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PRODUCT INNOVATION AND DIFFUSION IN THE
WOOD-BASED PANEL INDUSTRY

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INNOVATION AND PRODUCT DIFFUSION
IN THE WOOD-BASED PANEL INDUSTRY

By

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ABSTRACT

PRODUCT INNOVATION AND DIFFUSION IN THE
WOOD-BASED PANEL INDUSTRY

By

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The diffusion of particleboard and southern pine plywood is examined in this study. The effects of diffusion on wood requirements are analyzed along with the roles of various factors affecting the diffusion of panel product innovations.

Particleboard wood requirements are projected to increase from 5.4 million tons in 1979 to between 9.3 and 10.5 million tons in 2000. Over the same period, southern pine plywood wood requirements are projected to increase from 4.5 million tons to between 6.8 and 7.7 million tons. The projections are based on (1) an aggregate panel consumption submodel, (2) a logistic function submodel, and (3) average wood requirements per unit of output.

Though aggregate panel consumption is a function of expected economic activity, diffusion of specific panels is based on many interacting factors, many of which are not amenable to quantitative analysis. Among the more important factors are: panel characteristics, building codes and standards, process innovations, economic variables, raw material price and availability, and competition from other wood-based panels.

Two diffusion submodels, the logistic function and the Gompertz curve, are used to estimate potential market shares and growth rates

for the panels. However, these models are not useful for explaining the diffusion process. Multivariate models were utilized to provide a partial explanation for this process.

Southern pine plywood's rapid diffusion was enhanced by (1) its similarity to existing low quality softwood plywood, (2) its accepted standardization coinciding with initial production, (3) its low price relative to western softwood plywood, and (4) its regional advantage. The large amount of raw material available for processing promoted the establishment of the southern pine plywood industry. Factors which will eventually slow its diffusion include: (1) almost total reliance on one end-use, sheathing, (2) rising stumpage costs, and (3) competition from new structural panels.

Particleboard's diffusion was aided by its many end-use applications, its declining relative price, and the large amounts of residues available for processing. The slow evolution of standards and particleboard's atypical characteristics initially hindered its diffusion. As new specialized products capture portions of particleboard's end-use markets and as competition for raw materials increases, its market share growth will continue to slow.

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To my wife, Becky, Je t'aime et merci. To Karin, our daughter, goes my thanks for being so entertaining.

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SUMMARY AND CONCLUSIONS

The primary objective of this study is to analyze the effects of product innovations and diffusion on raw material requirements in the wood-based panel products industry. In addition, the roles of economic and other factors in determining the direction and diffusion rate of panel product innovations are examined.

Particleboard and southern pine plywood are the primary panels analyzed in this study. Total wood requirements for these panels are projected to increase substantially by the end of this century (see Table 1). When compared to 1979 levels, particleboard wood requirements and the corresponding consumption levels are projected to increase between 49 and 61 percent by 1990 and between 71 and 93 percent by 2000. Similarly, southern pine plywood wood requirements and consumption are projected to increase between 33 and 44 percent by 1990 and between 53 and 72 percent by 2000.

Particleboard and southern pine plywood consumption and wood requirements were projected based on: (1) an aggregate panel consumption submodel, (2) a logistic function submodel, and (3) average wood requirements per unit of output. U. S. disposable personal income and time were used as exogenous variables in the submodels. The projections were based on extrapolation of past diffusion trends and on expected economic activity.

Table 1. Projected total wood requirements for particleboard and southern pine plywood at high, medium, and low levels of disposable personal income, 1990 and 2000.

Year	Income level	Wood requirements	
		Particleboard	Southern pine plywood
		(thousand tons)[1/]	
1990	High	8710	6452
	Medium	8388	6213
	Low	8045	5960
2000	High	10464	7703
	Medium	9844	7245
	Low	9270	6823

[1/] In thousands of tons, dry weight (ovendry)basis for particleboard and in thousands of tons, based on ovendry mass and volume at 12 percent moisture content for southern pine plywood.

Source: Table 31.

The aggregate panel consumption submodel was estimated for projecting total panel consumption in 1990 and 2000. The model included all wood-based panels for which consumption and production data were available and covered all panel end-uses. Secondary time series data were not available for examining year-by-year consumption of panels in specific end-uses such as new housing, residential upkeep and improvement, manufacturing, and new nonresidential construction. This is a limitation of the submodel since penetration into different end-use markets is likely to vary for a given panel.

Total panel consumption was estimated to be a positive function of U. S. disposable personal income, an important determinant of wood-based panel products, demand household formation, and furniture consumption. The submodel fits the long-term trend very well, but performs poorly during periods of great market fluctuations experienced during the 1972 to 1979 period. The strong reliance of wood-based panels on the construction industry led to this cyclic pattern of panel consumption.

The submodel is not structured to project business cycles; instead, it is used to estimate long-term trends in panel consumption based on different levels of disposable personal income. The impacts of changes in family structure, family formation, and possible substitution of other products for panels are not incorporated in this univariate submodel.

The diffusion of new products can most readily be seen in terms of market shares. Market share, that is, a given panel's percent of the total panel market, was used in this study as a measure of panel diffusion. Both univariate and multivariate diffusion models were estimated to provide some quantitative information about panel diffusion.

Though no two panels will follow the same diffusion path, the diffusion paths of particleboard and southern pine plywood evinced S-shaped patterns. This pattern is supported by diffusion theory which hypothesizes that diffusion follows a sigmoid pattern. That is, panel diffusion starts slowly, accelerates through an inflection point, and slows as the process nears completion.

Two nonlinear models, the logistic function and Gompertz curve, were used to estimate this pattern, but yielded different results regarding potential market shares and growth rates. Higher potential market shares and longer periods to grow from 20 to 80 percent of the potential resulted when the Gompertz curve was estimated. Results comparing the two models were more consistent for the southern pine plywood data than for the particleboard data. The growth rate of southern pine plywood was approximately twice as rapid as the particleboard rate. For example, the period of time required to grow from 20 to 80 percent of the potential was 7 years for southern pine plywood and 14 years for particleboard based on the logistic function.

Several assumptions are implied when the logistic function and the Gompertz curve are used to estimate past diffusion trends and project future trends. First, the functions imply that new products will gain in market share up to some maximum or potential level. Second, the proportion of market share already gained is an important determinant of future levels. Finally, the increase in market share is a function of supply, demand, and other factors.

These assumptions highlight some of the major limitations of of simple nonlinear models. Though intuitively a panel will increase in market share only up to a maximum level, there is no independent means for estimating that level. Therefore, market share projections are based on a nonlinear extrapolation of past trends. A number of factors that will influence the potential are examined in this study; however, it is not possible to satisfactorily estimate the extent to which a panel will diffuse in a complex market. Similarly, the models provide no explanation of factors affecting diffusion.

In order to assess the usefulness of these functions for projecting trends and potential market shares under different conditions of data availability, five time periods of varying length for particleboard and southern pine plywood were fitted with the logistic function and the Gompertz curve. For most data sets tested, the logistic function yielded more conservative estimates of market share potential than did the Gompertz curve. Thus, model selection affects projections. In all cases where the standard error of the potential was small, over 85 percent of market potential had been reached by the last year of the data series. Therefore, these diffusion functions should be used for projections only when the diffusion process is substantially underway as was the case with particleboard and southern pine plywood.

Despite the shortcomings of the nonlinear functions, they are useful for studying diffusion. For example, the S-shaped models represent the diffusion pattern better than simple linear trend models. In addition, they provide an estimate of potential market share and a measure of the rate of panel diffusion. As a result, they can be used to estimate the relative magnitude of future particleboard and southern pine plywood diffusion.

While the univariate models are useful in depicting temporal diffusion trends, they are not very helpful in understanding the role supply and demand factors play in determining panel consumption and diffusion. The supply and demand factors influencing particleboard and southern pine plywood diffusion were screened by means of structural supply and demand equations.

On the demand side, product price and multifamily (3 or more units) housing starts were inversely related to quantity demanded. One and two unit housing starts, mobile home shipments, and furniture manufacturing exhibited a positive relationship in the particleboard case. In the southern pine plywood case, western softwood plywood price and one and two unit housing starts were significant variables with positive signs; increases in these variables are expected to lead to increases in southern pine plywood demanded, all things being equal.

In the particleboard supply equation, adhesives price and wages had negative signs while lumber production and energy price had positive signs. The negative signs were expected since increases in input prices lead to shifts in the supply curve, ceteris paribus. Lumber production was used as a proxy for raw material (wood furnish) availability and had the expected positive relationship to quantity supplied. For the time period analyzed, the net effect of energy prices on the quantity of particleboard supplied was positive indicating that competing products were adversely affected by price increases to a greater degree. The most significant supply factor in the southern pine plywood supply equation was mill productivity. As productivity increased, quantity supplied increased holding other variables constant.

The same factors which influence supply and demand for a panel also influence its diffusion. Table 2 presents data relating market share and price trend data for major wood-based panels since 1969. Apparent domestic consumption of western softwood plywood, hardwood plywood, and insulation board remained relatively stable over 1969 through 1979 period indicating they are mature products. Hardboard, particleboard, and southern pine plywood consumption more than doubled over the same period; they are substantially into market share growth stage and are approaching maturity.

The increased price of western softwood plywood and competition from newer panel products contributed to its decrease in market share. Lack of suitable domestic wood supplies, competition from other panels, and fast growth of newer panel segments led to a decrease in hardwood plywood's market share. The relative flexibility and greater diverstiy of end-uses for competing panels accounts for the decreased market share for insulation board.

Particleboard and hardboard increased in market share and decreased in relative price over the 1969 through 1979 period. This inverse relationship corresponds to the expected demand price-quantity relationship and is further corroboration of the role demand factors can play in panel diffusion. Southern pine plywood's market share-price relationship is the same when viewed relative to western softwood plywood, a substitute in the sheathing market.

Lagged market share variables along with the supply and demand variables discussed above were tested as explanatory variables in a temporal multivariate market share model. The lagged market share variables were included to show the accumulated effects of supply,

Table 2. Wood-based panel product market share (diffusion) and price trends, 1969 and 1979.

Panel type	Year/trend[1/]	Market share (percent and trend)	Price[2/] (index and trend)
Western softwood plywood	1969	38.1	100
	1979	28.3	130
	Trend	Decreasing	Increasing
Southern pine plywood	1969	10.5	100
	1979	20.5	94
	Trend	Increasing	Fluctuating
Particleboard	1969	6.2	100
	1979	9.6	49
	Trend	Increasing	Decreasing
Hardboard	1969	17.5	100
	1979	23.2	75
	Trend	Increasing	Decreasing
Hardwood plywood	1969	14.4	100
	1979	8.4	74
	Trend	Decreasing	Decreasing
Insulation board	1969	13.2	100
	1979	8.5	87
	Trend	Decreasing	Decreasing

[1/] 1969 through 1979 trend.

[2/] Relative to all commodities producer price index, 1969=100.

Source: Appendix

demand, and qualitative factors on product diffusion. The seemingly unrelated regression results presented in Table 3 were not significantly different from the ordinary least squares results. The analysis indicates that past market share was a significant variable in the diffusion of product innovations. For southern pine plywood and particleboard, end-use market demand factors were also significant explanatory variables. Particleboard market share growth was a positive function of furniture and mobile home market growth. Interestingly, southern pine plywood market share growth was greatest during periods when housing starts declined.

The spatial aspects of diffusion were examined for southern pine plywood in relation to western softwood plywood. A model relating the percent of softwood plywood shipments to 29 Rand-McNally Major Trading Areas was formulated. As the distance from a Pacific Northwest supply point (Portland, Oregon) to the Major Trading Areas increased and as the number of southern plywood plants near the Major Trading Areas increased, the southern pine plywood market share increased. Transportation cost is one of the main factors leading to these results and to southern pine plywood's regional advantage in the eastern United States.

A number of qualitative factors that are not amenable to statistical modelling play an important part in promoting and hindering product diffusion. Among the more important factors are: characteristics of the good, building codes and standards, process innovations, and raw material price and availability. Other factors such as nonwood product competition, product promotion, research and development activities, and government policies, also influence product diffusion,

Table 3. Estimated parameters of the multivariate, temporal diffusion submodel for particleboard and southern pine plywood using seemingly unrelated regression analysis.

Dependent variable (Y)	Explanatory variables (X)	Regression coefficient (b)	Standard error of b
Particleboard market share[1/]	Lagged market share	.712930	.079887
	Index of furniture and fixtures manufacturing	.000224	.000094
	Mobile home shipments	.000027	.000007
	Constant	- .012022	.006770
Southern pine plywood market share[2/]	Lagged market share	1.004440	.006770
	Housing starts, 1 & 2	- .000035	.000009
	Constant	.051362	.008771

[1/] Estimates based on data from 1964 through 1979. $\bar{R}^2 = .97$, D.W. = 2.30.

[2/] Estimates based on data from 1964 through 1979. $\bar{R}^2 = .99$, D.W. = 2.01.

Sources: Tables 24 and 25.

but are beyond the scope of this study.

There are similarities and differences in these factors and their roles in the diffusion process. The qualitative and quantitative factors presented in Table 4 provide a basis for explaining differences in particleboard and southern pine plywood diffusion. In addition, the factors provide a framework for examining other new products.

Figure 1 summarizes the effects of qualitative factors on the diffusion of particleboard and southern pine plywood over the product life cycle. Notable similarities between the panels were the testing and modifying of production processes and the large amount of raw materials potentially available for processing before and during the product introduction stage. These factors will undoubtedly be important to future product successes.

Southern pine plywood's rapid diffusion was enhanced by (1) its similarity to other existing low quality softwood plywood, (2) its accepted standardization coinciding with initial production, (3) its low price relative to western softwood plywood, and (4) its regional advantage. To a large degree, these factors led to southern pine plywood's broad acceptance in the marketplace. Factors which may eventually slow its diffusion include (1) almost total reliance on one end-use, sheathing, (2) rising sawlog costs, and (3) competition from new structural panels.

Particleboard diffusion was somewhat slower than southern pine plywood's market share growth. Particleboard's unique properties have led to wide acceptance over time, but during its introductory stage the uniqueness was a hindrance. A multitude of end-use applications and declining relative prices have aided particleboard's

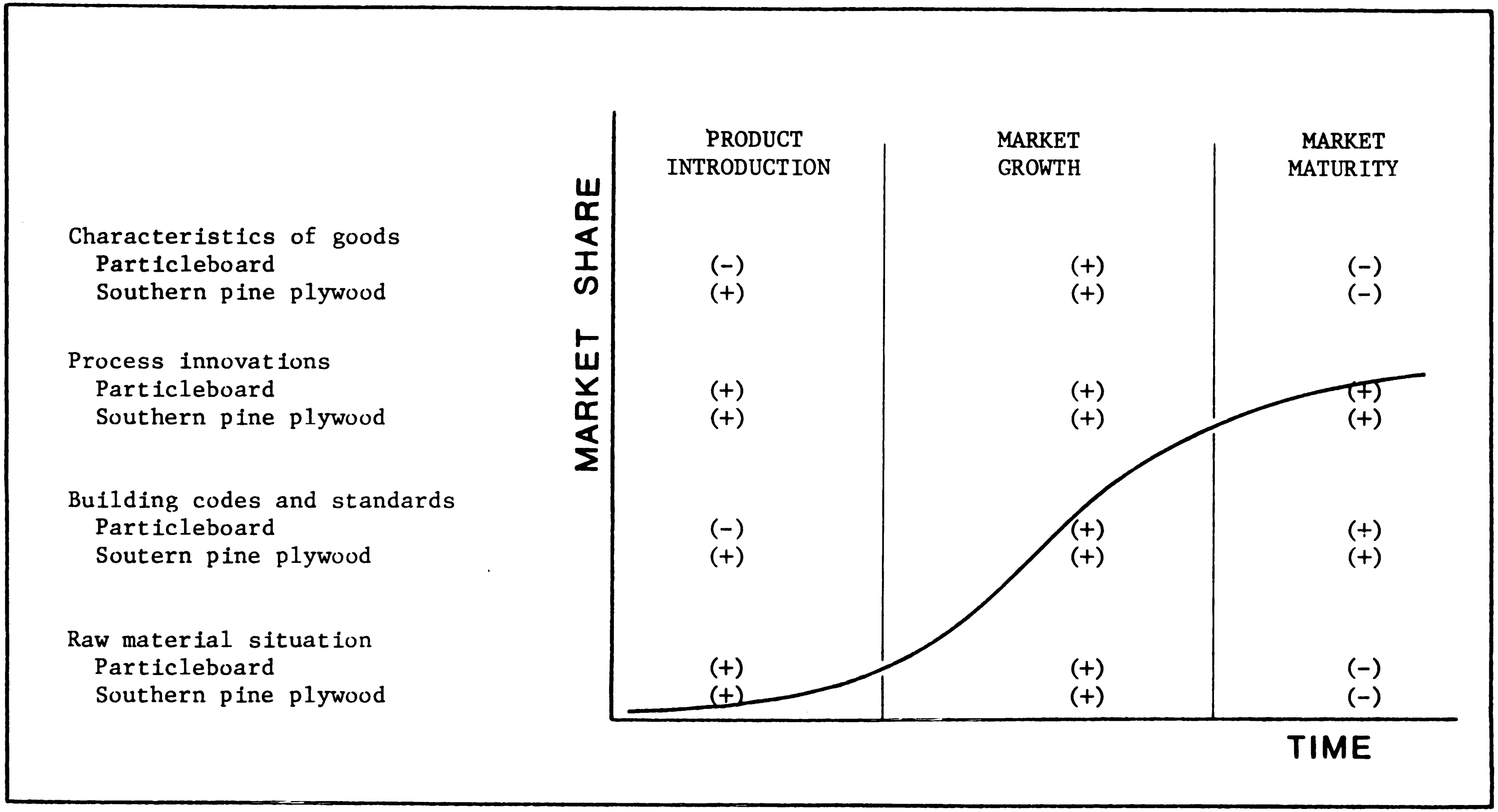


Figure 1.--Roles of qualitative factors in promoting (+) or hindering (-) particleboard and southern pine plywood diffusion over time.

Table 4. Summary of factors influencing particleboard and southern pine plywood consumption and diffusion.

Factor	Particleboard	Southern pine plywood
(1) Product character	Unique properties originally	Equivalent to other low quality plywood
(2) Standards	Gradual modifications	Immediate classification
(3) Processes	Imported and modified; industry and government research	Imported and modified; industry and government research
(4) Primary uses	Furniture corestock, underlayment	Sheathing
(5) Price	Generally declining	Fluctuating
(6) Raw Material situation	Massive residues available originally	Large volumes of sawtimber stocks available originally
(7) Supply and demand model factors	Product price, substitute prices, end-use market activity, input prices, residue availability	Product price, substitute prices, end-use market activity, input prices, productivity
(8) Diffusion sub-model factors	Accumulated market success, end-use market activity	Accumulated market success, end-use market activity, regional location advantage

diffusion.

In general, if a panel has product characteristics similar to those of an existing product, diffusion occurs more readily. This phenomenon is due to decreased consumer resistance to a familiar product. For example, waferboard, medium density fiberboard and composite panels are more acceptable because particleboard and hardboard had gained widespread approval prior to their introduction. Eventually, the physical characteristic limitation of a panel will slow its diffusion in the total market. That is, it will diffuse only through end-use markets for which it is suited.

The development of process innovations is important in all stages of a product's life. Major innovations may lead to the formation of new industries, and "nuts and bolts" innovations during the market growth and maturity stages may keep a panel competitive with its substitutes. Overall, process innovations promote the diffusion of products.

Formal standards promoted the acceptance of particleboard and southern pine plywood. They were especially helpful in the case of southern pine plywood for which standards existed when the first panels were introduced. More rapid acceptance occurred as a result. For particleboard, the slow evolution standards initially hindered its diffusion. In general, early development of standards and code approval will aid in the diffusion of newer panel products.

The availability and price of wood inputs are also important supply factors influencing the past direction of the panel products industry. Large quantities of relatively inexpensive manufacturing residues spurred the establishment and growth of the particleboard industry. Likewise, the high price and reduced availability of Douglas-fir peelers contributed to southern pine plywood's establishment and growth as a panel product. The volume of southern pine sawtimber growing stock was equally important. Over time, increased cost and decreased availability of wood inputs will hinder the diffusion of a given panel. However, if the capital is available for investment, the existence of large quantities of raw materials can promote the establishment of panel industries and lead to the introduction of new products.

In conclusion, projections are difficult to make when large amounts of pertinent information are available and even more difficult when little is available. One example of a projection by an industry expert based on few trend data is the following:

> ...talk about dozens of new plywood plants in the South during the next decade does not seem justified. Land ownership problems, availability of raw material on lands dedicated principally to other products, and the as yet unfelt price competition from the massive western industry all seem to militate against over-rapid expansion. A total of perhaps 8 or 10 mills during the coming decade may be a more realistic estimate (Fassnacht, 1964).

This projection was surpassed by the end of 1965 when the twelfth plant started production. Due to the complexity of the diffusion process and lack of data on the newest products, estimates on the magnitude of their diffusion would only be speculative. However, some general statements can be made regarding the direction of product innovation and its effects on wood requirements based on the review of qualitative factors.

First, new products will utilize more diverse raw materials and in greater quantities than has been the case in the past. Waferboard and composite board are ample evidence of this trend. Roundwood engineered into flakes, particles, and strands by equipment, such as the chipping lathe headrig, is becoming more widespread. Increased production, particularly of waferboard, indicates new panels can be competitive even during periods of low market activity.

Second, many products that will play a significant role in satisfying panel product demand at the turn of the century are just becoming known or may still be on the drawing board. The gains by particleboard and southern pine plywood are cases in point. Raw material availability was important to the success of those products, and presently underutilized resources may be the key to future successes.

Third, the evolution of standards and the awareness of their importance has opened the door for future product innovations. As standards become based on performance criteria rather than composition, new panels will be engineered to compete with existing panels. Standards being developed by the American Plywood Association are examples of this type of evolutionary and innovation-promoting standard.

Finally, new product and process innovations expand our resource base as they diffuse through the market. The new products, in turn, slow the diffusion of existing, traditional products.

INTRODUCTION

Technological change is a major factor influencing economic growth and productivity. Technological change and its subsequent diffusion through an industry can shift supply functions through process innovations and demand functions through product innovations (Bentley, 1970). The initial effect of a process innovation is a new relationship between inputs and outputs, whereas, the initial impact of a product innovation is the substitution of one product for another. Over time, innovations lead to significant changes in raw material and other input requirements and extensive substitution of new products in various end-uses.

The interaction of social, political and economic factors influences the rate and magnitude of diffusion. In order to get more insight into the complex process of the diffusion of product innovations, the relationships between these factors must be analyzed in their historic context.

The Problem

In 1974, Congress enacted the Forest and Rangeland Renewable Resources Planning Act. This act requires the United States Forest Service to periodically assess the present and anticipated uses of our Nation's renewable forest resources. Research Work Unit 4151 at the United States Forest Service Forest Products Laboratory is responsible for projections of timber requirements and trends in harvesting, processing, product design and end-use technology of wood products. As such, they are interested in trends of advancing technology in the wood-based panel products industries and their effects on the relationships between wood product consumption and timber use. The impact of product innovation on raw material requirements has not been adequately assessed in the past. The purpose of this research study is to investigate factors influencing product innovation and diffusion in the wood-based panel products industries and the effects of these changes on raw material requirements.

Presently, the Resources Planning and Assessment Staff Unit uses historical data as a base for resource demand and supply projections. This implicitly assumes a continuing stream of technological changes and innovations for the future based on little specified knowledge of factors affecting the diffusion of innovations in the past (U.S. Department of Agriculture, Forest Service, 1977). By identifying forces that have historically influenced the diffusion of innovations, the forces can be incorporated in future models.

Two major forest product innovations requiring wood inputs are particleboard and southern softwood plywood. Particleboard was an obscure panel product in the early 1950's, but over 6.3 billion square feet (3/8-inch basis) were consumed in 1976 (U.S. Department of Agriculture, Forest Service, 1980). Southern pine plywood comprised zero percent of United States softwood plywood production in 1964; yet, in 1976 it had captured over 36% of U.S. output (Anderson, 1979). Factors influencing these product innovations and their diffusion will be useful in assessing newer panel products such as medium density fiberboard, composite board and waferboard.

Objective of the Study

The primary objective of this study is to analyze the effects of product innovations and diffusion on raw material requirements in the wood-based panel products industry. The secondary objective is to hypothesize the future roles economic and other factors will play in determining the direction and diffusion rates of panel product innovations.

Framework for Analysis

Product innovation and diffusion are complex phenomena involving both economic and noneconomic factors (Warner, 1974). Economic factors include product prices, input prices, substitute prices and end-use market activity. Product characteristics, standards and building codes are examples of noneconomic factors.

Due to this complexity, several approaches for examining innovation, diffusion and their effects are useful. First, process innovations, product innovations and end-uses (existing and potential) can be described. Second, economic, social and physical input trends that may influence the rate and direction of innovation and diffusion can be identified and evaluated. Finally, mathematical models can be used to relate trends in these factors to innovation, diffusion and raw material requirements.

The first two approaches are qualitative in nature. Major process innovations can be described and classified as to (1) year of adoption, (2) adopting company, (3) location, and (4) origin of process. By examining these traits, a greater understanding of innovation and diffusion can be gained. This information is enhanced when coupled with trend data on inputs, production, prices, product standards and other important factors.

Though there is presently insufficient knowledge of important factors to adequately forecast future technologies and their effects in the wood-based panel products industry, mathematical models can be used to quantify some effects of existing product innovations. Product consumption, price and raw material requirements are some major effects of concern to forest economists.

The analytical approach most commonly used by economists is to model supply and demand, separately or simultaneously (McKillop, 1967; McKillop, Stuart, and Geissler, 1980; Mills and Manthy, 1974). These models provide estimates relating product consumption and production to various factors including price, income and population, but they do not directly yield estimates on the rate of adoption and potential market share of new products. Econometric models for particleboard and southern pine plywood supply and demand are used in this study to corroborate the role of economic variables in product diffusion.

