's economy in terms of employment, plant investment, and product sales.

The status of the particleboard industry is important in an overview context but in order to obtain a perspective of the industry's proficiency relative to its use of imput factors for optimum production output, the following chapter will present a discussion of the methodology underlying the production function analysis. This is fundamental to an economic understanding of how an industry efficiently converts factors of production into an output commodity.

CHAPTER IV

PRODUCTION FUNCTION ANALYSIS

In the preceding chapter an overview of the particleboard industry of Oregon was presented in which production and factor input trends were discussed. No attempt was made to specify how inputs might be varied in order to produce stipulated amounts of particleboard, but rather, they were treated as entities separate from the actual production process. In this chapter, the methodology underlying the determination of economically efficient input allocation in the production process will be discussed; and will form the basis for understanding the aggregate production function analysis of the particleboard industry of Oregon presented in Chapter VI.

Production is generally defined as a process in which certain input factors are converted into certain other commodities or services referred to as products. The conversion process is carried out in an individualistic production unit, called a firm in economic theory but for the purposes of this study, a plant.

Factors of Production

The factors of production as viewed by classical economists consisted of land, labor, and capital. These classifications were intended to reflect basic differences in their economic characteristics.

Land, which can neither be created nor destroyed, was distinguished by these indestructable qualities. Labor, the services of individuals, was distinguished by the fact that its use was neither a source of satisfaction or dissatisfaction to the individual. Capital was classified as an aggregation consisting of tools of production such as buildings, equipment, improvements to land, and goods in service.

Recent empirical analysis of production has come to deemphasize the classical selection of land as a major factor of production. Land is now treated as a form of capital so that the principle analytical factors of production are commonly labor, capital, and managerial talent, managerial talent relating particularly to the allocation of factors of production used in a given plant.

Production Function

In the production process, given factors of production such as capital and labor are combined in some allocative manner by managers to form a product, such that an input-output relationship exists at the level of the plant. The problem of determining how to combine given quantities of input factors, in order to produce the stipulated quantity of output, is generally considered to be technological rather than economic. However, when the problem arises of whether to produce more of one output or less of another, or to vary inputs in order to produce a given output, or perhaps to vary both, then the realm of economics is breached and economic decisions have to be made.

The production function defines the physical or technological input-output relationship existing between factors of production and the resultant output. It is a concept largely developed by early economists who proposed general algebraic hypotheses relative to agricultural outputs. The first empirical attempt to apply the function to non-farm industries occurred during the period 1899-1922, largely through the efforts of C. W. Cobb and Paul H. Douglas who applied the work of earlier economists to American manufacturing industries (Douglas, 1948).

The production function is generally associated with input-output relationships which prevail at the level of the firm or plant. However, for analysis of inter-plant production relationships, such as for an industry, the production function should be developed by aggregating the individual plant production functions for all plants comprising the industry. Generally these data are not available, so the alternative is to utilize aggregated industry data from published census documents, recognizing that the resulting function derived from this source of information will be somewhat different from one implied by the theory of the firm. Technological differences commonly exist among plants in a given industry; consequently some of the homogenity of individual plants is lost in industry data aggregation, such that a plant with optimum allocation of factor inputs may be obscured if other plants are using sub-optimum combinations of inputs. Nevertheless, if the industry is small, e. g., number of plants, the plants are located in close proximity to one another, and all plants have equal opportunity to obtain raw materials and labor from similar environs, data aggregation should not present a serious problem.

Production Function Models

In empirical studies of an industry, it is often difficult to specify models which appropriately express the true relationship between factor inputs and production output. This is due to the non-experimental nature of many types of economic relationships and the physical limitations in obtaining a complete composite of input information. Several basic models, ranging from single equations with numerous variations to simultaneous equations, have been proposed for production function analysis. As Love indicates, in selecting the model and estimating the economic relationship involved, one is estimating an approximation (Love, 1966). As such, there is an element of uncertainty when undertaking an empirical analysis. Any econometric investigation must be taken as a first approximation to an understanding of the input-output relationships exhibited by the production function, and process logic possessed by the investigator should play an important interpretative role.

Two basic approaches to production function estimation are possible. One approach is to regard the production function as one of a number of interdependent relationships constituting a model of the production process. This is a simultaneous equation approach and consists of the entire system of equations which specify the profit maximizing conditions underlying the basic input-output relationship. Alternatively, the single equation approach may be adopted with the production function being considered as a single independent relationship. This approach implies that the production function is not influenced by other relationships relevant to the economic environment surrounding the production process.

The question of which approach to use depends to a large extent upon the logic, physical or economic, that underlies the production process. From a computational standpoint, a single equation model is often regarded as an alternative to the more precise, but computationally cumbersome, simultaneous equation model. Another factor, which lends credence to the selection of single equation models, is the argument that profit is a stochastic variable. If profit is influenced by the unpredictable nature of production input services and by the time lag between resource commitment and production process completion, then profit is uncertain. The implication is that resources must be committed before profit can accrue (Moroney, 1963). With profit uncertain, the single equation model may be regarded as adequate for production analysis.

Since this study was concerned only with the relationship of production inputs in the production process, and recognizing the implication that production input commitment must be made before profits are realized, the single equation model was adopted for use in this study.

Cobb-Douglas Production Function Model

One single equation model commonly used in production function analysis is the Cobb-Douglas model (Griliches, 1967; Moroney, 1967). Cobb and Douglas (1928) pioneered the work in evaluating efficiency of aggregate production inputs relative to the laws of production. They proposed a general model which was subsequently modified to the following form:

$$O = I K^{a} L^{b} e$$

where O = output, I = intercept, K = capital input, L = labor input, e = random disturbance, a = elasticity of production with respect to capital, and b = elasticity of production with respect to labor.

This exponential production function model has several features that make it desirable for empirical production analysis.

1. The Cobb-Douglas production function model has constant elasticities of output with respect to capital and labor inputs. This infers that if either input is zero, then output is zero. If one input is held constant and the other allowed to vary, marginal

productivity will decrease as input use increases. As the input is increased, output increases but at a decreasing rate at high levels of input use.

2. Although the model is non-linear as described, it can be readily transformed into a linear form by logarithmic transformation, taking the form:

$$\log O = \log I + a \log K + b \log L + \log e$$

This permits the model parameters to be estimated by the computationally simple method of ordinary least squares. The parameters, a and b, are the elasticities of production with respect to their associated production input.

3. Marginal productivities may be obtained directly as the product of the elasticity of production and its respective average productivity.

4. The estimation of model parameters, using the Cobb-Douglas model, involves fewer degrees of freedom than other forms which allow increasing or decreasing returns to scale. This is particularly important in a study of this type where the number of sample plants is relatively small.

5. In addition to being elasticities, the parameters of the model, being pure numbers, can be added to show returns to scale even though the associated inputs have different units of measure. If $a + b > 1$, $a + b < 1$, or $a + b = 1$, increasing, decreasing, or

constant returns to scale are indicated for the production process.

6. In linear form, log I, a, and b become statistical estimates of the function variables I, K, and L respectively and can be used to make inferences about the population.

The remaining term of the production function requiring elaboration is the variable e or random disturbance. This variable indicates the amount by which the dependent variable (O) exceeds or falls short of the central measure of the function. The inclusion of this variable is rationalized in three ways:

1. All factors affecting output, such as technological and educational progress, are not known or may not be quantifiable. Consequently, they are represented by the disturbance term.
2. There is a basic unpredictable characteristic of production process inputs which is assumed to be random. Recognition of this inherent behavior is incorporated in the disturbance term.
3. Sample measurements are frequently not made without error and these errors are embodied in the disturbance term. The incorporation of the disturbance into the production function model permits the assumption that ordinary least squares estimates of the regression coefficients are unbiased and have minimum variance.

Although several contemporary researchers have criticized the Cobb-Douglas production function model as not being the correct form of the production process, Griliches (1967) appears to reasonably well sum up contemporary thought on the use of the model. He states that his results did not prove the Cobb-Douglas function to be the correct form of an industrial production model, but neither was there strong evidence against the use of it. He further states that until better evidence is presented, there is no reason to give it up as an accepted model to use in production function analysis.

Based on the desirable features of the model and the lack of conclusive proof disputing its use, it was decided to use the Cobb-Douglas single equation model for empirical analysis in this study.

Production Analysis Data

Data used in the estimation of production functions are generally either cross-section or time series. Cross-section data consist of information collected for individual industrial plants at a particular point in time, generally aggregated for a period of one year. When this method of data accumulation is extended in incremental time periods, it is possible to trace the operating behavior of an industry over time. This pattern of analysis permits the estimation of operating characteristics such as technological change, production input utilization, and plant capacity utilization that may be characteristic to individual plants but tends to change slowly over time.

Time series consist of input and output data obtained over time and may be for a single plant, aggregated for an industry, or aggregated for intra-industry analysis. Typically, these data points are equidistant in time.

There are several points of criticism directed toward the use of time series data in production analysis.

1. The ideal situation when analyzing a production function is to have the input-output relationship expressed in physical units. Generally this is not possible when aggregate data are utilized due to a heterogeneous product mix. Consequently, a mixture of stocks and flows exists. Output is generally expressed as a form of aggregate value added due to the need for a common denominator to express product differences. This implies that inputs are not treated as separate factors of production, but rather as a subtraction from the total value of output. This treats the inputs as having a fixed relationship to output which in reality may not be the case.

2. When data are aggregated over time, there is the possibility that technological changes, variations in utilization of plant capacity, personnel, and other factors may change over time and be masked by the overall time span of the study. An

associated problem is the limited number of observations in time series data associated with portions of the production function. Therefore, the underlying portion of the production curve may be improperly estimated, and not reflect the operating characteristics of an industry.

3. There is the problem of serial correlation between successive data points in a time series of observations. Model parameters, when estimated under these circumstances and analyzed by least squares techniques, do not possess minimum variance properties and contribute to biased estimates.

In order to minimize the problems of data aggregation and serial correlation, cross-section data were used to estimate annual variations in production utilization of inputs. An additional analysis was performed using time series data to test the hypothesis that the Cobb-Douglas production function model tends to overestimate returns to scale when time series data are used. This is a feature of the model that other investigators have mentioned. The time series analysis also acted as a rough check on the results obtained from cross-section analysis.

Production Function Variables

The variables utilized in the production function analysis for the particleboard industry of Oregon were output expressed in physical units, and inputs of capital and labor expressed in dollar units and man hours respectively.

Output

In the particleboard industry, output is expressed in physical units of a thousand square feet (3/4-inch basis). This is a standard conversion made by all plants even though certain products are produced in thicknesses other than 3/4 inch. This measure follows closely the conventional theory of the firm classification for output. Although the product may be heterogeneous in thickness, the common standard thickness statistic places all plants in the industry on a comparable product reporting basis. This variable was obtained from existing plants by interview and for those plants no longer in production, the data were obtained from annual July issues of Timberman and Forest Industries trade publications.

Labor

The measure most appropriate to use as a labor service statistic is number of man hours worked by production workers (Klein, 1962). Although the properties of man hours may differ because (1) man hours do not give an accurate picture of the worker time actually utilized in production, and (2) man hours do not indicate differences in individual worker ability, the measure does give a representative account of labor input into the production process.

Labor services data were obtained from the Oregon State Department of Labor from which annual man hours and wages could be determined.

Capital

The capital variable is the most elusive variable to classify, primarily because of its durability. Many attempts have been made by investigators to obtain a satisfactory measure appropriate for use in production analysis (Kendrick, 1961). Capital, as specified in this study, consisted of production equipment, buildings, and personal property of individual particleboard plants.

In the production function framework, if one assumes that the stock of capital represented in the production function is a demand for the services of capital (equipment, buildings, and personal property), then the flow of capital would appear an appropriate measure of the capital input. In order to measure the flow of capital, it was decided initially to sample plants in the industry by using electrical power consumption as a proxy variable for capital. This can be justified on the assumption that power consumption captures quality and quantity changes in the production process which are not adequately revealed when capital is measured in the usual way by book value. Electrical power consumption is also useful because it gives a measure of the physical productivity of capital.

An objection to use of this proxy variable might be raised because technological development may appear to increase the performance of equipment without increasing power consumption. This would imply that quality changes are underestimated by measuring capital in terms of power consumption. This objection does not seem warranted since personal experience indicates that changes in horsepower and associated power consumption have accompanied changes in particleboard production equipment.

Power consumption data were obtained from electrical power suppliers for those plants not obtaining their service wholly or in part from captive generating facilities.

In order to increase particleboard plant sample size to facilitate statistical analysis, a study was conducted of the correlation between capital value of equipment, buildings, and personal property of individual particleboard plants as determined from state and county tax records and electrical power consumption for these plants.

To establish value of capital stock for taxation purposes, the Oregon State Department of Revenue uses a conservative depreciation schedule covering the actual life of capital items. The actual life concept has been derived to approximate the true operating life of capital and exceeds the useful life concept used as an accounting basis for capital depreciation. Annual adjustments are made to the actual life base which reflect changes in capital stock based on alterations, additions, or deletions of capital items.

Actual life criteria are based on studies conducted by Revenue Department personnel in conjunction with manufacturers of equipment to judge the time span from installation or construction to actual disposal of equipment. The subjective nature of judging this type of information, particularly in the case of new innovations, raises a question as to its value as a basis for capital flow estimation. However, the conservative nature of the depreciation schedule and the Revenue Department's updating of equipment and building value, based on physical condition audits by assessors familiar with particleboard operations and capital items, implies a fair approximation to capital quality changes.

The results of ordinary least squares regression analysis, Table 4. 1, indicated a fairly good correlation between capital value and electrical power consumption. If the assumption of electrical power consumption as an indicator of capital flow is valid, then it could be reasonably assumed that tax assessment values could be used as the capital variable. Since no evidence was uncovered to discredit the use of power consumption as a proxy for capital, it was decided to estimate capital values for those plants in which only power consumption data were available. The capital variable used in the cross-section and time series analyses was the actual or estimated tax

Table 4.1. Least squares regression results for estimation of capital from electrical power consumption, particleboard industry of Oregon, 1958-1970.

