ANTICIPATING THE MARKET FOR TECHNOLOGICAL INNOVATIONS IN THE HOME BUILDING INDUSTRY

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Abstract

This thesis attempts to establish an evaluation criteria for innovations in the home building industry by recognizing the definitive characteristics of successful innovations. This goal is realized through a study of both the structure of the home building industry and its social system and their interaction with the development, adoption and dissemination of innovation. As a result of this study, the criteria of the most importance to the success of an innovation in home building have been identified as: *Newness and Relative Advantage*, *Fit with Existing Facilities and Skills*, *Market Size and Expected Company Share*, *Market Positioning*, *Distributional Characteristics*, and the *Overall Profit Contribution*.

Thesis Supervisor: Professor Fred Moavenzadeh
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Introduction

The basic goal of this thesis is to establish an evaluation criteria for innovation in the home building industry by recognizing the characteristics of successful innovations. This goal will be realized through the study of the structure of both the home building industry and its social system and their interaction with the development, adoption and dissemination of innovation.

The American Dream is in danger. The cost of the home is increasing faster than household income, causing homeownership costs to skyrocket out of the reach of a new generation of adults. Does innovation in the technology of homebuilding hold answer to the future of the American Dream?

Material and labor costs currently account for approximately fifty percent of the cost of the home. This is the portion of the cost which can be reduced through the use of innovative products and practices in home building. Innovations are either major breakthroughs in technology or incremental in nature, and may affect either productivity and building costs, or the quality of the home. Most innovations within the home building industry have been incremental. The slow, stepwise creep of innovations into home building is the root of the popular misconception that there haven't been any innovations in the home building industry. One glance at the list of innovations in the appendix of this paper should serve to dispel this myth.

Chapter One is an introduction to the home building industry and the interaction of the individuals involved in the industry. A hiostorical perspective of the rising costs of home ownership and the home will be presented along with an understanding of the factors which have caused the increases in price. Also, the changing nature of the home, the consumer, and the home buiding industry will be presented.

Chapter 2 will begin dealing with the nature of innovation both conceptually and within the home building industry. This chapter will analyze the interaction of the different players within the home industry social structure and their individual influences on the development and acceptance of innovation in home building. The home is a product regulated by the *government*, produced by the *builder* for the *consumer*, with products made by the *manufacturer*. Chapter 2 also defines the characteristics of innovations and their relation to the home building industry and the social system.

Chapter 3 discusses the process of adoption and dissemination of innovation. The adoption process represents the steps taken by the builder or consumer in deciding whether or not to adopt an innovation. Different factors affect the different steps of this process. The dissemination of innovation is the communication and the rate of acceptance of innovations into the industry, which is influence by communication systems, change agents and other factors.

Chapter 4 develops an evaluation criteria for innovations in the home building industry. The criteria discussed will be broken down into product criteria, market criteria and finance criteria. In each of the three areas evaluated, their specific characteristics will be discussed with regard to the active participants in the social structure of the home building industry; the builder, the home owner and the manufacturer.

Chapter 5 presents five case studies on the development and dissemination of innovation; innovations in the energy efficiency of home appliances, low emmisivity window coatings technology, the development of vinyl siding, the acceptance of performance rated standards for structural wood panels, and the development and dissemination of wood foundation systems. Also, there will be a discussion of the application of the evaluation criteria developed in Chapter 4 as it applies to each case study.

In conclusion, Chapter 6 will catagorize the evaluation criteria presented in Chapter 4 into three rankings; characteristics which are necessary for the success of en innovation in home building, characteristics which would greatly improve an innovations chance for success, and those characteristics which are important but not crucial to the success of the innovation.

Chapter 1

Introduction to the Home Building Industry

A new generation of adults are today in danger of losing the American Dream. During the last fifteen years the housing crisis has taken root. For the first time "middle income families and first time buyers, who earlier were the majority of new home buyers, became the minority." [Comptroller 82] According to the U.S. department of Commerce, Bureau of the Census "Decenial Census of the U.S." from 1940 to 1980 there has been a steady increase in the percent of owner occupied dwellings from 43% to 65% (Figure B-1), but if current trends in home costs continue, this value will drop for the first time since World War II.

1.1 The Cost of the Home

What has happened to the dream? The skyrocketing increases in the cost of the average home have been brought about by many factors. From 1965 to 1984 alone the average home price increased from $21,500 to $97,000 (Table 1-I and Figures B-2,B-3) corresponding to a real increase of 51%. This is not a geographically isolated problem. By comparing the median home prices in the different regions of the United States, we can see that the phenomena of increasing home prices involves every area of the country (Table B-I and Figure B-4).

1.1.1 Homeownership Costs

To better illustrate how this increase in home prices impacts the American family, one can compare the average household income and the average cost of the home (Table 1-II). Although the ratio between the per capita disposable income (Figure B-5) and the average

AVERAGE AND MEDIAN COST
NEW PRIVATE HOME
IN CURRENT AND CONSTANT (1972) DOLLARS

YEAR	AVERAGE PRICE X$1000	MEDIAN PRICE X$1000	ADJUSTED AVE. PRICE X$1000 (1972=100)	ADJUSTED MEDIAN PRICE X$1000 (1972=100)
1963	19.3	18.0		
1965	21.5	20.0	28.9	26.6
1970	26.6	23.4	29.0	25.6
1971	28.3	25.2	29.5	26.2
1972	30.5	27.6	30.5	27.6
1973	35.5	32.5	33.5	30.7
1974	38.9	35.9	33.8	31.2
1975	42.6	39.3	33.9	31.2
1976	48.0	44.2	36.3	33.4
1977	54.2	48.8	36.3	33.4
1978	62.5	55.7	41.6	37.0
1979	71.8	62.9	43.9	38.5
1980	76.3	64.4	42.8	36.2
1981	83.0	68.9	42.4	35.2
1982	83.9	69.3	40.5	33.4
1983	89.8	75.3	41.2	35.0
1984	97.6	79.9	43.7	35.8
1985	100.8	84.3		

Source:

International Trade Administration, U.S. Department of Commerce, *Construction Review*, (monthly).

Note: Adjusted values calculated with 1972 GNP deflator as defined by the U.S. Bureau of Economic Analysis.

Table 1-I: Average and Median Cost of New Private Homes

COMPARISON OF HOUSEHOLD INCOME AND THE AVERAGE PRICE OF A NEW PRIVATE HOME 1965-1984

YEAR	AVERAGE SIZE DISP. INCOME (1)	AVE. HOUSEHOLD INCOME (2)	HOUSEHOLD INCOME / AVE. HOUSE COST (3)
1965	$8014.00	$21,500.00	.373
1970	10,600.00	26,600.00	.398
1975	14,920.00	42,600.00	.350
1978	18,605.00	62,500.00	.298
1979	20,380.00	71,800.00	.284
1980	22,168.00	76,300.00	.290
1982	25,527.00	83,900.00	.304
1983	27,237.00	89,800.00	.303
1984	29,504.00	97,600.00	.302

Sources:

(1) U.S. Bureau of the Census, 1970 and 1980 Census of the Population, Current Population Reports.

(2) Data calculated from per capita disposable income (Table B-II) and average size household values.

(3) See Table 1-I

Table 1-II: Ratio of Household Income and Home Prices

price of the home have remained stable over the last twenty years (Table B-II), the number of people per household in the United States has steadily declined from 3.29 in 1965 to 2.71 in 1984. This decline in occupants per has created a corresponding real decline in the income per household. Because of this decline in the number of people per household the price of the home has increase 24% faster than houshold income between 1970 and 1984. Household income is not keeping pace with the cost of the home, and the American Dream is slipping away.

1.1.2 Breakdown of Building Costs

There are several factors which contibute to the rising costs of housing. A comparison of the breakdown of various costs involved in building the home between 1970 and 1980 was done by Merril Lynch; Pierce, Fenner and Smith (Table 1-III). This comparison shows the two major contributors to the rising cost of the house to be increased land values and increases in the cost of financing a home. The cost of land has increased 141% more than the overall increases in the cost of the home, while financing costs have increased 216% times the overall increase in cost during the same period.

1.1.2.1 Finance Costs

The cost of financing the home is dependent on the interest rates available to the home buyer. Each percent increase in the interest rates has a multiplying affect on the overall cost of the home by increasing the compounded cost of borrowing money. Therefore, increases in interest rates increase the net effective cost of the home, automatically limiting the number of people who can qualify for loans to buy homes.