Mathematical diffusion functions, on the other hand, have been widely used to model the diffusion process. The modified exponential function, the Gompertz curve, and the logistic function are examples of diffusion functions used by researchers (Lekvall and Wahlbin, 1973). The functions are used to fit empirical observations and to make predictions concerning developments in diffusion processes already underway.

Selection of the appropriate diffusion model or functional form poses a problem and is decided on the basis of observed data (Maddala, 1977). A considerable amount of empirical research supports the use of the logistic function to describe the diffusion process for new products. Since observed market share data for particleboard and southern pine plywood follow an S-shaped pattern, the logistic model will be utilized in this study because it provides information on the rate and magnitude of product diffusion. Results based on the Gompertz curve are also presented. The models assume that diffusion follows a sigmoid pattern starting slowly, accelerating through an inflection point, and slowing as the diffusion process nears completion.

The diffusion models are used to compare the diffusion of particleboard and southern pine plywood. The purpose in studying these products is to compare their rates of adoption, potential market shares, and wood requirements along with differences and similarities of factors affecting the diffusion process. This information will be used to hypothesize on the roles these factors will play on other existing and future wood-based panel products.

Scope of the Study

A number of important product innovations have occurred in the wood-based panel products industry since World War II. This study focuses on two product innovations so that the study will be manageable and because time series data are available only for a limited number of innovations. Rather than studying the products of individual firms, aggregate product forms and their related wood requirements are analyzed.

Data utilized in this study are primarily from various Census of Manufactures, Current Industrial Reports, and forest products publications. The product forms studied are particleboard which corresponds with Standard Industrial Classification (SIC) 2492, Particleboard, and southern softwood plywood which is a component of SIC 2436, Softwood Veneer and Plywood. The time frames are years 1955 to 1979 for particleboard and 1964 to 1979 for southern pine plywood.

These product forms have shown significant growth in recent years. The number of plants producing particleboard in North America increased from 23 in 1955 to 72 in 1979. Particleboard production increased from an estimated 140 million square feet (3/8-inch basis) to over 7.2 billion square feet during this period. Three plants were responsible for the production of 80 million square feet (3/8-inch basis) of southern pine plywood in 1964. Seventy-two southern plywood plants produced approximately 7.6 billion square feet in 1979. Southern pine plywood accounted for 41.2 percent of United States softwood plywood production in 1979.

Definition and Concepts

Economic and management literature are replete with definitions of technology and related concepts. For this study, the following commonly used definitions will apply. Technology is defined as the social pool of knowledge of the industrial arts (Schmookler, 1966). Technological change is regarded as the advance of technology whose rate is determined by new technology produced in any given period. Technique is a specific method of producing a good or service; change of technique is "...the employment of existing but unused technology" (Manthy, 1974).

An innovation is defined by the National Research Council (1978) as the introduction of new things or methods. Implementation by industry or some other group is required by this definition. In a given industry, the first enterprise to adopt a new technique is considered an innovator. Subsequent adopters are imitators. This study focuses on innovation and subsequent adoption or diffusion.

Technological innovations, which are implemented technological changes, are classified in three categories: "nuts and bolts" innovations, major technological advances and creation of large new systems (National Research Council, 1978). "Nuts and bolts" innovations are exemplified by product differentiation and minor changes in production processes. Major technological advances, which are examined in this study, provide opportunities for new processes or products. The creation of a large new system may or may not be based on a new technology, but it does require a new combination of techniques in a complex manner.

Another often cited classification distinguishes product innovations from process innovations (Schmookler, 1966). New commercial products are product innovations, whereas process innovations are new methods used for creating products. Major process innovations in the particleboard and southern plywood industries are identified in this study. Products can be viewed as (1) general product classes (e.g. wood-based panels), (2) product forms (e.g. particleboard and southern pine plywood), and (3) brands (e.g. GP Particleboard and Plum Creek Fiberboard) (Kotler, 1976). This study analyzes the diffusion of product forms in the wood-based panel products industry. Market share is analyzed as the indicator of panel diffusion. Hereafter, product forms will be referred to as products.

Innovation and product diffusion have a variety of effects. For example, they may cause changes in the nature and quantity of wood inputs utilized. Other effects include factor and product substitution, the creation of new resources, and changes in industry structure.

METHODS OF EXAMINING INNOVATION, PRODUCT DIFFUSION, AND ITS EFFECTS

In order to assess the effects of product innovations on raw material requirements in the wood-based panel products industry, an understanding of the diffusion process and factors influencing successful diffusion is paramount. Historical examination of interacting factors such as process innovations, products characteristics, building codes and standards, raw material situations, and economic data series are useful in analyzing product innovation and diffusion. In addition, econometric models can be used to supplement our knowledge and to measure some effects of product diffusion. Specifically, the models can be used to estimate future panel consumption, rates of diffusion, market shares, and wood requirements.

The rationale for examining specific interacting factors is presented in the following section. Since this is an aggregate analysis, these factors were selected on the basis of economic theory and a literature review (Leefers, 1979). The final section of this chapter provides the basis for the models used and the estimation procedures employed in this study.

Interacting Factors

The interaction of social, political, and economic factors influences the rate and direction of technological change (Rogers and

Shoemaker, 1971). Following the first implementation is the diffusion of the innovation. In this case, the primary focus is on the diffusion of particleboard and southern pine plywood, factors influencing their diffusion, and the effects of diffusion in terms of wood requirements. The magnitude of diffusion is the primary determinant of wood requirements for the new product.

A concept frequently used to describe the path a product follows over time is the product life cycle (McCarthy, 1975). Figure 2 illustrates this concept in terms of sales. There are four major stages in the life of a product: (1) product introduction, (2) market growth, (3) market maturity, and (4) sales decline. Introduction is a period of slow growth and is followed by a stage of more rapid growth. Maturity is a period when sales slow due to widespread acceptance by most buyers. The final stage marks the decline of product sales (Kotler, 1976). This decline is often caused by new products replacing the old.

Support for the life cycle concept is based on the hypothesis that new products must overcome customer reluctance or resistance to established purchasing patterns (Buzzell, 1966). The idealized S-shaped product life cycle curve, of course, does not hold for all products, and the period of time for each stage may vary dramatically. For example, product classes such as wood-based panels may continue in a growth or mature stage for long periods of time.

Since product innovation and diffusion are closely related to existing products and markets, it is important to view the introduction and growth of products in the context of the whole market. New products that will have a significant long-term effect can be expected to grow

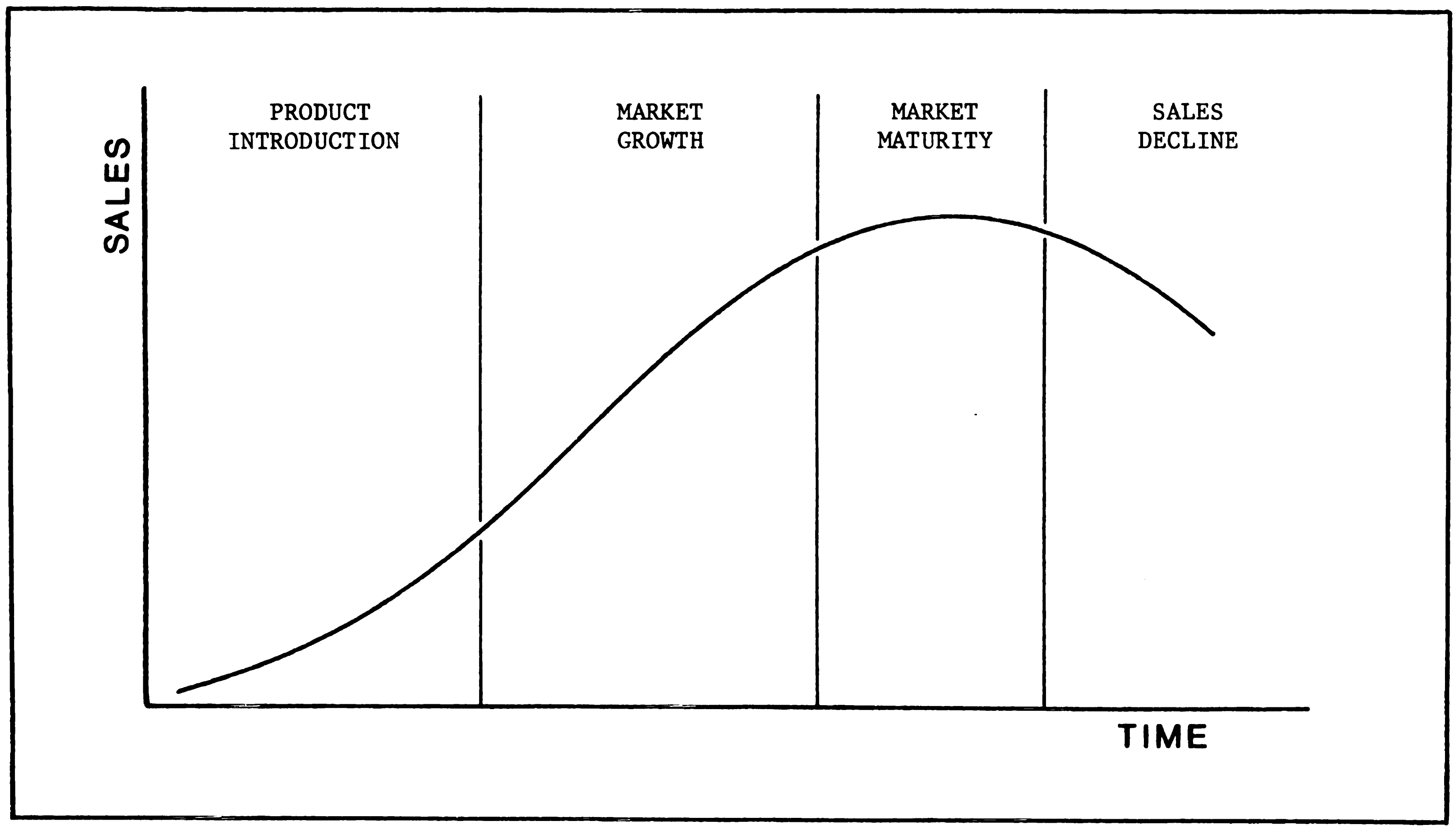


Figure 2. Product life cycle.

at a faster rate than the market. The diffusion of new products in the market can most readily be seen in terms of market shares.

The product life cycle can be redefined using market share of consumption rather than sales as the variable of interest. Any demarcation between the various stages is subjective.

For this study, the product introduction stage is the period which begins with the product innovation and ends when the panel has reached twenty percent of its potential market share. Though the distinction between the introductory stage and the market share growth stage is somewhat arbitrary, one characteristic of the growth stage is the point of maximum marginal market share growth (inflection point). After this point, market share growth slows. The mature stage is a period when market share initially stabilizes indicating that the growth rate of product form consumption is equal to the growth rate of product class consumption. The mature stage can also exhibit a decline in market share with growing or stable product form consumption. Existing products are expected to exhibit this condition as new products are introduced. The decline stage is identified as a long period during which product consumption and market share decline.

The market share associated with a particular product innovation is determined by the interaction of supply, demand and other forces along a path to maximum market share (Griliches, 1957). Since the data available on individual brand diffusion and intrafirm process adoption are limited, this study analyzes the impact of aggregate variables on product form diffusion.

Characteristics of Goods

Traditional demand theory permits economists to analyze the effects of different preferences on demand, but provides no mechanism for tracing the effect on demand of changes in physical properties of goods (Lancaster, 1971). Traditional microeconomic analysis begins with a preference map. At that stage, the characteristics of the goods, other than price, have already been absorbed into the analytical framework. Though the characteristics (e.g., weight, color, size, etc.) may change, this information is rarely used at a later stage in demand theory analysis.

Product variants, model changes, and new goods are difficult to incorporate into traditional economic models. Either (1) the changes are ignored or (2) the variant is treated as an entirely new good. In practice, our ability to investigate physical changes in goods is limited by the data available on the altered goods.

When changes are ignored, the characteristics of the variant are implicitly absorbed into the aggregate product grouping. For instance, graded density particleboard may be viewed simply as particleboard. In the second case, the variant is treated as a new good which acts as a substitute for the original product. As a substitute, we explicitly acknowledge that certain comparable attributes or characteristics link the new with the old. Southern pine plywood, for example, can be treated as a new good, as a substitute for western softwood plywood, and not simply as more softwood plywood.

Ultimately, the utility a good will provide establishes the extent to which it will be used vis-a-vis other goods. This utility, in part, is closely related to the characteristics and properties of the good. Theoretically, the demand for new goods could be predicted based on observed behavior of consumers toward existing goods with similar characteristics (Lancaster, 1971). In principle technical data concerning product attributes will determine the closeness of substitution. Thus, the characteristics of a particular wood-based panel determine the range of uses to which it is suited and the extent to which it can substitute for other products.

Though any good possesses a number of physical properties, not all properties are relevant to choice between goods. From a practical standpoint this situation is further exacerbated by the fact that individuals react differently to specific attributes depending upon their own preferences. Therefore, in an aggregate analysis it is difficult to objectively ascertain which characteristics increase the probability of an innovation's successful diffusion. This is especially true for products that have many properties and a multitude of potential applications.

A useful method of incorporating characteristics into traditional economic analysis is to identify relevant physical properties emphasizing those properties that are most pertinent to specific end-uses. In some instances, a product's characteristics may remain unchanged over time. However, knowledge regarding the product and its characteristics will increase in a free market as time passes. This increased knowledge may be due to marketing efforts, word-of-mouth, and other factors.

Process Innovations

Within a product class, process innovations can chdnge the production function for existing products or serve as the basis for new product forms and products. The new processes can be developed within or outside the adopting industry and can be imported from other countries. Regardless of the origin, process innovations have played a major role in defining the characterisitics of panels as they exist today.

Many technological innovations have been adopted in the wood-based panel industry. These innovations range from "nuts and bolts" innovations such as using forklifts for loading plywood into railroad cars (Cour, 1955) to the creation of large new systems such as the Georgia Pacific's Fordyce, Arkansas, plywood plant (Baldwin, 1977).

The effects of adopting new processes are reflected in prices of finished goods, raw material utilization, and products available in the market. As is the case with characteristics of goods, process innovations are difficult to incorporate in an aggregate analysis. However, many important process innovations can be identified and their roles described.

The speed of adoption of new techniques has been analyzed by Mansfield (1963). His study supports the hypothesis that speed of adoption is a positive function of firm size and expected returns. In more concentrated industries, process diffusion generally is more rapid due to the trialability and observability of the innovation and the high degree of intrafirm communication, ceteris paribus (Rogers and Shoemaker, 1971).

Building Codes and Standards

Building codes and product standards are "'evolutionary documents' that have been amended to accept new products and test methods as they have been developed (Pease, 1980)." The nature and flexibility of the codes and standards are factors determining how rapidly new products will gain acceptance. If panels do not have code approval, they cannot be used for many potential end-uses (Brown, 1979). If standards are nonexistent, poor quality products will sometimes be produced. The result is bad publicity and fewer sales (Anonymous, 1966a).

New standards are created to encompass new products, to recognize more wood species, and to account for changing log quality (Anonymous, 1966b). The standards, in effect, change to accommodate raw material situations, process and product innovations, and the producers' capabilities.

Economic and Marketing Factors

As mentioned previously, supply, demand and other factors influence the diffusion of new products. Product prices and consumption in various end-uses represent the interaction of supply and demand over time (Risbrudt, 1979). Consumption data can be transformed readily into market share data once the total market and appropriate measurement units are defined.

Marketing professionals view the period of growth in product consumption and in knowledge about the product as the initial stages of the product's life cycle (Kotler, 1976). The marketing mix of product, price, place and promotion changes as the product moves from the introductory stage through the growth stage.

The initial message for new products is a description of what they are and what they do. The characteristics, unknown to potential users, must be promoted. As knowledge concerning the physical attributes of a product increases, a marketer's activities must be shifted to other facets of the product mix. As time passes, most potential consumers become aware of a product's characteristics and act accordingly. The eventual result is a slowing of market share growth.

The availability of distribution channels determines whether or not products reach potential consumers. Since most new panel products are developed by companies with existing distribution channels, the "place" marketing factor is not included explicitly in this analysis.

Panel products can be classified as either industrial goods or consumer goods depending on their end-use. Unfortunately, most end-use information is derived from production rather than consumption statistics (Food and Agriculture Organization of the United Nations, 1976). The major end-uses in terms of volume for panels are new housing, residential upkeep and improvement, manufacturing, and new nonresidential construction (U.S. Department of Agriculture, Forest Service, 1979). Since panel demand generally is derived from demand for final consumer goods (e.g., houses, furniture, etc.), changes in end-use consumption will influence the diffusion of new products. That is, if end-use consumption is growing, market penetration is more likely.

All other things being equal, increases in product prices are expected to hinder the diffusion of new products. Skimming price policies (i.e., higher prices) will lead to slower gains in market share than penetration price politices (i.e., lower prices) (McCarthy, 1975). Changes in price may be caused by shifts in supply, demand, or both.

The prices of competing products are important factors, too. As competing products become more expensive relative to new products, market penetration is enhanced for new products, ceteris paribus.

Income and population are expected to influence market share growth since they also affect long-term demand. Disposable personal income is an important determinant of demand for wood-based products and influences household formation and furniture consumption (U.S. Department of Agriculture, Forest Service, 1979).

Finally, the availability of products in the market is influenced by transportation costs. As the distance from the producing region increases, inplace cost increases. As a result, product innovations produced in a given region have a competitive advantage over imported products, ceteris paribus.

Raw Material Situations

The raw material situation has always played a key role in the development of the forest products industry. Timber availability and depletion historically caused the movement of the logging industry into the Lake States on to the South and the Pacific Northwest and now, back to the South.

The panel products industry is also influenced by wood supplies. In the West, Douglas-fir is important for plywood production; loblolly, shortleaf and longleaf pine are the main plywood species in the South; and an assortment of species in the form of roundwood and residues is utilized nationwide in the other panels. The availability and price of these materials will determine, in part, the competitiveness of the various panels and the direction of future panel developments.

Labor, capital, energy and adhesives are other input factors affecting product innovations in the wood-based panel industry. The plywood industry has evolved from labor-intensive operations using animal glue and wooden presses into a capital-intensive industry with multi-platen presses and a variety of glues (Cour, 1955). Likewise, particleboard plants have grown in size and complexity requiring new combinations of inputs. Energy inputs are becoming more expensive, and particleboard mills are now competing for residues with plants which may burn the residues for energy production. In total, these factors will lead to changes in processing and input utilization.

Models

There are many approaches to modelling the demand for an existing product and its substitution for other products. Some approaches used are:

(1) Methods based primarily on the autocorrelation properties of the time series to be forecast,

(2) Methods conceived on the basis of a Markov process which hypothesizes that demand is a random variable, and

(3) Structural econometric models which attempt to provide causal explanations for the phenomenon studied (Quandt, 1964).

The first approach includes time series decomposition in which trend, cyclic and seasonal components are identified. The second approach involves a brand switching matrix which can be used to calculate market shares. The last approach is based on economic hypotheses and can be subjected to statistical testing. This study utilizes the first and third approaches for analyzing the diffusion or product innovations, factors influencing diffusion, and the effect of diffusion on wood requirements.

The model hypothesized for this study is composed of three submodels: (1) the aggregate panel market submodel, (2) the market share submodel, and (3) the wood utilization submodel. The aggregate panel market submodel is an econometric model based on relatively gross economic variables (Mills and Manthy, 1974). The market share submodel is an extensive examination of trends in new product diffusion. Both simplistic trend models and multivariate econometric models are used and compared. The wood utilization submodel is based solely on published data relating wood inputs to panel output. The two submodels requiring econometric analysis and the purpose for the models are presented in Figure 3.

Mathematically, the three submodels can be related to total wood requirements as follows:

$$WR_i(t) = C(t) \times M_i(t) \times U_i(t) \tag{1}$$

where: $Wr_i(t)$ = wood requirements for panel products i at time t,

$C(t)$ = aggregate panel consumption at time t,

$M_i(t)$ = market share of panel product i at time t, and

$U_i(t)$ = average wood requirement per unit of panel i output at time t.

Theoretically, this model can be expanded by considering panel consumption and market share by end-use category. However, in practice it is difficult to expand the model because published data are generally based on production rather than consumption statistics. To the extent possible, end-use trends are incorporated in the discussion.

Aggregate Panel Market Submodel

The aggregate panel market is equivalent to the general product class, wood-based panels. Product classes have long life histories because they are highly population related (Kotler, 1976). Three steps are required in modelling aggregate panel consumption. First, the

Submodel	Purposes
Aggregate panel market	(1) Estimate past consumption and test model parameters
	(2) Project future consumption
Market share	(1) Estimate past market shares and test model parameters
	(2) Estimate past market share trends
	(3) Estimate diffusion rates
	(4) Project future market shares

Figure 3. Submodels requiring econometric analysis and the purpose for using the submodels.

extent of the market is determined, that is, which products will be included in the analysis? Second, a plausible method of aggregating dissimilar products is developed. Third, an aggregate model based on the first two steps is hypothesized.

Since the emphasis of this study is on intra-industry competition between wood-based panels, substitutes such as aluminum, concrete, plastic, and so on are not explicitly considered. Empirical results from a study by McKillop, Stuart, and Geissler (1980) support not including non-wood structural product prices as explanatory variables for wood-based panel products.

Two complimentary approaches are used to determine which products are included in the analysis. One approach is to examine panels in terms of end-uses; those panels having similar end-uses can be included in the aggregate model. The second approach is based on economic theory. A demand function can be estimated in linear or log-linear form, and the coefficients associated with other panel prices will indicate which panels are economic substitutes and which are complements.

The demand for a good is a function of tastes and preferences, the price of the good, income, and the price of the other goods (Greenwald and Associates, 1973). Since there is no prior knowledge regarding the appropriate functional form for the demand curve, two simple models were estimated for this study: the linear demand curve and the constant elasticity demand curve (Hirshleifer, 1976). Estimation procedures are discussed in the final section of this chapter.

The linear demand function has the following form:

$$Y = b_o + b_1P_y + b_2I + \sum_{i=3}^{n} b_iP_i + e \qquad (2)$$

where:

Y = quantity of the panel demanded

P_y = price of panel demanded

I = income,

P_i = prices of substitute and complement panels

b_o = constant

b_i = coefficients estimating the change in quantity demanded associated with a one unit change of the variable, ceteris paribus

e = unexplained variation of Y.

The coefficients associated with P_i have the same signs as the cross-elasticities. The coefficient is positive if the good is a substitute for Y and negative if the good is a complement (Hirshleifer, 1976).

The log-linear demand function is similar to the linear form, except (1) the variables are the logarithms of variables used in the linear model and (2) the coefficients, b_i, become estimated elasticities. The elasticities associated with the logarithms of prices of other goods are cross-elasticities of demand. As such, if the estimated cross elasticity is positive, the goods are substitutes. If the cross-elasticity is negative, the goods are complements.

An important factor that must be considered in determining which panels will comprise the total market is the panel with which comparisons and statistical analyses are made. If a panel with relatively few end-uses is selected, the total panel market will be smaller and market shares for individual product forms will be larger. By selecting a panel with many end-uses, the opposite results are achieved. As long as the panels under the study, particleboard and southern pine plywood, are included in the analysis, the panel used as the basis for comparisons is not critical. This condition exists because the total market can be disaggregated to individual panels.

Markets can be defined in terms of dollar sales or physical units. Physical units are used in this study to allow estimation of wood requirements. As mentioned previously, physical consumption data for all panels in various end-uses are not available over time. Therefore, the mathematical models used in this study utilize data aggregated over all end-uses. Supplemental end-use data are analyzed where possible.

In order to determine the total physical consumption of panel products, a method of aggregation must be developed. Ideally, the total market would be defined as the total surface area of substitute panels consumed in a period of time. However, available data do not permit this approach.

Two alternative approaches can be used. One approach is to select a standard thickness for all panels, convert all panel consumption data to that thickness, and add the new panel data to determine the total market. This approach was used by the U.S. Forest Service in determining panel consumption on a 3/8-inch basis (U.S. Department of Agriculture, Forest Service, 1979). A different approach is used in this study. Panel production, consumption, and wood utilization factors are generally reported in standard measures unique to each panel. These standard measures are closely related to average thicknesses used in various end-uses. Therefore, the surface measures with various standard thicknesses have been aggregated to define the total market. In using this approach, disaggregation by market share yields the surface area in terms of conventional standard measures.

Having developed a method for selecting and aggregating substitute panels, an aggregate consumption model was developed. This model was used to project long-term future panel consumption based on projections of exogenous variables in the model (Stone and Marcin, 1978). The general form of the model is as follows:

$$C(t) = a_o + \sum_{i=1}^{n} a_i x_i + v \tag{3}$$

where:

$C(t)$ = aggregate panel consumption at time t

x_i = exogenous variables that shift demand and supply functions

a_o = constant

a_i = coefficients estimating the change in total panel consumption associated with a one unit change in the respective exogenous variables, ceteris paribus

v = unexplained variation in $C(t)$.

The most commonly used and available exogenous variables are gross national product (GNP), disposable personal income (DPI), population and time. These variables are extremely collinear (average $r = .989$ for the 1955 to 1979 period) so each one was tested individually as an explanatory variable. Based on statistical results and its role in housing and furniture purchase, disposable personal income was selected as the exogenous variable for projecting future panel consumption. Low, medium, and high values for disposable personal income were used (U.S. Department of Agriculture, Forest Service, 1979).

Though the appropriate functional form for the model is unknown, Hair (1967) infers that the semi-log form with logarithms of independent variables has substantial empirical support. Both the linear model above and the semi-log model were tested in this study. The semi-log model was selected for future consumption projections due to statistical performance and empirical support.

There are several problems with this type of model: (1) the estimated relationship may not be stable over the period of estimation and the period of projection, and (2) the explanatory variables have to be projected, too (Maddala, 1977). In addition, there are statistical problems discussed in the last section of this chapter.