Year	Regression equation (Est. capital = $\hat{a} + \hat{b}$ Power con.)	n	R^2
1958	$\hat{C} = 18260.08 + .4992P$ (.0148)	2	.9736
1959	$\hat{C} = 63654.19 + .5797P$ (.1436)	4	.8813
1960	$\hat{C} = 207054.76 + .2075P$ (.0197)	4	.9604
1961	$\hat{C} = 38187.56 + .3181P$ (.0283)	6	.9848
1962	$\hat{C} = 69447.73 + .5136P$ (.1155)	5	.8947
1963	$\hat{C} = 552524.58 + .2594P$ (.0434)	5	.9708
1964	$\hat{C} = 188568.42 + .3808P$ (.0214)	5	.9721
1965	$\hat{C} = 234423.35 + .7873P$ (.2105)	6	.8813
1966	$\hat{C} = 33834.03 + .4222P$ (.1371)	5	.9307
1967	$\hat{C} = 757810.29 + .4952P$ (.0854)	7	.9680
1968	$\hat{C} = 893114.16 + .4132P$ (.0441)	7	.9609
1969	$\hat{C} = 24923.29 + .6017P$ (.1927)	8	.8616
1970	$\hat{C} = 889816.13 + .5381P$ (.2174)	8	.8491

assessment value for equipment, buildings, and personal property obtained from state and county tax records or estimated from power consumption data.

Sample Units

As previously mentioned, the individual particleboard plant was selected as the appropriate sampling unit on which to make observations. The majority of plants producing particleboard are physically distinct entities such that their production inputs are not greatly influenced by integrated manufacturing operations. Those plants that were members of an integrated complex did not appear to be structured such that external influences biased the production process or influenced input data.

Production Input Efficiency

A manager of a particleboard plant, contemplating the use of additional variable production inputs to increase production, is likely to ask himself (or his economist if he has one) three questions: (1) If we buy another unit of a variable production input, what will it cost? (2) If we add another unit of a variable production input to the production process, how much will it add to production output? (3) If we sell that amount of additional output, how much will it add to our revenues? These three questions form the basis for identifying production input efficiency.

Assuming a competitive input market in which the actions of a single plant will not affect the price of an input, the answer to the first question would be the price of the variable input. The answer to the second question would be the marginal physical product which the variable input contributes to output. Economists refer to the change in output caused by a one unit increase of a variable input as the marginal physical product. The reply to the third question would be the value of the marginal physical product or the marginal physical product multiplied by its market price.

The highest price the rational manager would be willing to pay for the production input is one equal to the value of the marginal product. As long as the price of the input is less than its value of marginal product, it would pay to increase the use of the input. This is because the contribution of the input to revenue is greater than its cost. Therefore, efficient production input use may be defined as the production condition in which the value of the input's contribution to production output is equal to its cost. Under a given state of production technology, any deviation from this efficient level of production input use signifies less than a profit maximizing level of operation.

The discussion in this chapter covered the concept of the production function and the production function model used to estimate the efficiency of aggregate production input use. Production function variables were discussed along with their method of determination.

The chapter concluded with a discussion and definition of production input efficiency.

As a first step toward the determination of multi-factor production input efficiency for the particleboard industry of Oregon, the following chapter will present a discussion of the technical-economic relations between particleboard output and production inputs.

CHAPTER V

TECHNICAL-ECONOMIC RELATIONS BETWEEN PRODUCT AND PRODUCTION INPUTS

In the particleboard industry of Oregon, there are several different processes which, with alternative combinations of factor inputs, will yield the product particleboard. It is the purpose of this chapter to discuss the technical-economic relations between factor inputs and particleboard output and attempt to determine if available data support the contention that the particleboard industry of Oregon has experienced an increasing trend toward capital intensification.

Capital input in particleboard production is generally influenced by the type of process used and the scale of operation, more sophisticated processes requiring highly developed, expensive equipment. As the scale of output increases, durable, high speed equipment as well as enlarged building facilities and associated services such as electrical power, fire protection, and heating are required. The major component of capital in the particleboard industry is production equipment, in 1970 averaging 60 percent of total investment cost. Plant buildings and land were a relatively small part, 16 percent, of overall investment (Gray, El Saadi and Curtis, 1970).

Flow inputs associated with production equipment, such as wood, resin and wax, natural gas, oil, electricity, and maintenance and operating supplies, are generally expressed by the costs of these inputs. Wood and resin inputs, where used in this study, could only be estimated from production output data and consequently could not be used as valid independent variables in later production function analysis.

Equipment operating costs in particleboard manufacture are generally expressed in terms of operator's man hours and constitute the labor input. Labor input is an aggregation of operator's man hours as well as other labor services such as maintenance, janitorial, and warehousing and shipping, exclusive of supervision. Supervision input is classified as a separate input entity, relating to managerial talent, an input which could not be obtained for this study.

Capital Input

As previously discussed, capital input used in this study was the capital value of equipment, buildings, and personal property for individual particleboard plants. These data were obtained from state and county tax records where possible, or else estimated from power consumption data where tax records were not available or were not shown separately for the particleboard facility in an integrated plant complex.

Table 5.1 shows the distribution of total capital and capital per thousand square feet of production for different plant size

Table 5.1. Production and capital and labor production inputs by size of plant output, 1955-1970 (production in square feet).

	Plant size		
	Small (0-30)	Medium (30-60)	Large (61+)
		Total capital ($)	
1955	1,561,760 (100%)		
$/M	128		
Total production	12,236,000 (100%)		
1960	8,049,240		
$/M	111		
Total production	72,339,800 (100%)		
1965	15,753,170 (72,3%)	1,911,210 (8.8%)	3,899,450 (18.0%)
$/M	87	55	52
Total production	180,807,000 (61.5%)	34,994,000 (13.0%)	74,400,000 (25.5%)
1970	7,235,660 (19.0%)	7,026,740 (18.6%)	23,779,280 (62.4%)
$/M	72	51	48
Total production	99,904,000 (13.6%)	138,448,000 (18.8%)	499,414,000 (67.6%)
		Labor (MH)	
1955	112,800 (100%)		
MH/M	9		
Ave. wage ($/hr)	1.80		
1960	480,000 (100%)		
MH/M	7		
Ave. wage ($/hr)	1.94		
1965	826,600 (53.2%)	295,620 (19.3%)	406,580 (27.5%)
MH/M	5	8	5
Ave. wage ($/hr)	2.73		
1970	395,000 (12.1%)	375,160 (11.4%)	2,501,040 (76.5%)
MH/M	4	3	5
Ave. wage ($/hr)	3.44		

classifications in 1955, 1960, 1965, and 1970. In 1955, production was confined to small sized plants with capital per thousand square feet averaging $128. In 1970, capital per thousand square feet of production had decreased 44 percent to $78 for the small sized plants while output had increased 715 percent. In 1965 and 1970, the decrease in capital per thousand square feet between the small and large sized plants for each of the two years was 40 and 33 percent respectively.

There appeared to be a high degree of correlation between the capital value per thousand square feet of production and the scale of operation. As plant output increased, less capital per unit of production was required to produce this output. There was also evidence that capital value per unit of output declined over time within the same plant size group. The capital input-particleboard output relationship suggested that unit capital costs, as reflected by capital input, decrease for different plant capacities as the scale of output increases. This evidence suggested that since particleboard is a relatively homogeneous product, economies of scale accruing to capital were influenced by size of plant output and that capital costs decreased as plant output increased. Since capital costs per unit of production also decreased over time within the same plant size group, it would appear that economies of scale accruing to capital were also influenced by technological gains in production equipment and materials plus improvements in abilities of operating and supervisory personnel.

Labor Input

Although the particleboard industry of Oregon is not generally regarded as being labor intensive, discussions with industry personnel seemed to indicate that as the price of labor increased relative to other inputs, management tended to seek out less costly substitutes for labor. Table 5.1 shows that between 1955 and 1970, average wage increased 91 percent while man hours per thousand square feet decreased from nine to four, or 55.6 percent in the small sized plant group. During 1965, man hours per thousand square feet increased from five to eight between the small and medium sized plants and returned to five man hours for the large sized plants. In 1970, man hours increased from four per thousand square feet of production in the small sized plant group to five for the large plants. This would seem to indicate that economies of scale or reduction of average cost did not apply to labor input as output increased. However, the reduction in man hours per unit of output in association with increases in average labor wage for the small and medium sized plants would seem to indicate that capital improvements have been incorporated, leading to a subsequent reduction in man hours required per thousand square feet of output. This tends to reinforce the belief that the particleboard industry of Oregon has become more capital intensive since its inception in 1955 and that technological innovation has contributed to increased production output.

Production Input Cost Trends, 1955-1970

The percentage cost distribution of production and overhead for a 12 million square foot capacity particleboard plant in 1955 and 1970 is shown in Table 5.2. These data are intended to provide a general indication of the order of magnitude for labor, capital, and material costs in particleboard production but, due to the relatively small plant size, should not be construed as being indicative of the industry as a whole. The data give some indication, however, of the cost trends that have occurred over this time span. The major flow inputs of wood and resin-wax show an 18 percent increase in wood costs and a 45 percent decrease for resin-wax costs. Labor costs have remained relatively constant. The largest percentage increase is reflected in capital depreciation, on a tax basis, and interest. Since the interest rate on corporate bonds increased approximately 160 percent (3.53 to 9.11 percent) from 1955 to 1970 (Council of Economic Advisors, 1972), and depreciation data were aggregated and calculated for tax purposes, it was not possible to obtain inferences regarding capital intensification from the depreciation-interest values.

Unavailability of cost data for other plant sizes did not permit additional cost analyses for substantiation of cost trends as scale of plant operation increased.

The analysis indicated that the particleboard industry of Oregon

Table 5.2. Distribution of production and overhead costs for a 12 million square foot particleboard plant in Oregon, expressed as a percentage of total costs, 1955-1970.

	Percent		Percent change
	1955	1970	
Wood	11	13	+ 18
Resin & wax	36	20	- 45
Labor	16	18	+ 1
Operating & maintenance supplies	4	4	-
Sales & shipping	2	6	+200
Electricity	1	2	+100
Natural gas	4	1	- 75
Taxes	16	16	-
Administration expenses	3	4	+ 30
Capital depreciation & interest	7	16	+130

Source: Data obtained from J. Clarke, retired plant manager, Brownsville, Oregon. August, 1972.

became more capital intensive between 1955 and 1970 and that the industry experienced lower capital value requirements per unit of production as the scale of operation increased. The result for labor indicates that total labor services increased proportionately more than capital between 1955 and 1970. However, the labor service requirement per unit of output did not decline as the scale of operation increased. This would appear to indicate that the quality of capital has been more effective in increasing output than has the quality of labor services.

The analysis of single inputs and their relationship to output are insufficient measures of industry performance, failing to show how management combines multiple inputs in the production process to obtain efficient minimum cost input use. Consequently, the following chapter will analyze the interaction of capital and labor inputs, by means of the Cobb-Douglas production function model, to determine if the industry used capital and labor inputs in their most efficient least-cost proportions.

CHAPTER VI

AGGREGATE PRODUCTION FUNCTION ANALYSIS

In the discussion of technical-economic relationships between single factor inputs of capital and labor and output, it was indicated that the particleboard industry of Oregon substantially increased its capital value and that the average cost of capital decreased as output increased between 1955 and 1970. Labor requirements per thousand square feet of output remained relatively constant during this same time span. However, the interaction of capital and labor in the production process and the allocation of these inputs by management to attain a specified output were not examined.

It is the objective of this chapter to define the production function of the particleboard industry of Oregon for each of the years, 1958 through 1970, and to examine the economic efficiency relationship of capital and labor in the production process annually from 1962 to 1970.

The concept of the aggregate production function occupies a central place in the economics of production and resource allocation. A production function embodies the technical relations between inputs and output at the industry level and provides a measure of the amount of inputs required by type to produce the industry's product, particleboard. The analysis of this chapter will examine the relationship between the inputs of capital and labor and the output of particleboard and attempt to determine, where possible, if the particleboard industry of Oregon has used inputs efficiently in its production process. This is done under the assumption that inputs were purchased in a perfectly competitive market. This is a reasonable assumption when one recognizes that particleboard producers are competitive with each other and with other industries situated in their immediate environment for labor services and capital goods.

As previously mentioned, output is particleboard expressed in square feet on a standard 3/4-inch basis. Labor input is man hour services employed in the production of particleboard. Capital input is the capital value of equipment, buildings, and personal property associated with sample plants.

The analysis used cross-section and time series data from a sampling of plants for each year, 1958 through 1970. An attempt was made to analyze data for the years 1955 to 1957 but the regression analysis results indicated negative elasticities and large standard errors. These results plus the small sample sizes in these years raised the question as to the reliability of the data. Consequently, the analyses for these years was omitted.

Cross-section Analysis

Cross-section data for each of the years, 1958 through 1970, was analyzed, using the Cobb-Douglas production function model. The model parameters were estimated by least squares regression and provided estimates of returns to scale and input elasticities of production, the latter necessary for the computation of mean marginal productivities of production inputs. The marginal productivities permitted the estimation of production input efficiency during 1962 through 1970, the years in which census data on particleboard price were available.

As previously mentioned, the Cobb-Douglas production function model was utilized, the function being transformed into the following linear form to permit the use of least squares regression:

$$\log O = \log I + a \log K + b \log L + \log e$$

where

O = output

I = intercept

K = capital input

L = labor input

a = elasticity of production with respect to capital

b = elasticity of production with respect to labor

e = random disturbance

log = logarithmic transformation of variable to base 10

The reasons for this choice were primarily because the model yields elasticities of production directly, reveals condition of returns to scale, and requires few degrees of freedom for estimation.

Production Function Results

The least squares solution of the production function for 1958 was:

$$\log O = 1.0964 + .7889 \log K + .6802 \log L$$
$$\qquad\qquad (.2782) \qquad\quad (.2487)$$

$$n = 8 \qquad R^2 = .7069$$

The standard errors for the estimated coefficients are shown in parentheses under the coefficient.

Elasticity of Production. The input coefficients in the transformed model measure the estimated elasticity of production for each production input. These elasticities were tested in association with their standard errors of estimate to determine if the elasticity was significantly different from zero. If significant, the elasticity estimates the percentage change in output associated with a one percent increase in the use of the input. The test hypothesis was that a or b = O using the t statistic:

$$t = \frac{\text{a or b} = O}{\text{std. error of a or b}}$$

The test statistic for a and b, 2.835 and 2.735, were both significantly greater than zero at the 95 percent level of significance, inferring that both influence output. A one percent increase in capital assets providing a .79 percent increase in output and a one percent increase in labor man hours providing a .68 percent increase in output. Since both elasticities were less than one, decreasing returns to both capital and labor prevail. This provides an estimate of production output changes as one or the other input is varied, all other inputs remaining constant.