Mortgage rates, as defined by Federal Home Loan Board reached a peak in 1982 at 15.14%. These high interest rates have contributed to the marked disparity between homeownership costs of the home buyers and the existing home owners, because existing home owners bought their homes during periods of lower interest rates. In 1980, new home

APPROXIMATE COST BREAKDOWN FOR NEW SINGLE-FAMILY HOMES

	1970 COST	1970 PERCENT	1980 COST	1980 PERCENT	1970-80 PERCENT CHANGE
LAND	$4,450	19%	$15,500	24%	248.3%
LABOR	4,500	19	10,350	16	130.0
MATERIALS	8,650	37	22,000	34	154.3
FINANCING	1,600	7	7,700	12	381.3
OTHER	4,200	18	9,050	14	115.5
	--------	---	--------	----	----
TOTAL	$23,400	100%	$64,600	100%	176.1%

Source:

Merrill Lynch, Pierce, Fenner and Smith, "Housing Industry", a Merrill Lynch Basic Report, January 1982, p.28.

Note: "Labor" refers to on-site labor and "Other" refers to overhead, profits, etc..

Table 1-III: Cost Breakdown for New Single Family Homes

buyers spent 55% percent of their income on home ownership, as compared with the existing home owner who spent 20% of their income on the home (Figure B-6). "For most [existing] American home owners, the gigantic increase in home prices translated into an increase in their wealth" [President 82], because the value of their homes increased without a corresponding increase in costs.

On the other hand, even with increased home ownership costs, D.B. Diamond of the Journal of the American Real Estate and Urban Economics Association proposes that since the value of the home is increasing faster than other factors, that the net effective costs of home ownership have changed little in twenty years. The difference is that people pay larger bills in the present to gain larger capital gains in the sales of the home in the future. Diamond developed an index of the net effective costs of home ownership over time [Diamond 80]. This "Index of net effective costs is based on the sum of mortgage interest, property taxes, utilities, insurance, maintenance, and repair expenses, reduced by tax savings and expected capital gains, for a constant-quality (1974) house." (Figure 1-1)

During the last three years interest rates have been dropping and the corresponding finance costs have dropped as well (Table B-III). The relative importance of finance costs on the cost of the house may be diminishing at this point in time, but it is important to realize that the the decreases in finance costs have not arrested the continuing real increases in the price of the home.

1.1.2.2 Increase in Land Values

Increases in land values have also contributed to the increases in home prices. The relative increase in home land values versus home prices can be determined by comparing two different home price indicators. One is the square foot cost of the home including the value of the lot and the other is the square foot cost excluding the value of the lot (Table 1-IV). Since 1970, there has been an increase in the real value per square foot including the lot of 34% while the price per square foot of the home excluding the lot has increased 25%.

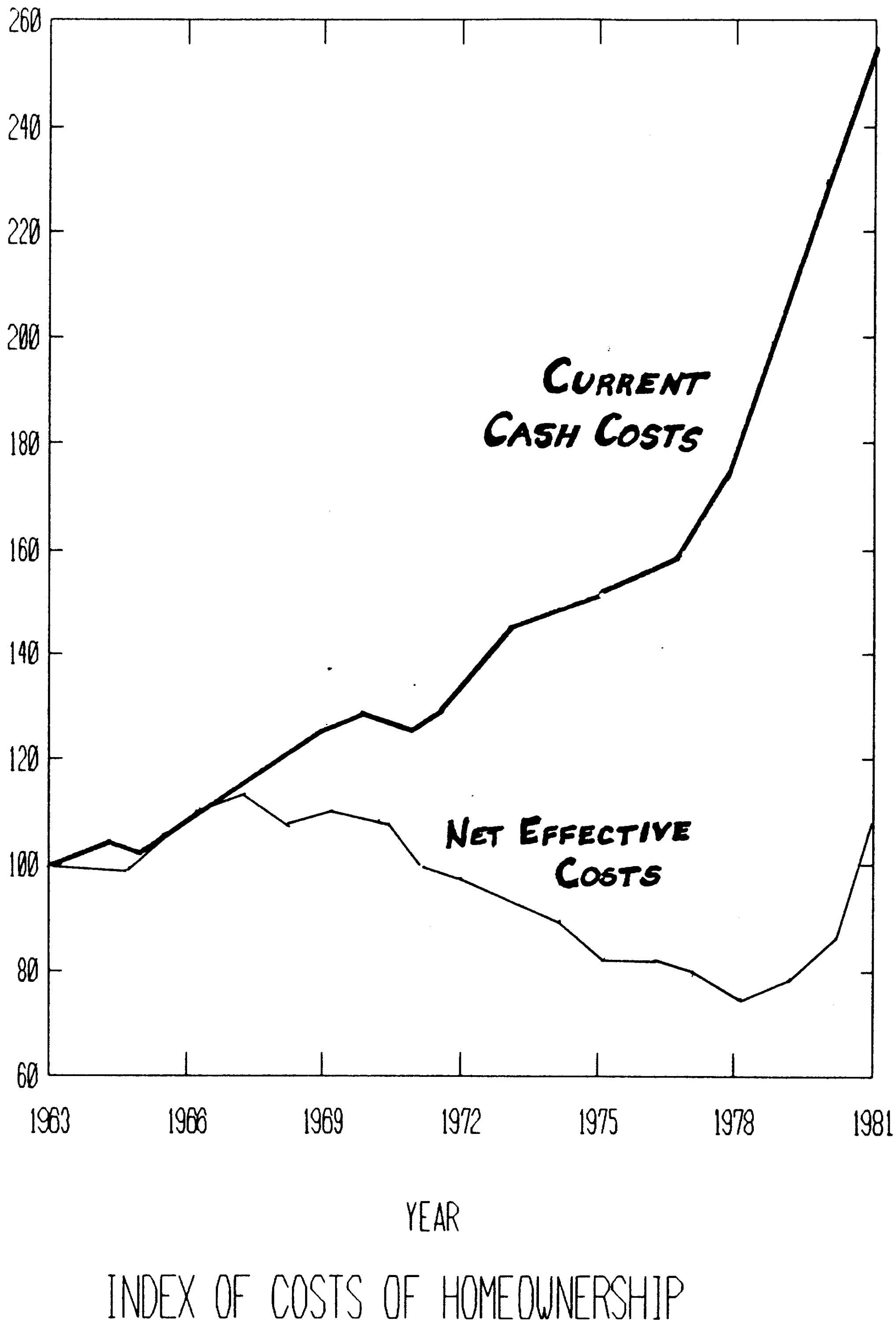

Figure 1-1: Indexes of Homeownership Costs

COMPARISON OF AVERAGE PRICE PER SQUARE FOOT RESIDENTIAL CONSTRUCTION WITH AND WITHOUT THE VALUE OF THE LOT INCLUDED IN CURRENT AND CONSTANT(1972) DOLLARS

YEAR	AVERAGE PR. W/O LOT PER SQ.FT. (1)	AVERAGE PR. W/ LOT PER SQ.FT. (2)	ADJUSTED PR. W/O LOT PER SQ.FT.	ADJUSTED PR. W/ LOT PER SQ.FT.
1965		$13.57		$18.23
1970	$14.00	17.73	$15.30	19.33
1974	19.00	22.94	16.52	19.94
1975	21.10	25.90	16.77	20.58
1976	22.70	28.24	17.16	21.34
1977	25.35	31.51	18.08	22.49
1978	28.50	35.61	18.95	23.68
1979	32.40	40.79	19.83	24.97
1980	35.20	44.88	19.73	25.16
1981	38.20	48.54	19.53	24.82
1982	39.75	49.64	19.17	23.94
1983	40.70	51.61	18.93	23.97
1984	42.90	54.53	19.20	24.41

Sources:

(1) U.S. Bureau of the Census, Construction Reports, *Characteristics of New One-Family Homes*, (yearly).

(2) Data calculated from average price of new homes, International Trade Administration, U.S. Department of Commerce, *Construction Review*, (monthly), and the average square footage of new homes, *Characteristics of New One-Family Homes.*

Note: Adjusted values calculated with 1972 GNP deflator as defined by the U.S. Bureau of Economic Analysis.

Table 1-IV: Comparison of Average Price per Square Foot of Home With and Without Value of Lot Included

Here, increased land values are responsible for one quarter of all increases in the cost of the home, representing a 9% real increase in the value of the home in fourteen years.