Market Share Submodels

Four market share submodels were used to estimate the diffusion of particleboard and southern pine plywood: two were univariate nonlinear models and two were multivariate linear models. The univariate models, the logistic function and the Gompertz curve, were used for analyzing the diffusion trend and rate over time. One multivariate model was used to analyze factors influencing the market share of particleboard and southern pine plywood over time. The other multivariate model was used to analyze factors affecting the market share of southern pine plywood over space.

Supply and derived demand structural equations for particleboard and southern pine plywood were estimated to screen variables used in the multivariate diffusion models and to isolate factors associated with the interaction of supply and demand. Since projections of these variables are not available, only the nonlinear univariate models were used to project future diffusion of the panel products.

The diffusion of successful product innovations, including most grades of paper and board, evinces an S-shaped pattern (Warner, 1974; Hair, 1967). The logistic function and the Gompertz curve have been used to model this diffusion pattern (Griliches, 1957; Buongiorno and Oliveira, 1977; Mansfield, 1961). The general form for these univariate functions is M = f(t) where M is the market share for a product innovation and f(t) is a simple nonlinear function of the time that has elapsed since the introduction of the innovation.

The specific form for the logistic function is:

$$M = P \left[e^{-(a+bt)} \right] -1 \qquad (4)$$

where:

M = market share

P = potential or maximum market share constant

a = location constant (determines horizontal movement of curve)

b = proportionality constant (determines rate of increase of market share)

t = time (1955 = 1, 1956 = 2, ..., 1979 = 25)

e = 2.71828, the exponential constant

The function is monotonically increasing and lies between two asymptotes, M = 0 and M = P. The function is symmetric with a point of inflection at P/2 (Oliver, 1964).

The Gompertz curve has the form:

$$M = P \left[a^{(b^t)} \right] \qquad (5)$$

where:

M = market share

P = potential or maximum market share constant

a and b = constants determining the growth rate of market share

t = time (for particleboard: 1955 = 1, 1956 = 2, ..., 1979 = 16)

This curve is asymmetric and approaches P asymptotically. The point of inflection is at P/e (Lekvall and Wahlbin, 1973).

The logistic function is one of the most widely used diffusion functions in empirical research. Mansfield (1961) developed a strong theoretical basis for using the logistic function to study the diffusion of innovations. His work has been modified here to show its applicability to market share diffusion.

Mansfield's basic premise is that the proportion of firms that have not adopted an innovation at time t that will introduce the innovation by time t+1 is a function of (1) the proportion of firms that already adopted it by time t, (2) various economic variables, and (3) other unspecified variables. By making a number of restrictive assumptions, he argues that the number of firms that have adopted an innovation over time can be approximated by the logistic function.

A number of Mansfield's assumptions can be modified to show their relevance to diffusion in terms of market shares. First, the function implies that new products will gain in market share up to some maximum level. This level can range from zero to one hundred percent of the market. Statistical estimation procedures, however, do not impose any restriction on the maximum level.

Second, the proportion of market share already gained is an important determinant of future levels. This assumption is based in part on the role knowledge and learning play in economic growth (Arrow, 1962). As use of the innovation becomes more widespread, uncertainty concerning the innovation is reduced, thereby increasing adoption of successful innovations.

Finally, the proportionality constant, which determines the rate of increase of market share, is a function of supply, demand, and other factors. The constant also has been defined as the rate of imitation

(Mansfield, 1961), the rate of acceptance (Griliches, 1957), and the proportionate rate of growth (Maddala, 1977). In essence, this assumption acknowledges that a multitude of factors influence acceptance of new products.

In order to gain insight into the usefulness of the univariate models under different conditions of data availability, the model parameters were estimated and compared for twenty different time periods. In addition to the model parameters, two additional statistics were estimated: (1) the inflection point and (2) the number of years required for the product to increase from 20 percent to 80 percent of potential market share. The latter statistic was calculated as an indicator of the diffusion rate, and is equivalent to the market share growth stage discussed previously.

The multivariate model utilized to estimate the market share trend over time consists of one identity and two equations. By aggregating over all end-use markets at a point in time, the sum of the market shares of substitute products is equal to one, i.e.,

$$\sum_{i=1}^{n_t} M_i(t) = 1 \qquad (6)$$

$M_i(t)$ is the percentage of the aggregate wood-based panel market (in decimal form) of the i^{th} product at time t and n_t is the number of products in the market at time t. The market share functions each contain one endogenous variable which is influenced by a group of exogenous variables. The functional form was:

$$M_1 = a_o + \sum_{i=1}^{n} a_i x_i + u_1 \qquad (7)$$

$$M_2 = b_o + \sum_{j=1}^{m} b_j x_j + v_2 \qquad (8)$$

where:

M_1 and M_2 = market share of particleboard and southern pine plywood, respectively

x_i and x_j = exogenous variables affecting particleboard and southern pine plywood, respectively

a_o and b_o = constants

a_i and b_i = structural coefficients estimating the change in market share for particleboard and southern pine plywood associated with a one unit change of the variable, ceteris paribus

u_1 and v_2 = unexplained variation of M_1 and M_2

The two equation model was estimated as a system of seemingly unrelated regression equations and by ordinary least squares. Annual market share data from 1955 through 1979 for particleboard and from 1964 through 1979 for southern pine plywood were used in the model. Portions of the study period were relatively stable while other portions were turbulent in nature.

The influence of transportation costs and regional availability of a product innovation, southern pine plywood, was examined in the following model:

$$M = c_o + c_1 N + c_2 D + \sum_{i=3}^{n} c_i x_i + e \tag{9}$$

where:

M = the percent of all softwood plywood shipments attributed to southern pine plywood in a Rand-McNally Major Trading Area (MTA) in 1978

N = the number of southern pine plywood plants in the state containing the MTA and in adjacent states in 1978

D = the distance from Portland, Oregon in miles

x_1 = additional exogenous variables

c_o = constant

c_1, c_2 and c_i = structural coefficients

e = unexplained variation of M

Data for twenty-nine Major Trading Areas were included in the analysis. The sample was comprised of the top 20 softwood plywood markets and the top 20 southern pine plywood markets. The model provides a method for examining the spatial diffusion of southern pine plywood in 1978.

Estimation Procedures

Several statistical problems must be considered when applying econometric analysis for estimation, parameter testing and projection. The appropriate method of estimation, completeness and identification, autocorrelation, multicollinarity, and specification errors are of particular concern. These factors must be considered for each submodel.

Methods of Estimation

Estimation methods were determined for five functional relationships: (1) the supply-demand models for determining substitutes and screening variables, (2) the aggregate panel market submodel, (3) the univariate nonlinear market share submodels, (4) the multivariate market share submodels, and (5) the southern pine plywood spatial diffusion submodel.

The supply-demand models contain endogenous price and quantity variables that are simultaneously determined in the market. If ordinary least squares (OLS) is applied to a single equation in a model and more than one endogenous variable is included in the equation, OLS estimates will be biased and inconsistent due to correlation between endogenous variables and the disturbance term. The OLS estimating technique, however, provides an optimal solution in the case of recursive models (Johnston, 1972).

For more general simultaneous equation models, several estimating techniques have been developed which yield consistent estimates for large samples. The techniques are indirect least squares (ILS), two-stage least-squares (2SLS), limited-information maximum likelihood (LIML), three-stage least-squares (3SLS), and full information maximum likelihood (FIML). The first three techniques are classified as single-equation methods and the 3SLS and FIML techniques are systems methods.

The systems methods were not considered for this study because they require large samples to be useful. The sample sizes for the simultaneous equation models were $n = 13$ and $n = 11$ for particle board and southern pine plywood, respectively. The sample size was restricted by the availability of comparable product price data.

Both the ILS and the LIML methods require the use of all exogenous variables in the model. In addition, ILS requires exact identification (by the order condition) for unique solutions. Due to sample size and the number of exogenous variables considered in the supply-demand models, ILS and LIML were not used in this study.

Two-stage least squares (2SLS) was selected as the method of estimation for the simultaneous equation model because (1) it is a single-equation method, (2) it provides consistent estimates even with over-identification, and (3) it is characterized by low bias and small variance. In any case, the selection of a given estimation technique for small sample simultaneous equation models is based on results of Monte

Carlo studies and personal preference.

The instrumental variable method of 2SLS estimation was used in this study. When all exogenous variables in the complete model are used as instruments, the instrumental method is identical to 2SLS. Valid estimation can be based on fewer than all instruments when a complete model involves a large number of exogenous variables (Hall and Hall, 1978). That is, a demand function can be estimated even when the supply equation is not fully specified.

A number of supply and demand variables were used as instruments in developing the final model specification (see Appendix for a list of variable names and their values). In order to prevent the first stage regression from being completely deterministic, a set of instruments not exceeding the sample size was used in each equation.

The aggregate market and the southern pine plywood spatial diffusion submodels were estimated by means of ordinary least squares. This aggregate model included one endogenous variable and one endogenous variable and several exogenous variables. Provided the OLS assumptions were not violated, the estimators will be unbiased and have minimum variance for the class of linear estimators.

The Gompertz curve and the logistic function parameters were estimated by nonlinear least squares. The statistical technique involves the minimization of the sum of squared residuals when the regression equation is nonlinear in its parameters. Gauss's method of estimation was used as the procedure for minimization (Hall and Hall, 1978). An alternative technique was used by Griliches (1957) to estimate model parameters. However, this technique was not used because it was based on an independent and somewhat arbitrary estimate of potential market share.

The multivariate market share submodels contain the appropriate endogenous market share variable and a series of exogenous supply and demand variables in each equation. Two techniques were used for estimation: ordinary least squares and seemingly unrelated regression.

The OLS technique assumes implicitly the regression disturbance in one regression model is not correlated with the disturbance in another regression model. Since this condition is not explicit, most market share analyses do not account for the relationship between error terms (Stern, 1964; Weiss, 1968). The parameter estimates based on OLS are included in this study for comparison with seemingly unrelated regression estimates.

Seemingly unrelated regression, on the other hand, is used in models that have mutually correlated disturbance terms. This condition is expected in equations (7) and (8) due to the market share identity (equation (6)). This subtle link allows estimation to proceed using the maximum amount of information regarding the model.

Completeness and Identification

These concerns apply not only to the supply and demand models estimated by 2SLS. The particleboard and southern pine plywood models contain two equations (a supply and demand function) and two unknowns (panel price and quantity). Therefore, the models are statistically complete.

Apparent consumption data for particleboard and production data for southern pine plywood were used as the quantity supplied and quantity demanded variables in the functions. The wholesale price index for the particleboard industry (1967=100) and the wholesale price index for southern softwood plywood (1969=100) were used as both supply and demand price. Price data was deflated by the wholesale price index for all commodities.

The equations in this study are all identified by the rank condition and overidentified by the order condition (Maddala, 1977). Therefore, the equations are estimable. The instrumental variable method of estimation requires that at least one instrument (predetermined variable) from another equation be used for each endogenous variable other than the "dependent" variable. Overidentification simply makes additional instruments available.

Autocorrelation

Autocorrelation among error terms causes several statistical problems. First, the estimated coefficients are still unbiased, but no longer have the minimum variance property. Second, the standard error estimates of the coefficients may underestimate the true standard error. Finally, tests using the t distribution are no longer strictly applicable (Neter and Wasserman, 1974).

The Durbin-Watson statistic was used to test for the presence of autocorrelation. For sample sizes smaller than 15, the test ranges were extrapolated (Durbin and Watson, 1951). The test was inconclusive or showed no autocorrelation for all multivariate linear models.

The Durbin-Watson test indicated autocorrelation in the univariate aggregate panel submodel and in the univariate nonlinear models. This was expected as the omission of one or more key variables in business and economic regression equations often leads to positively autocorrelated error terms. These equations, when used for projections, will produce inefficient estimates (Johnson, 1971). However, this is not a problem in this study since projection confidence intervals are not used.

Multicollinearity

Though predetermined variables may be highly correlated, this does not inhibit obtaining a good fit to the data. Multicollinearity has several effects on statistical estimation. There is a loss in the precision of estimation, that is, it is difficult to disentangle the effects of the collinear variables. Also, coefficient estimates are very sensitive to particular sets of sample data.

Multicollinearity always exists in economic variables. The degree of effects is the major concern. Two methods were used to reduce the apparent effects of multicollinearity in the models. First, if two variables were extremely collinear (simple correlation between the two of .99 or greater), one was dropped from the study and the other was retained to represent the pooled effect of the collinear variables. In the case of somewhat equivalent variables such as housing starts and residential construction expenditures, only one variable was retained in the final model though both were retained for test runs. Second, extensive test runs were used to examine the addition and deletion of variables for different sample sizes.

Even with this two step process, the selection of the final equation variables was based on judgment. This was especially true in the case of the supply and demand equations.

Significance Tests

Variables were tested for significance using a one-tailed t-test. The test indicates the probability level at which the estimated coefficient sign is its true sign. For the aggregate panel market submodel, the Cochrane-Orcutt procedure (Maddala, 1977) was used for re-estimating and testing parameters after the presence of autocorrelation was indicated by the Durbin-Watson statistics. This procedure was used to statistically correct for first-order autocorrelation. After correction, all parameters were significant at the 1% alpha level.

Specification Errors

Specification errors can result from: (1) omission of relevant explanatory variables, (2) disregard for qualitative changes in variables, (3) inclusion of irrelevant variables, (4) inappropriate mathematical form used in estimation, and (5) incorrect assumptions concerning the disturbance terms in the regression (Kmenta, 1971). Initially, a large number of variables were selected based on economic theory and a literature survey. Many variables were later dropped due to high collinearity and the results of test runs.

The unavailability of data on important variables, such as, wood residue price for particleboard, would have some effects on final model parameters. When possible proxy variables were used to account for the hypothesized relationship between the dependent and excluded variables.

In an aggregate analysis, qualitative changes are ignored. In the case of wood-based panels, the lack of available data on panel quality changes inhibits incorporating changes into the analysis as an independent factor.

A number of functional forms are used in the analysis. Justification of particular mathematical forms was presented on a case by case basis in previous sections of this chapter. Standard assumptions regarding the disturbance term were made with the exception of the seemingly unrelated regression. In that case, correlation between the disturbance terms in the individual equations was assumed.

PAST TRENDS IN INNOVATION AND PRODUCT DIFFUSION

Qualitative and quantitative factors interact as new products diffuse through the market. By examining past trends in these factors, some insight into their relationship to successful diffusion is gained. Many of the factors are intertwined; however, they are presented separately to emphasize their importance.

Particleboard and southern pine plywood are successful product innovations. They have gained widespread acceptance in end-use markets. Their product characteristics play a large role in this acceptance. In addition, product standards, building codes, process innovations, raw material price and availability, and various economic factors have been instrumental in this diffusion process.

Product Characteristics

Panel products possess three general characteristics: physical properties, strength properties, and working properties. Physical properties include density, moisture content, water absorption, and fire resistance. Examples of strength properties are bending strength perpendicular to the plane, deflection under load, impact resistance, and screw holding. Accuracy to size, machining properties and surface quality are the primary working properties (Akers, 1966).

Property comparisons of different panels are made with consideration of end-use requirements. Due to its properties, particleboard is used extensively in furniture and construction, whereas, southern pine plywood is used only in construction.

Particleboard Characteristics

Particleboard is:

> A generic term used to describe panel products made from discrete particles of wood or other ligno-cellulose material. Other materials can be added to the production process to improve the board. Thermosetting resins are added to the particles to serve as a binder. The particles are bound into a solid board when the particles and resins are placed under heat and pressure (Dickerhoof and McKeever, 1979).

Particleboard is produced in a variety of densities and thicknesses. For brevity, only the general panel characteristics are presented here.

Particleboard is a popular core panel in furniture because it has excellent gluing qualities on all planes and superior working properties. The surface quality is especially important due to the increasing use of thin veneers as laminates. The panel surface is uniform and the panels stay flat making it a good product for furniture manufacturers (U.S. Department of Agriculture, Forest Products Laboratory, 1974).

Particleboard characteristics are well suited for construction, too. After manufacture, the board is constant and uniform in its properties. Its use as floor underlayment is attributed, in part, to its impact resistance and flatness. However, particleboard is more susceptible to damage by excessively damp and wet conditions than plywood panels. The ability of manufacturers to create large panels enhances particleboard's acceptance as mobile home and prefabricated house decking.

In general, the flexibility of manufacturing processes have permitted particleboard to be tailored to specific end-use characteristics. A key factor in particleboard's future success will be the continued modification of its characteristics.

Southern Pine Plywood Characteristics

Plywood is defined as:

> ...a flat panel built up of sheets of veneer called plys, united under pressure by a bonding agent to create a panel with an adhesive bond between plys as strong as or stronger than the wood. Plywood is constructed of an odd number of layers with grain of adjacent layers perpendicular. Layers may consist of a single ply or two or more plys laminated with grain direction oriented parallel to the long dimension of the panel. The odd number of layers with alternating grain direction equalizes strains, prevents splitting, and minimizes dimensional change and working of the panel (U.S. Department of Commerce, National Bureau of Stands, 1974).

The primary species utilized in southern pine plywood are loblolly, longleaf, and shortleaf pine. Slash and spruce pine are used to a lesser extent.

Plywood characteristics vary considerably. The veneer grades used as plys determine the quality of the final product. CD sheathing is the mainstay of the southern pine plywood industry. However, plyform, underlayment, 303 siding, and AC/Ad panel production is increasing (Baldwin, 1977).

Structural plywood panels such as CD sheathing are engineered for end-uses where tension, compression, shear, cross-panel flexural properties and nail bearing are important (U.S. Department of Commerce, National Bureau of Standards, 1974). Grade C face veneer restrictions are well suited to southern pine species since small knots, discoloration, and synthetic repairs are permitted. Grade D back veneers have fewer restrictions.

Process and Product Trends

Processes adopted by the U.S. panel industry often are imported from other countries. As the number of processes increases, products become more varied and specialized. The result is greater acceptance of wood-based panels in end-use applications.

Particleboard Process and Product Trends

Particleboard was developed in this country to utilize waste wood and to compete with established wood products (Reid, 1958). The industry has grown as new processes and products have emerged. The major processes used in the manufacture of particleboard are the extrusion process and the platen press process. Product characteristics vary according to the process used.

Early attempts to produce particleboard in the United States during the 1920's failed primarily due to the lack of suitable adhesives. During the 1930's and early 1940's, several breakthroughs in resin production and application enabled particleboard production to proceed. The resin shortages during World War II gave way to reindustrialization following the war; the particleboard industry has grown dramatically since that time (Moslemi, 1974). A number of types of particleboard and production techniques have been developed over the post-war years. The alternative production methods often were developed to avoid infringement on Swiss and German patents (Akers, 1966).

Akers (1966) identified four general types of particleboard: (1) single layer, platen pressed, (2) three layer platen pressed,

(3) graded density, platen pressed, and (4) extruded board. These boards can be produced in a variety of thicknesses and in a range of densities. The final product is determined primarily by market requirements.

The single-layer, platen pressed board was the first type developed. The boards were homogeneous and utilized planer shavings, industrial wood residues, and flax shives as raw materials. The particles are in a random criss-cross pattern parallel to the surface of the board. Early single layer boards were produced in batches. The first domestic continuous press process was designed by Ralph Chapman and installed in the Chapwood plant at Philomath, Oregon in 1957 (Anonymous, 1957a).

The three-layer board is similar to the single-layer type, but has a sandwich construction with courser materials placed between flakes or other material for smoother surfaces. This process allows for greater bending strength and was first used in furniture as coreboard.

Fred Fahrni, a Swiss engineer, developed the first 3-layer type of board which became known as Novoply in the United States. The United States Plywood Corporation began producing Novoply in 1951 at their Anderson, California, plant. Edwin Behr developed a similar board in West Germany for use in furniture. The Behr process was first introduced to the United States in 1957 by Roddiscraft, Inc. at Arcata, California (Anonymous, 1957c). Though it was the first of its type in the U.S., twenty-one similar plants had been built previously worldwide.

The graded density board, originally manufactured in 1958 by Baehre Metallwerke in West Germany, was designed with a high density surface and a low density core. Finer particles are near the surface, and unlike three-layer boards there are no abrupt changes between particle sizes. The boards are used in furniture and building construction. The Bahre-Bison process is used widely in the United States. Edwin Behr also developed a graded density board.

Other platen press particleboard manufacturing systems adopted in the formative years of the industry were designed by major companies, such as Industrial Development, Miller Hofft, and Columbia Engineering and by various smaller companies (Mottet, 1962). The processes were usually tailored to the raw material available and to specific end-use needs.

Extruded boards are made by forcing the wood and resin mix through two parallel metal platens. The particles are perpendicular to the surface of the board. As a result, the board has low bending strength and is used as a corestock for furniture.

The three extrusion processes most used in this country are: (1) the Kreibaum process, (2) the Lanewood process, and (3) the Chipcraft process (Mottet, 1962). The Kreibaum vertical extrusion process was developed by Otto Kreibaum in West Germany and first used in the United States by the Jasper American Manufacturing Company at Henderson, Kentucky in 1954. The Lanewood process for horizontal extrusion was installed initially by the Lane Company at Alta Vista, Virginia in 1953 (Anonymous, 1957b). One of the earliest Chipcraft horizontal extrusion process was installed by Berkline Corporation, Morristown, Tennessee, in 1953 (Anonymous, 1957b).

Three recent developments in product or process design are waferboard, oriented strand particleboard, and Mende process particleboard. These newer panels are discussed in final chapter along with newer process innovations. The production of new panels is another indication of continuing innovation in this industry.

The raw materials for particleboard are industrial wood residues, forest residues, roundwood, resins and additives. The wood materials are prepared by hammermill or flaker, dryed and screened, mixed with adhesives and additives, formed into boards, and pressed. In addition to major process innovation and diffusion, evidenced by new production systems, improvements in many aspects of the production process have occurred. Recent capital expenditures presented in Table 5 indicate that refinement in processes rather than construction of new plants is occurring in the particleboard industry.

The traditional method for preparing particles is to use an assortment of attrition mills, hammermills, chippers, ring flakers and drum flakers. Refinements in this equipment and in screening continues to improve the uniformity of materials used in manufacturing (Food and Agriculture Organization of the United Nations, 1976). The shaping lathe headrig and "fingerling" production are among the newest developments in flake preparation (McSwain, 1977).

Particle dryers have increased in size and efficiency. In some cases, wood residues are being utilized as an energy source for drying. Particle moisture, once measured by hand sampling, is now monitored and controlled by infrared spectrometers and devices measuring electrical resistance. After drying, the particles are stored or blended with resins and additives. Short-retention-time blenders have replaced many long-retention-time blenders over the past 15 years (McSwain, 1977).

Urea-formaldehyde and phenol-formaldehyde are the primary resins

Table 5. New capital expenditures for plant and equipment in the particleboard (SIC 2492) industry, 1972 and 1977 (in millions of dollars).

Year	Capital Expenditures	
	New buildings and other structures	New machinery and equipment
1972	$2.7	$32.1
1977	3.2	29.3

Sources: U.S. Department of Commerce, Census of Manufactures, 1972, 1975b; U.S. Department of Commerce, Census of Manufactures, 1977, 1980b.

blended with the wood particles. Interior particleboard is made with urea-formaldehyde resins and exterior particleboard is bonded primarily with phenol-formaldehyde. Both are water soluble and thermosetting. Urea-formaldehyde is used more extensively in the industry according to available data (see Table 6). Improvements in adhesive cure time and tack control have occurred over the years. Experimentation is increasing with alternative binders such as isocyanates, cement, malamine based resins, and tannin formaldehyde adhesives as industry concern for resin cost and availability continues (Coppens, Santana, and Pastore, 1980; McSwain, 1977).

Additives are also blended in with the adhesive and wood particles. Common additives are rosin and/or paraffin emulsion as water repellents, phenol formaldehyde for added strength, penta-chlorophenol and arsenical compounds for fungus and insect protection, and borate for fire retardancy (Akers, 1966). By changing the additive mix, new board characteristics can be attained.

The next stage in the production process, board forming and transport, has undergone several changes as the industry has evolved. The improvements are concentrated in platen press systems which account for the majority of particleboard produced in the United States. Some of the most notable advances in this area are the increased size and sophistication of matforming equipment, the development of fiber allignment systems, and the introduction of caulless transport systems. These innovations allow for a broader range of wood inputs and create product variants for end-use markets (Food and Agriculture Organization of the United Nations, 1976; McSwain, 1977).

Platen-type and continuous prepresses have been developed for

Table 6. U.S. resin consumption by type used in the manufacture of other platen type particleboard, selected years (in millions of pounds).

Year	Quantity of resin consumed[1/]	
	Urea formaldehyde	Phenol formaldehyde and other types
1966	262.0	6.2
1969	631.7	25.0
1972	1215.2	22.6
1975	1025.6	11.6

[1/] Dry basis prior to 1969; wet basis beginning in 1969.

Source: U.S. Department of Commerce, Bureau of the Census, selected years(a).

caulless transport systems. The prepresses reduce the maximum press opening needed which leads to faster press closing. The result is a reduction in surface precuring, increased core density, and better internal bonds. Particleboard presses are either continuous types or discontinuous single-opening or multi-opening types. Modifications in single-opening presses have improved their competitive position in recent years, but multi-opening presses are still dominant. Shorter press cycles, larger board sizes, and better thickness control are the main advantages of single-opening presses. The development of continuous presses for thin (Mende) particleboard production is another example of recent improvements in board pressing (McSwain, 1977).

Board finishing and secondary processing is the last step in the production process. Notable advances in this processing stage include the extensive adoption of wide-belt sanders and improvements in laminating and curing. These advances lead to broader acceptance of particleboard due to increased quality.

Southern Pine Plywood Process and Product Trends

The southern pine plywood success story is based on adopting techniques for peeling small diameter logs, developing suitable resins, and utilizing substantial southern timber resources. The small sized low quality peeler logs are used primarily for construction grade plywood.