Returns to Scale. The returns to scale characteristic of the industry for 1958 was obtained by adding both capital and labor elasticities of production: a + b = RTS. As previously mentioned, if returns to scale are less than, equal to, or greater than 1, decreasing, constant, or increasing returns prevail, indicating that output increases at a rate less than, equal to, or greater than the rate at which the inputs increase. The returns to scale for 1958 was 1.4691 which seemed to indicate increasing returns to scale for capital and labor. However, when this statistic was tested for the hypothesis that a + b = 1 using the t test

$$t = \frac{a + b - 1}{\text{std. error of } a + b},$$

which indicates if the sum of elasticities of production are significantly different from one; it was found that constant returns to scale were indicated for the industry in 1958. The calculated value was 1.150 which was significantly less than the 95 and 99 percent levels of significance with six degrees of freedom.

The standard error of estimate for the combined elasticities was determined as follows:

$$[\text{var. } a + \text{var. } b + 2 \text{ cov. } (a \times b)]^{1/2}$$

Therefore, constant returns to scale were indicated suggesting that output increased in direct proportion to increases in capital and labor during 1958. The returns to scale information provides an estimate of the change in output to be expected by a given increase of all inputs included in the regression model.

However, Heady and Dillon (1961) in a discussion of returns to scale point out the possibility that returns to scale may be biased unless all production inputs are included in the production function. They suggest that for the range of samples used, returns to scale will be underestimated if the excluded inputs vary less than proportionately with changes in the included inputs. They also suggest that neglecting quality differences in other production inputs may lead to biased estimates of returns to scale.

Since the only other input data available were electrical power consumption which was closely correlated with capital (Table 6.2) and wood and resin adhesives, it was not possible to conclude that excluded inputs varied less than proportionately with the included inputs. Tables 3.2, 3.3, 3.4, and 3.5 would seem to suggest that wood and resin inputs increased at approximately twice the rate of capital and labor inputs. Therefore, based on the available data, there is no evidence indicating that returns to scale are underestimated.

<u>Coefficient of Multiple Determination.</u> The coefficient of multiple determination or R^2 measures how well the variation in output was accounted for by the two inputs. The closer this value approaches one, the better is the explanation of output variation by the inputs. The difference between one and the value of R^2 indicates the amount of random disturbance which is not accounted for by the included input variables. For 1958, R^2 was .7069, implying that approximately 71 percent of the variation in production output was explained by capital and labor inputs.

Associated with the coefficient of multiple determination is the correlation coefficient which measures the correlation between the variables used in the regression model. This value ranges from -1 to +1, the closer the values are to +1, the higher the degree of correlation between variables. The following are the correlation coefficients obtained for 1958:

	Output	Capital	Labor
Output	1.0000	.7550	.5891
Capital		1.0000	.3157
Labor			1.0000

The desired situation is to have variables with high correlation between the dependent and independent variables and low correlation between independent variables. The data are fairly representative of this although it had been hoped that the labor input would have had higher correlation with output.

The above data do not appear to be out of line with accepted theory, so it may be inferred that based on the sample data, the particleboard industry of Oregon in 1958 operated with decreasing returns to scale for capital and labor when considered individually, but constant returns to scale when the input elasticities were combined.

The above analysis was outlined to indicate the procedure used for each year, 1958 through 1970. The individual regression results for each year are presented in Table 6. 1.

The analysis of regression results indicated that constant returns to scale for combined inputs prevailed for the particleboard industry each year, 1958-1970. A statistical t test of returns to scale, which was discussed in Chapter IV, revealed that none of the annual returns-to-scale values were significantly different from one at the 95 percent level of significance. This would imply that output increased in direct relationship to increases of the combined inputs, capital and labor.

Increasing returns to scale was indicated for capital individually in 1963. In 1963, capital value increased 41 percent over that of 1962 primarily due to the start-up of a large automated plant that had incorporated expensive production equipment into its production process. The influence of this plant probably accounts for the increasing returns to capital in 1963.

All input coefficients appear to be well estimated for each of the

Table 6.1. Regression analysis results for the particleboard industry of Oregon, 1958-1970. Cobb-Douglas production function model.

Year	Coefficients K	Coefficients L	RTS	R^2	n		Correlation O	Correlation K	Correlation L
1958	.7889	.6802	1.4691	.7069	8	O	1.0	.7550	.5891
	(.2782)	(.2487)	(.4080)			K		1.0	.3157
	$O = 1.0964\, K^{.7889} L^{.6802}$					L			1.0
1959	.7916	.8673	1.6589	.8523	8	O	1.0	.7083	.4849
	(.3015)	(.3179)	(.463)			K		1.0	.2105
	$O = .8210\, K^{.7916} L^{.8673}$					L			1.0
1960	.9256	.8648	1.7804	.8434	9	O	1.0	.7004	.5729
	(.2083)	(.2424)	(.358)			K		1.0	.4522
	$O = -2.5107\, K^{.9256} L^{.8648}$					L			1.0
1961	.7957	.4762	1.2719	.8469	10	O	1.0	.7624	.8124
	(.2487)	(.1412)	(.308)			K		1.0	.5792
	$O = 1.7552\, K^{.7957} L^{.4762}$					L			1.0
1962	.9069	.4724	1.3739	.9233	9	O	1.0	.9431	.5772
	(.1334)	(.1672)	(.376)			K		1.0	.4364
	$O = .4651\, K^{.9069} L^{.4724}$					L			1.0
1963	1.1350	.3763	1.5113	.9122	9	O	1.0	.8815	.8295
	(.3699)	(.1344)	(.433)			K		1.0	.6187
	$O = -1.5952\, K^{1.1350} L^{.3763}$					L			1.0

(Continued on next page)

Table 6. 1. (Continued

Year	Coefficients K	Coefficients L	RTS	R^2	n		Correlation O	Correlation K	Correlation L
1964	.6327	.7430	1.3757	.9443	9	O	1.0	.9122	.6625
	(.2069)	(.2192)	(.367)			K		1.0	.7594
	$O = .7758\ K^{.6327}\ L^{.7430}$					L			1.0
1965	.6756	.8380	1.5136	.8499	11	O	1.0	.6184	.7590
	(.2724)	(.3195)	(.475)			K		1.0	.5058
	$O = .8366\ K^{.6756}\ L^{.8380}$					L			1.0
1966	.5109	.5419	.8956	.8956	13	O	1.0	.8225	.7586
	(.1555)	(.1831)	(.383)			K		1.0	.5807
	$O = 2.0654\ K^{.5109}\ L^{.5419}$					L			1.0
1967	.7087	.6377	1.3464	.8864	11	O	1.0	.8527	.6981
	(.2017)	(.2272)	(.455)			K		1.0	.5881
	$O = -.6002\ K^{.7087}\ L^{.6377}$					L			1.0
1968	.4484	.5949	1.0433	.8690	12	O	1.0	.8463	.8092
	(.1652)	(.2057)	(.583)			K		1.0	.5897
	$O = 3.9111\ K^{.4484}\ L^{.5949}$					L			1.0
1969	.4736	.4855	.9591	.9020	13	O	1.0	.8313	.8249
	(.0996)	(.1046)	(.366)			K		1.0	.5204
	$O = 2.1299\ K^{.4736}\ L^{.4855}$					L			1.0
1970	.4606	.5998	1.0604	.8950	12	O	1.0	.7957	.8869
	(.1151)	(.1266)	(.383)			K		1.0	.6002
	$O = 1.6201\ K^{.4606}\ L^{.5998}$					L			1.0

annual regressions, having relatively small standard errors. All coefficients were found to be significantly different from zero at the 95 percent level, indicating that decreasing returns prevailed annually to capital and labor when considered individually, with the exception of capital in 1963 as explained above.

The correlation coefficient between capital and labor in 1964 appears high with respect to the correlation between inputs and output. However, with the high R^2 (.9443) and the small input coefficient standard errors, there is no reason to believe that the equation was not properly specified.

The analysis so far does not indicate the degree of efficiency experienced by the particleboard industry but does provide the information necessary to calculate marginal productivities, from which subsequent efficiency comparisons can be made.

Under perfectly competitive market conditions for inputs, which is assumed in this study, the rational manager operates in an efficient manner if he utilizes factor inputs to the point where the value of the marginal product is equal to the average cost of the input.

The next stage in this analysis is to determine the marginal products for inputs of capital and labor. Marginal product measures the contribution which each input makes to output and is determined by the relationship between average product for the input under consideration and the elasticity of production for the input (Klein, 1962).

The elasticity of production is:

$$e = \frac{\text{change in output/output}}{\text{change in input/input}}$$

or

$$e = \frac{\text{change in output}}{\text{change in input}} \times \frac{\text{input}}{\text{output}}$$

where marginal product is

$$\frac{\text{change in output}}{\text{change in input}}$$

and average product is

$$\frac{\text{output}}{\text{input}}$$

Marginal product of a particular input is therefore equal to elasticity of production (e) times the average product for that input. This illustrates an advantage claimed earlier for the Cobb-Douglas production function: elasticities of production for the inputs are derived directly as exponents of respective inputs.

Marginal Product of Capital Analysis, 1958-1970

The values used for the determination of average product were geometric means or estimated means after transformation to antilogs for the respective output and inputs (Carter and Hartley, 1958). The standard error for marginal product was calculated from the standard error of estimate for the respective elasticity of production.

The results of marginal product for capital, labor, and power are shown in Table 6.2.

Table 6.2. Marginal products of capital, labor, and power consumption, particleboard industry of Oregon, 1958-1970, expressed in square feet (3/4-inch basis).

Year	Capital		Labor		Power consumption	
	MP	Std. error	MP	Std. error	MP	Std. error
1958	8.71	3.07	142.94	52.26	2.26	.92
1959	14.64	5.57	148.44	54.32	2.37	1.09
1960	7.99	1.79	203.86	57.80	2.48	.53
1961	10.17	3.18	183.81	46.27	3.48	1.34
1962	14.04	2.06	156.30	55.32	2.43	.34
1963	11.54	3.76	200.18	71.49	2.33	.73
1964	11.18	3.66	152.73	45.06	3.70	.82
1965	8.57	3.37	212.49	80.02	1.07	.55
1966	8.90	2.71	209.33	70.72	1.98	.60
1967	9.06	2.57	228.98	81.58	2.17	.52
1968	9.17	3.38	270.36	93.48	1.96	.56
1969	9.94	2.09	246.36	53.08	2.06	.43
1970	8.33	2.73	287.44	60.67	1.51	.59

The estimated marginal product of capital, in association with its standard error, indicates the increase in output resulting from a one dollar increase in capital. From 1958 to 1962, marginal productivity of capital increased from 8.7 to 14 feet. From 1962 to 1970, marginal productivity of capital decreased from 14 to 8.3 feet, suggesting that capital was used in excessive amounts relative to labor.

Since constant returns to scale were indicated from the production function analysis, it would appear that increases in output between

1958 and 1964 were largely augmented by improvements in the quality of capital. This is reflected somewhat by observing returns to scale for capital (Table 6. 1) where capital contributed rather consistently to increased output over the contribution of labor. Commencing in 1964 and extending to 1970, capital apparently had less influence on output than did labor. This is reflected by the relatively larger elasticities for labor over capital, indicating the increased influence of the labor input on output.

Capital Efficiency

Capital input efficiency was determined by comparing the value of marginal product of capital with the cost of capital. As long as the revenue to be gained from producing an additional unit of output exceeds the cost of producing that unit, it will pay the rational manager to increase the use of capital to the point where its contribution to revenue equals its cost. This is the point of optimum capital efficiency as well as being the point of least cost for the inputs.

The value of marginal product of capital was estimated by multiplying average price of particleboard per square foot (Table 3. 7) times the marginal product of capital (Table 6. 2) for those years in which average particleboard price was available, 1962-1970.

Cost of capital was estimated from Baa bond interest rates reported in Moody's Investor's Service tables. The decision to use this particular rate was reached after observing the interest rates associated with corporate borrowings for those corporations having particleboard plants in Oregon. This information was contained in Standard and Poor's Investment Guides and Walker's Manual of Western Corporations and Securities. The data from these publications indicated that Baa bond interest rates would be a good approximation to average capital cost on an annual basis from 1962 to 1970.

Capital cost determinations were made by multiplying the amount of capital associated with the production of marginal product times the bond interest rate for the particular year. The results for value of marginal product of capital and cost of capital are shown in Table 6. 3.

Table 6. 3. Comparisons of estimated value of marginal product and average cost of capital for particleboard industry of Oregon, 1962-1970.

Year	Marginal product (sq. ft.)	Std. err. MP (sq. ft.)	Value MP ($)	Std. err. VMP ($)	Average cost ($)
1962	14.04	2.06	1.375	.202	.045
1963	11.54	3.76	.916	.298	.033
1964	11.18	3.66	.760	.249	.028
1965	8.57	3.37	.840	.300	.031
1966	8.90	2.71	.792	.241	.030
1967	9.06	2.57	.788	.224	.057
1968	9.17	3.38	.899	.321	.046
1969	9.94	2.09	1.163	.259	.039
1970	8.33	2.73	.741	.243	.039

These results indicate that the particleboard industry was not using capital in sufficient quantities to obtain an efficient use of the capital input. Since the cost of capital was substantially less than its contribution to revenues, indicated by the value of the marginal product, additional capital input should have been utilized. The use of capital should have been increased until the marginal rate of return, value of marginal product, was equal to the cost of capital. Based on this evidence, the particleboard industry did not efficiently use capital input in the production of particleboard for the years 1962 to 1970.

Marginal Product of Labor Analyses, 1958-1970

The estimated marginal productivity of labor refers to the increase in output resulting from an increase of one additional man hour of labor. From 1958 to 1970, the labor input has shown a relatively steady increase in its contribution to output, increasing from 142. 9 to 287. 4 square feet in terms of marginal productivity. As previously discussed, capital contributed proportionately more to output from 1958 to 1964, but commencing in 1964, labor contributed proportionately more to output than did capital. This suggests that increasing returns to education and improvements in the quality of labor have tended to augment production output during the latter years of the analysis. The increased contribution of labor to output is reflected in returns to scale for labor (Table 6. 1) in which proportional increases in labor input contributed rather consistently to increased output between 1964 and 1970 over the capital input.