Exclusionary zoning is an issue which has encouraged rising land values. Exclusiionary zoning occurs when local administrative bodies restrict the development of land in their jurisdiction. These restrictions may be in the form of zoning ordinances or excessive land development fees. This practice is refered to as "exclusionary" because the people who are already living in a community are excluding others from joining. Also, in popular communities, exclusionary zoning creates a limited supply for a given demand for housing, increasing the value of the existing homes and the wealth of its citizens.

On the issues of excessive land development and municipal fees a Comptroller General's Report to the Congress in 1982 stated that:

> "Our 1978 report on housing affordability problems pointed out that in many communities housing costs have been increased by adoption of restrictive and expensive land development requirements. For example, of the 87 communites we contacted during this 1978 review, some had (1) specifications or standards for streets and related site improvements that in comparison to acceptable less costly alternative standards could increase the cost of the house by as much as $2,655, (2) requirements for 150 to 200 foot wide lots that further increase site improvement costs, and (3) expensive municipal fees as high as $3,265 a house for such items as local reviews, permits, inspections, and utility connections." [Comptroller 82]

1.1.3 Increase in the Value of the Home

A simplified explanation for increases in housing values involves the issues of supply and demand. "Shortage of land, materials and labor drove the price of housing higher and faster that the rise in the Consumer Price Index (CPI)" [President 82]. During a period of high inflation in the 1970's, land values began to skyrocket. In reaction, the individual's view of the home went through a transition during this same period. The home became much more than a place to live, it became a means of investing money that would protect the home owner from the devaluation of the dollar. As people's view of the value of land went up, the real value of land went up as well.

"Stimulated by the accelerating increase in home prices, consumers enormously increased their demand for single family houses, which were regarded as the best hedge inflation; the safest investment of family funds. ....A substantial portion of the increase in home ownership during the 1970's undoubtedly was attributed to speculative investment in housing caused by high inflation rates and the tax treatment of home ownership." [President 82]

1.2 The Home

1.2.1 Price Index of New Homes

The quality of the home is increasing. With each generation of Americans the American Dream has expanded. Statistics from the Bureau of the Census show that in 1940 almost half of American homes lacked some form of plumbing. By 1979 this figure dropped to close to 1% (Figure B-7). For the more recent past, a measure of the increase in the quality of the home sold over time is the "Price Index of Houses Sold in the United States". This index is developed from data obtained form the Census Bureau's Housing Sales Survey which was started in 1963.

"The price index is intended to measure changes over time in the sales price of new one-family houses which are the same with respect to ten important characteristics as the houses sold in the United States in 1977. The ten characteristics used are: floor area, number of stories, number of bathrooms, air-conditioning, type of parking facility, type of foundation, geographic division within region, metropolitan area location, presence of fireplace, and size of lot.... The ten characterisics account for approximately 64 percent of the variation in the selling price of new one-family houses." [Census 85]

By comparing the current average price per house to the 1977 equivalent house price, the difference in the quality of the home over time becomes clear (Table 1-V and Figure B-8). In 1963, a 1977 equivalent home would cost $4,100 more to build than the average house built in 1963. Similarly, there was a $4,300 increase in the quality of the average house sold in 1984 than in the 1977 equivalent home built with 1984 dollars.

PRICE INDEX OF HOUSES SOLD IN THE UNITED STATES: 1963-1984, 1977=100; AVERAGE PRICE OF HOMES AND CURRENT PRICE OF THE AVERAGE 1977 HOME

YEAR	PRICE INDEX INCL. LOT	AVE. SALES PRICE X$1000 1977 EQUIV. HOME PRICE	SOLD EACH YEAR
1963	43.2	23.4	19.3
1964	43.5	23.6	20.5
1965	44.4	24.0	21.5
1966	46.2	25.1	23.3
1967	47.5	25.8	24.6
1968	50.0	27.1	26.6
1969	53.8	29.2	27.9
1970	55.3	30.0	26.6
1971	58.3	31.6	28.3
1972	62.1	33.6	30.5
1973	67.5	36.6	35.5
1974	73.8	40.0	38.9
1975	81.7	44.3	42.6
1976	88.7	48.1	48.0
1977	100.0	54.2	54.2
1978	114.5	62.1	62.5
1979	130.8	70.9	71.8
1980	145.2	78.7	76.4
1981	157.4	85.3	83.0
1982	161.5	87.6	83.9
1983	165.5	89.7	89.8
1984	171.9	93.3	97.6

Source:

U.S. Bureau of the Census, Census Bureau's Housing Sales Survey.

Table 1-V: Price Index of Homes Sold in the U.S.

1.2.2 Improvements in the Quality of the Home

How has the quality of the home improved? The major improvements in the quality of the home which have increased its value are the increase in the number of bathrooms (square footage cost of bathrooms is several times that of the house in general), increase in square footage, and increase in the number of amenities included in the sales price of the house. The median square footage of the house has increased 7.6% from 1965 to 1984 (Table B-IV and Figure B-9), in spite of an 18% decrease in the number of occupants per household during the same period (Table 1-II). "Similarly, the percentage of new conventional (single family detached) homes with air conditioning more than doubled [from 1964 to 1978] and the percentage with two or more baths increased from 46% in 1963 to 73% in 1978" [President 82]. Also from 1963-1984, stoves, dishwashers, and refrigerators included in the price of the home rose from 76% to 95%, 26% to 73%, and 6% to 13% respectively [Census 85].

1.2.3 Consumer Attitude

One possible reason for the continued increase in the quality of the house in the face of rising costs may involve the change in consumer attitude about the home which was discussed earlier. Looking on the home as an investment, the home buyer would like to buy the home that will have the greatest resale value. Also, since the price of homes continues to increase faster than inflation, the more money that the home buyer invests in the home, the greater will be the return on the investment when it is sold.

> "Homeowners who made purchases on the basis of future sales price of the homes in fact took the risk of possible deterioration in the residential real estate market. If home prices do not continue to rise, the real burdens assumed by home buyers in the past few years may prove much heavier than expected at the time of purchase." [President 82]

1.3 The Home Owner

1.3.1 The Changing Lifestyle in America

The lifestyle of the American is changing. There are fewer people and more wage earners per household. With the increased pace of life, the home itself has become a time saving convenience and comfort package. Indicators of the changing role of the home may be indentified through the consumer goods we find in the home today. The trend toward larger hot water storage tanks and more bathrooms per house may reflect the change in morning household activites. The multiple wage earners of the modern family may prefer the convenience of not having to deal with 'who gets the bathroom first?'. We have pretimed coffee makers that brew our morning cup of coffee while we sleep, electric hairdryers to dry our hair, cuisinarts to chop our vegetables, automatic dishwashers to wash our dishes, automatic garage door openers to speed us in and out of the home, and microwave ovens that cook a full meal "in minutes".

1.3.2 Consumer Preferences in the Home

With regard to consumer preferences in the characteristics of the home:

> "Surveys repeatedly find that we want energy-efficient homes. An example: in 1985 the National Association of Home Builders asked 920 randomly selected home owners what they wanted most in their next house. The leading answer: greater energy efficiency; 68 percent choose this. The second most popular item: less exterior maintenance (chosen by 47 percent). Only 23 percent of the respondents named a bigger lot as the most wanted amenity when they buy a new home." [New 86]

Consumer interest in energy efficiency was sparked during the energy crisis of the early seventies. Fuel and energy bills multiplied during this period. Energy prices have continued to rise as illustrated by the relative increase in the fuel and utilities portion of the Consumer Price Index (CPI) compared to the CPI for all items over time (Table B-V and Figure B-10). Because consumers became uncomfortably aware of their dependence on energy during this period, they pressured producers of consumer goods (cars, houses, appliances, light fixtures) to produce energy efficient products. The effects of the energy crisis on the development of innovations in home products will be discussed in more detail in Chapter 5.

1.4 The Home Building Industry

1.4.1 The Housing Industry and the Economy

The home building industry is very large, making up approximately 3% of the Gross National Product (GNP) (Table B-VI). The home construction portion of the GNP and the Value of New Residential Construction as defined by the Department of Commerce, vary greatly from year to year, according to the cycles in the industry.

> "Construction [including home building] is known to be one of the most cyclical industries. Since 1967, there have been three cyclical peaks: in 1968, 1973, and 1978. Increases in the cost and the reduction in the availability of credit have been the chief causes of the last three consecutive downturns." [MacAuley 81]

The dependence of the home building industry on the interest rates becomes apparent when comparing, over time, the number of new housing starts and the prime interest rate. (Table B-III and Figure 1-2). There is almost an exact negative correlation between the prime interest rate and housing starts. As the prime interest rate goes up, the number of housing starts for that year goes down.