A substantial number of process innovations have been incorporated in the rapidly growing southern pine plywood industry. Many of these have been installed during plant construction. Recent trends in nationwide capital expenditures are presented in Table 7. Approximately $26 million of the 1972 total expenditures and $45 million of the 1977 total occurred in the South (U.S. Department of Commerce, Census of Manufactures, 1972, 1975a; U.S. Department of Commerce, Census of Manufactures, 1977, 1980a).

Before the first southern pine plywood plant was opened in December, 1963, considerable industrial research had taken place. Promising yield trials of southern pine logs in western mills provided an impetus for interest in the South (Fassnacht, 1965). Though considerable government and industry experimentation in an attempt to find suitable adhesives was ongoing, Georgia Pacific Corporation's development of the first adhesive capable of satisfactorily laminating southern pine was a major breakthrough (Koch, 1972 and Anonymous, 1980d). With the adoption of high-speed automatic lathes, the southern plywood boom was underway; thirty-four plants began operation in the first five years of the industry's existence. These plant startups indicate which companies were innovators and early imitators (see Table 8).

The production process begins in the log yards used to store and sort logs in the South. Huge jib cranes often are used to stack and move the logs (Baldwin, 1977). Once inside a plant, the logs are peeled with automated, high-speed lathes. Only rotary-peeled veneer is produced (Koch, 1972). Back-up rolls, high-speed log charging, and geometric chuck centering increase the efficiency of the process (Food and Agriculture Organization of the United Nations, 1976; McSwain, 1977).

Southern pine veneer is mostly sapwood. It is cut from logs averaging 14 inches in diameter with 4 to 6 inches left as core. Jet

Table 7. New capital expenditures for plant and equipment in the softwood veneer and plywood (SIC 2436) industry, 1972 and 1977 (in millions of dollars).

Year	Capital Expenditures	
	New buildings and other structures	New machinery and equipment
1972	$ 9.0	$56.5
1977	10.6	95.1

Sources: U.S. Department of Commerce, Census of Manufactures, 1972, 1975a; U.S. Department of Commerce, Census of Manufactures, 1977, 1980a.

Table 8. Southern pine plywood producers, capacity, and plant startup years by city and state, 1963 to 1968.

Producer	Location	Capacity[1/]	Startup Year
Georgia-Pacific	Fordyce, AR	120	1963
Kirby Lumber Co.	Silsbee, TX	60	1964
Southern Pine Lbr. Co./ U.S. Plywood	Diboll, TX	80	1964
Scotch Lumber Co.	Fulton, AL	60	1965
Georgia-Pacific	Crossett #1, AR	130	1965
Georgia-Pacific	Crossett #2, AR	130	1965
Santiam-Southern	Ruston, LA	75	1965
Vancouver Plywood Co.	Oakdale, LA	100	1965
Weyerhaeuser Co.	Philadelphia, MS	36	1965
Weyerhaeuser Co.	Plymouth, NC	80	1965
Owens-Illinois	Lufkin, TX	72	1965
Georgia-Pacific	Emporia, VA	100	1965
Georgia-Pacific	Savanah, GA	90	1966
Columbia-Southern Corp.	Minden, LA	60	1966
Louisiana Plywood Co.	Dodson, LA	80	1966
Olinkraft, Inc.	Winnfield, LA	60	1966
U.S. Plywood-Champion	Holden, LA	108	1966
Vancouver Plywood Co.	Florien, LA	100	1966
Chesapeake Bay Plywood Co.	Pocomoke City, MD	60	1966
Delta Pine Plywood Corp.	Beaumont, MS	90	1966
Georgia-Pacific	Louisville, MS	90	1966

Table 8 (cont'd.)

Weyerhaeuser Co.	Jacksonville, NC	70	1966
Arkla Chemical Corp.	Chiefland, FL	90	1967
Georgia-Pacific	Chiefland, FL	90	1967
Great Northern Plywood	Cedar Springs, GA	60	1967
South-Ply, Inc.	Natchitoches, LA	60	1967
Tremont Lumber Co.	Joyce, LA	36	1967
Georgia-Pacific	Gloster, MS	65	1967
Triangle Plywood Corp.	Moncure, NC	60	1967
MacMillan Bloedel	Pine Hills, AL	100	1968
Union Camp Corp.	Chapman, AL	80	1968
U.S. Camp Corp.	Waycross, GA	60	1968
Anthony Forest Products	Plain Dealing, LA	60	1968
Georgia-Pacific	Russelville, SC	90	1968

1/ Capacity measured in million square feet, 3/8-inch basis.

Source: Anonymous, 1978.

dryers are the predominant method for drying the plys (Koch, 1972). Experimentation with various dryer configurations (baffle arrangements, temperature settings, drying times, and so on) continues in the South. However, drying is still a major bottleneck in the production process (Food and Agriculture Organization of the United Nations, 1976).

Curtain coaters, spray lines, and soft roll spreaders are used for glue waste while cutting down on manpower requirements. Most southern pine plywood is glued with phenol-formaldehyde resins (Food and Agriculture Organization of the United Nations, 1976; McSwain, 1977).

The mechanization of the production process has increased in recent years. One example of mechanization was the advent of automatic layup systems in 1968 (Mast and Pease, 1969). These systems provide an efficient means for continuous production (DeLess, 1975). Large plant size is one result of extensive automation. Faster cure time, automatic charging, and automatic discharging equipment are examples of increased mechanization in pressing. Other improvements include better blister detection, new patching and plugging materials, and more extensive use of wide-belt sanders and improved abrasives (Food and Agriculture Organization of the United Nations, 1976).

Product Standards and Building Codes

Product characteristics and product standards are tied to building codes and panel end-uses. Panel standards generally fall into two categories: general descriptive type standards and specific end-use standards (Frashour, 1961). The former are developed to encompass most producing companies, whereas the latter are more exacting and restrictive. Government Commercial Standards and Voluntary Product Standards are examples of general descriptive type standards. Typical end-use standards are FHA (Federal Housing Administration) Interim Standards, Industry Association Standards, and ASTM (American Society for Testing and Materials) Standards.

The Voluntary Product Standard (previously called the Commercial Standard) is voluntary, however, grademarking based on the standard is believed to promote product acceptance in the market (Anonymous, 1971b). The purpose of the Commercial Standard is "...to establish quality criteria, standard methods of testing, rating, certification, and labeling of manufactured commodities (U.S. Department of Commerce, National Bureau of Standards, 1966a)."

Particleboard Standards

Particleboard standards evolved from the 1956 FHA Interim Standard for Floor Underlayment, Kitchen Countertops to be Overlaid with Plastics, and Wardrobe Doors to the Commercial Standard CS236-66, Mat-Formed Wood Particle Board, issued in 1966.

A number of standards for specific end-uses were developed between 1956 and 1966. Particleboard standards for specific end-uses have been promoted by the National Particleboard Association (NPA). Examples of these standards are: NPA-1, Standard for Particleboard for Mobile Home Decking; NPA-2, Standard for Particleboard Decking for Factory Built Housing; and NPA-3, Specification for Particleboard Floor Underlayment Coated with Wax-Polymer Type Hot-Melt Coatings (U.S. Department of Commerce, National Bureau of Standards, 1977).

The 1966 Standard contains information on interior and exterior panels including panel form, materials, dimensions, dimensional tolerances, and properties. Inspection, test methods, marking, and certification are described in the commercial standard, too. The property requirements for mat-formed particleboard are based on type of use (interior or exterior) and panel density (U.S. Department of Commerce, National Bureau of Standards, 1966a). CS236-66 was recently updated as ANSI (American National Standards Institute) A208.1 (Anonymous, 1980c). The new standard consolidated existing particleboard standards such as ANSI A161.1 for kitchen cabinets and ANSI A161.2 for countertops.

Plywood Standards

Standards applicable to southern softwood plywood have existed throughout the short life of the product. The first Commercial Standard was CS259-63, Southern Softwood Plywood, which was in existence when the first panels were produced. This undoubtedly paved the way for more rapid acceptance of this new panel. CS259-63 was combined with Commercial Standards for Douglas Fir Plywood and Western Softwood Plywood in 1966. Product Standard PS 1-66, Softwood Plywood, Construction and Industrial, was the result (U.S. Department of Commerce, National Bureau of Standards, 1966b). PS 1-66 was updated and re-issued in 1974 as Voluntary Product Standard PS 1-74, Construction and Industrial Plywood.

PS 1-74 covers "...the wood species, veneer grading, glue bonds, panel construction and workmanship, dimensions and tolerances, marking, moisture content, and packing of plywood intended for construction and industrial uses (U.S. Department of Commerce, National Bureau of

Standards, 1974). Test methods are also included. Plywoods are classified by their exposure capability (interior or exterior) and grade. In general, higher grades have more restrictions on the veneer quality. The primary panel grade for southern pine plywood is interior CD sheathing with exterior glue. Interior, intermediate and exterior glues can be used with interior type plywood.

Since they provide consistency, standards are desired by producers, distributors, specifiers, architects, home builders and contractors. The standards often are adopted in model, state, and city building codes.

Building Codes

Building codes are the legal minimum criteria which must be met in new construction, alteration and modification of buildings. According to a 1976 study (Vogel, 1976), over 7000 building codes existed in the United States. The study covered three Model Building Codes, twenty State Building Codes, and thirty City Building Codes. CS236-66 and PS 1-74 were included in the study. The particleboard standard was referenced in two Model Building Codes (the 1975 Basic Building Code and the 1973 Standard Building Code), nine State Building Codes, and six City Building Codes. The plywood standard was referenced in the same Model Building Codes, eleven State Building Codes, and seventeen City Building Codes. As expected, the more traditional product, plywood, had gained wider acceptance.

Building codes can prevent or allow the utilization of new products in construction. Therefore, acceptance of product standards by building regulatory agencies is necessary for the widespread diffusion of panel innovations. Ventre (1979) studied the adoption of innovations in residential construction. He found that the regulatory agencies acted as technological gatekeepers and in the aggregate adopted innovations slowly at first, then more rapidly until adoption finally leveled off. As more regulatory agencies accept innovations, adoption by the construction industry is facilitated and product diffusion is increased.

Product Consumption, Price and End-Use Trends

Total consumption and price trends reflect the interaction of supply and demand over time. An important factor in determining total panel product demand is economic activity in end-use markets. One indication of a panel's competitiveness in a given market is its ability to penetrate the market successfully.

Particleboard Consumption, Price and End-Use Trends

Particleboard consumption in the United States increased from 70 million square feet (3/4-inch basis) in 1955 to 3586 million square feet in 1979 (see Table 9). Available price data indicates that the wholesale price of particleboard relative to other goods has declined since 1967. Rising costs for transportation, energy, and adhesives along with increased competition for particleboard furnish may reverse this trend in the future.

The declining price is one impetus for the increased consumption of particleboard; particleboard's diverse uses is another (see Table 10). Particleboard is used primarily as core stock, floor underlayment, and mobile home decking. For 1979, 48.4 percent of the particleboard

Table 9. U.S. particleboard production, imports, exports, apparent consumption, and price index, 1955-1979 (in millions of square feet, 3/4-inch basis)[1/].

Year	Domestic production	Imports	Exports	Apparent consumption[2/]	Deflated wholesale price index[3/] (1967=100)
1955	70	-	-	70	-
1956	111	-	-	111	-
1957	183	-	-	183	-
1958	250	-	-	250	-
1959	296	-	-	296	-
1960	268	-	-	268	-
1961	326	-	-	326	-
1962	408	-	-	408	-
1963	496	1	-	498	-
1964	638	2	-	640	-
1965	803	4	-	807	-
1966	997	1	-	998	-
1967	1115	1	2	1114	100.0
1968	1425	1	6	1420	98.9
1969	1716	12	14	1714	105.3
1970	1764	3	10	1757	65.4
1971	2394	8	20	2382	62.9
1972	3117	14	45	3086	62.8
1973	3494	17	77	3434	68.5
1974	3104	7	112	2999	55.0
1975	2539	17	84	2472	46.4

Table 9 (cont'd.)

1976	3202	51 4/	96	3157	54.8
1977	3592	130 4/	75	3647	54.7
1978	3610	150 4/	16 5/	3744	68.5
1979	3501	186 4/	100	3587	52.0

1/ Does not include medium density fiberboard and Mende process board.

2/ Apparent consumption = domestic production + imports - exports.

3/ Particleboard industry output wholesale price index (1967=100) deflated by the wholesale price index for all commodities (1967=100) not available prior to 1967.

4/ Estimated from import data reported in weight.

5/ Under review by Bureau of the Census.

Sources: Lambert, 1980; Phelps, 1977; U.S. Department of Commerce, Bureau of the Census, selected years(c); U.S. Department of Commerce, Bureau of the Census, selected years (d); U.S. Department of Commerce, Bureau of Industrial Economics, 1980; U.S. Department of Labor, Bureau of Labor Statistics, selected years; Wright and Phelps, 1967.

Table 10. Percentage of total particleboard industry production by end-use, 1973 (in percent).

Intended end-use	Percent of total industry Production
Floor underlayment	27
Furniture core	27
Mobile home decking	15
General purpose core stock	10
General purpose stock, furniture core, cabinets	8
Cabinets	4
Door core	4
Siding	1
Factory-built housing, decking	1/
Other	4

1/ Less than 0.5 percent.

Source: Dickerhoof, 1976.

market was for industrial grades, 34.6 percent was for floor underlayment, 8.6 percent was for mobile home decking, 3.6 percent was for door core, and miscellaneous uses comprised the remaining 4.8 percent (Lambert, 1980). Activity in these end-use markets determines the particleboard product mix to a large extent.

Changing styles in the furniture industry have influenced particleboard consumption. As the trend toward cleanline furniture continues, particleboard's properties become more desirable (Wilson, 1975). The furniture production index, which measures physical output, increased 185 percent from 1960 to 1976. Particleboard consumption in furniture increased 1533 percent during the same period (see Table 11). Though not as dramatic, increases in average per unit consumption of particleboard has also occurred in the housing and mobile home markets (Dickerhoof, 1978; Wilson, 1975).

Southern Pine Plywood Consumption, Price and End-Use Trends

Southern pine plywood production increased from 80 million square feet (3/8-inch basis) to 7650 million square feet over the 1964 to 1979 period (see Table 12). Most production is consumed domestically. For example, less than seven-tenths of one percent of 1978 shipments were exported (Anderson, 1979).

The deflated price of southern pine plywood has fluctuated in response to residential construction activity in recent years. During slack periods in construction, panel prices decline. As activity increases, prices rebound. Though stumpage prices are rising in the South, proximity to the major markets in the Eastern United States will continue to enhance southern pine plywood's in-place cost advantage

Table 11. Particleboard[1/] consumption in manufacturing in the United States by product group, 1960, 1965, 1970, and 1976 (in millions of square feet, 3/4-inch basis).

Year	Product Group			Total	Furniture production index (1967=100)
	Household furniture	Commercial and institutional furniture	Other products		
1960	56	34	12	106	71.8
1965	312	119	45	476	93.1
1970	590	290	80	960	108.1
1976	950	460	100	1510	132.7

[1/] Includes medium-density fiberboard, waferboard, flakeboard, and composite board.

Source: U.S. Forest Service, 1980.

Table 12. U.S. southern pine plywood production and price index, 1964-1979 (in millions of square feet, 3/8-inch basis).

Year	Production	Deflated wholesale price index[1/] (1969=100)
1964	80	-
1965	402	-
1966	1140	-
1967	1779	-
1968	2373	-
1969	2875	100.0
1970	3315	81.1
1971	4410	89.8
1972	5319	102.8
1973	5560	105.1
1974	5130	84.0
1975	5676	80.4
1976	6814	101.0
1977	7447	116.0
1978	7898	115.2
1979	7650	94.0

[1/] Southern pine plywood wholesale price index (1969=100) deflated by the wholesale price index for all commodities (1969=100); not available prior to December, 1968.

Source: Anderson, 1979; U.S. Department of Labor, Bureau of Labor Statistics, selected years.

relative to Douglas fir plywood (Holley, 1969).

Unlike particleboard, southern pine plywood production is almost exclusively for CD sheathing. The product mix for southern region shipments in 1978 was: 91 percent sheathing, 5 percent sanded, and 4 percent specialties (Anderson, 1979). The majority of shipments were to the southern region. According to one source (Baldwin, 1977), the product mix will shift to higher value added products, such as plyform, underlayment, and siding, after mill operations stabilize with efficient production of sheathing. However, until that time, consumption will be predominantly in the form of sheathing in the housing and mobile home markets.

Raw Material Situation

The price and availability of inputs into the productive process influences the competitiveness of any product. The inputs can be in the form of wood, adhesives, labor, energy, or capital. As price increases or as availability becomes restricted, there will be a response in the price and production level of the panel product.

Particleboard Raw Material Situation

As mentioned previously, one factor that spurred the growth of the particleboard industry was the availability of residues from wood processing plants. Examples of wood inputs used in particleboard are: planer shavings, plywood residues, furniture and veneer manufacturing residues, and millwork residues.

In 1956, approximately 50 percent of particleboard wood inputs came from sawmills. Veneer plants and furniture plants accounted for

30 and 14 percent of the inputs, respectively, with other wood processors supplying the remaining 6 percent (Reid, 1958). The situation has changed since 1956; the sources of material now include pulp-type chips and roundwood (see Table 13). Planer shavings were the primary residue used in the West and South in 1973, and roundwood was the most important source in the North (Dickerhoof and McKeever, 1979). More recent data indicates planer shavings are declining in importance relative to other residues (Food and Agriculture Organization of the United Nations, 1976; U.S. Department of Commerce, Census of Manufactures, 1977, 1980).

The availability of wood furnish is dependent on productive activity in supply industries. Also, the trend toward non-residue sources is due to: (1) new sawmill technology that improves sawlog utilization, (2) new pulp and paper industry technology for utilizing residues in production, and (3) increased use of residues as an energy source (Wilson, 1975). In addition, other composition board products are competing for many of the same raw materials.

Though a large portion of wood inputs are now purchased, there is no satisfactory measure for the price trend in wood furnish for particleboard. However, as industry is forced to utilize more non-residue furnish, the furnish cost will increase considerably (Wilson, 1975).

In order to estimate wood requirements, some measure of physical input to product output is needed. According to data collected by Dickerhoof (1976), 1.51 tons of wood raw material (dry weight basis) were used to produce one thousand square feet (3/4-inch basis) of particleboard on average during 1973. Approximately 88 percent of the

Table 13. Type and percentage of raw material used by the particleboard industry, 1973.

Type of raw material	Percent used by total industry
Planer shavings	65
Plywood mill waste	10
Sawdust	9
Roundwood	7
Chips (pulp-type)	5
Slabs, edgings, and trimmings	3
Veneer core	1/
Other	1

1/ Less than 0.5 percent.

Source: Dickerhoof, 1976.

furnish was softwood. By assuming the input mix does not change appreciably, this factor can be used to estimate wood requirements given panel consumption. Several measures have been developed for converting material requirements to cubic foot measures, but they are not used in this study (Risbrudt, 1980; Wright and Phelps, 1967).

As mentioned earlier, the end of resin shortages after World War II made more resins available to manufacturers. The price of adhesives and resins relative to all commodities (1967=100) was 100.2 in 1979 (see Appendix). However, this does not reflect the trend that has persisted since 1972 which shows adhesive prices have increased 34 percent more than all commodities. The delivered cost of resins increased at the same rate as the cost of all materials used in the particleboard industry between 1972 and 1977 (see Table 14). Continued materials cost increases will exert upward pressures on particleboard prices.

Average hourly earnings of production workers did not increase as rapidly as adhesive prices from 1972 through 1979 (see Table 15). The number of production workers and the total hours they work is determined by economic activity in end-use markets and the degree of mechanization in the industry. Particleboard output per production hour worked (3/4-inch basis) was 226 square feet in 1972 and 330 square feet in 1977; labor-saving process innovations being adopted by industry are responsible for part of this increase.

Energy costs have risen sharply in recent years. As the cost of energy enters in at each stage of wood harvesting and processing, final product prices are expected to rise. However, energy also influences the cost of competing materials. Therefore, the net effect of

Table 14. Delivered costs of resins and total materials, containers, and supplies cost to the particleboard industry (SIC 2492), 1972 and 1977.

Year	Delivered cost		Total materials, containers, and supplies cost (million dollars)
	Urea and melamine resins (million dollars)	Phenolic and other tar acid resins (million dollars)	
1972	$52.1	$ 5.2	$138.4
1977	77.1	10.9	213.0

Source: U.S. Department of Commerce, Census of Manufactures, 1977, 1980b.

Table 15. Production workers, hours worked, and average hourly earnings in the particleboard industry (SIC 2492), 1972 through 1977.

Year	Number of production workers (1000)	Hours worked by production workers (millions)	Average hourly earnings of production workers (dollars)
1972	6.4	13.8	$3.75
1973	6.5	13.8	2.92
1974	6.1	12.8	4.06
1975	4.5	8.9	4.66
1976	4.6	9.3	5.09
1977	5.0	10.9	5.55

Source: U.S. Department of Commerce, Census of Manufactures, 1977, 1980b.

the rising energy cost is difficult to determine (Wisdom, 1977).

In the short run, rising energy prices will have two effects on the particleboard industry. First, the industry will attempt to reduce consumption of purchased energy. This is borne out by available data on purchased energy per unit of particleboard output and by industry efforts to become more energy self-sufficient (Egan, 1980; TenWolde, 1979). Second, other wood processors will begin competing for residues as a source of energy (Wilson, 1975). Though competition will cause residue prices to rise, significant quantities of unused manufacturing residues still exist. For example, there were 547 thousand cubic feet (solid basis) of unused manufacturing residues in 1976 while only 330 thousand cubic feet of particleboard furnish were consumed (U.S. Department of Agriculture, Forest Service, 1979).

As presented earlier, recent trends in capital expenditures have been primarily in the area of new machinery and equipment. However, considerable capital has been invested in the form of new plants over the years; 72 plants were operating in 1979 as compared to 23 in 1955.

Southern Pine Plywood Raw Material Situation

As was the case with particleboard, raw material availability has played an important role in the growth of the southern pine plywood industry. In the South, the net volume of softwood sawtimber on commercial timberlands increased 39 percent from 1962 to 1977 despite the growth of the plywood industry (U.S. Department of Agriculture, Forest Service, 1979). Volume increases were recorded in every diameter class.

Net softwood sawtimber growth to removal ratios, however, have been declining, especially on forest industry lands (see Table 16).

Table 16. Softwood sawtimber net annual growth to annual removal ratio on forest industry and all commercial timberland in the South, 1962, 1970, and 1976.

Year	Net growth to removals	
	Forest industry lands	All southern commercial timberlands
1962	2.14	1.65
1970	1.29	1.42
1976	.91	1.28

Source: U.S. Department of Agriculture, Forest Service, 1979.

The result may be increased competition for softwood sawtimber on other lands and increased stumpage costs. In fact, average 1978 stumpage prices (in 1967 dollars) for southern pine sawtimber sold from National Forests in the Southern Region were 33 percent higher than prices paid in 1969 (U.S. Department of Agriculture, Forest Service, 1979). Southern softwood plywood prices in 1978 were only 15 percent higher than the 1969 level.

Table 17 presents Bureau of the Census data on log consumption for plywood in the South. The data are based on local log scales and are not strictly comparable over a long period of time.[1/] In general, there is no discernable trend in the log requirements per unit of output. By assuming an average specific gravity of .51 for southern softwood species and an additional 5 percent of veneer volume that will be compressed into a 3/8-inch panel, approximately 1,168 pounds of wood (ovendry mass and volume at 12 percent moisture content) are required per thousand square feet (3/8-inch basis) of southern softwood plywood (U.S. Department of Agriculture, Forest Products Laboratory, 1974).

Bolt diameter, core diameter, and processing efficiency will determine wood requirements in terms of softwood bolts. As bolt diameter decreases and core diameter increases, more bolts are needed to product 1,000 square feet of 3/8-inch plywood (Koch, 1972). By maintaining a stable bolt diameter and reducing core diameter, greater yields per bolt and improved lathe productivity are possible.

[1/] Comparability problems resulted in discontinuing this data series in 1979 (Ambler, 1980).

Table 17. Comparison between southern yellow pine plywood production and log consumption, 1964-1978.

Year	Plywood production (thousand square feet, 3/8-inch basis)	Log consumption (thousand feet, log scale)	Log consumption to production ratio
1965	373,069	141,351	.379
1966	1,099,701	430,150	.391
1967	1,709,589	652,065	.381
1968	2,349,089	897,047	.382
1969	2,802,674	1,059,783	.378
1970	3,315,840	1,234,809	.372
1971	4,312,386	1,589,454	.369
1972	5,200,541	1,945,464	.374
1973	5,437,085	2,004,134	.369
1974	4,915,954	1,823,637	.371
1975	5,438,724	1,930,678	.355
1976	6,789,680	2,467,255	.363
1977	7,438,344	2,745,311	.369

Table 17 (cont'd.)

1978	7,753,170	2,878,485	.371

Source: U.S. Department of Commerce, Bureau of the Census, selected years(b).

The net effects of increases in phenol-formaldehyde resin prices, labor costs, and energy prices on the consumption of plywood are difficult to determine a priori. While southern pine plywood utilizes more expensive resins, resin content per panel is lower in plywood than in composite panels. On the other hand, Douglas fir plywood requires less expensive urea-formaldehyde resins to obtain comparable interior grade qualities; therefore, southern pine plywood is at a cost disadvantage in that respect. Lower transportation costs lessen the effects of the resin cost differential though.

Historically labor costs in the South have been below the national average. The annual average rate of increase in weekly earnings, however is greater than the national average (Irland, 1972). Over time, this will tend to reduce southern labor cost advantages. Labor wages are influenced by productivity. In the veneer and plywood industry, output per production hour worked has been above the average for all manufacturing. Process innovations have contributed to this trend (Farris, 1978). Hence, productivity gains may offset rising labor costs.

The effect of increases in energy price on the southern pine plywood industry differs from the effects on the particleboard industry. For example, residues are now being used as fuel for dryers reducing dependence on purchased energy as is the case with particleboard. Competition for wood raw materials, though does not increase as a result.