Labor Efficiency

To determine if labor was being efficiently used in the production of particleboard, it was necessary to compare the value of marginal product for labor with its cost.

The value of marginal product for labor was estimated by multiplying the price of particleboard (Table 3. 7) times the marginal product of labor (Table 6. 2) for each of the years 1962 to 1970.

The cost of labor was determined by multiplying the average labor wage per square foot of output times the marginal product of labor for each of the years 1962 to 1970. Average labor wage for the particleboard industry was estimated from data furnished by the Oregon Department of Labor. The results of estimated values of marginal product and cost of labor are shown in Table 6. 4.

These estimates indicate that the particleboard industry was not efficient in its use of labor between 1962 and 1970. Labor was contributing more to output than it was receiving in the form of wages. Therefore, it would have been advantageous for the industry to hire additional labor up to the point where labor's contribution to output revenue was equal to its cost. Based on these results, labor was

Table 6.4. Comparisons of estimated value of marginal product and average cost of labor for particleboard industry of Oregon, 1962-1970.

Year	Marginal product (sq. ft.)	Std. err. MP (sq. ft.)	Value MP ($)	Std. err. VMP ($)	Average cost ($)
1962	156.30	55.32	15.317	5.421	1.876
1963	200.18	71.49	15.892	5.667	3.003
1964	152.73	45.06	10.386	3.064	1.985
1965	212.49	80.02	20.820	7.842	3.190
1966	209.33	70.72	18.630	5.294	2.273
1967	228.98	81.58	19.921	7.097	2.987
1968	270.36	93.48	26.495	9.161	4.062
1969	246.36	53.08	28.824	6.210	3.947
1970	287.44	60.67	25.582	5.400	4.319

underutilized and the industry was inefficient in its use of the labor input from 1962 to 1970.

The results of mean marginal productivity analysis for capital and labor indicate that the particleboard industry was inefficient in its use of both capital and labor inputs from 1962 to 1970. Neither capital nor labor were receiving a return commensurate with their contribution to production. For most efficient use of these inputs, their utilization should have been increased so as to equate the value of their marginal product with their cost.

Time Series Analysis

A production function using time series data for the period 1958 through 1970 was also derived in order to compare results obtained from this approach with those from the cross-section analysis. This was done to serve as a general check on the average estimated marginal products for capital and labor obtained from the cross-section analysis. It was also performed to test the hypothesis advanced by Griliches (1963a) that the cumulative effects of technological changes over time may indicate increasing returns to scale for time series data even though cross-section data indicated constant returns. The model used was the Cobb-Douglas production model, variables being total production output, capital, and labor for the aforementioned years.

The least squares regression results are shown in Table 6. 5.

Production Function Results

The coefficients for capital and labor are both significantly greater than zero at the 95 percent level of significance, having calculated t values of 4. 559 and 3. 761 respectively with 11 degrees of freedom. Therefore, both inputs influence output. The coefficient for capital indicated diminishing returns to capital, a one percent increase in capital resulting in a .55 percent increase in output. The coefficient for labor indicated constant returns to labor, a one percent increase in labor resulting in a one percent increase in output.

The combination of the two inputs, reflected in returns to scale, indicated increasing returns to scale for capital and labor. A one percent increase in production inputs resulted in a 1. 59 percent

Table 6.5. Regression results for time series data, particleboard industry of Oregon, 1958-1970.

Coefficients		RTS	R^2	n	Correlation			
K	L					O	K	L
.5531	1.0384	1.5915	.9929	13	O	1.0	.9740	.8956
(.1213)	(.2761)	(.3855)			K		1.0	.7672
					L			1.0

$$O = .7585\ K^{.5531}\ L^{1.0384}$$

Durbin Watson K = 3.619
L = 3.467

increase in output. A test of the hypothesis that a + b = 1 indicated that their sum is significantly different from one, verifying that increasing returns to the inputs occurred for time series data. This is in contrast to cross-section data analysis in which all years, when statistically checked, indicated constant returns to scale from 1958 to 1970.

The reason for the difference is undoubtedly due to the influence of technological change which in the case of time series data tends to be cumulative. Studies of other industries infer a tendency for the Cobb-Douglas production function derived from time series data to give indications of increasing returns to scale when none exist (Griliches, 1962a).

The high correlation of multiple determination, .993, indicates that the variation in output is well explained by the inputs. Correlation coefficients indicate a high correlation between inputs and output as well as a fairly high inter-correlation between capital and labor. However, the presence of small coefficient errors, a high multiple determination coefficient, and an indication by the Durbin-Watson test statistic that serial correlation is not present, would all seem to indicate that the regression is well estimated.

Marginal Product Results

The marginal products of capital and labor were calculated to determine how well time series data results agreed with average marginal products obtained from cross-section data.

The marginal product of capital was 8.27 square feet with a standard error of ± 1.81 square feet. This indicates that the addition of one dollar of capital to the production process will increase output between 6.46 and 10.08 (8.27 ± 1.81) square feet. The average marginal product obtained from cross-section data was 9.92 square feet. Therefore, it may be concluded that the marginal product comparisons between the two types of data analysis showed close agreement.

A marginal product comparison was also made for labor. A marginal product of 242.81 ± a standard error of 28.25 square feet was obtained from time series data as compared to an average marginal product for labor of 212.96 from cross-section data. This would seem to indicate that the time series analysis overestimated labor productivity based on the average value from cross-section analysis.

It was not possible to state anything about the trend of marginal product with time series data over time since only one time period was considered, 1958-1970. Also, it was not possible to state any conclusions regarding the efficiency of input use from the time series analysis since average price data were not available for the entire time period.

The objective of this chapter was to define the aggregate production function for each of the years, 1958 through 1970, and to measure the economic efficiency of capital and labor input use on an annual basis from 1962 to 1970, years in which relevant price data were available. The analysis indicated that the particleboard industry of Oregon operated under constant returns to scale for each of the years, 1958 through 1970. Thus, firms of various sizes were able to survive in particleboard production in spite of a trend during this period toward larger sized plant operations.

Inefficient use of capital and labor inputs were indicated for each of the years, 1962 to 1970, inferring that management was doing an ineffective job toward minimum cost attainment for these inputs.

The following chapter will continue the discussion of particleboard industry efficiency, with emphasis on economies of scale. In earlier chapters, it was alluded that economies of scale and associated lower average costs accrued to the larger capacity plants, so the combination of partial input cost data and the survivorship technique for average cost estimation will be utilized to attempt to measure empirically relative economies of scale.

CHAPTER VII

ECONOMIES OF SCALE

In the cross-section analysis of the preceding chapter, the particleboard industry of Oregon was found to have operated under constant returns to scale for capital and labor inputs for each of the years, 1958 through 1970. This indicated that output increased in direct proportion to the amount of the two inputs used. In addition, inefficient utilization of capital and labor inputs was found to have existed annually from 1962 to 1970, years in which relevant marginal cost and average cost determinations could be made. This indicated that managers were not using either input in sufficient quantities to obtain a minimum cost operating condition during the nine years analyzed.

In a further attempt to examine particleboard industry efficiency, this chapter analyzes economies of scale in an attempt to estimate the industry long run average cost curve and discuss those conditions where large capacity particleboard plants might possibly experience economies of scale.

The expression "economies of scale" is used by economists to designate the cost advantages or economic efficiencies that a large physical plant may have over a small one. Most of the empirical evidence on economies of scale support the so-called L-shaped long run average cost curve. Wiles (1955) maintains that decreasing costs at high output are rare. Johnston (1960) also maintains a belief in the preponderance of evidence supporting an L-shaped pattern of long run average cost. A similar conclusion was reached by Bain (1956) in his study of 20 American industries.

Actual measures of economies of scale in particleboard production could be attempted either in individual plants, providing sufficient cost data were available, or in some aggregate way using cross-section or time series data. Ideally, cross-section cost data on firms of different size would yield the best results, as previously explained in Chapter IV. However, cost data for individual plants were not available; therefore, another method for deriving a measure of decreasing costs at large scale production, the survivorship technique, was utilized (Stigler, 1958).

Survivorship Method

The fundamental hypothesis of the survivorship method of estimating economies of scale is that competition between different sizes of plants sifts out those plants that are least efficient while the more efficient survive in the industry. The concept of efficiency in the survivorship context refers to the relative change in production output which a plant or plant group experienced. The more rapidly the percentage share of output decreases, the more inefficient the plant group is considered to be. The assumption is then made that the more rapid the rate at which a plant group loses its share of industry output, the higher is its average cost of production relative to the costs for plants of the most efficient size.

The long run average cost curve for an industry is the envelope of the average cost curves of individual plants within the industry (see Figure 7. 1). Since the inefficient plants are assumed to have higher average costs of production relative to the more efficient plants, the position of the inefficient plants would be at a relatively higher level on the industry average cost curve.

By observing plant groups in an industry and their relative percentage change of production output over time, these plant size groups may be classified as to their relative efficiency. Since efficiency by assumption reflects average cost, it is possible to construct a hypothetical average cost curve which indicates whether economies of scale are present for an industry.

The survivorship technique involves the following steps: (1) classification of plants in an industry by size, and (2) determination of which size classes are increasing or decreasing their shares of total output. A requirement of the survivorship technique is that plants used in the analysis should be competing with plants in their own size class as well as with plants of other sizes. Observation of

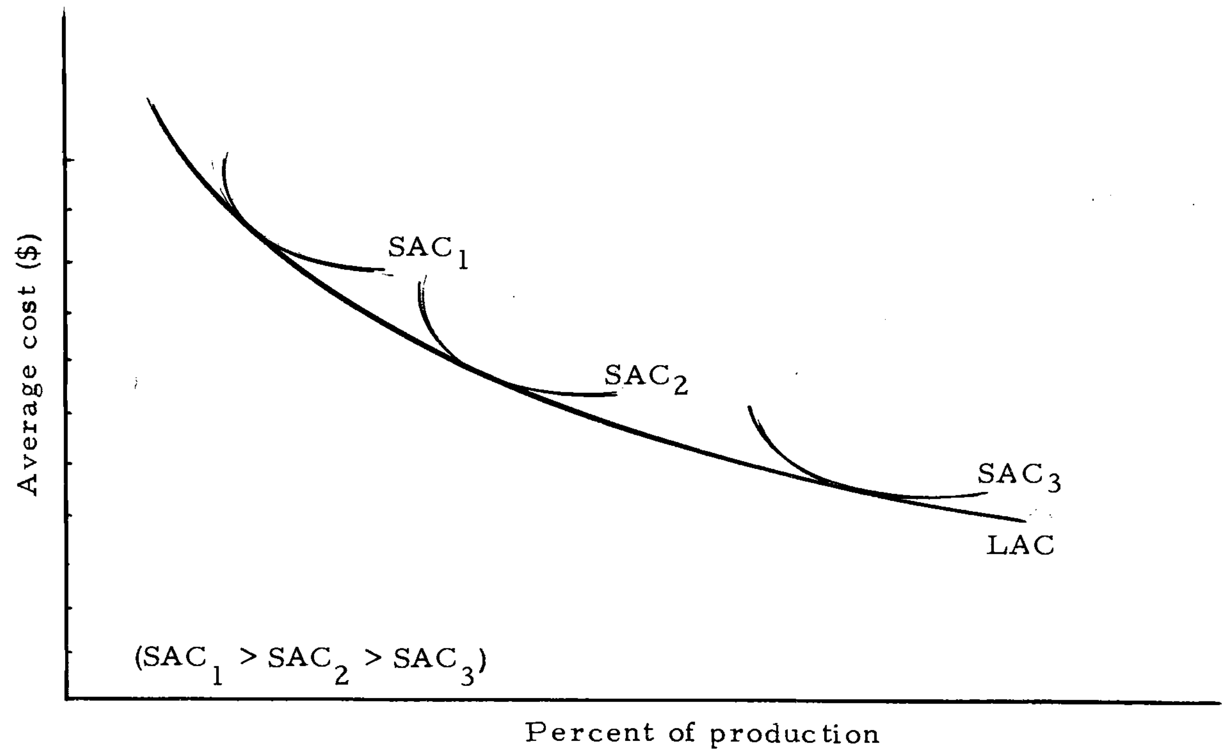

Figure 7.1. Hypothetical shape of long run average cost curve for particleboard industry of Oregon.

competitive relations within the particleboard industry in Oregon indicates this requirement is satisfied.

The output of individual plants in the particleboard industry of Oregon was grouped into the size classes shown in Table 7. 1 and their percentage distribution of output determined.

These data show that there has been an appreciable decrease in output shares for plants with less than 80 million square feet of annual production, inferring that with the possible exception of plants with outputs exceeding 100 million square feet, diseconomies of scale and inefficiencies exist for the smaller plants. The large percentage increase in output shares for the largest plants implies they are experiencing economies of scale and operating near optimum size, or at least are more efficient than the smaller plants.

Qualitatively, the above data could be expressed in the form of a hypothetical long run average cost curve for the industry as shown in Figure 7. 1. Although the data do not measure actual average cost and thus permit drawing a cost curve to scale, they do permit drawing some inferences about the probable shape of the long run average curve, which therefore appears to be downward sloping over the range of output.

Estimated Industry Average Cost Curve

Further evidence which supports the general shape of the

Table 7.1. Economies of scale, percentage of particleboard production by size class, Oregon, 1955-1970.