There has been some attempt recently to increase the amount of money available for home loans through the deregulation of lending institutions in the late seventies. At this point it is too early to determine the effect that the deregulation will have on the housing industry and the severity of the building cycles.

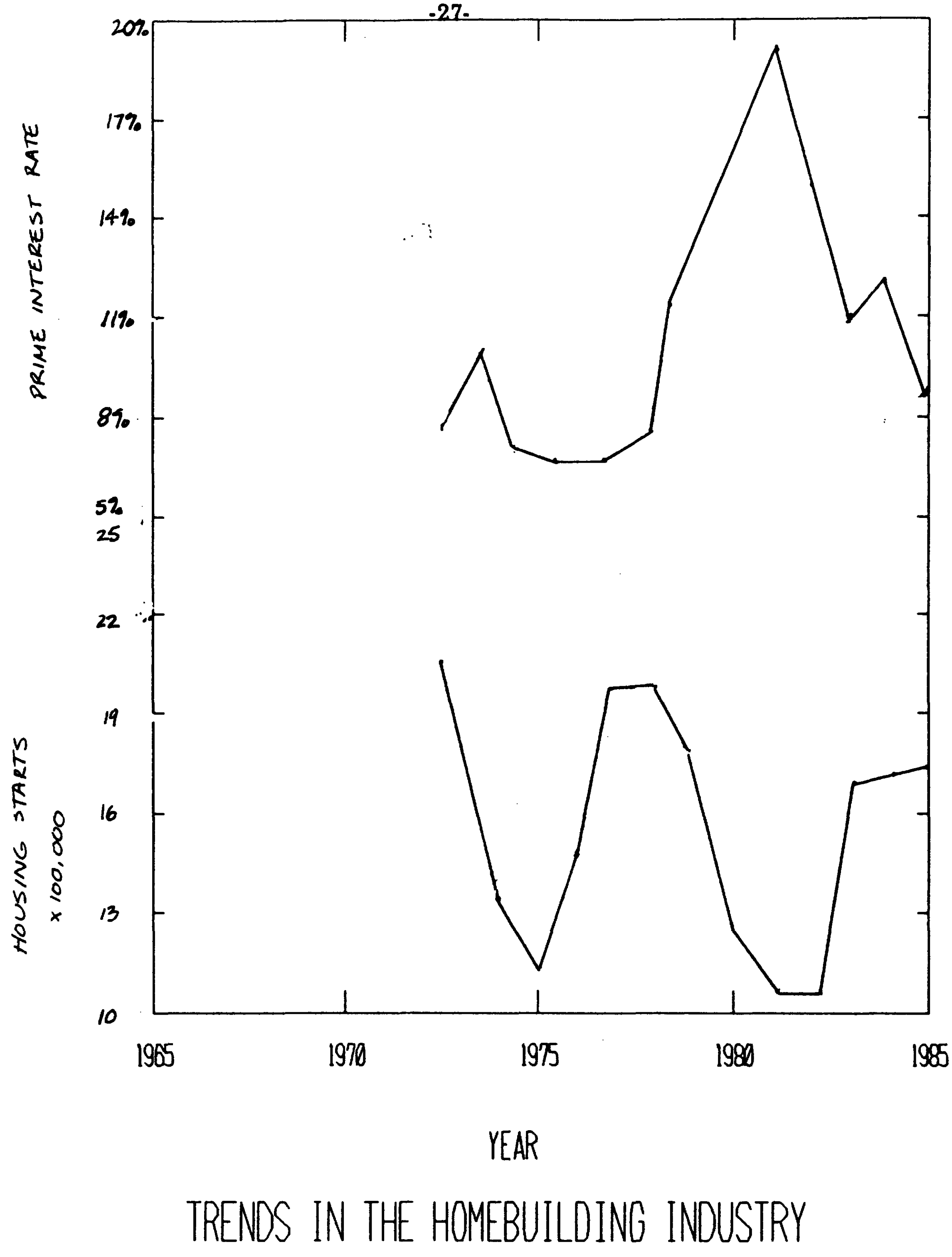

Figure 1-2: Trends in Home Building Construction

1.4.2 Housing Starts

A substantial majority of housing starts originate in the private sector (Figure B-11). Within private construction two thirds of the homes started are single family dwellings (Table B-VII and Figure B-12). The proportional distribution of single and multi-family dwellings has remained fairly stable over the last 25 years. Regionally, there have been significantly more housing starts in the south than in any other region in the country (Figure B-13). The number of homes started in the Midwest and Northeast have exibited a small declined over time.

1.4.3 Employment and the Builder

There are over 100,000 home builders in the United States, the majority of which build less than 25 homes per year [Comptroller 82]. Between 1967 and 1977 the number of self employed persons in construction rose 46%, substantially faster than the rise in the number of employees in construction overall (24%). A "reason for the sharp increase in self employment between 1972 and 1977 is the home building slump that occured during 1974 and 1975. Many unemployed construction workers went into business for themselves and were successful during the recovery in 1975 and 1978." [MacAuley 81]

Home builders adapt to the cyclical nature of the industry by avoiding capital investment which require loans. This way a builder avoids the difficult responsiblity of loan repayment during lean times. Also, the builder maintains flexibility by hiring employees on a contract by contract basis when work is available. This same flexible job market drives up the cost of labor. "The extreme cyclicality of the housing construction in the 70's has reduced the relative efficiency of the production system. Skilled workers had to get more for their time on the job because they had to expect so many weeks of unemployment" [President 82]. The home construction firms exhibit some flexibility themselves. "When market conditions change, they move out of home building and into more promising construction endeavors. In so called 'bad' years : 1967, 1974, and 1975, nearly 20% of member firms surveyed by the National Association of Home Builders (NAHB) in 1977 switched to other businesses." [President 82]

1.4.4 Construction Costs

Between 1965 and 1980 construction costs increased faster than the inflation rate as measured by the GNP deflator [MacAuley 81]. Interest rates have increased faster than material prices and average hourly earnings. The Composite Cost Index, " a weighted average of a variety of specialized cost indexes developed for different types of construction", is compiled by the Bureau of the Census. The CCI has risen faster than three price series: construction workers average hourly earnings, producers price index for all construction materials, and interest rates on short term business loans (Table 1-VI[1]).

> "There are at least three explanations for this suprising development. First unit labor costs have risen faster than the average hourly earnings because of declined productivity. Second, financing costs have risen much faster than interest rates, because of the interest rate multiplier which is applied to the loan amount. Third, there are additional cost factors besides those listed in the Table 1-VI, such as taxes, rental costs, return on equity capital, overhead costs, capital goods costs and purchasing services." [MacAuley 81]

1.4.5 Productivity Trends

Within the construction industry as a whole, from 1965 to 1979, labor costs went up 213%, chiefly due to a decrease in productivity on the job site (Table B-VIII). During this period productivity in construction decline 1.6% per year (Table B-IX). "Output per worker

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[1]Note on Sources for Table 1-VI: The Department of Commerce Composite Construction Cost Index is compiled by the Bureau of the Census, and is in effect a weighted average of a variety of specialized cost indexes developed for different types of construction. The Producer Price Index for all construction materials was developed by the Bureau of Labor Statistics (BLS), and is a weighted average of price indexes for a wide variety of building products. The average hourly earnings in construction also developed by the BLS, represents the average hourly earnings of all construction workers and non-supervisory employees of construction establishments. The data on interest rates are collected by the Federal Reserve System, and this series represents the average interest rates that banks charge for short-term business loans. In practice most construction loans probably carry a higher interest rate than the average business loan, but it is likely that the interest rate trends for construction loans are similar.

TRENDS IN CONSTRUCTION COSTS AND INPUT PRICES, 1965-1980

YEAR	DEPT. OF COMMERCE COMPOSITE COST INDEX 1972=100	CONSTR. WORKERS AVE. HOURLY EARNINGS	PRODUCER PR. INDEX FOR ALL CONSTR. MATL. 1967=100	INTEREST RATES SHORT-TERM BUSINESS LOANS (PERCENT)
1965	67.2	$3.71	95.8	5.06
1970	88.6	5.24	112.5	8.48
1971	94.8	5.69	119.5	6.32
1972	100.0	6.06	126.6	5.82
1973	108.7	6.41	138.5	8.30
1974	126.9	6.81	160.9	11.28
1975	138.4	7.31	174.0	8.65
1976	143.9	7.71	187.7	7.52
1977	56.3	8.10	204.9	7.84
1978	175.7	8.66	228.3	9.80
1979	199.0	9.27	251.4	13.18
1980	221.7	9.94	266.4	15.17

PERCENT CHANGE 1965-1980

+230	+168	+178	+200

Source: See text.