By 1979, seventy-two softwood plywood plants were operating in the South. This represents a huge influx of capital into an industry that began in late 1963. This capital has created large, efficient mills with modern processing equipment. Innovations continue to be incorporated in new plants as they are built. As a result, the southern plywood industry competes successfully with other panel products industries.

MODELLING PRODUCT DIFFUSION

Prior to analyzing diffusion in terms of market shares, the products to be aggregated were selected. First, general wood-based panel end-use markets were determined for panels with available consumption or production data. Second, structural demand equations were estimated for particleboard. Finally, panels were aggregated to form the total panel market.

Aggregate Panel Market Submodel

Table 18 presents an overview of panels and their end-use markets. In many cases panels can act as substitutes for one another, but they can also be complements and inputs into other panel products. For example, hardboard and particleboard are substitutes as floor underlayment. Insulation board and hardwood plywood can be complements in the sense that a wall system may have a finished interior wall hardwood panel backed with insulation board sheathing. An example of a panel as an input, is the use of particleboard as a core material in plywood sheets. Thus, the relationships among panels are complex.

Since particleboard is one of the panels being examined in this study and because it has numerous end-uses, it was selected initially as the panel on which to base the total panel market. Table 19 presents the estimated parameters of the linear and log-linear structural demand equations. As expected, the positive signs associated with hardwood

Table 18. Wood-based panels and selected end-use markets.

Panel	End-use markets
Douglas fir plywood	New residential construction (floors, siding, roofs, walls, shelving); residential upkeep, repairs and additions; furniture; industrial markets; non-residential construction.
Southern pine plywood	New residential construction (walls, roofs); residential upkeep, repairs and additions.
Hardwood plywood	New residential construction (walls); residential upkeep, repairs and additions; furniture.
Particleboard	New residential construction (floors, shelving); residential upkeep, repairs and additions; furniture.
Hardboard	New residential construction (floors, walls); residential upkeep, repairs and additions; furniture.
Insulation board	New residential construction (walls, roofs).
Medium density fiberboard	New residential construction (siding), furniture.

Sources: Anderson, 1980; Carney, 1977.

Table 19. Estimated linear and log-linear structural demand equations based on product prices and income[1/]

Equation	Dependent variable (Y)	Explanatory variables (X)	Regression coefficient (b)	Standard error of b
(1) Linear[2/]	Particleboard quantity (Y)	Particleboard price (X_1)	-31.28	8.36
		Hardwood plywood price (X_2)	33.39	14.64
		Softwood plywood price (X_3)	31.87	7.61
		U.S. disposable personal income (X_4)	3.69	2.10
		Constant	-5042.60	2331.10
(2) Log-linear[3/]	ln (Y)	ln (X_1)	-1.32	.38
		ln (X_2)	1.43	.55
		ln (X_3)	2.01	.56
		ln (X_4)	.90	.99
		Constant	-8.70	7.00

[1/]See equation (2) on page . Equations fitted with data from 1967 through 1979. See Table 22 for

Table 19 (cont'd.)

supply instruments.

2/ $\bar{R}^2$ = .94, D.W. = 2.49

3/ $\bar{R}^2$ = .93, D.W. = 3.07

Note: All estimated coefficients have at least an 80 percent probability of having the correct sign.

and softwood plywood price indicate that they are net substitutes for particleboard. Hardboard and insulation board prices were included in test runs of the model, but were deleted because of (1) their collinearity with each other, (2) hardboard's collinearity with hardwood plywood, and (3) little additional variance being explained by their inclusion.

In order to accomodate the entire range of end-uses and the complexity of product substitution, all panels listed in Table 14 were included in the total market. Hence, the substitutability of hardboard and medium density fiberboard for particleboard in furniture as well as the use of insulation board for sheathing can be enveloped in the model.

Apparent consumption data were developed for particleboard, hardboard, insulation board, and plywood other than southern pine plywood. For southern pine plywood and medium density fiberboard, production data were used in the model. This poses few problems since southern pine plywood is primarily a domestic product at this time and medium density fiberboard comprises a minute portion of the total market. Hereafter, both production and consumption data will be generalized as consumption data.

Figures 4 and 5 present consumption data for the panels in the total market. The total market is growing over time but is very cyclic in nature. This is due primarily to the strong reliance of wood-based panels on the construction industry. Non-southern softwood plywood which is comprised mostly of Douglas-fir plywood is a mature product maintaining a high level of the total consumption. It is also characterized by a declining market share. Hardwood plywood and insulation board are also mature products with declining market shares.

Figure 4.--Total panel, non-southern softwood plywood, southern softwood plywood, and particleboard consumtion, 1955-1979.

Legend:

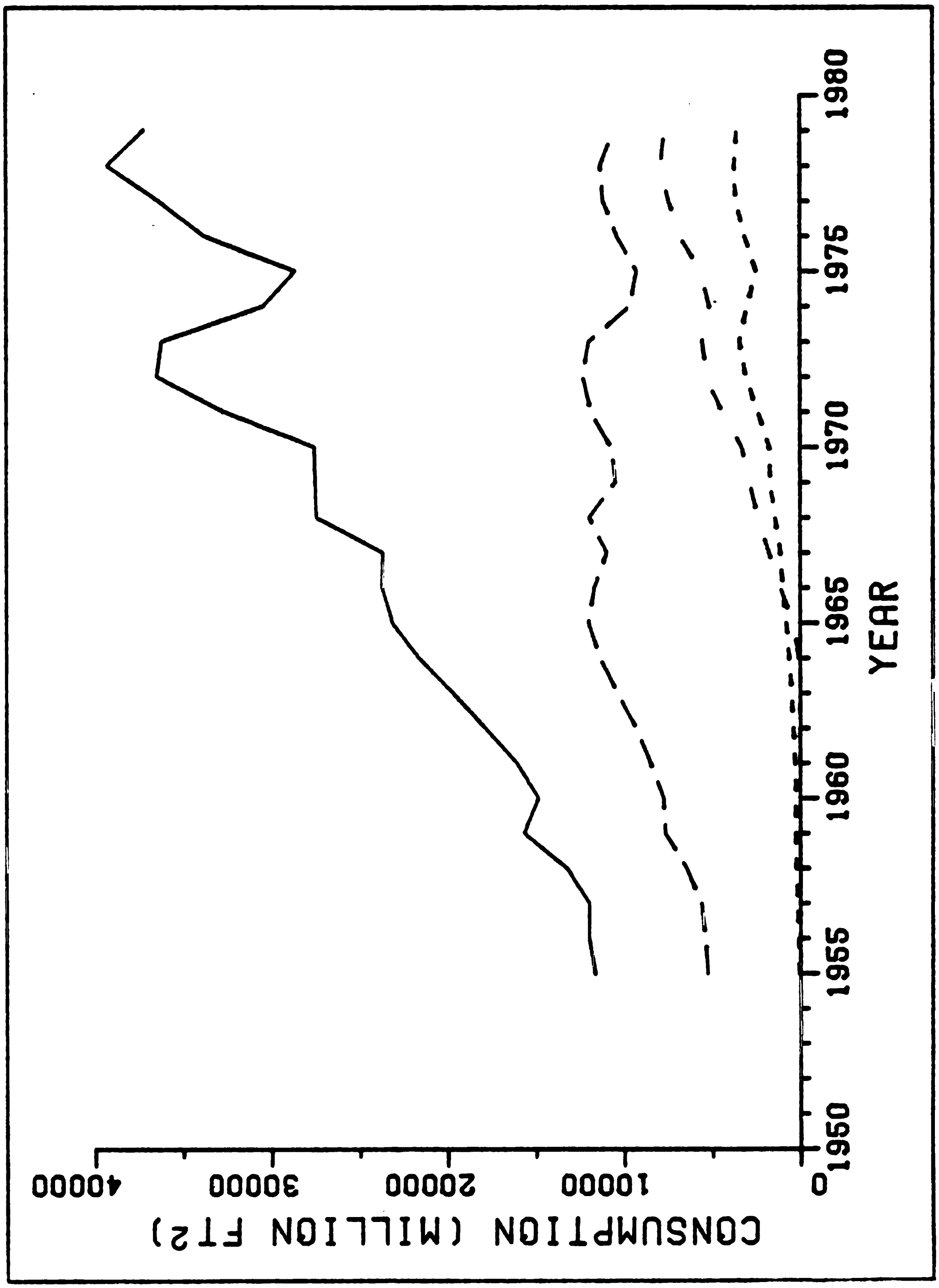
Totoal panel consumption (standard measures) ————————

Non-southern softwood plywood consumption (3/8-inch basis) —— —— ——

Southern pine plywood consumption (3/8-inch basis) — — — — — —

Particle board consumption (3/4-inch basis) -----------------

Figure 4.


CONSUMPTION (MILLION FT2)
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40000
YEAR
1950
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1960
1965
1970
1975
1980

Figure 5.--Total panel, hardboard, hardwood plywood, insulation board, and medium density fiberboard consumption, 1955-1979.

Legend:

Total panel consumption (standard measures) ———————

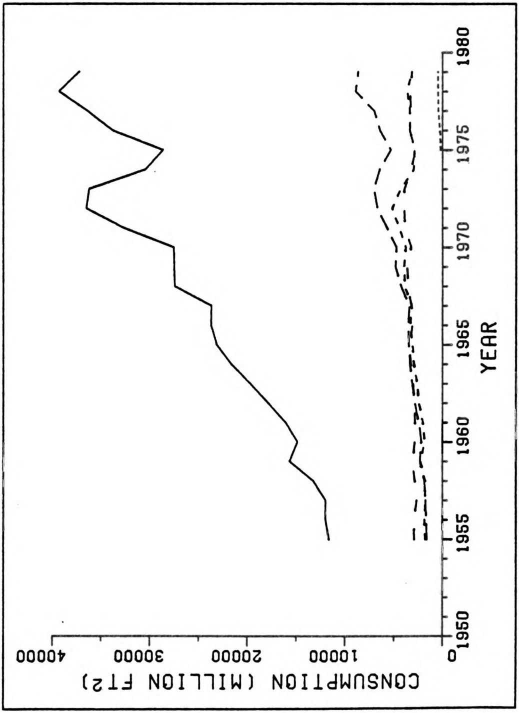
Hardboard consumption (1/8-inch basis) —— —— —— —— —— ——

Hardwood plywood consumption (3/8-inch basis) --------------

Insulation board consumption (1/2-inch basis) — — — — — — —

Medium density fiberboard consumption (3/4-inch basis) ----------

Figure 5.


CONSUMPTION (MILLION FT2)
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1965
1970
1975
1980

Southern pine plywood, particleboard, hardboard, and medium density fiberboard are increasing in terms of consumption and market shares. The first three panels are substantially into the growth stage while medium density fiberboard is probably in its introductory stage. The diffusion of particleboard and southern pine plywood through the market is illustrated in Figure 6 and 7, respectively.

An aggregate panel consumption submodel was estimated with ordinary least squares using total panel consumption as the independent variables. The final form of the model was:

$$\underset{(9496.55)}{C = -184025} + \underset{(1464.30)}{32220.1} \times \ln(DPI) \qquad R^2 = .95,\ D.W. = 1.21$$

where:

C = total panel consumption (standard measures)

DPI = U.S. disposable personal income in billions of 1972 dollars

Since the presence of autocorrelation is indicated by the Durbin-Watson statistic at the 5 percent alpha level, the equation was re-estimated using the Cochrane-Orcutt technique. Using the one-tailed t-test, both coefficients were significant at the .0005 alpha level. Estimated coefficients changed relatively little so the above model was retained for projection purposes.

The model fits the long-term trend data very well, but performs poorly during periods of great market fluctuations. This was evident when estimates for total panel consumption were compared to actual consumption during the 1972 to 1975 period.

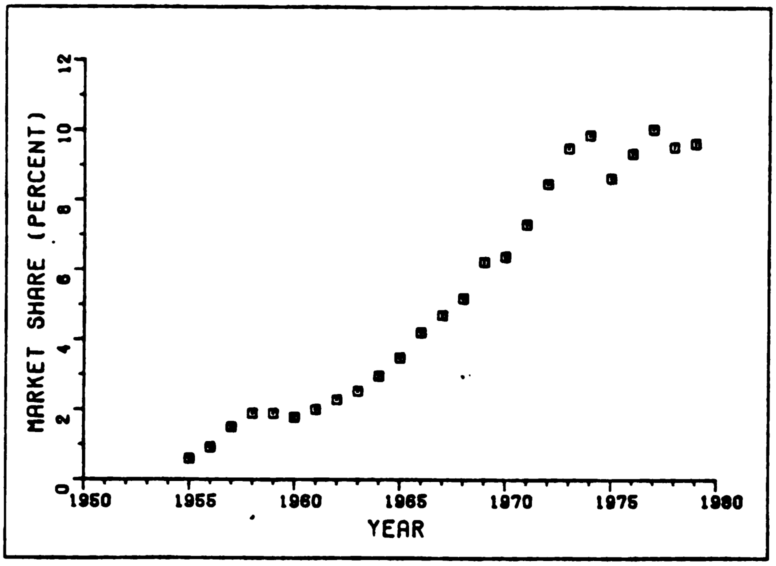

Figure 6.--<u>Market share of particleboard as a percent of total panel consumption, 1955-1979.</u>

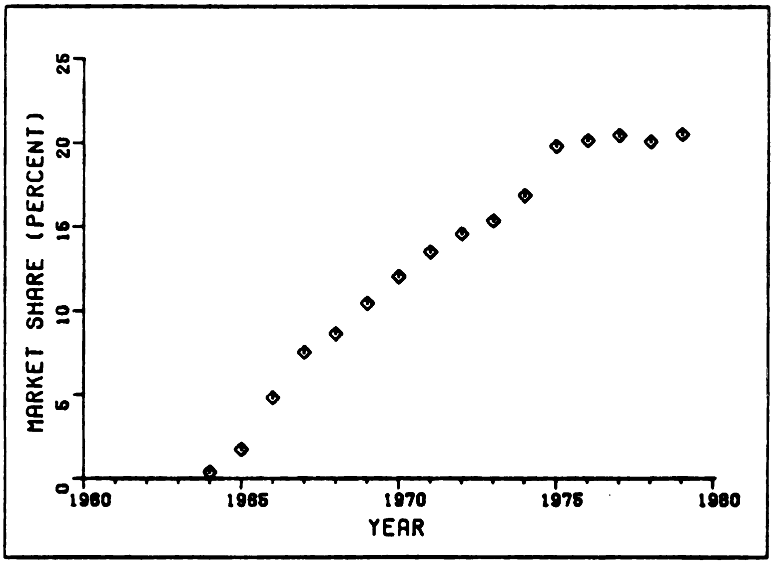

Figure 7.--<u>Market share of southern pine plywood as a percent of total panel consumption, 1964-1979.</u>

Market Share Submodels

Four market share submodels were estimated to examine different aspects of the diffusion. The logistic function and Gompertz curve submodels were used to estimate the time trend in market share diffusion, the growth rate of panel diffusion, and the inflection points. These trend models were used to project future market shares in the next chapter. Two multivariate models were estimated to examine temporal and spatial aspects of diffusion.

Logistic Function and Gompertz Curve Submodels

The market share data in Figures 5 and 6 were fitted with a simple linear trend model using ordinary least squares and with the nonlinear submodels using nonlinear least squares. The regression results are reported in Tables 20 and 21. The fitted nonlinear functions are illustrated in Figures 8 through 11.

Several general conclusions can be derived from the regression results. First, the S-shaped models represent the diffusion process better than the linear models. Second, the logistic function is slightly superior to the Gompertz curve for the particleboard data, and the opposite is true in the case of the southern pine plywood. Third, as espected given the model formulation, the potential market share (P) and the period of time (growth rate) required for a panel to grow from 20 percent to 80 percent of its potential are greatest for the Gompertz curve. Finally, the growth rate of southern pine plywood was approximately twice as rapid as the particleboard rate. In fact, the logistic function proportionality constant (b) which determines the diffusion rate is substantially greater for southern pine plywood than for particleboard.

Table 20. Estimated parameters[1/] of linear time trend[2/] for southern pine plywood and particleboard.

Years	Panel type	Parameters A	Parameters B	Durbin-Watson (D.W.) statistic	R^2
1964 - 1979	Plywood	-.115 (.015)	.014 (.015)	.44	.954
1955 - 1979	Particleboard	-0.005 (.003)	.0044 (.0002)	.46	.950

1/ Standard errors in parentheses.

2/ Linear time trend: Market share = A + B (time) + v. Time is measured as 1955 = 1, 1956 = 2, ..., 1979 = 25. Unexplained variation in market share is represented by v.

Table 21. Estimated parameters[1/] of the logistic function and Gompertz curve for particleboard and southern pine plywood.

Product/ years	Function	Parameters P	Parameters a	Parameters b	Durbin-Watson statistic	R^2	Inflection point (year)	Growth rate[2/] (years)
Particle-board, 1955 - 1979	Logistic	.111 (.006)	-3.067 (.195)	.221 (.021)	.92	.98	1968	14
	Gompertz	.141 (.018)	.020 (.008)	.902 (.016)	.67	.97	1967	19
Southern pine plywood, 1964 - 1979	Logistic	.211 (.008)	-5.840 (.605)	.379 (.044)	.75	.98	1969	7
	Gompertz	.223 (.010)	.034 (.012)	.784 (.021)	.96	.99	1968	8

1/ Standard errors in parentheses. Time is measured as 1955=1, 1956=2, ..., 1979=25 except for the southern pine Gompertz curve when 1964=1, 1965=2, ..., 1979=16.

2/ Number of years required for market share to grow from 20 percent to 80 percent of potential (P).

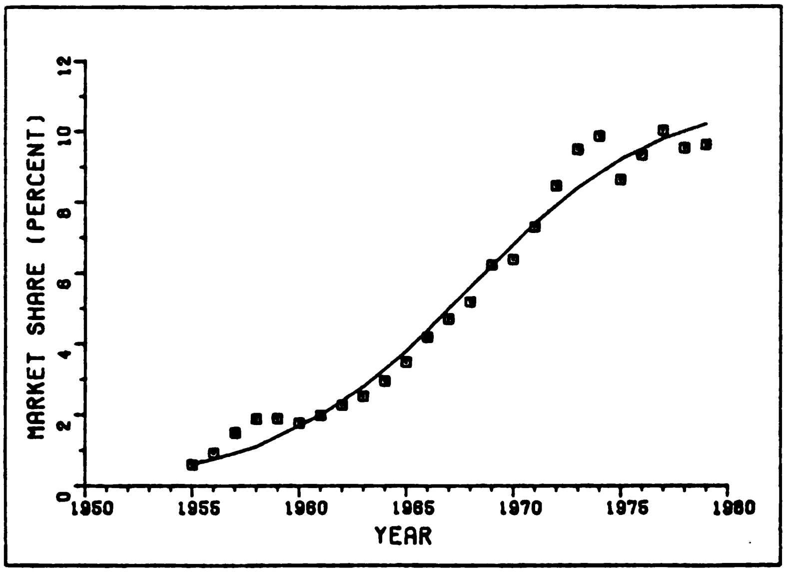

Figure 8.--Logistic function fitted to particleboard market share data, 1955-1979.

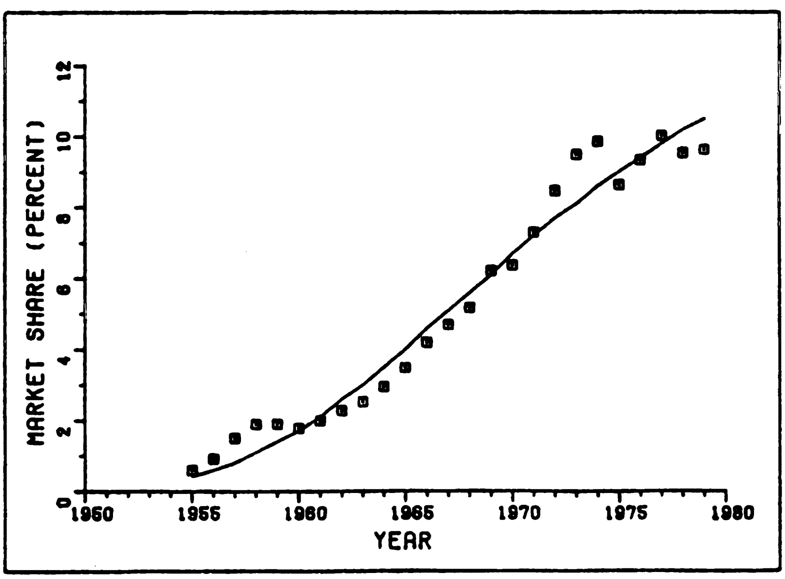

Figure 9.--Gompertz curve fitted to particleboard market share data, 1955-1979.

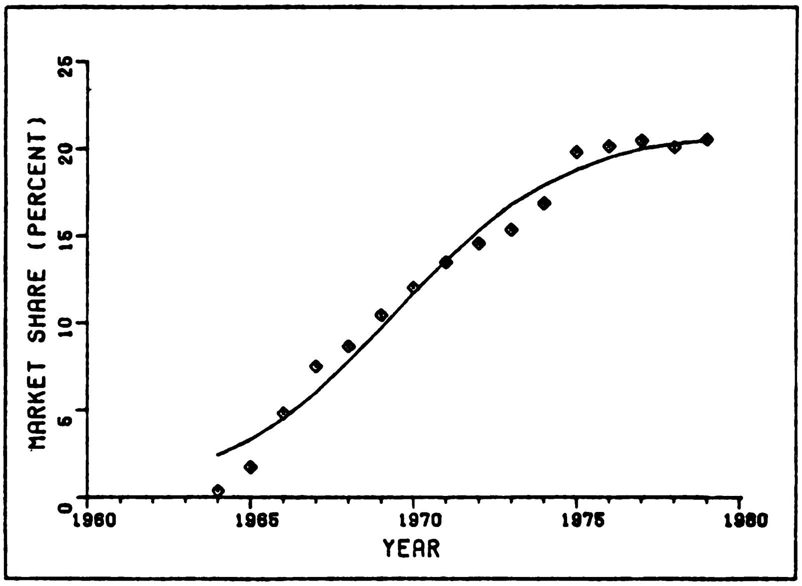

Figure 10.--Logistic function fitted to southern pine plywood market share data, 1964-1979.

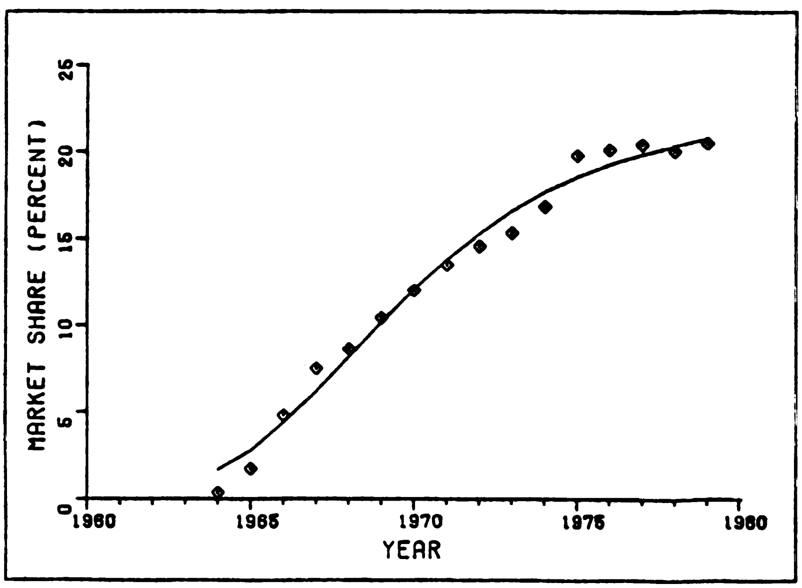

Figure 11.--Gompertz curve fitted to southern pine plywood market share data, 1964-1979.

Based on the Durbin-Watson statistics at the 5 percent alpha level, autocorrelation is present in all models. For projection purposes, this does not pose a problem. It is interesting to note that the 1979 actual marekt share has surpassed more than 80 percent of the estimated potential in all cases except the Gompertz curve for particleboard. The implications of this result on projections are discussed in the next chapter.

Multivariate Diffusion Submodels

While the univariate models are useful in depicting temporal diffusion trends, they are not very helpful in understanding the role supply and demand factors play in determining panel consumption and diffusion. Two multivariate models were used to gain insight into the effects of supply and demand factors. Time series data were used in the first model and cross-sectional data were used in the second model. Estimated structural supply and demand equations were used to screen variables for the time series model.

Tables 22 and 23 present the structural demand and supply equations for particleboard and southern pine plywood, respectively. Though the results must be interpreted with the power of the t-test as a restriction, the signs of the coefficients were generally the expected signs.

For particleboard demand, quantity demanded is a positive function of one and two unit housing starts, mobile home shipments, and furniture manufacturing. These relationships are expected since they are the primary end-use markets for particleboard. Particleboard price and housing starts with three or more units exhibited the opposite

Table 22. Estimated structural demand and supply equations for particleboard.

Equation	Dependent variable (Y)	Explanatory variables (X)	Regression coefficient (b)	Standard error of b
(1) Demand[2/]	Particleboard quantity	Particleboard price	-3.59	1.98
		Housing starts, 1&2 units	1.86	.21
		Housing starts, 3+ units	-3.88	.58
		Mobile home shipments	6.63	.92
		Index of furniture manufacturing	28.14	1.77
		Constant	-2996.46	360.05
(2) Supply[3/]	Particleboard quantity	Particleboard price	-32.13	11.12
		Adhesives price	-25.59	17.83
		Energy price	14.36	9.67
		Wages	-2615.73	1514.36
		Lumber production	347.91	106.46
		Constant	-381.38	3676.99

[1/] Equations fitted with data from 1967 through 1979.

[2/] $\bar{R}^2$ = .99, D.W. = 2.54

[3/] $\bar{R}^2$ = .89, D.W. = 2.85

Note: All estimated coefficients have at least an 80 percent probability of having the correct sign except the constant in the supply equation.