Size class (MM sq. ft. 3/4"-basis)	Year														
	1955	1956	1957	1958	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
0-20 (1)	100	100	100	100	100	100	52.5	42.2	8.4	9.2	5.7	5.3	1.4	.7	.6
20.1-40 (2)							47.5	57.8	63.9	65.4	43.1	26.0	21.9	20.3	16.8
40.1-60 (3)									27.7	0	11.2	17.3	31.2	22.9	13.9
60.1-80 (4)										25.4	0	13.2	11.8	9.5	8.8
80.1-100 (5)											40.0	38.2	16.1	13.9	24.8
100.1-120 (6)													17.6	15.4	0
120.1-140 (7)														17.3	35.1

Class 1 - % change 1962-1970: -98.5, -10.9 per year
Class 2 - % change 1962-1970: -64.9, - 7.4 per year
Class 3 - % change 1964-1970: -50.0, - 7.2 per year
Class 4 - % change 1965-1970: -65.5, - 9.4 per year
Class 5 - % change 1966-1970: -38.1, - 7.6 per year
Class 6 - % change 1968-1970: - No Sample - 1970
Class 7 - % change 1969-1970: +103.0, +51.6 per year

industry's long run average cost curve may be obtained by utilizing average cost values presented in Chapter III. These average costs were estimated for wood, resin, and labor during 1955, 1960, 1965, and 1970. Although these three factor inputs do not constitute the total costs of production, they do represent an estimated 50 to 70 percent of manufacturing costs per thousand square feet. Consequently, it was felt that the curve resulting from the partial cost-output relationship would give a fair approximation of the shape of the industry's long run average cost curve.

This curve is represented in Figure 7.2 and was derived from a regression equation fitted by least squares having the form:

$$Y = 2.6112\, X^{\underset{(.0081)}{-.1127}}$$

$$R^2 = .970$$

Y = average cost per thousand square feet-wood, resin, and labor

X = production, square feet

Although this is not an accurate representation of total manufacturing cost, it does tend to confirm the results obtained from the survivorship technique, indicating that larger plants are operating at lower average costs. It may then be inferred that larger plants are experiencing economies of scale and may be classified as being more efficient in their scale of operation.

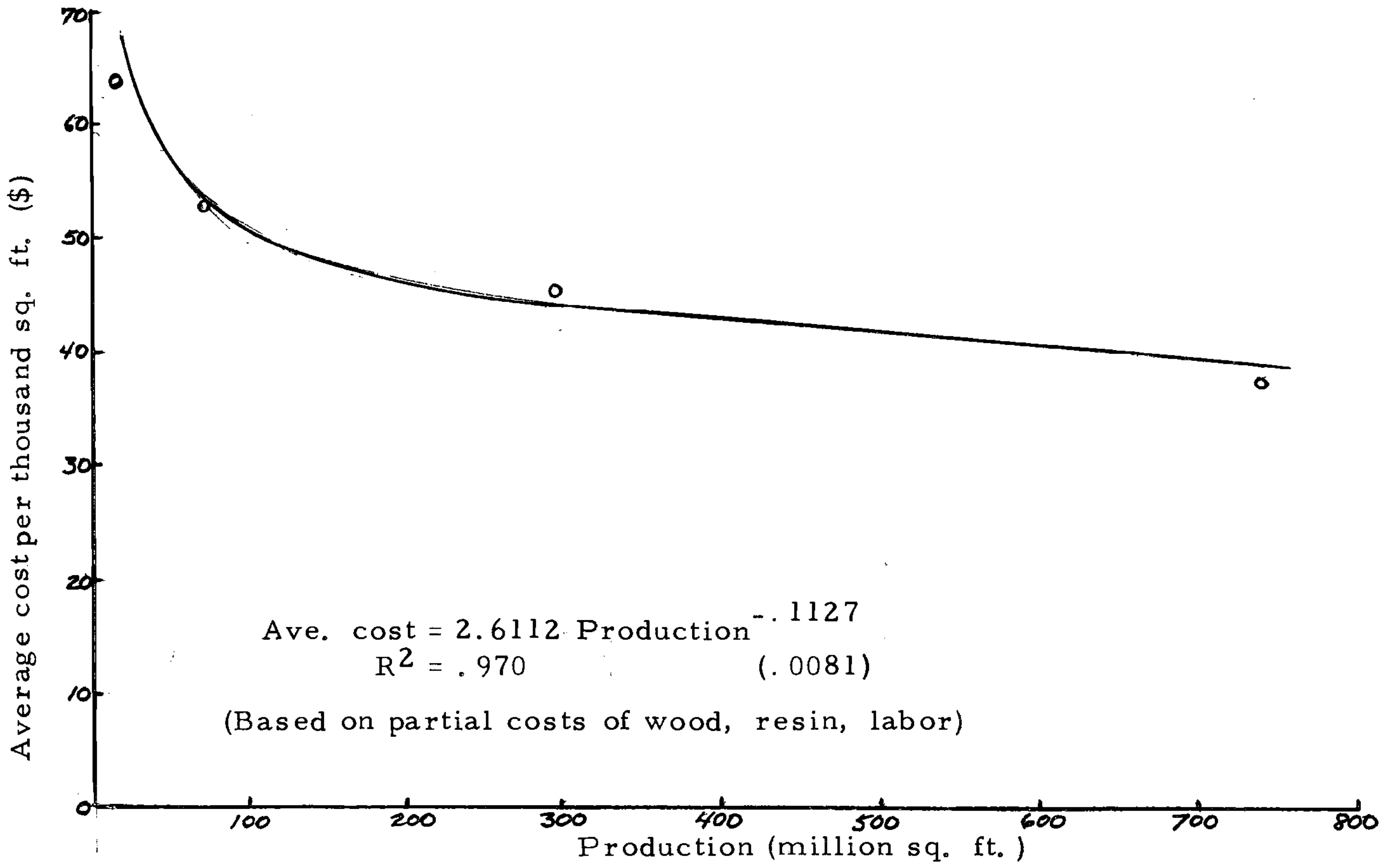

Figure 7.2. Estimated long run average cost curve for the particleboard industry of Oregon, 1955-1970.

Possibilities for Economies of Scale

The question might appropriately be asked as to why economies of scale can exist in large plants, recognizing that largeness and economies of scale are not synonymous. While largeness may be a necessary condition for economies of scale, it does not in itself guarantee economies of scale.

It is commonly argued that diseconomies of scale are common to large plants due to difficulties in administration, decision making, asset fixidity, and motivation of salaried personnel, to mention a few. This study would seem to indicate that if these conditions exist in the large plants, there are apparently economies of scale present which tend to override them.

Some reasons why particleboard plants may experience economies of scale follow. One interesting possibility arises in financing, which during the early stages of the particleboard industry, played an important role in industry instability. During the first six years of the industry, 1955-1960, the majority of plants were small operations, individually owned, whose entrepreneurs had limited financial resources. Their size limited the ability to obtain funding for maintenance of operations and expansion; consequently, many of these small operations failed due to financial constraints. As large corporations entered the industry with their financial soundness and ability to obtain funds at the prime lending rate or at reduced rates on notes secured by inventories, their cost of financing was reduced. Particleboard plants, owned by these corporations, were favored in expanding their scale of operations by lower interest charges, thus incurring economies of scale in financing over the smaller members of the industry.

Another important advantage to Oregon's larger particleboard producers is economies of scale in transportation since the majority of particleboard production is exported to other regions. The large capacity plant is able to capture economies of scale through qualifying for special transportation rates. These rates are generally based on loading ten or more rail cars per day, transporting them on the same train, and unloading the cars in one day. Smaller plants do not have the production capacity or concentrated sales distribution to maintain this program; consequently, they are not able to capture economies of lower transportation rates.

Another factor contributing to economies of scale for large plants is warehouse space. The larger the capacity of warehouse facilities, the lower the cost per square foot for storage of in-process and processed product. Associated with warehouse and transportation economies is the element of a distribution warehouse chain commonly utilized by large multi-product forest products corporations to aid in the distribution of a product line to localized areas. By utilizing this intermediate storage facility, particleboard plants can ship large volumes of product to a central location, thus capturing economies of scale for transportation and also economies of large size product lines which permit the establishment of this type of distribution system.

Probably the most important economy of scale incurred by large particleboard plants is that of physical plant efficiency with associated specialization of labor and supervision. By incorporating costly but otherwise efficient production equipment capable of high volume production, these plants are physically capable of producing in such quantity that cost per square foot is substantially reduced over that of less capital intensive plants. In order to accomplish this, the plant must have warehouse, sales, and distribution channels capable of handling the high volume of production. In turn each of these channels offers economies of scale as previously mentioned.

Economies of scale in procurement of operating supplies and material inputs would be another important element characteristic of large size particleboard plants. This is particularly relevant to resin purchases. Resin adhesives constitute the major percentage of manufacturing costs; consequently, any cost savings in purchasing this input is an important element of efficiency for achieving economies of scale. By negotiating with resin suppliers for large volume purchases of resin, the large plant is in a position to obtain lower rates per pound. At the extreme, the resin supplier may actually install a resin plant adjacent to a particleboard plant, thus eliminating resin transporting costs and permitting additional economies of scale in procurement of resin.

This list of economies of scale peculiar to large particleboard plants is not exhaustive but rather indicative of the possibilities that large volume producers have in achieving lower production and marketing costs. Where these outweigh diseconomies, the large plant is able to efficiently exploit its lower cost advantages. As smaller plants observe this discrepancy in their own cost situation, they tend to expand the scale of their operations. The result is a general expansion of the industry as has been characterized by the particleboard industry of Oregon.

This chapter continued the discussion of industry efficiency, with emphasis on economies of scale at the plant level. The survivorship technique, which was used to measure decreasing cost, indicated an appreciable decrease in output shares for plants with annual production less than 80 million square feet, inferring that diseconomies of scale exist for smaller capacity plants. For plants with capacities greater than 80 million square feet, increasing output shares were indicated inferring that these plants were experiencing economies of scale or at least were more efficient than the smaller plants. The survivorship analysis suggested that average cost for the industry was lower per thousand square feet of production at higher outputs. The downward sloping average cost curve as output increases was substantiated by a partial cost analysis which indicated that larger capacity plants were operating at lower average costs and experiencing economies of scale, thus were more efficient in their scale of operation.

The following chapter will attempt to determine if there are differences in efficiency between various plants within an industry for a given year.

CHAPTER VIII

MEASUREMENT OF PARTICLEBOARD PLANT EFFICIENCY

Chapter VI was concerned with an analysis of input use in particleboard production from 1958 through 1970 and measured how efficiently the particleboard industry of Oregon utilized factor inputs of capital and labor by comparing the value of marginal product and average cost of each input for the years 1962 to 1970. However, the results of that aggregate production function analysis gave no indication of efficiency of individual particleboard plants. The analysis in this chapter, therefore, turns to the measurement of efficiency for individual plants from 1962 through 1970.

Concept of Individual Plant Efficiency Frontier

An industry consisting of a number of plants, each plant producing a homogeneous product, possessing perfect knowledge, having identical production functions, maximizing profits perfectly, and operating in the same economic environment would possess identical input and output levels for each plant (Nerlove, 1965). However, in the real world differences in productive capabilities exist among plants and are the result of differences with respect to technological knowledge, amounts of fixed factors, managerial capability, ability to maximize profits, and the economic environment within which a plant operates. The ranking of plants according to differences between plants is the basis for the measure of total plant efficiency, which is defined as the extent to which a plant actually uses production inputs in order to maintain a given level of output relative to the input prices (Farrell, 1951). The concept of total efficiency is an ordinal measurement consisting of two components, technical and price efficiency (Farrell, 1951).

Technical efficiency, which refers to the choice of production functions among those actually used by plants in the industry, based on the most conservative production function attainable for a given output, is an indirect measure of managerial expertise. The second component of total efficiency, price efficiency, refers to the proper or improper choice of input combinations based on the factor prices for a given output.

In production theory, the optimum combination of factor inputs within the constraints of fixed factors and factor prices, is attained at the point where the ratio of factor inputs equals the ratio of input prices and represents the least cost operating conditions. Under the conditions of constant returns to scale, which was found to exist in annual aggregate production function analyses of Chapter VI, perfect competition in the input market, and a standardized environment within which the plants of the particleboard industry of Oregon operate, the concept of economic efficiency may be conceptualized in Figure 8.1.

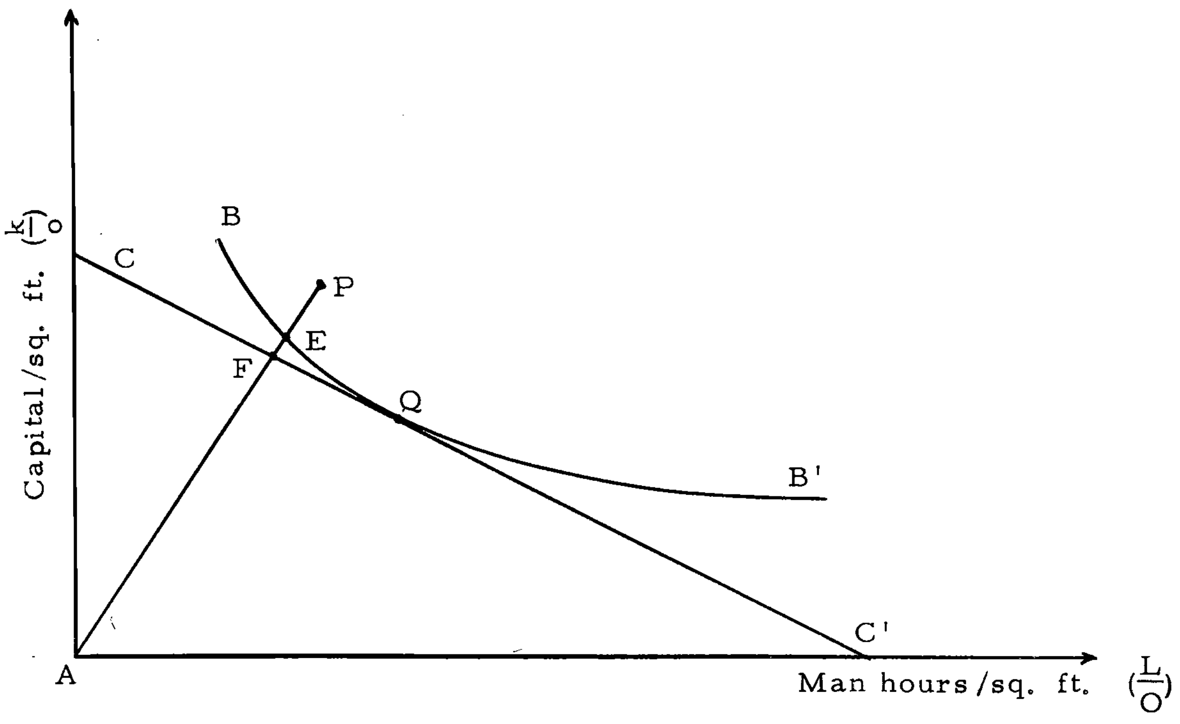

Figure 8. 1. Concept of relative plant economic efficiency.