Table 1-VI: Trends in Construction Costs and Input Prices

in construction is 40% lower than the industrial average, yet construction wages are on average 35% higher than in manufacturing." [Slocum 86]

Productivity or output per hour worked is defined by the Bureau of Economic Ananlysis as the "gross product originating in the construction industry divided by the total hours worked by all employees and self employed persons in the industry."

In the following discussion on productivity, it is important to note that the statistics available apply to the construction industry as a whole. It may or may not be valid to transpose the issue of the decline in productivity onto the home building sector of the construction industry.

1.4.5.1 Factors Affecting the Decline in Productivity

There are many factors which might explain in part the reduction in productivity. The following is a discussion of those factors that apply most directly to home building [MacAuley 81].

Some believe that the "disparity from one jurisdiction to the next in the way in which model building codes are accepted, interpreted, amended, and enforced" [Mandatory 86], has caused a decrease in productivity and an increase in the costs of home building.

Also, "a situation that may be developing in construction is the substitution of labor for capital and energy. Wage rates have not increased as rapidly as capital and energy costs" [MacAuley 81]. The difference in costs causes the builder to use manpower rather than more sophisticated materials and equipment in attempt to be cost effective, even if it represents a less efficient use of labor.

Another factor may be the fast-tracking of construction jobs. This involves speeding up the construction process. Fast-tracking is a way of decreasing the capital costs of construction. The time cost of money is high, so the more quickly a job is completed, the less money is spent in borrowing capital. Fast-tracking decreases productivity by requiring that different trades be present on the site at the same time. Because the workers must share space they cannot work as efficiently as they would on a normally paced job.

Finally, the apparent decrease in productivity may be due in part to the shift in construction from the site to the factory.

> "Although the real Gross Product Output for the construction industry has been decreasing since 1968, the GPO in construction materials has increased during that same period, suggesting that some of the apparent decline was actually a shifting of work from the building site to the factory floor as more prefabricated materials are used. It is also possible that the work shifted to the factory floor was performed at a higher than average level of productivity when it was done on the construction site, thus explaining some portion of the productivity decline." [MacAuley 81]

1.4.5.2 Productivity in Home Building

A study was done by the NAHB in 1976 on productivity in the residential building trades [NAHB 79]. This study was written to "help builders determine the proportionate amounts of productive time spent by selected building trades working on typical single family and low rise apartments." One of the objectives was to "determine the amounts of productive-direct, productive-support and non-productive time spent by several building trades."

The study concluded that the average productive-direct time spent by building crews was 65.4%, which is an acceptable level in industry. The masonry trade was found to be the least productive of the various building groups with half of the cases showing over 20% non-productive time.

In its conclusions the NAHB study suggested that builders should strive for improvements (1) in the efficiency and effectiveness of supervision, (2) in materials management, (3) in communication to avoid rework and (4) in the analysis of needed crew sizes and skill requirements.

1.5 Conclusion

The cost of the American home continues to increase along with home ownership costs. Increases in both the cost of land and the cost of financing have contributed to the past increases in the cost of the home. Today, the influence of financing costs is diminishing as interest rates decline. The quality of the home is also increasing, responding to the changing needs of the consumer.

The home building industry is made up of many small companies that are adaptive to the cyclical demands for housing. The cyclical nature of the industry is caused in part by the changes in the cost and availability of money for loans. Increases in the cost of construction materials and the decline in the productivity of the construction industry may also be contributing to the increases in the cost of home construction.

Chapter 2

Innovation and the Social System

> "There are four crucial elements in the analysis of the diffusion of innovation: The *innovation*, its *communication* from one individual to another in a *social system*, over *time*". (Katz 1961) [Rogers 62]

This chapter is introduces concepts associated with innovation in home building. It will define the basic concept of "innovation" and present a framework of catagories and applications in home building. Varying motivations in the development of innovation and the influence of the major players of the home building social system will be explored. Finally, the characteristics of innovation will be presented.

The conceptual framework for the model of characteristics of innovations and their adoption and dissemination processes are borrowed from E.M. Rogers' Communication of Innovation (The Free Press of Glencoe, New York, 1962). Rogers' objective in analyzing over 500 studies of innovation was to "point out the common threads running through all research traditions on the diffusion of innovation".

2.1 Innovation

An innovation is an idea or product that is perceived as new by the individual. A product or material does not have to be objectively new to qualify as an innovation. Most of the idea and product innovations used in home building are adaptations of innovations developed for other industries. Examples of innovations representing this lateral movement of technology into home building include:

1. Electronic, integrated, home control systems which incorporate ideas and equipment common place in business telcommunication systems.

2. Industrialization of the building process and the use of prefabricated components which were adapted from the manufacturing industry.

INNOVATIONS

NEW MATERIALS	BREAKTHROUGHS
NEW PRODUCTS	INCREMENTAL ADVANCES
NEW BUILDING SYSTEM	IMPROVE PRODUCTIVITY
	IMPROVE QUALITY

Figure 2-1: Innovations

3. Polybutelene pipe fixtures which were modelled after quick fit connections for pneumatic tools.

4. Heat mirror films that selectively admit light and reflect heat which were originally designed for airplanes to de-ice cockpit windows.

5. Plywood, so common in home construction today, which was originally developed for ship building.

2.2 Innovations in Home Building

Technological innovations in home building represent developments in materials, products or ideas. A new lightweight, structural, insulative type concrete might represent an innovation in material [Concrete 86], as would new long lasting rubber roofing membrane materials [Rossiter 85] [Dupuis 85], or a new wood product made from waste materials [Ek 86] [Maloney 85]. Similarly, a structural, insulative stress skin panel, which is made up of expanded insulative foam sandwiched between two layers of interior and exterior sheathing material such as drywall and plywood [Panelized 86] [Bliss 85], is innovative both as a product and as an idea. It is an innovative product in using old materials (plywood, gypsum board, insulation) to create a product with innovative properties. Stress skin panels are also an innovative idea in creating an efficent material to strength ratio by placing the stiffest material (plywood and gypsum board) at the points of highest stress.

Many innovations available to the builder today involve innovative ideas. Many of these types of innovations involve new material saving building and design techniques [Hanke 86a] [Stroh 84] [di Marne 86Marne] [McClintock 86]. By and large, they may be adopted independent of the restrictions that other sectors of the social structure may impose. They do not require special products or materials, or new code or consumer acceptance. An example of this type of innovation might be 24" o.c. framing system, which saves in labor and materials over the standard 16" o.c. framing system.

In the diffusion of innovation, often the idea of a new product or material must be accepted along with the product. The home owner first had to accept the idea of plastics in and on the home before plastic products (vinyl siding, fiberglass showers stalls) could be accepted by the consumer [Wigotsky 84].

Another issue in the acceptance of innovation involves the discontinuance of existing practices. In the decision to change framing technique from balloon framing to whole house trusses [Adams 86a], the builder not only must accept the new truss system, but be prepared to set aside a time tested practice he is familiar with. This decision involves moving against the inertia of the industry. Home building, being a very traditional industry, has great inertia against change of any kind. This issue is a characteristic of the social structure of the home building industry and will be taken up later in more detail.

2.3 Types of Innovations

Conceptually, innovations in home building may be broken down into four categories: *Breakthroughs*, and *incremental advances*, which affect *productivity* and the *quality* of the home.

2.3.1 Breakthroughs

Breakthroughs are new materials, products or processes representing large advances in the home building industry. A large breakthrough significantly impacts either the building costs or the quality of the home product. Vertically integrated, industrialized home building, which incorporates design, material management, and production, may well represent a breakthrough in home building cost reduction. This system, which is currently being used by firms in Sweden and Japan [Schipper 85] [Congress 86] [Sackett 85], basically applies the technology currently available in manufacturing and, to some extent, the mobile home industry [Comptroller 82] [Nutt-Powell 85], to custom home construction. Likewise, computerized home control systems, which allow flexibility in the use and control of appliances in the home, may illustrate a breakthrough affecting the quality of the home [Ashley 86a].