Table 33

Table 23. Estimated structural demand and supply equations for southern pine plywood.[1]

Equation	Dependent variable (Y)	Explanatory variables (X)	Regression coefficient (b)	Standard error of b
(1) Demand[2]	Southern pine plywood quantity	Southern pine plywood price	-62.87	14.40
		Western softwood plywood price	78.40	11.94
		Housing starts, 1&2 units	4.14	.80
		Housing starts, 3+ units	-2.71	.46
		Constant	-901.38	798.41
(2) Supply[3]	Southern pine plywood quantity	Southern pine plywood price	39.94	17.76
		Southern pine sawlog stumpage price	19.45	19.71
		Plywood mill productivity	109.92	10.65
		Constant	-13322.30	1496.47

[1] Equations fitted with data from 1969 through 1979.

[2] $\bar{R}^2$ = .97, D.W. = 2.10

[3] $\bar{R}^2$ = .93, D.W. = 1.56

Note: All estimated coefficients have at least an 80 percent probability of having the correct sign.

relationship. As price increased, ceteris paribus, quantity demanded decreased. This is the expected demand price-quantity relationship. Multifamily units utilize only a small portion of particleboard relative to other end-use markets (U.S. Department of Agriculture, Forest Service, 1974). The direct competition of multifamily units with mobile homes and one and two family homes leads to this statistical result.

As expected, particleboard quantity supplied declines as wages and adhesives prices increase. Lumber production was used as a proxy for planer shavings availability and has the expected positive relationship. This result must be viewed with caution since residue price would be a more appropriate supply variable and because solid wood products production is positively correlated with residential construction. The net effect of increasing energy prices on particleboard was positive over the test period. In supply functions, increases in board price are associated with increases in quantity offered in the market. The only unexpected sign was the negative sign on particleboard price. This perverse relationship may be due to the general negative trend in particleboard prices (see Table 9) and the predominance of demand in determining price-quantity relationships.

Sheathing is the primary market for southern pine plywood, and as a result, one and two unit housing starts are positively correlated with plywood quantity demanded. The role of western softwood plywood as a substitute for southern pine plywood is indicated by the positive sign on the former price. As was the case with particleboard, multifamily housing starts have a negative effect on plywood quantity demanded.

The southern pine plywood supply equation had the expected signs on price and productivity variables. As either price or productivity i

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increases, producers offer more plywood in the market. As the price of inputs increases, a negative effect on quantity supplied is expected. The sign on stumpage price was positive; however, it was only significant at the 20 percent alpha level and the power of the test was very small. Despite the statistical result, stumpage price was retained in the equation because the cost of stumpage (1) is an important factor in the total cost of producing the panel and (2) is expected to increase in importance as competition for stumpage intensifies. The positive correlation between product price and stumpage price and the small sample size may have led to this result.

The final supply and demand equations were derived through an iterative process in which many variables were examined for inclusion in the regressions. Additional variables considered in the particleboard equations were: weighted price of substitutes, total U.S. dwelling starts, disposable personal income, index of all manufacturing, value of residential construction, value of residential additions and alterations, value of private nonresidential buildings, value of public buildings, percent of all housing starts that were multifamily units, output per plant, softwood plywood production and railroad freight revenue per ton-mile. Other variables, in addition to those above, examined for inclusion in the plywood equations were: one unit housing starts in the South, percent of total U. S. one unit housing starts in the South, five or more unit dwelling starts in the South, total dwelling starts in the South, personal income in the South, plywood mill wages, adhesives prices, and energy prices.

The variables in Tables 19, 22, and 23 and lagged market share variables were tested as explanatory variables for the models described by equations (7) and (8). The lagged market share variables were included to show the accumulated effect of supply, demand qualitative factors on product diffusion. In short, they were used as proxies for past market success and the knowledge gained by users as a result of that success.

The regression results presented in Tables 24 and 25 corroborate the importance of past success and accumulated knowledge in the diffusion of the new products. In fact, the adjusted R^2 for particleboard and southern pine plywood were .94 and .98, respectively, without the end-use market variables included in the model.

In the particleboard submodel, economic activity in the furniture and fixtures industry and the mobile home industry are important variables for particleboard diffusion. This was an expected result since particleboard made substantial inroads in both markets. However, the combined effects of those two variables were small when compared to the importance of the lagged market share variable.

The effect of using seemingly unrelated regression estimates was a slight shift in the estimated coefficients and a reduction in the magnitudes of the standard errors. Based on that result, the ordinary least squares particleboard model was estimated for the 1956 through 1979 period. The resulting regression[1/] was:

$$\underset{}{M} = \underset{(.005083)}{-.011552} + \underset{(.073876)}{.719247} \times M(-1) + \underset{(.000085)}{.000216} \times IMF + \underset{(.000007)}{.000027} \times MOBILE$$

where:

M= particleboard market share (in decimal form)

M(-1) = particleboard market share lagged one year

[1/]Standard error in parentheses.

Table 24. Estimated parameters of the multivariate, temporal diffusion submodel for particleboard[1/].

Table 24. Estimated parameters of the multivariate, temporal diffusion submodel for particleboard[1].

Explanatory variables	Ordinary least squares estimates[2]		Seemingly unrelated regression estimates[2]	
	Regression coefficient (b)	Standard error of b	Regression coefficient (b)	Standard error of b
Lagged market share	.712525	.092247	.712930	.079887
Index of furniture manufacturing	.000224	.000108	.000224	.000094
Mobile home shipments	.000027	.000009	.000027	.000007
Constant	-.012047	.007818	-.012022	.006770

[1] Estimates based on data from 1964 through 1979. $\bar{R}^2 = .97$, D.W. = 2.30.

[2] There is no significant difference in these equations.

Note: All estimated coefficients have at least an 80 percent probability of having the correct sign.

Table 25.

Table 25. Estimated parameters of the multivariate, temporal diffusion submodel for southern pine plywood.[1/]

Explanatory variables (X)	Ordinary least squares estimates estimates[2/]		Seemingly unrelated regression estimates[2/]	
	Regression coefficient (b)	Standard error of b	Regression coefficient (b)	Standard error of b
Lagged market share	1.004410	.031734	1.004440	.028605
Housing starts, 1&2 units	- .000035	.000010	- .000035	.000009
Constant	.051367	.009731	.051362	.008771

[1/] Estimates based on data from 1964 through 1979. R^{-2} = .99, D.W. = 2.01.

[2/] There is no significant difference in these equations.

Note: All estimated coefficients have at least an 80 percent probability of having the correct sign.

IMF= index of furniture and fixtures production (1967=100)

MOBILE= manufacturers shipments of mobile homes (in thousands of units)

The adjusted R^2 was .99, and the Durbin-Watson statistic was 2.29. The results were very comparable to those derived from the shorter time period.

In the southern pine plywood market submodel, the lagged market share variable was again the most significant variable. The negative sign on one and two unit housing starts was contrary to expectations. However, closer examination of housing starts and market share trends shows that the greatest increases in market share were attained during periods when housing starts were declining. This was due in large part to southern pine plywood producers' ability to cut plywood prices to a greater extent than western producers could.

The interaction of factors influencing diffusion over time, in general, do not incorporate spatial aspects of diffusion. For example, local products have limited potential because knowledge of products is restricted to a given geographic region. By 1978, knowledge regarding southern pine plywood was fairly extensive. Therefore, a spatial diffusion model was examined to gain insight primarily into the effects of transportation costs on spatial diffusion. Distance from Portland, Oregon (DIST) in miles and the number of southern pine plywood plants in adjacent states plus the number of plants in the state containing the major portion of Rand McNally Major Trading Areas (PLANTS) were used as explanatory variables. The sample was developed by crossing the top 20 U. S. softwood plywood markets and the top 20 southern softwood plywood markets. The resulting sample size was 29.

The a priori expectation was that the percent (PERCENT) of total softwood plywood shipments attributed to southern pine going to a Major Trading Area would increase as the distance from Portland increases and as the number of nearby southern pine plywood plants increases. This model provides a rough indication of the regional advantage panel products can develop. The results of the regression[1/] were:

$$\underset{(6.78)}{\text{PERCENT} = -10.60} + \underset{(.003)}{.023} \times \text{DIST} + \underset{(.21)}{1.37} \times \text{PLANTS} \qquad \bar{R}^2 = .83$$

As expected, the regional proximity of the panel's producers and the distance from the major competing panel's supply region were positively related to the market penetration of the new product. Transportation cost is the main factor leading to these results.

Two additional variables were tested for inclusion in the model. Total plywood shipments to the Major Trading Area in 1978 and total housing starts in the Trading Area's major metropolitan areas were used as proxies for market activity. Though factor market penetration may be expected in large, dynamic markets, neither variable was significant at the 20 percent alpha level. Inclusion of the variables did not improve the explanatory power of the model. Thus, southern pine plywood attained spatial diffusion which was determined to a large extent by its proximity to Eastern markets.

[1/] Standard errors in parentheses.

PROJECTIONS AND NEWER PRODUCT INNOVATIONS

The projection model formulated for this study was that future wood requirements for a given panel project would be a function of future aggregate panel consumption, the panels market share, and the average wood requirements per unit of panel output. Disposable personal income was selected as the exogenous variable for the aggregate panel consumption submodel time was the exogenous variable in the nonlinear diffusion submodels. Wood inputs per unit of output, on a weight basis, were assumed to remain constant over the projection period. Bolt diameter, core diameter, and processing efficiency will determine wood requirements in terms of roundwood volume; one study assumes that wood requirements per unit of output, on a volume basis, will fall ten percent during the 1976 to 2030 period for lumber and plywood (Adams and Haynes, 1980). For this study, however, wood requirements were projected on a weight basis.

Rather than project consumption for particleboard and southern pine plywood based on both nonlinear submodels, the models were examined more closely to determine which best represented the diffusion pattern for each panel. In this examination, insight was gained into the usefulness of these models for projections under different conditions of data availability

Following selection of the market share submodels is the projection of panel consumption and wood requirements. Finally, interacting factors that will influence future diffusion are discussed, including newer product innovations.

Comparison of Logistic Function and Gompertz Curve for Projecting Market Shares

Market share projections based on the logistic function and the Gompertz curve are presented in Table 26 and in Figures 12 through 15. The Gompertz curve market share projections are always greater than the logistic function projections for the complete data sets. In the case of particleboard, the disparity between estimates will lead to great differences in projected wood requirements. For example, the particleboard projection for the year 2000 would be 23 percent greater if the Gompertz curve rather than the logistic function were used for projections.

Since it is desirable to assess the reliability of these functions for projecting future panel market shares under different conditions of data availability, five time periods of varying length for each panel were fitted with the logistic function and the Gompertz curve. Regression results are presented in Table 27 for particleboard and in Table 28 for southern pine plywood. Preliminary results from these tables indicate that the logistic function yields a better fit than the Gompertz curve for particleboard and that there is little difference in the case of southern pine plywood. The adjusted R^2, Durbin-Watson statistic, and standard error associated with market share potential (P) were the basis for the preliminary conclusions.

By comparing the actual market share in the last year of a

Table 26. Market share projections based on nonlinear diffusion functions, 1990 and 2000 (in percent).

Panel product	Function	Year 1990	2000
Particle-board	Logistic	11.00	11.07
	Gompertz	12.83	13.64
Southern pine plywood	Logistic	21.06	21.07
	Gompertz	22.19	22.28

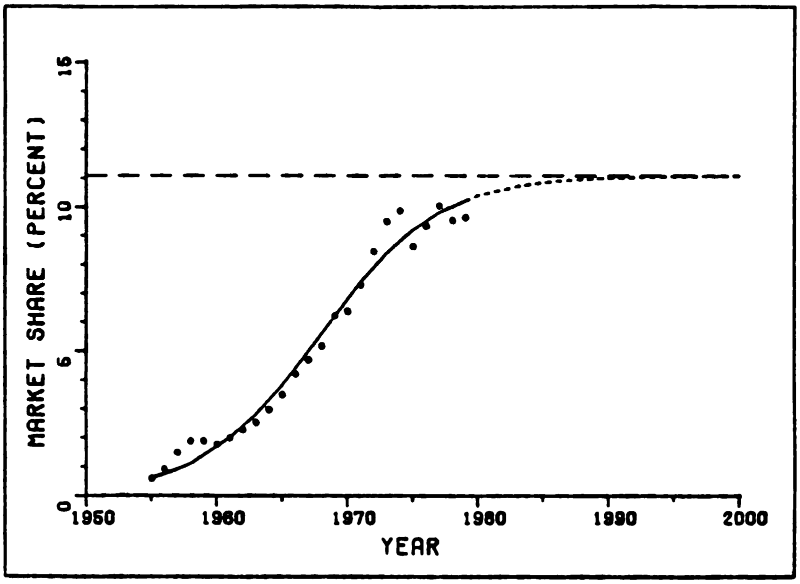

Figure 12.--Particleboard market share projections based on the logistic function, 1980-2000.

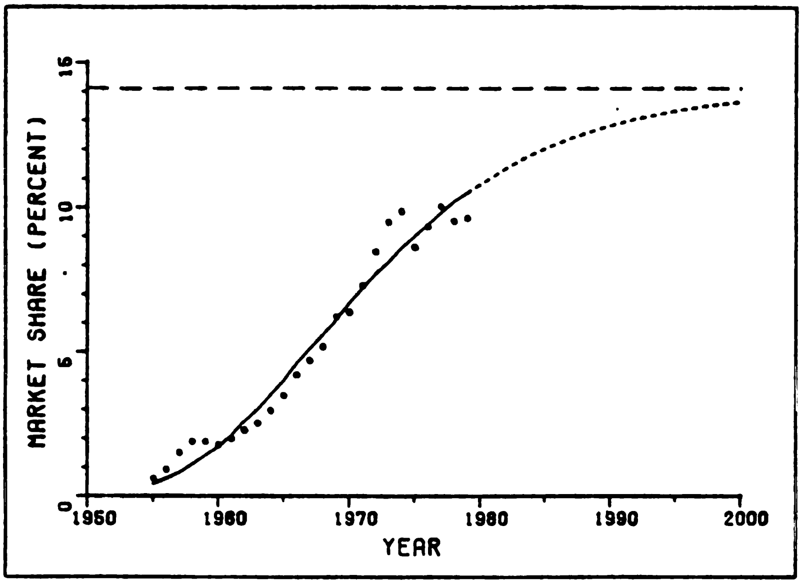

Figure 13.--Particleboard market share projections based on the Gompertz curve, 1980-2000.

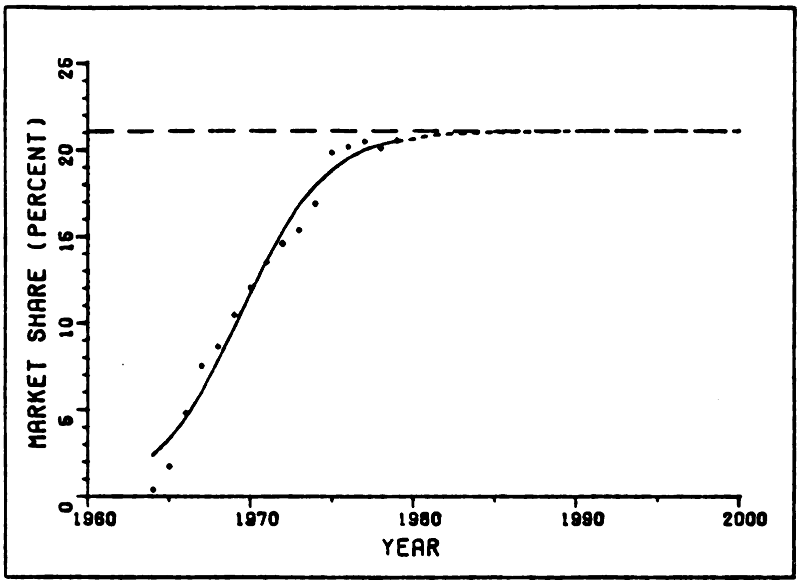

Figure 14.--Southern pine plywood market share projections based on the logistic function, 1980-2000.

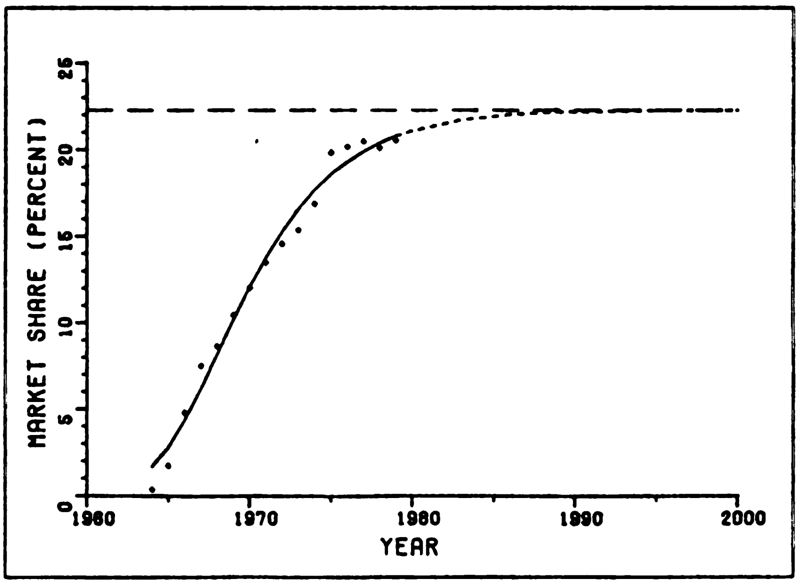

Figure 15.--Southern pine plywood market share projections based on the Gompertz curve, 1980-2000.

Table 27. Estimated parameters[1/] of the logistic function and Gompertz curve for particleboard, selected years.

Years	Function	Parameters P	Parameters a	Parameters b	Durbin-Watson statistic	$\bar{R}^2$
1955-1979	Logistic	.111 (.006)	-3.067 (.195)	.221 (.021)	.92	.98
	Gompertz	.141 (.018)	.020 (.008)	.902 (.016)	.67	.97
1955-1975	Logistic	.142 (.024)	-3.059 (.135)	.184 (.022)	1.21	.98
	Gompertz	.362 (.240)	.015 (.006)	.946 (.018)	1.13	.97
1955-1964	Logistic	.033 (.010)	-1.320 (.275)	.289 (.128)	.97	.87
	Gompertz	.034 (.009)	.167 (.047)	.812 (.090)	1.01	.88
1955-1959	Logistic	.020 (.022)	-2.069 (.406)	1.032 (.250)	2.61	.97
	Gompertz	.022 (.003)	.068 (.056)	.523 (.130)	2.62	.95

Table 27 (cont'd.)

1962-1979	Logistic	.104 (.004)	-3.709 (.337)	.275 (.030)	1.36	.97
	Gompertz	.113 (.009)	.0007 (.0018)	.845 (.023)	1.10	.96

[1]/Standard errors in parentheses.

Table 28. Estimated parameters[1/] of the logistic function and

Table 28. Estimated parameters[1/] of the logistic function and Gompertz curve for southern pine plywood, selected years.

Years	Function	Parameters P	Parameters a	Parameters b	Durbin-Watson statistic	$\bar{R}^2$
1964-1979	Logistic	.211 (.008)	-5.840 (.605)	.379 (.044)	.75	.97
	Gompertz	.223 (.010)	.034 (.012)	.784 (.021)	.96	.98
1969-1979	Logistic	.225 (.013)	-4.479 (.837)	.287 (.057)	1.25	.96
	Gompertz	.235 (.019)	.055 (.047)	.813 (.045)	1.18	.96
1964-1977	Logistic	.212 (.013)	-5.788 (.722)	.375 (.055)	.71	.97
	Gompertz	.231 (.017)	.037 (.014)	.795 (.027)	.93	.98
1964-1972	Logistic	.153 (.008)	-8.494 (1.135)	.626 (.091)	1.00	.98
	Gompertz	.164 (.008)	.013 (.008)	.677 (.031)	1.30	.99

Table 28 (cont'd.)

Table 28 (cont'd.)

1964-1970	Logistic	.119 (.009)	-11.928 (2.174)	.946 (.184)	1.70	.97
	Gompertz	.131 (.010	.003 (.004)	.573 (.053)	2.07	.98

[1]/Standard errors in parentheses.

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sample set with the estimated potential market share, the limitations of the nonlinear functions become evident. The computations presented in Tables 29 and 30 show that: (1) over 85 percent of market potential was already achieved in cases when the standard error of the potential was small and (2) the potential market share was consistently underestimated in samples based on the first half of the available data. Therefore, the deterministic diffusion functions should be used for projecting only when the diffusion process is substantially underway.

For most data sets tested, the logistic function yielded more conservative estimates of market share potential than did the Gompertz curve. After comparing the statistical results, the logistic function was selected for particleboard projections. Additional regression tests made on the southern pine plywood data indicated that the estimated market share potential associated with the logistic function was more stable than the potential associated with the Gompertz curve as the sample size approached 16 (total sample). Hence, the logistic function was selected for projecting future southern pine plywood market shares. Projections and factors expected to play a major role in slowing the diffusion of particleboard and southern pine plywood are discussed in the remainded of the chapter.

Projections of Panel Consumption and Wood Requirements

Based on high, medium, and low estimates of U. S. disposable personal income, total panel consumption is projected to range from 48.5 to 52.5 billion square feet in 1990 and from 55.5 to 62.6 billion square feet in 2000. Historically, the greatest annual consumption

Table 38. Comparison of particleboard's market share potential to the last market share achieved in

Table 29. Comparison of particleboard's market share potential to the last market share achieved in selected samples.

Years	Function	Market share potential (percent)	Last year actual market share[1] (percent)	Last year actual to potential market share ratio[2]
1955-1979	Logistic	11.1	9.6	.86
	Gompertz	14.1	9.6	.68[3]
1955-1975	Logistic	14.2	8.6	.60[3]
	Gompertz	36.2	8.6	.24[3]
1955-1964	Logistic	3.3	3.0	.91
	Gompertz	3.4	3.0	.88
1955-1959	Logistic	2.0	1.9	.95
	Gompertz	2.2	1.9	.86
1962-1979	Logistic	10.4	9.6	.92
	Gompertz	11.3	9.6	.85

1/ Last year of sample time period, e.g., 1979 is the last year of the 1955-1979 sample time period.

2/ Last year actual market share divided by market share potential.

3/ Large standard error associated with estimated potential.

Table 30. Comparison of southern pine plywood's market share potential to the last market share achieved

Table 30. Comparison of southern pine plywood's market share potential to the last market share achieved in selected samples.

Years	Function	Market share potential (percent)	Last year actual market share[1/] (percent)	Last year actual to potential market share ratio[2/]
1964-1979	Logistic	21.1	20.5	.97
	Gompertz	22.3	20.5	.92
1969-1979	Logistic	22.5	20.5	.91
	Gompertz	23.5	20.5	.87
1964-1977	Logistic	21.2	20.5	.97
	Gompertz	23.1	20.5	.89
1964-1973	Logistic	15.3	15.6	1.02
	Gompertz	16.4	15.6	.95
1964-1970	Logistic	11.9	12.0	1.01
	Gompertz	13.1	12.0	.92

1/ Last year of sample time period, e.g., 1979 is the last year of the 1964-1979 sample time period.

2/ Last year actual market share divided by market share potential.

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was in 1978 when 39.3 billion square feet of panels were consumed.

Projected particleboard and southern pine plywood consumption and wood requirements are presented in Table 31. The projections are based on the logistic function diffusion trends and estimates of disposable personal income. The 2000 medium income level projections are 82 and 62 percent greater than the 1979 volumes for particleboard and southern pine plywood, respectively. The same percentages apply to wood requirements on a weight basis. The projected average annual growth rates are well below those experienced in the industry during the 1960's and 1970's.

The U.S.D.A Forest Service (1979) projected higher levels of particleboard consumption than were estimated in this study (see Table 32). However, panels other than particleboard were included in the Forest Service estimates. The Forest Service projections were based on price trends that have prevailed during the last two decades.

The southern pine plywood production projections estimated by the U.S.D.A. Forest Service (1979) are similar to those developed in this study for 1990 (see Table 33), but all 11 percent lower in 2000. The Forest Service projections for plywood are based on stumpage prices that will equate stumpage quantity demanded to stumpage quantity supplied (U. S. Department of Agriculture, Forest Service, 1979). Other estimates of southern pine plywood production for 2000 are 9.9 and 10.2 billion square feet, 3/8-inch basis (Anonymous, 1981c; Haynes and Adams, 1979).

The trend model estimates are derived from simple projections of consumption and an extrapolation of market share trends given

Table 31. Projections of panel consumption[1] and total wood requirements[2] for high, medium, and low levels

Table 31. Projections of panel consumption[1/] and total wood requirements[2/] for high, medium, and low levels of disposable personal income, 1990 and 2000.

Panel Product	Function	Income Level[3/]	Panel consumption 1990	Panel consumption 2000	Wood Requirements 1990	Wood Requirements 2000
Particle-board	Logistic	High	5768	6930	8710	10464
		Medium	5555	6519	8388	9844
		Low	5328	6139	8045	9270
Southern Pine Plywood	Logistic	High	11047	13189	6452	7703
		Medium	10638	12405	6213	7245
		Low	10204	11682	5960	6823

[1/] In thousands of square feet, 3/4-inch basis for particleboard and 3/8-inch basis for southern pine plywood.

[2/] In thousands of tons, dry weight (ovendry)basis for particleboard and in thousands of tons, based on ovendry mass and volume at 12 percent moisture content for southern pine plywood.

[3/] See Table A21.

Table 32. Comparison of particleboard consumption projections made in this study with projections by the U.S. Forest Service (in millions of square feet, 3/4-inch basis).

Year	Logistic function trend and medium income level projection	Base level price and medium income level projection[1/]
1990	5555	7625
2000	6519	9020

[1/] Includes waferboard, flakeboard, composite board, medium density fiberboard, and similar products.

Sources: Table 31; U.S. Department of Agriculture, Forest Service, 1979.

Table 33. Comparison of southern pine plywood production projections made in this study with projections by the U.S. Forest Service (in billions of square feet, 3/8-inch basis).