Given two inputs, capital per square foot $(\frac{K}{O})$ and man hours per square foot $(\frac{L}{O})$, constant returns to scale, and a single output, a production function may be specified by BB'. The point of tangency (Q) of the price ratio of the two inputs (CC') with the production function (BB') determines the optimum or least cost combination of the factor inputs necessary to obtain the specified level of output. This is the point where the marginal rate of substitution for the two inputs is equal to the price ratio of the inputs.

A given plant in the particleboard industry may not be operating at point Q but may, for example, be operating at point P, indicating that it is utilizing a more costly combination of production inputs than is specified by the production function BB'. The ratio of distance AP relative to AE measures the extent to which the same amount of output could be produced with lesser amounts of the two inputs, capital and labor. The ratio of distance AP to AE is a measure of technical efficiency. The ratio of the distance AE to AF measures the reduction of costs at which the same output, as specified by the production function (BB'), could be produced with a proportional reduction in use of the two inputs. This ratio of distance AF to AE is referred to as price efficiency.

Total efficiency is the product of technical efficiency and price efficiency: $AE/AP \cdot AF/AE = AF/AP$.

When attempting to analyze plant efficiency, a problem arises in determining the most efficient production function from those actually in use by firms in the industry. However, it is possible to estimate an efficient production function by forming a convex envelope or frontier to those plants situated nearest the capital and labor input axes, these plants selected from a scatter of plants located at their coordinates of capital and labor. The fitted function represents the most conservative standard of efficiency consistent with the scatter of plants and represents the proxy for BB' in Figure 8. 1 (Farrell, 1951). An example of the fitted frontier is shown in Figure 8. 3 for 1970 and is designated by plants numbered 2, 3, 8, and 12.

The price ratio of inputs (CC' in Figure 8. 1) used in the analysis was determined from the average cost of capital and labor obtained in the marginal productivity analysis of Chapter VI for the respective year under consideration, 1962 through 1970. The slope of the price ratio was drawn tangent to the frontier or efficient production function, thus enabling the determination of total efficiency for each sample plant situated exterior to the production function frontier. The results are tabulated in Table 8. 1

Total Economic Efficiency

The measure summarizing differences among plants, relative to choice of production functions and choice of production input combinations, is total efficiency. The results of total efficiency determinations

Table 8. 1. Total economic efficiency and production for individual particleboard plants in Oregon, 1962-1970.

Efficiency (%)	Production (MM sq. ft.)	Efficiency (%)	Production (MM sq. ft.)
1962		1963	
100	15.70	100	19.71
97	16.19	93	16.20
68	5.20	75	38.00
66	26.75	65	25.25
66	16.80	63	17.64
65	5.00	58	21.19
65	32.80	27	2.25
57	2.67	26	3.33
38	4.00	19	2.50
Ave. 69	13.90	56	16.23
1964		1965	
100	21.50	100	30.00
86	24.00	80	21.86
83	28.76	72	30.62
63	7.50	61	74.40
62	33.10	61	9.00
60	57.50	60	34.99
46	25.56	39	23.09
42	6.46	38	23.91
19	3.33	27	2.50
		25	25.60
		21	7.20
Ave. 62	23.08	53	24.18
1966		1967	
100	55.18	100	66.10
97	23.00	81	42.82
93	25.64	77	100.00
80	26.38	67	92.77
76	89.30	63	42.24
76	38.63	59	31.60
73	9.00	51	30.43
63	82.18	48	28.92
53	18.32	48	17.81
48	26.78	37	39.98
43	24.00	27	9.00
33	30.00		
26	31.87		
Ave. 65	36.94	60	45.88

(Continued on next page)

Table 8. 1. (Continued)

Efficiency (%)	Production (MM sq. ft.)	Efficiency (%)	Production (MM sq. ft.)
1968		1969	
100	107.00	100	122.40
92	98.40	91	91.38
88	72.53	88	109.00
78	30.32	74	57.28
59	50.28	47	12.00
45	9.00	42	25.05
42	54.24	40	48.95
40	33.47	35	28.26
33	54.15	35	38.16
29	23.88	34	66.29
24	32.38	31	32.52
17	44.67	30	58.83
		28	29.67
Ave. 54	50.86	52	54.61
1970			
100	129.07		
83	122.00		
78	88.26		
58	51.96		
52	95.53		
45	12.00		
43	64.55		
43	30.14		
42	30.06		
35	36.23		
33	50.26		
27	27.70		
Ave. 53	61.48		

from 1962 through 1970 for selected plants (Table 8. 1) indicate that on the average, total efficiency of particleboard plants decreased approximately 16 percent from 1962 through 1970 (Figure 8. 2). This would seem to indicate that as average output per plant increases (340 percent from 1962 to 1970), it becomes more difficult for managers to: (1) adjust the production input combination for technical efficiency or (2) choose the least cost combination of inputs for price efficiency. Examination of the individual plant efficiency data (Table 8. 1) indicates that the larger capacity plants generally have the higher total efficiency ratings. This suggests that perhaps managers of the large capacity plants are more effective in adjustment of inputs for technical and price efficiency.

Technical Efficiency

In an attempt to determine which of the two efficiency components, technical or price, contributed to the decrease in total efficiency between 1962 and 1970, an analysis of technical efficiency was made for 1960, 1965, and 1970. The results are shown in Table 8. 2. As previously mentioned, technical efficiency measures the proper or improper choice of production function utilized by plants operating under the assumption of fixed production input proportions and similar economic environments. This is a measure of managerial expertise and estimates the ability of managers to substitute one production input for another while maintaining a constant level of output.

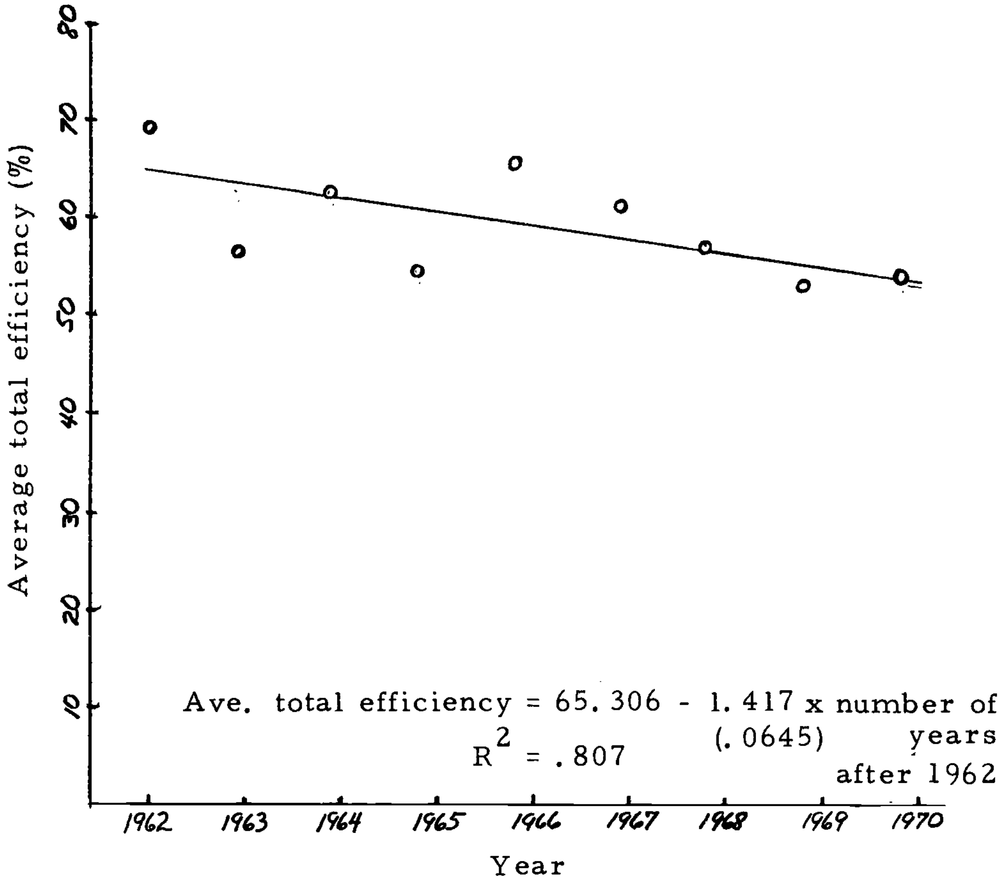

Figure 8.2. Change in average total efficiency, individual particleboard plants, Oregon, 1962-1970.

Table 8.2. Technical efficiency, production, and output index for particleboard plants in Oregon, 1960, 1965 and 1970.

Sample plant	Efficiency (%)	Production (MM sq. ft.)	Output index
		1960	
1	100.0	8.30	3.004
2	45.0	3.80	1.192
3	100.0	8.46	3.050
4	15.4	.86	.446
5	61.1	7.70	1.757
6	45.0	2.80	1.334
7	100.0	18.00	2.591
8	89.9	11.87	2.259
9	88.9	10.57	2.296
Ave.	71.7	8.04	
		1965	
1	50.8	25.60	1.568
2	71.7	34.99	2.145
3	69.6	74.40	2.048
4	100.0	2.50	.669
5	100.0	30.00	3.019
6	75.5	9.00	2.354
7	47.9	23.91	1.489
8	67.5	23.09	2.146
9	86.3	21.86	2.216
10	100.0	30.62	3.478
11	27.8	7.22	.896
Ave.	72.6	25.74	
		1970	
1	79.3	95.53	2.020
2	100.0	51.96	2.574
3	100.0	122.00	2.291
4	68.4	12.00	1.792
5	62.0	64.55	1.557
6	67.4	36.23	1.703
7	47.5	27.70	1.221
8	100.0	129.07	2.713
9	95.0	88.26	2.495
10	67.0	50.26	1.678
11	100.0	30.14	2.534
12	52.7	30.06	1.485
Ave.	78.2	61.48	

$$\text{Output index} = \frac{O/K - \overline{O/K}}{\overline{O}/K} + \frac{O/L - \overline{O/L}}{\overline{O}/L}$$

Average technical efficiency increased from 71.7 percent in 1960 to 78.2 percent in 1970 (Table 8.2), an increase of 6.5 percent or .6 percent per year. Average technical efficiency increased 5.6 percent from 1965 to 1970, an average increase of 1.1 percent per year. This implies that managerial expertise in obtaining technical efficiency increased very slightly during the latter portion of the 1960-1970 time period, a period when average plant output increased approximately 300 percent.

The increase in average technical efficiency values from 1960 to 1970 would suggest that the inability to properly allocate capital and labor for least-cost input combinations was the major reason for the reduction in total efficiency from 1962 to 1970. This substantiates the results from Chapter VI where it was concluded that the industry operated under constant returns to scale but that neither capital nor labor were efficiently used because they were not used in their least-cost combination.

Technical efficiency results indicate that the larger plants generally have associated higher efficiency ratings. It may be hypothesized that larger plant size can be an inducement to higher efficiency. The larger plants, which have incorporated high speed expensive production equipment, have developed extensive product lines and marketing channels in order to permit these plants to operate near maximum plant capacity levels. The diversity of product lines plus the marketing capability to handle the large volume of production permitted high levels of production per dollar of capital and per man hour of labor. The smaller plant operations, which do not possess economies of large scale and associated product line and marketing diversity, may be more subject to business cycle fluctuations and not able to experience the advantages of near-capacity operation. Consequently, the efficiency of smaller plants would be expected to be lower than that of larger plants.

Further evidence of the correlation between efficiency and output may be observed by examining the output index derived for individual plants and shown in Table 8.2. These indices were calculated as the sum of output per unit of labor and capital variations per plant measured from and then divided by the average output per unit of labor and capital respectively for all plants. These individual plant output indices indicated that higher levels of output per unit of labor and capital correspond fairly well to the higher efficiency ratings. This would appear to substantiate the previous discussion that larger plants were generally more efficient than smaller plants through effective allocation of factor inputs and maintenance of near-capacity levels of production.

Frontier Estimation

A criticism may be directed toward the frontier or indifference curve approach to individual plant economic efficiency determination. The major problem arises in the number of samples necessary to accurately determine the shape of the frontier over the relevant range of input data. The larger the number of samples, the greater should be the accuracy of the frontier and consequently, more confidence placed in the efficiency determination.

Difficulties also arise in obtaining accurate input price information and give rise to additional criticism in determining total economic efficiency. The accuracy of total economic efficiency is influenced appreciably by the slope of the input factor price ratio, a slight inaccuracy in the slope giving rise to considerable error of estimation for total efficiency.

In an attempt to determine how well the frontier method of total efficiency estimation compared with a Cobb-Douglas production function, data from the aggregate production function for 1970 were utilized, 1970 being the latest year for which input factor prices could be estimated and a year with a wide dispersion of individual plant output. Input coefficients obtained from the Cobb-Douglas production function of Chapter VI for 1970 were applied to capital and labor inputs relevant to the efficiency frontier estimated for 1970. The results are shown in Figure 8. 3.