2.3.2 Incremental Advances

Incremental advances, making up the largest portion of innovations, are stepwise improvements in an existing product or method. New weatherable [Wood 86] and non-toxic plastics [Lowering 85], incremental steps in plastics technology, will lead to more durable building products and open up new opportunities in the applications of plastics in home construction. Some possible application may include the increased use of plastics in roofing products, siding and window frames, and perhaps in the development of plastic modified gypsum interior panels and plastic structural members. An incremental step improving the quality of the home is the application of superinsulation technology. Superinsulation incorporates "tight" construction techniques and controlled ventilation systems to produce an energy efficient, quality home. [Adams 86a] [ESD 86a].

2.3.3 Increasing Productivity

Innovations that improve productivity can reduce on-site labor expenses. Increases in the labor costs involved in construction and in the time cost of money have motivated the development of innovations that decrease work time at the site. The use of prefabricated components (i.e. roof trusses [Kindel 86], wet cores, prehung doors, prefabricated windows and cabinetry) is cost effective in home construction. Prefabrication has the added advantages of being a quality controlled product which can be produced indoors with inexpensive labor, unhindered by inclement weather. Quality control and indoor production reduce productivity losses due to rework and adverse weather conditions. Innovative machines, such as the new cordless hand-held power tools [Cordless 86] [Hand 86] [Smay 85a] and the on-site framing machinery [Adams 86b], also improve productivity.

2.3.4 Improving the Quality

The final category of innovations involves improving the quality of the home as a product. Improved quality may mean (1) an increase in the number of amenities in the home, (2) a reduction in the maintenance requirements of the house and, (3) a reduction in the operating expenses of the home. A skylight with a rain activated closing mechanism [Philips 86], or a plastic tile that simulates the durabilty and beauty of marble are new products that improve the quality of the home.

Improvements in coating technology, increaseing the longevity of paints, reduce home maintenance requirements, as do improvements in the stain and wear resistance of carpeting [VanGelderan ??]. Similarly, high efficiency appliances [Geller 85a] [Lewis 86] and insulative low-emmisivity window coatings [Best 85] [Better 85] [Gilmore 86], are examples of innovations that can lower the operating costs of the home.

2.4 Market Pull/ Technology Push

Some type of need or motivation must be present for an innovation to be developed. Two theories that attempt to explain the motivation toward innovation are 1)the market pull theory and 2) the technology push theory. Market pull is where the market; the builder and the home buyer, require an innovation to fulfill a need. The development of ceramic interior partitions in Japan, initiated by the scarcity and high cost of wood there [Lord 86], and the development of energy efficient appliances [Geller 85a] in the U.S. during the energy crisis to meet the demand of the consumer, are examples of market pull. Technology push occurs when a new technology is casting about for a suitable application. The original introduction of plastics into home building and the current developments in computerized home control systems are examples of the technology pushing the product.

Practically speaking, the theories of market pull and technology push are not discrete

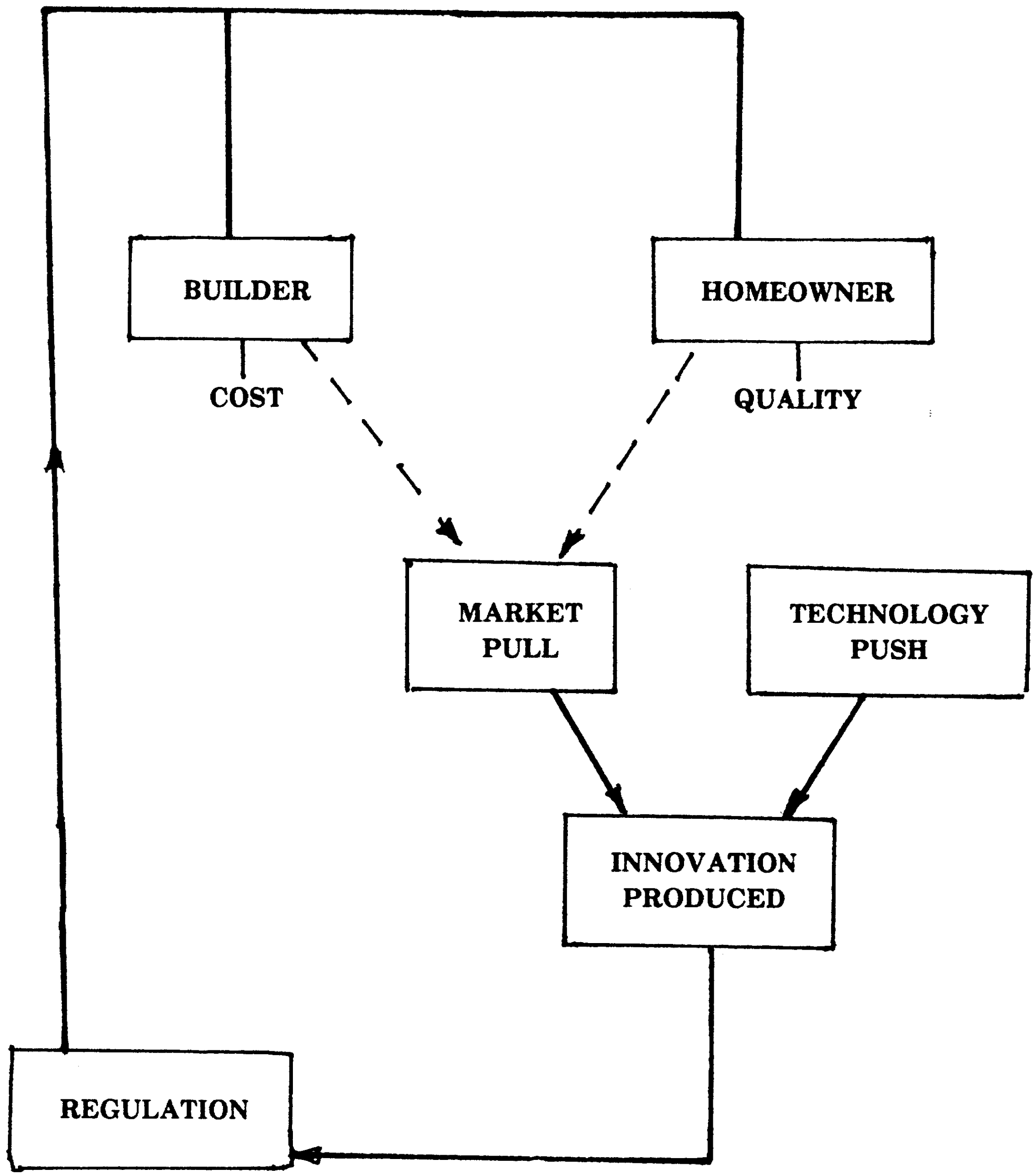

Figure 2-2: Market Pull and Technology Push

or independent. A market cannot demand an innovation for which the technology does not exist, and technology cannot push a product for which there is no market.

2.5 The Social System

Another approach to defining the medium for the development of innovations requires understanding the motives of the members of the social system involved in the industry. In home building participants in the social structure include the builder, the home buyer, the regulating bodies and the manufacturers of the innovations.

> "If we know what a society's culture is, including its particular systems of value and attitudes, we can predict with a fairly high degree of probability whether the bulk of its members will welcome or resist a particular technology." (Ralph Linton, 1952) [Rogers 62]

2.5.1 The Consumers of Innovation

In the home building industry there are two main consumer groups; the home builder and the home buyer. The home builder is interested in reducing the cost of building the home, while the home buyer is concerned with improving its quality. In contrast to the previous theory, these two motivations are independent. Interestingly, the interaction between the home builder and owner requires compromise on the part of each in order to reach an acceptable equilibrium.

A home builder, who is motivated to cut costs in every way possible, realizes the limitations imposed by the requirements of the owner, just as the owner must have reasonable expectations as to the quality of the house he will recieve for a given amount of money.