Year	Logistic function trend and medium income level projection	Equilibrium level price projections
1990	10.6	10.5
2000	12.4	11.1

Sources: Table 28; U.S. Department of Agriculture, Forest Service, 1979.

market potential. The other projections involve estimates of future price and quantity relationships in the stumpage and final product sectors. The trend in the price-quantity relationships is implicit in the former and explicit in the latter. The panel consumption and wood requirement projections vary considerably depending on which model is used and what assumptions are made regarding model variables.

Though the trend model is simple in design, it does indicate the direction and relative magnitude of future particleboard and southern pine plywood consumption. As was shown in the preceding chapters, many factors have influenced the diffusion of these panels. The expected effects of these factors on future consumption and wood requirements are discussed in the remainder of this section. Newer substitute panels are discussed in the final section of this chapter.

Future Particleboard Trends

Particleboard's unique properties and the flexibility of its manufacturing processes will continue to make it an attractive panel for various end-uses. One example of particleboard's diversity is Mende Process board or thin panelboard. The Mende Process board was developed by Wilhelm Mende and Company in West Germany (Anonymous, 1971a). The process has been modified over the last 10 years, but the primary component is a continuous press. Like batch produced particleboard, Mende Process board is used as furniture core stock and in construction (Food and Agriculture Organization of the United Nations, 1976). It also is used for door skins and wall paneling (Bryan, 1978). There were eight domestic thin panelboard plants in production during 1980 (Anonymous, 1981a).

Improvements in manufacturing processes and the diffusion of existing process innovations will lead to more efficient production in the future. Computerized process control systems, electron beam curing, and new binder developments are examples of process innovations that can make significant inroads in the particleboard industry (Blackman, 1978; Pease, 1977). Process developments will continue to play and important role in maintaining particleboard's competitive position.

Declining relative price has been an important factor in particleboard's diffusion. Particleboard price and consumption are correlated with the prices of substitutes, disposable personal income, end-use activity, input prices, and raw material availability. These factors will determine future consumption levels.

Traditionally, substitute prices have risen faster than particleboard prices. This trend is expected to continue in the future for softwood and hardwood plywood which rely on higher quality wood inputs. As income and end-use activity increase, particleboard consumption will also increase.

Supply factors may constrain future particleboard consumption. Adhesive prices and availability are major concerns for producers. Though the net effect of energy prices was estimated to promote particleboard consumption, long-term effects may be negative. For example, multiple unit dwellings requiring less particleboard per unit could be the new housing norm in another 20 years. Increases in other input prices are expected to hinder future consumption.

The availability and price of furnish is the problem most widely discussed by industry researchers. New sawmill production techniques are reducing planer shavings and sawdust per unit of output (Dickerhoof and McKeever, 1979). Also, lumber production is increasing more slowly than panel production and the available residues are more in demand as an energy source and for papermaking. Unused manufacturing residues, bark, logging residues, and roundwood are potential sources of future wood materials (Dickerhoof, 1976; Lehmann and Wahlgren, 1978; Lewis, 1965). Regardless of the source, greater handling and furnish preparation costs are expected (Wilson, 1975). The net effect is a slowing of the diffusion process as has been the case in recent years.

Thus, the traditional particleboard product is nearing the apex of its market share. Both supply and demand factors have been instrumental in its growth and will retard its future diffusion. However, newer panel products, such as, waferboard, medium density fiberboard, and composite panels are just beginning the diffusion process and will be the growth sector in the panel industry in the foreseeable future. They will play a major role in closing the projected consumption gap identified in Table 29.

Future Southern Pine Plywood Trends

Southern pine plywood manufacturers are diversifying their product mix. The characteristics required in CD sheathing were met by southern pine plys, and now higher quality plys are being marketed. Examples of higher value added products made from southern pine are: plyform, underlayment, 303 siding, and AC/AD panels. The addition of these products helps manufacturers offset rising log costs (Baldwin, 1977). Higher grade face plys also will be utilized in composite panels. Expansion into other grades is expected to help southern pine plywood capture a greater market share in the future.

Process changes will continue in the South so that producers can utilize more of the softwood resources. Productivity gains reflect the modern, efficient processes incorporated in southern plants(Farris, 1978). In fact, capacity is still expanding in the South despite economic conditions; Federal Paper Board recently announced plans for a new plant and International Paper has begun construction on another plant (Lambert, 1981). These plants are being built in anticipation of future demand.

Substitution of other products for softwood plywood may dampen future diffusion of the product. In a recent survey (Carney, 1977), builders mentioned hardboard, aluminum, and phenolic waferboard as products replacing plywood in new residential construction. Shifts to other products in nonresidential construction may be due to economics, fire codes, and other factors (Anderson, 1978).

Siding and All-Weather Wood Foundations are end-uses in which plywood may make significant progress. However, the concrete slab is the primary floor system in single-family homes in the South where southern pine plywood has its greatest acceptance (Carney, 1977). Therefore, North Central and Northeast markets have the greatest potential for southern pine plywood floor systems.

The southern pine plywood price trend is projected to increase at about the same rate as western softwood plywood prices until 2000 (Haynes and Adams, 1970). As a result, southern pine plywood will maintain its in-place cost advantage in the eastern United States. Higher value added products, rising population in the South, and increasing end-use activity should combine to provide larger markets for southern pine plywood in the future.

Supply factors will influence the diffusion of plywood, too. The most notable factor is the price and availability of softwood stumpage in the South. Hair (1980) has estimated that stumpage price in the South will rise at an average annual rate of 2.5 percent between 1976 and 2030. Though this is slightly below the rate experienced between 1969 and 1978, it is still a significant increase. Upward pressure on stumpage price is predicted due to increasing demand for all southern forest products, expected declines in softwood roundwood inventories, and low levels of regeneration on private non-industrial lands (Anonymous, 1981b and Hair, 1980). Eventually, the stumpage price increases will cause southern pine plywood to lose its competitive edge. Newer panels, such as waferboard and composite panels, will gain as a result.

Newer Product Innovations

Newer panel products that have been successfully introduced in the market give an indication of the direction of product innovation. As has been the case in the past, the new direction has important ramifications with regard to wood inputs. The introduction of Douglas fir plywood in 1907 as a door panel has had remarkable consequences (Cour, 1955). Likewise, a faulty press valve in 1924 that resulted in hardboard first being produced during William Mason's lunch hour has had a significant impact on wood utilization (Maloney, 1977). Particleboard and southern pine plywood are other examples of panels whose acceptance has altered perceptions of wood resources.

Rather than forging a new direction, the most recent product innovations simply are continuing a process that has been underway for years, namely, the utilization of more diverse wood materials. From an economic standpoint, there is a dynamic shift from scarce materials to less scarce materials. The increasing importance of southern pine plywood vis-a-vis Douglas fir plywood is a case in point. The use of manufacturing residues in particleboard is another example. More recently, waferboard, medium density fiberboard, and composite panels have added to the panel diversification trend.

A conceptual starting point for future wood-based panel products is Dr. George Marra's (1969) "Non-periodic Table of Wood Elements." He identified 14 elements beginning with logs and ending with cellulose. Veneer, chips, flakes, particles, and wood flour are among the elements. By combining wood elements with other panel inputs, such as, binders and chemicals, boards with a variety of characteristics can be developed. End-use requirements and processing technology will be key factors in determining how these elements will be used in the future.

The product innovations discussed in this section are not new in the sense that they were just recently introduced in the market, but they are new in the sense that they are only recently gaining widespread acceptance. Waferboard, for instance, has been manufactured in Canada since 1961 (Annonymous, 1962). Domestic medium density fiberboard production began in 1966, and composite panels were available as early as 1956 (Ananymous, 1980b; Elmendorf, 1956). Changes in standards, processes, panel prices, and the wood situation are factors leading to greater diffusion of these products.

The newer panels primarily compete with existing wood-based panels. One indicator of the expected competitiveness of newer panels with existing panels is industry's capital expenditure commitments. New mills and modernization projects scheduled for completion in 1979 and announced specific projects requiring capital expenditures are listed in Table 34. These projects accounted for over one-quarter of the committed $1 billion (Anonymous, 1980a). Waferboard was the most mentioned type of new panel plant.

The diffusion rates of these newer products will strongly influence the potential diffusion of existing products, such as, particleboard and southern pine plywood. For example, waferboard is gaining acceptance rapidly in the Midwest. As a result, the southern pine plywood potential in that area may be reduced. On the other hand, waferboard and southern pine plywood may act in concert to reduce the market share of western softwood plywood. Since few quantitative data are available on waferboard, medium density fiberboard, and composite panels, a qualitative review is presented in the remainder of this section. The review will aid in assessing the potential success of these panels.

Waferboard or Structural Flakeboard

Waferboard or structural flakeboard characteristics can vary due to a number of factors. Some of the most important factors are: wood species flake geometry, flake quality, flake alignment, average density, density gradients, layer thicknesses, and resin content (Geimer and Price, 1978).

Experimental flakeboard panels have been made with lodgepole pine, loblolly pine, sweetgum, southern red oak, Douglas-fir, sweetbay, red maple, black tupelo, white ash, post oak, yellow-poplar, and mixed species. Board properties for these panels are reported in General Technical Report WO-5, "Structural Flakeboard from Forest Residues" (U. S. Department of Agriculture, Forest Service, 1978). In general,

Table 34. New mills and modernization projects scheduled for completion in 1979 and announced specific projects requiring capital expenditures.

Company	Location	Type of Plant	Completion
B.C. Forest Products, Ltd.	Grand Rapids, Minn.	Waferboard plant modernization	1980
Louisiana-Pacific Corp.	Bemidji, Minn.[1/]	Waferboard	1980
Northwood Mills, Ltd.	Bemidji, Minn.	Waferboard	Future
Potlatch Corp.	Bemidji, Minn.	Waferboard	1981
Potlatch Corp.	Cook, Minn.	Waferboard	1981
Louisiana-Pacific Corp.	Hayward, Wis.	Waferboard	1979
Georgia-Pacific Corp.	Woodland, Maine	Waferboard	1981
Edward Hines Lumber Co.	Ontario	Waterboard	Future
Florex, Ltd.	Val d'Or, Quebec	Waferboard	1980
Normick Perron, Ltd.	La Sarre, Quebec	Waferboard	1980
Northwood Mills, Ltd.	Chatham, N.B	Waferboard plant modernization	1979
Edward Hines Lumber Co.	South Dakota	Waferboard	Future

Table 34 (cont'd.)

Weldwood of Canada, Ltd.	Slave Lake, Alta.	Waferboard plant Modernization	Future
Elmendorft Board Corp.	Claremont, N.H.	Oriented strand board	1981
Georgia-Pacific Corp.	Dudley, N.C.	Flakeboard, compositve panel	1980
Ellingson Timber Co.	Baker, Ore.	Composite panel	1979
Plyboard Corp.	Brownsville, Ore.	Composite panel	1979

1/ Looking for alternative location.

Source: Anonymous, 1980a.

a variety of species can be utilized to create boards with acceptable stiffness and strength for various end-uses.

In order to gain wide acceptance and to facilitate diffusion, code approval is needed. Canadian waferboard for sheathing was first approved by the New Jersey State Building Code in 1972. Subsequently, Canadian boards were approved by the Building Officials and Code Administrators International Conference of Building Officials (Jorgensen, 1978). Roof sheathing and wall sheathing are approved uses.

The American Plywood Association has begun to promote end-use or performance-rated standards. The new standards do not require particular types of wood materials to be used in the panels. Instead, they specify performance characteristics. For example, sheathing can be conventional veneered plywood, composite panels, or unveneered panels such as structural particleboard, waferboard, and oriented strand board, so long as the performance standards are met (Lambert, 1980). As a result, waferboard and other newer panels will penetrate the market more readily.

Waferboard production began in 1961. The first product was produced by Wizewood, Ltd. at Hudson Bay, Saskatchewan and was sold under the trade name of "Aspenite." The process used in the first plant was developed by Dr. James d'A. Clark to utilize green poplar logs in the production of a weatherproof phenolic-binded board (Anonymous, 1962).

Though waferboard production started in the early 1960's, construction on a second waferboard plant did not begin until 1969, and the first United States plant did not come on-line until 1973. By the end of 1980, eleven plants in Canada and the United States with

1.25 billion square feet of capacity (3/8-inch basis) were expected to be operating (Pease, 1980). As indicated in Table 34, continued expansion of waferboard capacity is planned.

The unique aspect of the waferboard manufacturing process is thick, manufactured wafers are used rather than traditional wood materials found in particleboard or hardboard. Since the wafers are large in size, less resin is required in the manufacturing process. In the case of structural flakeboard, the flakes are thinner than wafers, but no specific delineation exists (Dickerhoof and Marcin, 1978).

Several existing means for manufacturing wafers and flakes hold promise for the future. These include the spiralhead clipper, the shaping-lathe headrig, disk flakers, drum flakers, and ring flakers (Arola, 1978; Koch, 1978; Price and Lehmann, 1978). The best method for flaking will be dependent on the species and wood form (e.g., roundwood, chips, etc.) used.

One flakeboard variant is oriented strand board. Mechanical orientation of strands yields improved flexural strength in the aligned direction. Several existing waferboard plants have the capacity to orient wafers. The Elmendorf Board Corporation plant in Claremont, New Hampshire, will be the first plant constructed in the United States solely for the production of oriented strand board (Anonymous, 1979b).

Regardless of whether the panel is structural flakeboard, waferboard or oriented strand board, delivered price to major market areas will play a critical role in the diffusion of these products. In eastern Canada, waferboard's delivered cost advantage over softwood plywood produced primarily in British Columbia is an important factor in its market success (Dickerhoof and Marcin, 1978). The regional advantage is only partially offset by the greater shipping weight of waferboard.

Feasibility studies indicate that flakeboard production sites in the Eastern and Southern United States have the greatest potential for competing with softwood plywood. Higher plywood prices in the eastern markets, lower freight costs for flakeboard from the East and South, and lower labor and raw material costs are cited as factors contributing to this potential (Adams, 1978). The locations of existing and announced plants in Table 31 corroborate the eastern advantage.

Aspen is the primary wood species used by existing waferboard manufacturers. Aspen has been a little utilized species in the past, but competition for resources is increasing. In fact, one potential manufacturer decided to look for a new plant site after a competitor announced plans for construction in the same timbershed (Lambert, 1981).

There are, however, significant volumes of aspen in the East, especially in the Lake States. From 1970 to 1977, aspen and cottonwood growing stock on commercial timberlands in Lake States increased from 9.0 to 9.3 billion cubic feet (U.S. Department of Agriculture, Forest Service, 1974; U.S. Department of Agriculture, Forest Service, 1979). Aspen and cottonwood accounted for a greater percentage of Lake States' growing stock volume than any other species, hardwood or softwood. By considering other species for which experimental boards were tested, the potential wood resources for structural flakeboard can be expanded significantly.

The outlook for waferboard is promising despite current economic conditions. For instance, a Lake States' waferboard plant that started production in late 1979 is now producing panels on a seven day, 24 hour per day schedule even though most panel plants in the United States are operating well below capacity (Pease, 1981). Desired board characteristics, code acceptance, delivered price advantage, and large volumes of potential wood inputs will contribute to waferboard's rapid diffusion. Lack of consistent consumption data precludes quantitative estimates of waferboard's potential.

Medium Density Fiberboard

The second panel product currently gaining acceptance in the market is medium density fiberboard. In the United States, two types of medium density fiberboard are manufactured: one type is for exterior siding and the other is for interior applications, especially furniture (Food and Agriculture Organization of the United Nations, 1976). The panels are composed of compressed interfelted fibers, binders, and other material added to improve board properties.

For exterior siding, the boards are finished and coated for durability. Due to board surface properties, a high quality finish is obtained. Competing products include plywood, aluminum, and other hardboard siding. Dry, wet, and wet-dry processes can be used to manufacture this board (Food and Agriculture Organization of the United Nations, 1976).

In furniture applications, medium density fiberboard has a very smooth surface for finishing and good edge properties. The surface has less tendency for showthrough than particleboard, and the edge properties allow finishing without edge banding (Maloney, 1977). Particleboard is the primary competing product in this end-use. Dry processing with supplemental high radio frequency heating is a common means for manufacturing the furniture board (Food and Agriculture Organization of the United Nations, 1976). Numerous rocessing improvements have occurred in machining, sanding, laminating, embossing, and finishing medium density fiberboard (Anonymous, 1980e).

NPA 4-73 "Standard for Medium Density Fiberboard," is the standard promulgated by the National Particleboard Association for this product. In addition, medium density fiberboard is included in the industrialite class of Voluntary Product Standard PS 58-73, "Basic Hardboard" and in PS 60-73, "Hardboard Siding." Physical property requirements such as modulus of rupture, thickness tolerances, and screw holding ability are included in the standards (Maloney, 1977).

As mentioned previously, the first medium density fiberboard plant began production in 1966 and was located in Deposit, New York. Between 1969 and 1976, ten plants began production (Anonymous, 1980b). Thirteen plants were in operation by the end of 1979 in the United States (Lambert, 1980). Production figures for the 1975 through 1979 period are presented in Table 35. Market share increased from 0.75 percent to 1.3 percent during that period. Though the diffusion process has begun, too few data are available for a quantitative estimate of medium density fiberboard's potential.

Both hardwoods and softwoods are used in medium density fiberboard production. Ponderosa pine, southern pine, Douglas fir, and mixed hardwoods are used as furnish. Pulp chips, which are later fiberized, are the preferred form of raw material (Lehmann and Wahlgren, 1978). Therefore, producers must compete with the pulp and paper, particleboard, insulation board and hardboard industries for supplies.

Medium density fiberboard is more expensive than particleboard

Table 35. Medium density fiberboard production, 1975-1979 (in millions of square feet, 3/4-inch basis).

Year	Domestic production
1975	215
1976	280
1977	441
1978	480
1979	490

Source: Lambert, 1981.

on a comparable per unit basis. However, some furniture manufacturers are finding that it is very competitive in end-use cost. This is due to processing advantages such as machining, finishing, and shaping (Anonymous, 1980e). Computerized financial analysis is one tool being used to estimate end-use cost. As computer analysis increases, medium density fiberboard diffusion is expected to increase.

The outlook for this product is good in siding and furniture applications. Substitution for particleboard in furniture manufacture is the most promising market. Though there have been no new plants opened in the last few years, an economic recovery may lead to the construction of new plants and an erosion of particleboard's market share. Excellent panel characteristics, standardization, and a competitive end-use price are factors that will have a positive effect on medium density fiberboard's diffusion.

Composite Panels

Composite panels were made as early as 1955; hardwood veneer faces and a resin-impregnated, softwood fiber core were used (Elmendorf, 1956). However, little interest was shown in composite panels until recently. With rising wood costs, products utilizing more low cost wood and retaining a high quality appearance are becoming desirable. Composite panels, which have particleboard or oriented strand board cores and veneer faces, fit these requirements.

The composition core and veneer faces make composite panels slightly stiffer than plywood. The solid cores also reduce moisture penetration and subsequent cracking of plys receiving exterior exposure (Blackman, 1980). Manufacturing processes vary by producer; the components can be layed up separately or in the same process.

Composite panels meet the standards promulgated by the American Plywood Association for sheathing and flooring applications. Code acceptance has also been gained for some panels (McSwain, 1977). In those end-uses, the panels compete primarily with conventional plywood. Though price and production data are unavailable at this time, it is expected that the panel will be competitively priced. The use of low cost wood in the composite core is a major factor aiding this panel's ability to compete.

By making composite panels, manufacturers are able to utilize the entire veneer log in one product. As a result, increased yields from a given supply of logs are possible. Lehmann and Wahlgren (1978) estimated that a 40 percent yield increase from a veneer log supply is possible. By using small logs and culls for the composite panel, one manufacturer estimated that composite panel output would be twice the plywood output for a given volume of logs (Bryan, 1981). Either oriented strand board or particleboard can be used as the core panel (Blackman, 1980; Lehmann and Wahlgren, 1978). Therefore, composite panels offer flexibility with regard to core materials and stretch existing veneer supplies.

The first modern composite plant started production in 1975 and produced panels with softwood veneers and oriented strand cores (Anonymous, 1975). The same plant closed in 1979 due to environmental control costs and poor market conditions (Lambert, 1981). Two additional plants began production in 1979 and 1980. In addition, the U.S. Forest Service and the U.S. Department of Housing and Urban Development cooperated in a research and development program for composite panels in the mid-1970's (McSwain, 1977).

The outlook for composite panels is excellent. By early 1981, nine plants in the United States, including those listed in Table 31, indicated they were producing composite panels. Given the economic climate, this increase in capacity is quite remarkable. Code acceptance, resource utilization, and similarities to conventional plywood are factors that will promote the diffusion of composite panels.

Other Factors Influencing Panel Diffusion

Though a multitude of factors other than those discussed in preceding chapters and sections may influence product diffusion, only five have been selected for brief discussion in this section. The five factors are: (1) formaldehyde emission, (2) market conditions, (3) U.S. Forest Service policies, (4) research and development, and (5) nonwood product competition. Other influencing factors such as antitrust laws, patents, capital availability, and internal company policies are beyond the scope of this study.

Formaldehyde emissions during the production and use of panels, notably particleboard, have been acknowledged for some time. The specific effects of long-term exposure are not known with certainty, but some individuals are affected by the emissions. If regulations are mandated that limit allowable emissions, particleboard diffusion could be adversely affected. Publicity regarding formaldehyde release may have a similar impact on diffusion (Lambert, 1981). Foam insulation, however, may be affected to a greater extent due to its formaldehyde content. Adhesives product innovations, e.g., isocyanate-based binders, provide one means of overcoming diffusion barriers due to emissions problems (Ball, Redman, and Adams, 1979).

A second factor that may influence product diffusion is poor market conditions (Cox, 1974 and Dickerhoof, 1977). Plant managers may be unwilling to try unproven products during periods when economic activity in end-use markets is low. However, if the new product has been successful as was the case with southern pine plywood and waferboard, diffusion proceeds. In essence, the new products may gain in market share despite the poor performance of the entire wood-based panel sector.

U.S. Forest Service policies influence product innovation and diffusion through research activities and harvesting practices. Process and product research performed or funded by the U.S. Forest Service may lead to new processes, new products, or the dissemination of information (Fassnacht, 1964; Lehmann and Walhgren, 1978; U.S. Department of Agriculture, Forest Service, 1978). A less discussed impact on product diffusion may result from harvesting policies. If harvesting is restricted in a manner that increases final product cost, the diffusion of competing products is enhanced, ceteris paribus. Unfortunately, forest industry generally views harvesting policies (e.g., the allowable cut) as factors constraining their growth locally rather than promoting their growth nationally (Lambert, 1981).

Research and development is cited as another factor affecting innovation and diffusion (Cox, 1974). Research and development expenditures in the forest products industries are traditionally below those in other manufacturing industries (Risbrudt, 1979). No research and development expenditure data specific to the particleboard, southern pine plywood, and other new panel product industries is available, but it is likely that expenditure levels relative to other manufacturing industries are low. Research and development activities by government, universities, the equipment manufacturing industry, and the adhesives industry may help offset these low expenditure levels and mitigate any adverse effects on the diffusion process.

A final factor affecting product innovation, diffusion, and consumption is competition from non-wood products (Zivnuska, 1963). The prices of most competing materials have increased little relative to all goods since 1967 (U.S. Department of Agriculture, Forest Service, 1979). With the exception of western softwood plywood, most panel products have declined in relative price over the same period. Therefore, from a price standpoint, wood-based panels may be improving their position relative to competing materials. However, the substitution of other products for wood-based panels (see Table 36) will continue to be a major factor limiting the size of the panel market and the diffusion of panels within the industry.

Table 36. Examples of products substituting for wood-based panels in various end-uses.

End-use	Substitute material
Floors and foundations	Concrete, boards
Roof sheathing	Boards in single-family roof decks; concrete and metal in multifamily roof decks
Siding	Brick, aluminum, stucco, boards, steel, plastic
Wall sheathing	Plastic foam, foil-faced paperboard, gypsum products
Furniture	Plastics

Source: Anderson, 1980; Anonymous, 1979a.

APPENDIX

DATA USED IN ECONOMETRIC AND DIFFUSION MODELS

Table A1. U.S. particleboard production, imports, exports, and apparent consumption, 1955-1979 (in millions of square feet, 3/4-inch basis)[1/].

Year	Domestic production	Imports	Exports	Apparent consumption[2/]
1955	70			70
1956	111			111
1957	183			183
1958	250			250
1959	296			296
1960	268			268
1961	326			326
1962	408			408
1963	496	1		498
1964	638	2		640
1965	803	4		807
1966	997	1		998
1967	1,115	1	2	1,114

Table A1 (cont'd.)

1968	1,425	1	6	1,420
1969	1,716	12	14	1,714
1970	1,764	3	10	1,757
1971	2,394	8	20	2,382
1972	3,117	14	45	3,086
1973	3,494	17	77	3,434
1974	3,104	7	112	2,999
1975	2,539	17	84	2,472
1976	3,202	51 [3/]	96	3,157
1977	3,592	130 [3/]	75	3,647
1978	3,610	150 [3/]	16 [4/]	3,744
1979	3,501	186 [3/]	100	3,587

1/ Does not include medium density fiberboard and Mende process board.

2/ Apparent consumption = domestic production + imports - exports.

3/ Estimated from import data reported by weight.

4/ Under review by the Bureau of the Census.

Table A1 (cont'd.)

Sources: Lambert, 1980; Phelps, 1977; U.S. Department of Commerce, Bureau of the Census, selected years (c); U.S. Department of Commerce, Bureau of the Census, selected years (d); U.S. Department of Commerce, Bureau of Industrial Economics, 1980; Wright and Phelps, 1967.

Table A2. U.S. hardboard production, imports, exports, and apparent consumption, 1955-1979 (in millions of square feet, 1/8-inch basis).