The frontier was a close approximation to the Cobb-Douglas production function and the tangency of the price line to the frontier

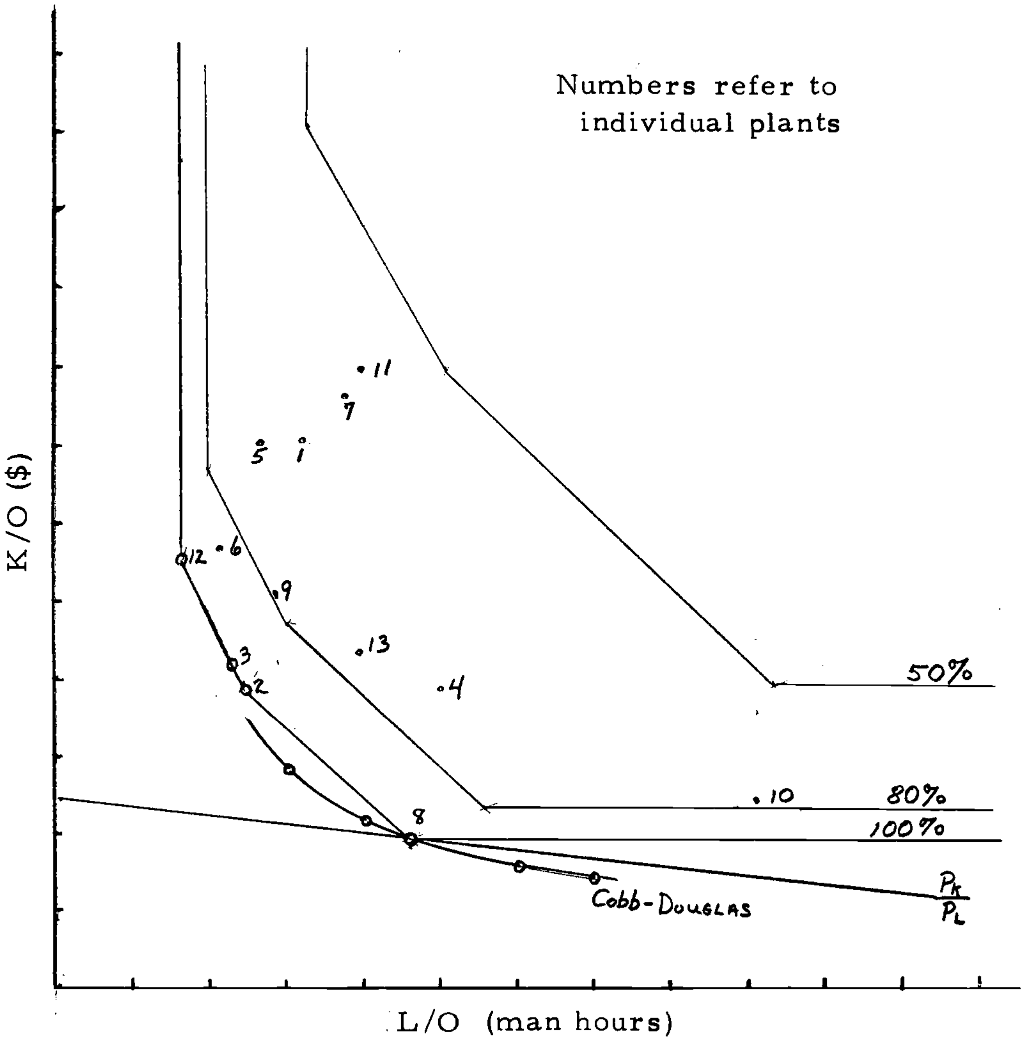

Figure 8. 3. Comparison of efficiency frontier and Cobb-Douglas production function for particleboard plants in Oregon, 1970.

appears to be a close approximation based on its tangency to the Cobb-Douglas production function. Figure 8.3 also shows the contour estimators for 80 and 50 percent technical efficiency in order to give a perspective of the relative positions of plants in input space during 1970.

Despite the potential criticism of the frontier method of efficiency determination, it was felt that a fair approximation of technical efficiency was obtained for the particleboard industry of Oregon. Particleboard personnel were asked in personal interviews to estimate the percentage of technical efficiency growth achieved by the industry from 1955 to 1970. Their estimates ranged from 5 to 22 percent, averaging 1.34 percent per year. The analysis of this chapter indicated a technical efficiency increase of 9.1 percent from 1960 through 1970. From a practical point of view, it would appear that an annual increase of .9 percent was a conservative estimate in light of the dynamic growth characteristics of the industry. The annual efficiency increase of 1.6 percent calculated for the period 1965-1970 would seem a more realistic figure based on the results of the personal interviews.

The steady increase in average technical efficiency from 1960 through 1970 seemed to indicate an increasing adeptness on the part of managers to effectively utilize factor inputs for optimum output, particularly for the large capacity plants. However, associated features such as marketing and distribution channels in combination with large scale plant operations undoubtedly played an important role in permitting maximum utilization of fixed capital equipment and labor for optimum input allocation, thus permitting efficient plant operations. Both technical and total economic efficiency increased with increases in particleboard plant output. The substantial increase in average plant output, 300 percent from 1965 to 1970, substantiated the conclusion that economies of large scale operation contributed to economic efficiency.

Fluctuations in annual production between 1965 and 1970 for small (less than 50 million square feet) and large (over 50.1 million square feet) particleboard plants may be observed in Table 8.3 which shows the production index by plant size and the associated economic efficiency rating.

The index values indicated that smaller sized plants experienced greater fluctuation in aggregate annual production than did the larger plants since 1965. The economic ratings also indicated that lower efficiencies were experienced by the smaller plants.

Smaller plants, not possessing integrated large scale distribution facilities, apparently experienced difficulties in effective input allocation and maintenance of capacity levels in comparison to larger members of the particleboard industry. This was reflected in lower relative economic efficiency ratings, inferring that managers were

Table 8. 3. Index of aggregate annual output, annual percentage change, and economic efficiency ratings for small and large particleboard plants in Oregon between 1965 and 1970.

Year	Small plants (0-50 MM sq. ft.)			Large plants (+50. 1 MM sq. ft.)		
	Average efficiency rating	Production index	% annual change	Average efficiency rating	Production index	% annual change
1965	52	1.00		61	1.00	
1966	62	1.92	+ 92.0	80	2.00	+100.0
1967	52	1.55	- 19.3	82	2.45	+ 22.5
1968	49	2.52	+ 62.6	70	2.79	+ 13.9
1969	36	2.60	+ 3.2	77	2.84	+ 1.8
1970	38	2.51	- 3.5	74	3.57	+ 25.8

1965 aggregate production = 1.00

unable to allocate fixed and variable input factors to the extent practiced by larger plant managers in order to obtain optimum production levels.

CHAPTER IX

SUMMARY

The objective of this study was to evaluate economic efficiency in the particleboard industry between 1958 and 1970. Measures of efficiency included aggregate capital and labor use in the production process, relative economies of scale, and relative technological differences between individual plants based on their use of capital and labor.

The rapid growth of the industry in terms of production, technological changes, and a trend toward larger plant operations raised the question of whether the industry was efficiently using capital and labor production inputs in the manufacture of particleboard. The measurement of input efficiency is important because it indicates to industry managers the extent to which inputs are contributing to an optimum least-cost condition.

Nationally, the number of plants in the particleboard industry increased from 25 in 1955 to 67 in 1970. Production capacity increased from 164 million square feet in 1955 to 2969 million square feet in 1970, an average annual increase of 20 percent; this increase reflected both the increase in number of plants plus the increase in average plant capacity which grew approximately five-fold between 1955 and 1970. Western plants have consistently had larger capacities than those in the South or North. In 1970, average capacity of

Western plants was approximately 1.7 times that of plants in the other two regions.

One factor which contributed to the larger size of the Western plants was large, concentrated supplies of sustained, low-cost, softwood residues from large sawmill and plywood operations, which enabled these plants to expand their scales of operation. Southern and Northern particleboard plants, faced with a somewhat less concentrated raw material base, have largely been captive plants, utilizing residues from a parent firm's primary processing operation to supply particleboard for subsequent processing into the firm's product, predominantly furniture. Consequently, these plants have tended to be small. The advent of the softwood plywood industry and increased softwood lumber production in the South has increased the supply of wood residues with the result that particleboard production and average plant size have both shown substantial increases in this region since 1968.

The two principle uses of particleboard have been furniture corestock and residential housing floor underlayment. In 1967, the West produced 88 percent of the floor underlayment and 60 percent of the industrial corestock in the United States. In 1970, the West's production of floor underlayment had decreased to 45 percent and industrial corestock to 55 percent, the South and North producing the balance. The rapid decrease in floor underlayment production in the

West reflected entry of the southern region into the production of this low cost commodity item.

Per capita consumption of particleboard increased from 0.20 square feet in 1955 to 3.54 square feet in 1970. This increase reflected increased use of particleboard in furniture and residential housing construction. The use of particleboard in wood furniture increased 220 percent between 1958 and 1967 and its use as floor underlayment increased 250 percent between 1959 and 1968.

The establishment and growth of the particleboard industry in Oregon was predominantly the result of an abundant and concentrated supply of low cost wood residues, chiefly Douglas-fir planer shavings, for which there was little competition from other residue processing industries and available resin technology.

Oregon's particleboard industry grew from an initial size of five plants in 1955 to 14 plants in 1970, this increase resulting in an average annual production increase of 40 percent during this time period.

The capital value of the particleboard industry of Oregon, consisting of tax assessed value of equipment, buildings, and personal property, increased at an average annual rate of 58 percent from 1955 to 1970. Average capital value per plant increased from $0.39 million in 1955 to $2.89 million in 1970. Underlying this increase in capital value was a trend toward larger plant facilities beginning about

1964 with the incorporation of high-speed expensive production equipment.

Employment in Oregon's industry doubled on a per plant basis every five years from 1955 to 1970, reflecting additional labor requirements of multi-shift operations and increased man hour requirements in associated operations such as panel processing, warehousing, maintenance, and shipping. Productivity per man hour and average hourly wage both doubled from 1955 to 1970, indicating that productivity increases kept pace with increases in labor costs.

Resin adhesive usage by Oregon's particleboard producers increased 44-fold from 1955 to 1970, but resin cost per thousand square feet of production decreased at an average annual rate of 4.2 percent during the same time period. This reflected the ability of resin suppliers to furnish urea formaldehyde adhesives at reduced prices due to a steady reduction of their raw material costs plus increased usage of these adhesives in particleboard and plywood manufacture.

The wood residue requirements for particleboard production increased 6000-fold between 1955 and 1970. In 1955, approximately one percent of the available supply of planer shavings was utilized by the particleboard industry but by 1970, 67 percent of the supply of planer shavings was required to meet particleboard production requirements. The per-ton cost of planer shavings remained relatively constant between 1955 and 1970, owing to the large supply base plus lack of serious competition for this type of residue from competing residue utilizing industries.

A comparison of Oregon's particleboard industry with the state's two leading forest products industries, softwood lumber and plywood, indicated that particleboard had substantial growth increases in per capita consumption, production, and value of shipments relative to softwood lumber and plywood. This demonstrated the ability of the industry to create an expanding export market within the United States despite market competition from alternative products and other producing regions.

To measure the economic efficiency of two resource inputs--capital and labor--utilized by the particleboard industry of Oregon, the aggregate production function was used. This function permitted both a technical and an economic analysis of the relationship between production output and the inputs of capital and labor, calculated from annual cross-section data from particleboard plants for the years 1958 to 1970, and fitted to the single equation Cobb-Douglas production function model. The estimators obtained from the model included three indicators of economic efficiency: estimated elasticity of production for each input, mean marginal productivity for each input, and estimated returns to scale for both production inputs.

Annual production function results indicated that when either the capital or labor input was separately increased, all other inputs remaining fixed, particleboard output increased at a less-than-proportionate rate for each of the years 1958 to 1970, except in 1967 when output increased at the same rate as capital. This implied that, all other production inputs remaining fixed, neither capital nor labor were used efficiently during the period, excepting capital in 1967. This illustrates the technical significance of the production function, that given some fixed inputs, further additions of other inputs, here capital or labor, have a smaller and smaller chance of contributing significantly to output. This is the concept of diminishing returns and indicates, that as more and more of an input are added to fixed production inputs, production decreases and the marginal physical product of the input will exhibit diminishing returns.

However, in the real world of the production process, all production inputs may be varied given sufficient time, thus it is often more realistic to measure the contribution to output of all inputs in combination. This is referred to as returns to scale. Since measurable inputs used in this study were capital and labor, returns to scale were obtained for these two inputs by adding their respective input coefficients and determining if the sum was significantly different from one, the standard measure of constant returns to scale. The results indicated that constant returns to scale accrued to both capital and labor during each of the years 1958 to 1970, implying that output increased at the same rate as the inputs were increased. Therefore, it was concluded from the cross-section analysis that capital and labor were both used efficiently in the production of particleboard between 1958 and 1970. This was based on constant returns to scale results which implied that capital and labor, when considered together, were contributing their proportionate share to output based on their addition as inputs.

Production function analysis using aggregate time series data for the entire period 1958 through 1970 revealed increasing returns to scale for capital and labor, reflecting another investigator's conclusions (Grivilches, 1963a) of the tendency for the Cobb-Douglas production function model to show increasing returns to scale from time series data when increasing returns were not statistically indicated from the cross-section data.

In an attempt to determine if capital and labor were paid their proportionate shares relative to their contribution to production, a comparison of average cost for each input and its corresponding estimated value of marginal product was made for the years 1962 to 1970, the years for which particleboard price data were available. Results indicated that neither capital nor labor were paid their proportionate shares from 1962 to 1970, and therefore, that the particleboard industry did not operate efficiently in the input market during these years. In order for the industry to operate at the optimum least-cost condition, it would have been advantageous for the industry to hire additional units of capital and labor up to the point where the average cost of the inputs was equal to the estimated value of their marginal products.

The trend toward large scale operations and capital intensification since 1964 raised the question of whether economies of scale were being experienced by the industry. An analysis of production output changes over time for three plant sizes indicated that plants with annual outputs less than 80 million square feet were losing their share of output over time in contrast to plants producing in excess of 80 million square feet annually. This indicated that the smaller plants were less efficient in their scales of operation and were experiencing higher average costs, suggesting diseconomies of scale. A partial analysis for wood, resin, and labor average costs indicated that with an increase in output of one percent, average cost of these input resources decreased 1.13 percent, implying that large scale operations were experiencing greater economies of scale, or lower average costs, than were smaller plants, and that the larger plants were more efficient in their scales of operation.

Total and technical efficiency analysis for individual plants indicated that total efficiency decreased approximately 16 percent from 1962 to 1970 but that technical efficiency increased approximately 10 percent from 1960 to 1970. The discrepancy between total and technical efficiency, would seem to indicate that individual plants were relatively inefficient in altering the relative use of inputs to reduce production costs. This implied that the price paid for the use of capital and labor was not equal to the contribution of these inputs to output (value of marginal product) and that the use of capital and labor should be increased until their contribution to output and cost are equated. The implication of this is that plant capacities should have been increased or perhaps new and larger plant facilities constructed, either approach having the potential to increase the use of both capital and labor to the point where cost and value of marginal product are equal.