The builder, who is essentially providing a product for the home owner, realizes that he must strike a balance between cutting construction costs and providing the owner the quality he requires. There are certain amenities more important to the home owner,

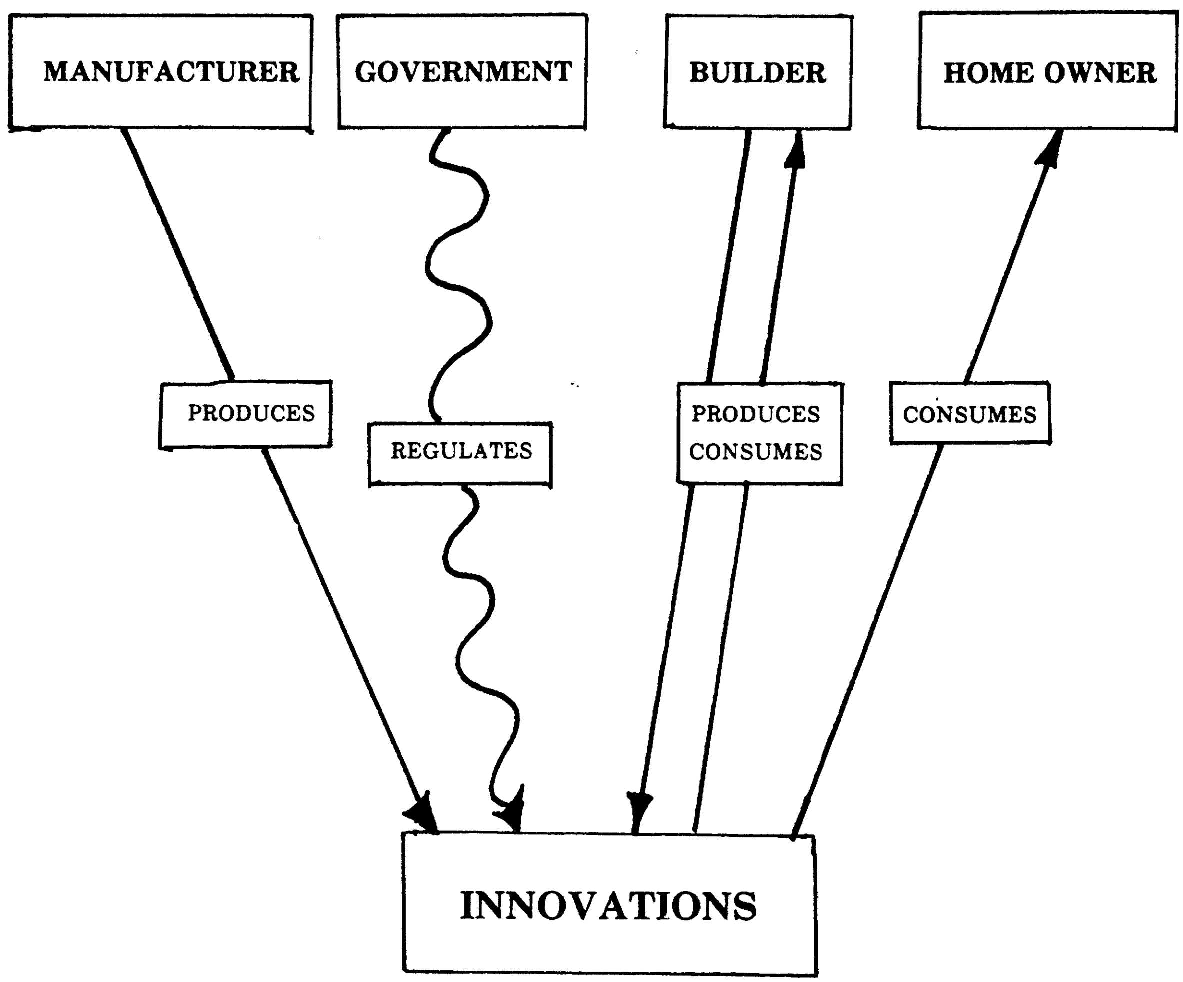

Figure 2-3: The Social System and Innovation

amenities the home buyer prefers and is willing to pay for. These amenities are the ones that builders strive to identify and provide for the home owner. For example, a home buyer may be very willing to pay an added amount for the home with central air-conditioning, a built in dishwasher, skylights and many bathrooms. Conversely, although the home buyer would enjoy such things as swimming pools, trash compactors and multi-head showers, he may not be willing to pay a premium for them.

2.5.2 Government

Although the government is not a direct consumer of innovation in home building, it plays a role in the process of acceptance of innovation through its policies. Local and state building codes, along with federal tax and economic policies, have both direct and indirect impact on the acceptance of innovation.

2.5.2.1 Federal Policies

Federal policy can have both direct and indirect influence on both the acceptance of innovation and on the home building industry as a whole. Innovations are often developed through organized research and development. In general, a substantial portion of research and development geared to benifit society is funded by the government. Unfortunately, "government support of construction related research is virtually non-existent" [Congress 86]. The government is not alone in its negligence. The construction industry, making up close to 10% of the Gross National Product each year, spends less than 1% of its income on research and development. In contrast, Sweden, with its population of $9 million, spends more each year on research and development in home building than the whole of the U.S. [Congress 86]. Similarly, Japan invested $300 million on research in industrialized home building techniques compared to 6 million invested by the U.S. on research in the same area. The importance of research and development on the long term growth of industry cannot be overemphasized. Several studies analyzing factors affecting productivity have determined that a significant percentage of the increases in productivity in industry are directly attributable to the results of research and development. If the people involved in the home building industry are truly concerned about the possibility of foreign competition, perhaps they should consider investing in the future through investment in research and development.

Federal policy can also influence the adoption of innovation through taxes and regulatory practices. During the energy crisis the government used both these tools to selectively encourage the development of energy saving technology. Tax incentives for investment in insulation and for the exploration and investment in alternative energy sources created a catalyst for the development of such innovations as superinsulation technology, solar heating and thermal windows. Government regulation during the same period required that major appliances carry labels of energy efficieny rating. This rating system allowed the consumer demand for lower utility bills to drive the market toward innovations in home appliances. Innovation in home appliances is the subject of a case study which will be taken up in Chapter 5.

2.5.2.2 Building Codes

Building codes represent the largest government influence on the home building industry. There are three major model codes in the United States; the International Conference of Building Officials (ICBO), the Building Officials and Code Administrators International (BOCA), and the Southern Building Code Congress International (SBCCI). Each local jurisdiction may define its own building code or, as most choose to do, accept one of the model codes and amend it to meet local needs. There is no requirement that local jurisdictions must use the most recent edition of a model code in most states, and many do not [NAHB 86a]. Therefore, acceptance of an innovation by the model codes does not assure acceptance on the local level. In fact, local interests may actively discourage specific innovations from being accepted by lobbying for restrictions in the local building codes

[California 77]. The dissemination of plastic piping used for water and sewage lines was hindered by objections raised by local plumbers. They were afraid that the plastic system simplified the installation of plumbing to such as degree that it endangering their jobs. A task force represented by the National Association of Home Builders (NAHB), ICBO, BOCA, SBCCI, the Council of American Building Officials (CABO), and the National Conference of States on Building Codes and Standards (NCSBCS) recommends that differences in the requirements of adjacent jurisdictions be reconciled through the adoption of state wide codes [NAHB 86a] [Mandatory 86]. Nine states have already enacted either a mandatory state code or a statewide code which can only be amended locally with state approval.

Building codes affect innovations by defining requirements for different parts of the construction of the home. The main role of building codes is the protection of life and safety of the occupants. Most building code requirements focus on the structural system of the home, placing few restrictions on the finishes in the home. As most of the cost of building a home is in the finishes, there is a limit to the impact that building codes can have on the acceptance of cost saving innovations in home building.

2.5.2.3 Performance versus Prescriptive Codes

There is a lot of discussion in the popular building press about the merits of performance versus prescriptive codes. Prescriptive requirements set a standard of what materials a builder may use and how to use them. Performance requirements define a minimum acceptable level for the structural, fire, etc. performance of an element of the building. Performance specifications allow for latitude in design, and create an environment for innovations in the structural system of the home. Prescriptive specifications are prefered by most builders, who tend to prefer time tested building practices. Many builders view performance codes as being to complex.

Although most building codes are both prescriptive and performance rated, the enforcement system preferentially accepts prescriptive building techniques. The performance specifications usually take the form of a qualifier within the code, which states that alternative systems to the one specified in the prescriptive code section may be used if one can prove equivalence. This situation shifts the burden of proof to the builder who wish to use an alternative system, or to the manufacturer who wishes to market a new product governed by the codes. This is not a large handicap if the system's acceptability can be verified with known engineering design principles. This is how various prefabricated truss designs gain code acceptance. Alternatively, a more exotic system that involves non-standard materials or connections might require extensive and expensive testing by a certified testing organization. Product manufacturers and manufacturing organizations like the American Plywood Association (APA) would use this system to gain code acceptance of a new product or building system.

The entire manufactured/mobile home industry in the United States falls under one code jurisdiction. This code is made up of performance specifications. If the arguement that differences in local code restrictions and the prescriptive nature of the codes are the major barrier to innovations in homes, we would expect to see a major difference in the number of innovative materials and methods used in the manufactured homes as compared to the site built home. Since this is not the case, perhaps building codes are not the major barrier to innovation they are believed to be.