Year	Domestic production	Imports[1/]	Exports[1/]	Apparent consumption[1/]
1955	1,470	152	17	1,605
1956	1,497	211	19	1,689
1957	1,556	197	19	1,734
1958	1,693	194	17	1,870
1959	2,021	322	17	2,326
1960	1,930	265	17	2,178
1961	2,154	282	17	2,419
1962	2,510	371	17	2,864
1963	2,709	455	23	3,141
1964	2,867	519	30	3,356
1965	2,917	589	35	3,471
1966	3,089	462	45	3,506
1967	3,002	455	42	3,415

Table A2 (cont'd.)

1968	3,693	625	52	4,266
1969	4,182	700	62	4,820
1970	4,340	463	77	4,726
1971	5,126	654	84	5,696
1972	5,671	1,098	101	6,668
1973	6,049	1,109	130	7,028
1974	5,845	775	175	6,445
1975	5,201	271	157	5,315
1976	6,125	491	189	6,427
1977	6,508	666	169	7,005
1978	7,810	1,175	93	8,892
1979	7,688	1,061	116	8,633

1/ Estimated using the annual million square feet to tons rate from McKeever (1979).
2/ Apparent consumption = domestic production + imports - exports.

Sources: McKeever, 1979; U.S. Department of Commerce, Bureau of Industrial Economics, 1980.

Table A3. U.S. insulation board production, imports, exports, and apparent consumption, 1955-1979 (in millions of square feet, 1/2-inch basis).

Year	Domestic production	Imports[1/]	Exports[1/]	Apparent consumption[2/]
1955	2,949	24	54	2,919
1956	2,973	30	59	2,944
1957	2,679	16	54	2,641
1958	2,884	25	38	2,871
1959	3,114	40	37	3,117
1960	2,848	31	36	2,843
1961	2,850	24	42	2,832
1962	2,885	40	43	2,882
1963	3,039	59	51	3,047
1964	3,262	62	51	3,273
1965	3,362	61	51	3,372
1966	3,079	64	48	3,095
1957	3,209	68	44	3,233

Table A3 (cont'd.)

1968	3,476	111	52	3,535
1969	3,623	91	64	3,650
1970	3,194	92	50	3,236
1971	3,839	93	66	3,866
1972	3,918	90	67	3,941
1973	3,914	86	78	3,922
1974	3,282	43	101	3,224
1975	2,856	31	76	2,811
1976	3,407	40	76	3,371
1977	3,331	50	80	3,301
1978	3,327	59	63	3,323
1979	3,168	49	49	3,168

1/ Estimated using the annual million square feet to tons ratio from McKeever (1979).

2/ Apparent consumption = domestic production + imports - exports.

Sources: McKeever, 1979; U.S. Department of Commerce, Bureau of Industrial Economics, 1980.

Table A4. U.S. hardwood plywood production, imports, exports, and apparent consumption, 1955-1979 (in millions of square feet, 3/8-inch basis).

Year	Domestic production	Imports	Exports	Apparent consumption[1/]
1955	1,355	442	2	1,795
1956	1,347	498	1	1,844
1957	1,177	597	1	1,773
1958	1,151	643	2	1,792
1959	1,346	938	3	2,281
1960	1,102	715	2	1,814
1961	1,305	727	3	2,028
1962	1,516	891	2	3,404
1963	1,683	935	1	2,617
1964	1,912	1,040	2	2,949
1965	2,049	1,047	6	3,090
1966	2,076	1,254	8	3,321
1967	1,916	1,244	8	3,152

Table A4 (cont'd.)

1968	2,009	1,886	14	3,882
1969	1,869	2,107	16	3,960
1970	1,796	2,047	58	3,784
1971	1,924	2,542	15	4,450
1972	2,030	3,156	26	5,159
1973	1,807	2,527	40	4,293
1974	1,401	1,644	68	2,977
1975	1,052	1,918	68	2,902
1976	1,083	2,356	79	3,360
1977	1,187	2,254	70	3,372
1978	1,173	2,492	30	3,634
1979	1,119	2,083	40	3,162

1/ Apparent consumption = domestic production + imports - exports.

Sources: U.S. Department of Agriculture, Forest Service, 1979; U.S. Department of Commerce, Bureau of the Census, selected years (c); U.S. Department of Commerce, Bureau of the Census, selected years (d); U.S. Department of Commerce, Bureau of Industrial Economics, 1980.

Table A5. U.S. softwood plywood production, imports, exports, and apparent consumption, 1955-1979 (in millions of square feet, 3/8-inch basis).

Year	Domestic production	Imports	Exports	Apparent consumption 1/
1955	5,284	2/	8	5,276
1956	5,432	-	15	5,418
1957	5,653	2/	15	5,639
1958	6,487	2/	12	6,475
1959	7,736	-	72	7,664
1960	7,759	11	13	7,757
1961	8,496	13	14	8,495
1962	9,315	13	17	9,311
1963	10,375	10	18	10,367
1964	11,455	5	28	11,431
1965	12,428	5	30	12,402
1966	12,849	3	48	12,804
1967	12,840	3	85	12,758

Table A5 (cont'd.)

1968	14,385	10	64	14,332
1969	13,538	15	199	13,354
1970	14,149	2	114	14,038
1971	16,353	3	99	16,258
1972	17,843	6	221	17,629
1973	17,929	9	411	17,527
1974	15,306	4	542	14,769
1975	15,706	7	791	14,922
1976	17,906	12	716	17,202
1977	18,877	18	287	18,608
1978	19,492	33	298	19,227
1979	18,588	18	402	18,204

1/ Apparent consumption = domestic production + imports - exports.

2/ Less than 500,000 square feet.

Sources: Phelps, 1977; U.S. Department of Commerce, Bureau of the Census, selected years (b); U.S. Department of Commerce, Bureau of the Census, selected years (c); U.S. Department of Commerce, Bureau of the Census, selected years (d); U.S. Department of Commerce, Bureau of Industrial Economics, 1980.

Table A6. U.S. southern pine plywood and medium density fiberboard production, 1964-1979 (in millions of square feet).

Year	Southern pine plywood production (3/8-inch basis)	Medium density fiberboard production (3/4-inch basis)
1964	80	
1965	402	
1966	1,140	
1967	1,779	
1968	2,373	
1969	2,875	
1970	3,315	
1971	4,410	
1972	5,319	
1973	5,560	
1974	5,130	
1975	5,676	215
1976	6,814	280

Table A6 (cont'd.)

1977	7,447	441
1978	7,898	480
1979	7,650	490

Sources: Anderson, 1979; Lambert, 1981.

Table A7. Total panel consumption and market share of consumption for western softwood plywood, southern pine plywood, and particleboard, 1955-1979 (in percent, decimal form).

Year	Total panel consumption1/	Market share3/		
		Western softwood plywood3/	Southern pine plywood4/	Particleboard5/
1955	11,665	.4523		.0060
1956	12,006	.4513		.0092
1957	11,970	.4711		.0153
1958	13,258	.4884		.0189
1959	15,684	.4887		.0189
1960	14,856	.5221		.0178
1961	16,100	.5276		.0202
1962	17,869	.5211		.0228
1963	19,670	.5270		.0253
1964	21,649	.5243	.0040	.0296
1965	23,142	.5185	.0171	.0349
1966	23,723	.4917	.0481	.0420
1967	23,672	.4638	.0751	.0471

Table A7 (cont'd.)

1968	27,435	.4359	.0865	.0518
1969	27,498	.3811	.1046	.0623
1970	27,541	.3893	.1204	.0638
1971	32,652	.3629	.1351	.0730
1972	36,483	.3374	.1458	.0846
1973	36,204	.3305	.1536	.0949
1974	30,414	.3169	.1687	.0986
1975	28,637	.3229	.1982	.0863
1976	33,797	.3074	.2016	.0934
1977	36,374	.3068	.2047	.1003
1978	39,300	.2883	.2010	.0953
1979	37,244	.2834	.2054	.0963

1/ In millions of square feet, standard measure; the sumation of particleboard, hardboard, insulation board, hardwood plywood and softwood plywood apparent consumption plus medium density fiberboard production.

2/ In percent, decimal form.

3/ Western softwood plywood market share = (softwood plywood apparent consumption - southern pine

Table A7 (cont'd.)

plywood production) ÷ total panel consumption.

[4/] Southern pine plywood market share = southern pine plywood production ÷ total panel consumption.

[5/] Particleboard market share = particleboard apparent consumption ÷ total panel consumption.

Sources: Tables A1-A6.

Table A8. Market share of consumption for hardwood plywood, hardboard, insulation board, and medium density fiberboard, 1955-1979 (in percent, decimal form).

Year	Market share			
	Hardwood plywood[1/]	Hardboard[2/]	Insulation board[3/]	Medium Density fiberboard[4/]
1955	.1539	.1376	.2502	
1956	.1536	.1407	.2452	
1957	.1481	.1449	.2206	
1958	.1352	.1410	.2165	
1959	.1454	.1483	.1987	
1960	.1221	.1466	.1914	
1961	.1260	.1502	.1759	
1962	.1345	.1603	.1613	
1963	.1330	.1597	.1549	
1964	.1362	.1550	.1512	
1965	.1335	.1478	.1457	
1966	.1400	.1443	.1305	

Table A8 (cont'd.)

1967	.1332	.1443	.1366	
1968	.1415	.1555	.1289	
1969	.1440	.1753	.1327	
1970	.1374	.1716	.1175	
1971	.1363	.1744	.1184	
1972	.1414	.1828	.1080	
1973	.1186	.1941	.1083	
1974	.0979	.2119	.1060	
1975	.1013	.1856	.0982	.0075
1976	.0994	.1902	.0997	.0083
1977	.0927	.1926	.0908	.0121
1978	.0925	.2263	.0846	.0122
1979	.0849	.2318	.0851	.0132

1/ Hardwood plywood market share = hardwood plywood apparent consumption ÷ total panel consumption.

2/ Hardboard market share = hardboard apparent consumption ÷ total panel consumption.

3/ Insulation board market share = insulation board apparent consumption ÷ total panel consumption.

Table A8 (cont'd.)

4/ Medium density fiberboard market share = medium density fiberboard production ÷ total panel consumption.

Sources: Tables A1-A7.

Table A9. Lagged southern pine plywood and particleboard market share data, 1956-1979 (in percent, decimal form).

Year	Lagged market share[1/]	
	Southern pine plywood	Particleboard
1956		.0060
1957		.0092
1958		.0153
1959		.0189
1960		.0189
1961		.0178
1962		.0202
1963		.0228
1964	.0000	.0253
1965	.0040	.0296
1966	.0171	.0349
1967	.0481	.0420
1968	.0751	.0471

Table A9 (cont'd.)

1969	.0865	.0518
1970	.1046	.0623
1971	.1204	.0638
1972	.1351	.0730
1973	.1458	.0846
1974	.1536	.0949
1975	.1687	.0986
1976	.1982	.0863
1977	.2016	.0934
1978	.2047	.1003
1979	.2054	.0953

[1] 1956 lagged market share = 1955 market share, 1957 lagged = 1956, etc.

Source: Table A7.

Table A10. U.S. disposable personal income, number of North American plywood plants, and number of southern pine plywood plants, 1955-1979.

Year	U.S. disposable personal income[1/]	Number of North American particleboard plants	Number of southern pine plywood plants
1955	425.9	23	
1956	444.9	32	
1957	453.9	36	
1958	459.0	43	
1959	477.4	49	
1960	487.3	51	
1961	500.6	53	
1962	521.6	53	
1963	539.2	51	
1964	577.3	50	3
1965	612.4	52	12
1966	643.6	58	23
1967	669.8	56	28

Table A10 (cont'd.)

1968	695.2	54	33
1969	712.3	57	34
1970	741.6	64	40
1971	769.0	64	49
1972	801.3	70	52
1973	854.7	72	53
1974	842.0	72	55
1975	859.7	72	57
1976	891.8	75	57
1977	929.5	81	59
1978	972.5	72	61
1979	994.8	72	72

[1/] In billions of 1972 dollars.

Sources: Anderson, 1979; Anonymous, 1957b; Lambert, 1980; U.S. Department of Agriculture, Forest Service, 1979; U.S. Department of Commerce, Bureau of the Census, selected years (a); U.S. Department of Commerce, Bureau of Industrial Economics, 1980; Wright and Phelps, 1967.

Table A11. Producer price indexes for all commodities, particleboard, hardboard, and insulation board, 1967-1979 (1967 = 100).

Year	All commodities	Particleboard[1/]	Hardboard[1/]	Insulation board[1/]
1967	100.0	100.0	100.0	100.0
1968	102.5	98.9	95.9	100.5
1969	106.5	105.3	93.7	102.2
1970	110.4	65.4	92.6	100.1
1971	114.0	62.9	88.7	100.4
1972	119.1	62.8	85.8	99.9
1973	134.7	68.5	78.1	90.3
1974	160.1	55.0	73.7	83.6
1975	174.9	46.4	67.3	82.3
1976	183.0	54.8	71.8	88.0
1977	194.2	54.7	73.5	91.6
1978	209.3	68.5	75.0	96.8
1979	235.5	52.0	69.9	85.1

Table All (cont'd.)

[1/]Producer price index deflated by producer price index for all commodities. Logarithm used in some regressions.

Sources: Phelps, 1977; U.S. Department of Labor, Bureau of Labor Statistics, selected years.

Table A12. Producer price indexes for softwood plywood, western softwood plywood, southern pine plywood[1/], hardwood plywood, and weighted particleboard substitutes[2/], 1967-1979 (1967 = 100).

Year	Softwood plywood[2/]	Western softwood plywood[2/]	Southern pine plywood[1/]	Hardwood plywood[2/]	Weighted particleboard substitutes[2/3/]
1967	100.0	100.0	-	100.0	100.0
1968	126.0	126.0	-	98.0	113.5
1969	130.7	107.3	100.0	97.6	114.7
1970	102.9	102.5	81.1	92.8	99.2
1971	111.4	110.8	89.8	88.3	102.3
1972	130.1	129.4	102.8	87.6	111.1
1973	144.0	145.0	105.1	83.7	115.6
1974	116.7	117.6	84.0	81.3	98.8
1975	114.7	116.0	80.4	68.3	96.3
1976	135.3	133.8	101.0	66.9	109.0
1977	152.3	149.6	116.0	65.8	120.0
1978	155.9	154.8	115.2	67.0	120.6

Table A13. (cont'd.)

1979	137.1	139.3	94.0	71.8	108.4

1/ 1969 = 100

2/ Producer price index deflated by producer price index for all commodities. Logarithm used in some regressions.

3/ Hardboard, insulation board, softwood plywood and hardwood plywood producer price indexes weighted by market shares.

Sources: Phelps, 1977; U.S. Department of Labor, Bureau of Labor Statistics, selected years.

Table A13. Data used[1/] in supply equations, 1967-1979.

Year	Adhesives and plastic resins price index[2/]	Fuels and related products price index[2/]	Wages[3/]	Lumber production[4/]	Southern pine sawlog stumpage price[5/]	plywood mill productivity[6/]
1967	100.0	100.0	2.37	34.7	-	63.5
1968	89.7	96.5	2.51	36.5	-	71.9
1969	84.9	94.9	2.57	35.8	51.70	84.6
1970	82.1	95.9	2.68	34.7	42.53	82.9
1971	78.0	100.2	2.76	37.0	48.79	98.0
1972	74.5	99.6	2.78	37.7	58.68	102.3
1973	68.4	99.7	2.70	38.6	73.83	104.9
1974	89.8	130.1	2.44	34.6	50.70	93.3
1975	103.4	140.1	2.45	32.6	34.71	99.6
1976	106.0	145.1	2.58	36.3	50.64	119.5
1977	101.7	155.6	2.62	37.9	55.02	126.2
1978	95.5	154.1	2.68	38.2	68.45	129.5

Table A13 (cont'd.)

1979	100.2	173.3	2.58	36.0	51.36	106.3

1/ Other than price and quantity data.

2/ Deflated with the producer price index for all commodities (1967 = 100).

3/ Hourly earnings for lumber and wood products workers deflated by the producer price index for all commodities, 1967 = 100.

4/ In billions of board feet.

5/ In dollars. Southern pine sawtimber stumpage prices from National Forests deflated by the producer price index for all commodities, 1969 = 100.

6/ Southern pine plywood production divided by the number of southern pine plywood plants.

Sources: Tables A6 and A14; Phelps, 1977; U.S. Department of Agriculture, Forest Service, 1979; U.S. Department of Commerce, Bureau of Industrial Economics, 1980; U.S. Department of Labor, Bureau of Labor Statistics, selected years.

Table A14. U.S. housing data used in demand equations, 1964-1979 (in thousands of units).

Year	Housing starts, 1&2 units[1/]	Housing starts, 3+ units[2/]	Total dwelling starts[3/]
1964	1056	505	1561
1965	1052	458	1510
1966	738	352	1196
1967	916	406	1322
1968	983	562	1545
1969	887	613	1500
1970	891	578	1469
1971	1239	846	2085
1972	1399	980	2379
1973	1199	859	2058
1974	936	417	1353
1975	937	234	1171
1976	1217	331	1548
1977	1515	475	1990

Table A14 (cont'd.)

1978	1498	525	2023
1979	1254	495	1749

1/ Total dwelling starts minus housing starts, 3+ units.

2/ Private only.

3/ Private and public.

Table A15. Data on value of construction in the United States, 1967-1979 (in millions of 1972 dollars)[1/].

Year	Value of residential construction[2/]	Value of residential additions and alterations	Value of private nonresidential buildings	Value of public buildings	Department of Commerce Composite Index
1967	26,222.4	7,343.9	24,294.2	13,787.3	72.4
1968	31,576.9	6,960.6	23,868.6	13,717.5	76.1
1969	31,367.6	7,112.5	25,580.4	13,579.2	82.7
1970	27,395.0	7,036.1	24,172.7	12,028.2	88.6
1971	36,989.5	7,180.4	23,712.0	12,022.2	94.8
1972	44,834.2	7,412.6	24,012.0	11,488.5	100.1
1973	46,078.2	6,692.7	25,376.3	11,918.1	108.7
1974	32.029.2	6,340.4	23,360.1	11,814.8	126.9
1975	24,861.3	7,893.8	19.080.2	11,180.6	138.4
1976	32,854.1	8,553.2	18,131.3	9,561.5	143.9
1977	42,065.9	9,090.9	18,358.9	8,188.7	156.3
1978	43,146.3	9,305.1	20,656.2	8,674.5	125.7
1979	39,372.2	9,136.3	23,696.4	7,944.4	199.6

Table A15 (cont'd.)

[1]/Current dollars divided by Department of Commerce Composite Index and multiplied by 100.

[2]/New houses only, value put in place.

Sources: U.S. Department of Commerce, Bureau of the Census, selected years (f).

Table A16. Other data used and tested for use in particleboard and southern pine plywood demand equations, 1955-1979.

Year	Index of furniture and fixtures manufacturing 1/	Index of all manufacturing 1/	Multifamily units as a percentage of all housing starts 2/	Mobile home shipments 3/
1955	66.2	58.2	8.0	110
1956	66.8	60.5	9.0	110
1957	65.0	61.2	13.0	111
1958	72.6	57.0	16.0	101
1959	71.8	64.2	15.7	121
1960	70.6	65.4	18.3	104
1961	77.6	65.6	23.5	90
1962	80.6	71.5	29.5	118
1963	85.9	75.8	34.2	151
1964	93.1	81.0	30.3	191
1965	101.0	89.7	29.4	217
1966	100.0	97.9	30.7	217

Table A16 (cont'd.)

1967	100.0	100.0	30.7	240
1968	105.4	106.4	36.4	318
1969	107.4	111.0	40.9	413
1970	108.1	106.4	39.3	401
1971	116.0	108.2	40.6	497
1972	130.6	118.9	41.2	576
1973	143.7	129.8	41.7	567
1974	137.6	129.4	30.8	329
1975	118.2	116.3	20.0	213
1976	132.7	130.3	21.4	246
1977	145.0	138.4	23.9	277
1978	155.8	146.8	25.9	276
1979	161.5	153.6	28.3	277

1/ 1967 = 100.

2/ Housing starts, 3+ units divided by total dwelling starts and multiplied by 100.

3/ In thousands of units

Table A16 (cont'd.)

Sources: Table A14; U.S. Department of Agriculture, Forest Service, 1979; U.S. Department of Commerce, Bureau of Economic Analysis, selected years; U.S. Department of Commerce, Bureau of Industrial Economics, 1980.

Table A17. Other data tested for use in particleboard and southern pine plywood supply equations, 1967-1979.

Year	Output per particleboard plant[1/]	Softwood plywood production[2/]	Railroad freight revenue per ton-mile[3/]	Plywood mill wages[4/]
1967	19.9	12,840	1.283	-
1968	25.3	14,385	1.325	-
1969	30.1	13,538	1.362	2.87
1970	27.5	14,149	1.443	2.99
1971	37.2	16,353	1.608	3.11
1972	44.1	17,843	1.634	3.47
1973	47.7	17,929	1.632	3.38
1974	41.7	15,306	1.876	3.05
1975	34.3	15,706	2.060	3.08
1976	42.1	17,906	2.118	3.31
1977	45.0	18,877	2.192	3.42
1978	52.0	19,492	2.328	3.55

Table A17 (cont'd.)

1979	49.8	18,588	2.575	3.40

1/ Domestic production divided by number of plants.

2/ In millions of square feet, 3/8-inch basis.

3/ In cents.

4/ In dollars. Softwood veneer and plywood production workers hourly earnings deflated by the wholesale price index for all commodities, 1969 = 100.

Sources: Tables A1, A5 and A10; U.S. Department of Commerce, Bureau of Industrial Economics, 1980.

Table A18. Demand data specific to the South, 1969-1979.

Year	One unit housing starts in the South[1/]	5+ unit dwelling starts in the South[1/]	One unit housing starts in the South as a percent of total U.S. one unit housing starts[2/]	Total U.S. one unit housing starts[1/]	Personal income in the South[3/]
1969	342	221	42.2	811	220.0
1970	377	207	46.4	813	229.0
1971	526	305	45.7	1151	238.9
1972	612	401	46.8	1309	258.5
1973	478	384	42.2	1132	277.1
1974	367	164	41.3	888	281.0
1975	366	60	41.0	892	285.8
1976	464	86	39.9	1162	303.7
1977	588	163	40.5	1451	319.3
1978	604	185	42.1	1433	339.6
1979	522	184	43.7	1194	353.5

Table A18 (cont'd.)

1/ In thousands of units.

2/ One unit housing starts in the South divided by total U.S. one unit housing starts and multiplied by 100.

3/ In billions of 1972 dollars. Deflated with the implicit price deflator for personal consumption expenditures, 1972 = 100.

Sources: U.S. Department of Commerce, Bureau of the Census, selected years (e); U.S. Department of Commerce, Bureau of Economic Analysis, selected years.

Table A19. Data used in spatial diffusion model, 1978.

Rand-McNally major trading area (MTA)	Southern pine plywood as a percent of all softwood plywood	Number of southern pine plywood plants in MTA and in adjacent states	Distance from Portland, OR in miles
Charlotte	84.9	11	2821
Atlanta/Chattanooga	85.3	19	2659
Houston	83.0	30	2233
Dallas/Ft. Worth	79.5	30	2043
Chicago	50.8	0	2112
Detroit/Toledo	58.7	0	2385
Memphis	86.7	27	2305
New Orleans	84.0	36	2541
Philadelphia	54.5	0	2872
Miami	82.0	11	3316
New York	35.0	0	2953
Richman/Norfolk	83.0	5	2906

Table A19 (cont'd.)

St. Louis	67.0	6	2096
Jacksonville	84.4	11	2968
Birmingham	82.6	21	2552
Washington/Baltimore	53.3	2	2797
San Antonio	81.7	30	2105
Cleveland	67.6	0	2453
Tampa/St. Petersburg	76.3	11	3084
Little Rock	78.7	36	2234
Portland	0.0	0	0
Los Angeles	0.0	0	970
San Francisco/Oakland	0.0	0	652
Seattle	0.0	0	175
Minneapolis/St. Paul	10.1	0	1690
Denver	7.5	0	1278
Salt Lake City	0.1	0	802
Boston	27.8	0	3085

Table A19 (cont'd.)

Milwaulkee	35.7	0	2026

Source: Anderson, 1979.

Table A20. Other data tested in the spatial diffusion model, 1978.

Rand-McNally major trading area (MTA)	Housing starts[1/] in 1978	Total 1978 plywood shipments, in millions of square feet, 3/8"-basis
Charlotte	5,054	692,572
Atlanta/Chattanooga	19,089	542,219
Houston	58,510	523,190
Dallas/Ft. Worth	27,229	541,873
Chicago	31,370	732,858
Detroit/Toledo	22,478	548,519
Memphis	4,609	365,450
New Orleans	7,496	357,521
Philadelphia	19,752	495,231
Miami	10,187	319,414
New York	7,099	719,795
Richarman/Norfolk	11,303	279,793
St. Louis	13,362	314,036

Table A20 (cont'd.)

Jacksonville	5,027	249,004
Brimingham	4,126	219,521
Washington/Baltimore	28,763	307,621
San Antonio	3,895	190,132
Cleveland	6,310	225,753
Tampa/St. Petersburg	19,243	190,839
Little Rock	1,515	181,506
Portland	14,797	1,169,879
Los Angeles	16,975	945,043
San Francisco/Oakland	13,336	851,866
Seattle	15,296	715,576
Minneapolis/St. Paul	18,059	434,957
Denver	21,043	423,390
Salt Lake City	11,538	397,662
Boston	3,922	342,093
Milwaulkee	5,525	329,665

Table A20 (cont'd.)

[1]/Building permits issued for 1,2,3 and 4 unit dwellings were used as a proxy for housing starts.

Sources: Anderson, 1979; U.S. Department of Commerce, Bureau of the Census, selected years (e).

Table A21. Projected high, medium, and low levels of U.S. disposable personal income, 1990 and 2000 (in billions of 1972 dollars).

Year	U.S. disposable personal income		
	High	Medium	Low
1990	1540	1450	1360
2000	2110	1880	1690

Source: U.S. Department of Agriculture, Forest Service, 1979.

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