The increase in technical efficiency from 1960 to 1970, which followed generally the increase in average plant size, implied that managers were more efficient in their technical ability to adjust production inputs for production gains in larger than in smaller plants. This was believed due to the ability of large scale operations to circumvent fluctuations in business conditions because of their integrated large scale distribution and marketing systems that permitted them to sustain near-capacity levels of operation, thus affording more effective and efficient use of production inputs. A derived annual production index substantiated this hypothesis somewhat by indicating that plants with outputs less than 50 million square feet were subject to rather wide fluctuations in output between 1965 and 1970. This production index for plants with outputs greater than 50 million square feet, on the other hand, exhibited less variation, implying that managers of the large scale operations were more efficient in their use of production inputs than were managers of the smaller scale operations.

Conclusions

The present study was concerned with the economic efficiency of production input use by the particleboard industry of Oregon during the time period 1958 to 1970. Specifically, analyses were made regarding efficient use of capital and labor inputs in the production process, economies of scale, and economic efficiency of input use by individual plants.

The crucial question centered around how the industry performed from a societal point of view. Apparently the particleboard industry had a mixed record in economic efficiency achievement. The industry was technologically progressive through capital intensification, and increasing quantities of particleboard were made available to consumers at prices they were willing and able to pay, as evidenced by the growth of the industry in Oregon in terms of production, per capita consumption, and value of shipments. The use of capital and labor in the production process as indicated by constant returns to scale implied that capital and labor were efficiently used from 1958 to 1970, output increasing in direct proportion to increases in the inputs.

However, inefficient use of capital and labor for optimum least-cost attainment was indicated annually from 1962 to 1970, years in which relevant particleboard price data were available. Capital and labor, expressed in terms of their value of marginal products, were contributing more to production than they were receiving in return for their services. This implied that the industry was not operating at a least-cost condition and that the use of these inputs should have been increased to the point where their contribution to revenue was equal to their cost. The practical implication of such a condition would be to increase the use of capital and labor inputs by means of new plant construction and expansion of existing facilities, such that an equilibrium of input cost and value of marginal product results.

The empirical results of individual plant efficiency implied that there may have been plants operating within the industry that were relatively less efficient in their use of production inputs than other plants under a given state of technology. The attrition of some of these less efficient plants with annual capacities less than 24 million square feet implied that economies of scale for large plants were real and substantial and that these economies of scale apparently facilitated efficient use of production inputs in large scale operations.

This study demonstrated that while there had been a trend toward capital intensification and large scale plant operations within the industry, an optimum least-cost condition had not been fully achieved in the use of production inputs. It was further demonstrated that relative economies of scale accrued to the larger sized plants and that these were generally more efficient in the use of production inputs than were smaller plants.

These results present a dilemma for the industry decision maker today when considering what scale of operation to select in order to remain viable in the face of competition from plants in Oregon's industry and in other producing regions.

The evidence would seem to imply that the best alternative is to take advantage of the latest equipment innovations through capital intensification, increase the scale of operation to take advantage of large plant efficiencies and economies of scale, adjust production inputs for efficient input use and optimum least-cost attainment, and develop a marketing system conducive to distribution of large scale operation output.

This would appear to rule out the continued existence of small scale plant operations with limited financial assets. However, it may be possible for this type of operation to remain a viable member of the industry in spite of the trend toward a larger, relatively more efficient scale of operation. One alternative a decision maker might consider to sustain near-capacity levels of production in small scale operations and thus achieve optimum allocation of production inputs would be to produce a quality particleboard and arrange to have it sold through marketing channels of a large forest products conglomerate. This would free the small operation of sales and distribution expenses and permit management to concentrate on operating refinements conducive to efficient input allocation.

Another possible alternative would be to produce a specialty product having the potential of high monetary gains to the producer but sold in a market not subject to cyclical demands. Such a scheme would permit sustained production levels, permitting an opportunity for efficient least-cost adjustment of production inputs.

The decision maker of a forest products conglomerate, contemplating entry into the particleboard industry or expansion of production capacity, has alternatives available to him that are less restrictive, due to economies of financing, than those facing a small independent operator. The conglomerate may decide to construct a new plant, expand an existing facility, or purchase the assets of an existing small-scale operation of sub-optimum efficiency that does not enjoy the affluence afforded by economies of scale. The latter approach, in conjunction with technological improvements to existing facilities through capital intensification and development of marketing economies, should improve the economic efficiency of an acquired plant by achieving sustained production levels, thus permitting efficient use of production inputs.

The decision maker associated with a plant, regardless of its size, must be continually aware of the low-cost raw material base which is slowly being depleted as the particleboard industry expands its production level and the demand for residues by other industries increases. In the future, captive supplies are likely to be insufficient to support requirements of large scale operations; consequently, competition for remaining market supplies will increase, undoubtedly leading to higher residue prices and increased use of higher cost chippable residues. Such developments will place a constraint upon industry and plant expansion and threaten inefficiencies in resource allocation through shortages in residue supply, particularly in localized areas.

Available alternatives to obtain economic efficiency in resource allocation vary with the scale of operation, but the common denominator required for all plant sizes centers on the ability of plant managers to sustain near-capacity levels of production.

The profitability of the particleboard industry and of individual plant operations, which was beyond the scope of this study, is the other side of the coin deserving analysis. It is recommended that a subsequent study be performed to examine the correlation between size of plant operation and profitability. The trend toward greater capital intensification and increases in the scale of individual plant operations would appear to suggest that profits are greater for the larger scale plants, but this study does not provide the information to substantiate this hypothesis.

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APPENDIX

Appendix Table 1. Particleboard plants in the United States, by location, capacity, and raw material used, 1955-1970.

Plant no.[a]	Plant name, region and state	Plant location	Annual capacity (million sq. ft. 3/4" basis)	Raw material[b]
		South		
Alabama				
1	Giles & Kendall**	Huntsville	7.0	Sfwd. Res.
Arkansas				
2	Forest Industries*, **	Hope	12.0	Do.
3	Georgia Pacific**	Crossett	70.0	Do.
4	International Paper**	Malverne	70.0	Do.
5	Owosso Mfg. Co.*	Benton	2.0	Do.
6	Singer Co.**	Trumann	5.0	Do.
7	United Wood Corp.	W. Memphis	8.0	Sfwd. & Hdwd.
Georgia				
8	Georgia Pacific**	Vienna	75.0	Sfwd. Res.
9	Weyerhaeuser**	Adel	35.0	Do.
Louisiana				
10	Georgia Pacific**	Urania	75.0	Do.
Mississippi				
11	Georgia Pacific**	Louisville	74.0	Do.
12	Gulf Naval Stores	Gulfport	3.0	Do.
13	Mississippi Wood Prod.*	Jackson	6.0	Hdwd. Res.
14	MPI Industries Inc.	Jackson	2.4	Do.
15	Kroehler Mfg. Co.**	Meridian	18.5	Sfwd. & Hdwd.
16	Sencore Industries*	Fernwood	3.0	Do.
17	US Plywood-Champion**	Oxford	100.0	Sfwd. Res.
North Carolina				
18	American Furniture Co.	No. Wilkesboro	5.0	Sfwd. & Hdwd.
19	Broyhill Furniture Fact.	Lenoir	5.0	Hdwd. Res.
20	Broyhill Furniture Fact.*	Newton	5.0	Do.
21	Caldwell Furniture	Lenoir	5.0	Do.
22	Carolina Forest Products**	Wilmington	12.0	Sfwd. Res.
23	Coreboard Prod. Corp.*	Raleigh	7.5	Sfwd. & Hdwd.
24	Dixie Chipboard Co.**	Rural Hall	12.0	Do.
25	Evans Products Co.**	Moncure	72.0	Sfwd. Res.
26	Forest Industries**	Black Mountain	12.0	Do.
27	Georgia Pacific**	Hallsboro	3.8	Hdwd. Res.
28	Hickory Mfg. Co.**	Hickory	2.3	Do.
29	International Paper**	Farmville	60.0	Sfwd. Res.
30	Lenoir Chair Co.**	Lenoir	4.5	Hdwd. Res.
31	Lenoir Furniture Co.**	Lenoir	7.3	Do.
32	New England Ind.	High Point	15.0	Do.
33	Nu Woods Inc.**	Lenoir	16.0	Do.
34	Souhegan Wood Prod. Co.*	Wilton	4.0	Sfwd. Res.

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Appendix Table 1. (Continued)

Plant no.[a]	Plant name, region and state	Plant location	Annual capacity (million sq. ft. 3/4" basis)	Raw material[b]
35	Thomason Chipboard Co.*	Fayetteville	4.0	Do.
36	W.M. Ritter Lumber Co.	Hallsboro	5.0	Hdwd. Res.
Oklahoma				
37	Weyerhaeuser**	Broken Bow	50.0	Sfwd. Res.
South Carolina				
38	Georgia Pacific**	Sumter	12.5	Hdwd. Res.
39	International Paper**	Greenwood	75.0	Sfwd. Res.
40	Poinsett Lumber & Mfg. Co.	Pickens	5.0	Hdwd. Res.
Tennessee				
41	Berkline Corp.*	Morristown	1.5	Do.
42	Cavalier Corp.*	Chattanooga	4.8	Do.
43	Tenn-Flake Corp.**	Chattanooga	50.0	Sfwd. & Hdwd.
Texas				
44	Evans Products**	Silsbee	72.0	Sfwd. Res.
45	Forest Industries*, **	Jacksonville	12.0	Do.
46	Temple Industries**	Diboll	95.0	Do.
47	Temple Industries**	Pineland	10.0	Do.
Virginia				
48	American Furniture**	Martinsville	10.0	Hdwd. Res.
49	Lane Co.*, **	Alta Vista	15.0	Do.
50	Masonite Corp.**	Waverly	60.0	Sfwd. Res.
51	US Plywood-Champion**	So. Boston	30.0	Do.
		North		
Illinois				
52	Rock Island Millwork Co.*	Rock Island	5.0	Do.
Indiana				
53	Storrs Wood Prod.**	Evansville	24.0	Hdwd. Res.
54	Swain Industries Inc.*, **	Seymour	6.6	Do.
Iowa				
55	Curtiss Co.*	Clinton	5.5	Sfwd. Res.
Kentucky				
56	Jasper-American Mfg. Co.*, **	Henderson	7.0	Do.
57	Tenn-Flake Corp.**	Middlesboro	50.0	Do.
Michigan				
58	Hart Wood Products	Hart	3.0	Hdwd. Res.
59	US Plywood-Champion**	Gaylord	40.0	Sfwd. & Hdwd.

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Appendix Table 1. (Continued)

Plant no.[a]	Plant name, region and state	Plant location	Annual capacity (million sq. ft. 3/4" basis)	Raw material[b]
Minnesota				
60	Cladwood**	Virginia	14.0	Sfwd. Res.
61	Wabash Screen Door*	Minneapolis	2.0	Do.
New Hampshire				
62	Granite Board Inc.*	Goffstown	12.0	Do.
New York				
63	Flakeboard Corporation	Jamestown	23.0	Hdwd. Res.
Pennsylvania				
64	Viko Furniture Corp.	Eldred	2.5	Do.
65	West Virginia Pulp & Paper**	Tyrone	20.0	Do.
66	Woodcore Inc.	Scottdale	3.0	Do.
West Virginia				
67	W. Virginia Forest Products**	Gassaway	20.0	Do.
Wisconsin				
68	Rodman Industries**	Marinette	20.0	Sfwd. Res.
69	Wynnewood Products Co.	Antigo	18.0	Hdwd. Res.
70	Weyerhaeuser**	Marshfield	40.0	Do.
		West		
Arizona				
71	Southwest Forest Industries**	Flagstaff	27.0	Sfwd. Res.
California				
72	Big Bear Board Products**	Redlands	30.0	Do.
73	Collins Pine**	Chester	24.0	Do.
74	Hambro Forest Products**	Crescent City	23.0	Do.
75	Humboldt Flakeboard**	Arcata	85.0	Do.
76	Neall Pressed Products	San Leandro	3.0	Do.
77	US Plywood-Champion*, **	Anderson	70.0	Do.
Idaho				
78	Pack River Co. *, **	Sandpoint	20.0	Do.
New Mexico				
79	Mexwood Products**	Albuquerque	30.0	Do.
Oregon				
80	Boise Cascade**	LaGrande	54.0	Do.
81	Brooks-Willamette**	Bend	100.0	Do.
82	Cascade Fiber**	Eugene	50.0	Do.
83	Chapwood*	Philomath	6.7	Do.

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Appendix Table 1. (Continued)

Plant no. [a]	Plant name, region and state	Plant location	Annual capacity (million sq. ft. 3/4" basis)	Raw material[b]
84	Chipboard Products*	Grants Pass	6.0	Sfwd. & Hdwd.
85	Cladwood**	Sweet Home	12.0	Sfwd. Res.
86	Clear Fir Products Co.*, **	Springfield	3.3	Do.
87	Duraflake**	Albany	170.0	Do.
88	Forest Industries**	Brownsville	30.0	Do.
89	Forest-Industries**	Dillard	70.0	Do.
90	Forest Industries**	White City	100.0	Do.
91	Haskins Wood Products	Swiss Home	.5	Do.
92	Lester Cedar Products	Sweet Home	7.0	Sfwd. & Hdwd.
93	Pope and Talbot**	Oakridge	30.0	Sfwd.
94	Roseburg Lumber**	Roseburg	100.0	Do.
95	Standard Board Products	Sweet Home	12.0	Sfwd. Res.
96	Timber Products**	Medford	60.0	Do.
97	Western Panel	Sweet Home	6.0	Do.
98	Weyerhaeuser*, **	North Bend	35.0	Do.
99	Weyerhaeuser**	Springfield	30.0	Do.
100	Willamette Fiber & Chipboard*	Sweet Home	10.0	Do.
Washington				
101	Columbia Hardboard	Everett	20.0	Do.
102	International Paper*, **	Longview	12.0	Do.
103	Sylvanal	Longview	.6	Do.
104	Versatile Products Inc.	Anacortes	3.0	Do.

*Plants operating 1955

**Plants operating 1970

[a]Numbers refer to plant locations on Appendix Figure 1.

[b]Sfwd. = softwood; Hdwd. = hardwood

Sources: U. S. Department of Agriculture, Forest Service; U. S. Department of Commerce, Bureau of Census; annual editions of the Directory of the Forest Products Industry; annual issues of Timberman and Forest Industries; Black Clawson report of April 1, 1971; and Evaluation of Waste Utilization Processes, 1957, Timber Engineering Company, Washington, D.C.

Appendix Figure 1. Map showing particleboard plants in the United States, 1970.