2.5.3 The Manufacturer

Lastly, we come to the manufacturer's role in the social system of home building. By manufacturer, we include producers of the innovative products used to build the home and, in the case of process innovation, the builder as the manufacturer of the home. Given the existence of a particular market demand or innovative technology, the manufacturer must decide what to produce. In deciding what to produce a manufacturer develops an evaluation criteria for determining the success of a new innovation. The remainder of this thesis deals with establishing an evaluation criteria for innovations in the home building industry.

2.6 Characteristics of Innovation

At this point we may begin to define the charcteristics of innovations that define what might be marketed in the home building industry. Later, after analyzing case studies, the relative importance of the various characteristics may be defined in developing a decision criteria for evaluating the success of the innovation.

The characteristics of innovation as defined by Rogers and modified by MacFadyen are the *relative advantage*, the *compatibility* with the existing culture and norms, the *complexity*, the *trialability*, and the *observability* of the innovation [Rogers 62] [MacFadyen 84] .

> "Kivlin (1960) probably completed the most adequate study on the relationship of characteristics of innovation to their rate of adoption.... [He] found highest correlation between rate of adoption and (1) relative advantage, (2) complexity, and (3) compatability. Kivlin [also] found either low or negative intercorrelation among four charateristics of innovations (divisibility [trialability], compatability, complexity, and advantage) which suggests they may be relatively independent of one another." [Rogers 62]

2.6.1 Relative Advantage

The relative advantage of an innovation refers to its advantage over the status quo. In order for an innovation to be accepted it must be better than the existing option in some way. Economic relative advantage is the chief instigator of innovation acceptance in our modern society. Economic advantage may be represented by a decrease in the building, maintenance or operation costs of the home, or by innovations which increase the value of the home. Improvement in the quality of the home, the quality of life of the occupants, and in safety, both in the home and in the building of the home, may be other relative advantages considered.

Some examples of the relative advantage of some innovative products in home building follow:

The relative advantage of energy efficient appliances is that they decrease the

CHARACTERISTICS OF INNOVATION

RELATIVE ADVANTAGE

COMPATIBILITY

COMPLEXITY

TRIALABILITY

OBSERVABILITY

Figure 2-4: The Characteristics of Innovation operating costs of the home [Geller 85a]. Not only do they save money through the initial energy savings, but they also reduce the impact of increasing energy rates on operating costs. In another case, the relative advantage of new residential sprinkler systems [Ruegg 85] [Woodcock 86] is in increasing the safety of the home for the occupants. Sprinklers may also cut the operating expenses of the home by decreasing insurance rates and municipal taxes which go towards fire departments. The use of 24" O.C. framing system could have a relative advantage in lowering both materials and labor costs of building [Stroh 84] . In each of these cases the relative advantages must be weighed against the limitations of other characteristics during the evaluation and adoption stages of the adoption process, which will be discussed later.

2.6.2 Compatability

> "Compatability is the degree to which an innovation is consistant with existing values and past experiences of the adopter. An idea that is not compatible with the cultural norms of a social system will not be adopted so rapidly as an idea that is compatible. Compatibility ensures greater security to the potential adopter and makes the idea more meaningful for him" [Rogers 62].

An innovation must be compatible with all aspects of the home building social system; the government regulation and inspection systems, the lifestyles and expectations of the consumer, the existing practices of the builder, and the manufacturing processes. The innovativeness of these different groups within home building also affects the compatibility of innovation.

2.6.2.1 Innovativeness

Perhaps the movement toward innovativeness in home building can be thought of as an innovation in its own right. The degree of this movement within home building can be exemplified through a discussion of the differences between a traditional and an innovative society [Rogers 62]:

1. Less developed technology vs. complex division of labor. The increased use of

prefabricated components in home building, dividing the labor in building the home, marks a trend toward innovativeness in the building community.

2. Relatively low literacy and education vs. high value on education and science. The American society is becoming more literate as a whole. With education comes the opportunity for expansion of existing knowledge and an environment for the development and acceptance of innovations. There is no doubt that the current generation of Americans is more accepting of innovations than past generations as the rate of change in technology steadily increases.

3. Little communication outside the social system vs. new ideas freely entering from outside sources. Although we live in the era of communication, home builders, who, as a group, are a fragmented, specialized, competative group, geared to local markets and rapid turnover, lack communication systems and unifying organizations. This creates a major barrier to the acceptance and dissemination of innovation in home building.

4. Absence of economic rationale vs. careful planning and economic rationale. This is related to the relative advantage of an innovation. For some types of innovations in home building the economic rationale plays a chief role. For others, such as consumer preference, the decision criteria is random in nature, as the home is a very personal 'product'.

Stress skin panels, a sandwich type product for home building which incorporates the exterior and interior sheathing with the insulation, is a good example of an incompatible innovation. By being a closed system stress skin panels do not allow for inspection of the structural system and insulative components on the site. This is incompatible with the inspection processes in most areas. Some panel systems have attempted to modify their designs to allow for site inspections by leaving off the interior panel, exposing the structure, mechanicals and insulation [Hughes 85a]. Panel systems are also incompatible with existing on-site building practices. They requires different craftsman techniques, equipment, and materials.

2.6.2.2 Current Building Practices

An innovation must be compatible with existing building practices to be successful in home building. The average builder is not a well educated, or cosmopolitan individual. His knowledge of building is gleaned exclusively from the builders before him, as there is no real forum for offering the builder an education in new building practices (exceptions do exist).

Also, the building industry is economically unstable with unpredictable cycles, creating a transient work force with limited skills. During bad times builders lay off extra employees and guard against unpayable debts by avoiding large capital investments [President 82]. The small profit margin in home building, and the fierce competition, also disinclines the builder to take on economic risks that might endanger their market share. Consequently, the builder will require some assurance of the advantage of using an innovation before he will consider it. Innovations which require a large capital investment by the builder will have difficulty gaining popularity regardless of the advantages they may offer.

Another factor affecting the application of innovation involves the risk of possible damage to the builder's reputation. According to a study done by the National Association of Home Builders for the Department of Housing and Urban Development found that "possible damage to builder's reputation was a real barrier to adopting cost saving innovations which involve using lesser amounts of materials (for example 2X3 studs) and eliminating components (for example floor bridging)." This study explains that "consumers often mistakenly fear that these innovations weaken the structure of the home.... competing firms frequently make a sales point out of their use of traditional materials" [Comptroller 82].

2.6.2.3 Lifestyles

An innovation must also be compatible with the home owners lifestyle and expectations. The average home owner likes stability in the basic home design. He wants to live in a house that looks like the one he grew up in and is more accepting of innovations which do not change the appearance of the home; hence the success of vinyl siding with its simulated wood grain and the failure of the Fuller geodesic domes. Although the appearance of the home may not be changing, the home owner is very accepting of innovations that increase the comfort and efficiency of the home.

Innovations must also be compatible with expectations of the consumer. The average home owner associates manufactured housing with a poor materials and shoddy craftsmanship, discouraging the development of custom industrialized building techniques which have been so successful in Japan and Sweden. At this point it would be very difficult to convince the average American that industrialized home building could offer him a better home for less money.

2.6.2.4 Conclusion

Incompatability of an innovation does not preclude its acceptance, but it does add to the cost of its development. The cost involved in gaining code acceptance when neccesary, in re-educating the building community, and in reforming public opinion can be very high, restricting the development and marketing of many innovations.

2.6.3 Complexity

Complexity creates possible difficulty in the use, understanding, or production of an innovation. Two general disadvantages of complexity are that people tend to dislike things they do not understand and that complexity increases the degrees of freedom for failure within a system. In home building, the simpler an innovation is to implement, use and inspect, the better. The limited resource of skilled craftsmen discourages the builder from using complex products, techniques or equipment. The home owner also dislikes overly complex products, believing that a whiz-bang egg cooker, carrot slicer and pillow fluffer may some day complicate their lives with sliced pillows and par-boiled carrots. With regard to the inspection process, as discussed before, the burden of proof of acceptability lies with the builder, who is generally reluctant to take this burden on.

2.6.4 Trialability

Trialability or divisibility involves how easily an innovation can be tested on a limited basis. The builder's aversion to risks and large capital investments requires that a builder must be able to evaluate an innovation without committing himself financially. For example, a builder might be more willing to try a new predecorated gypsum wall material, which eliminates the neccesity of painting interior walls, than a spray-in insulation process which would require purchasing special equipment.

2.6.5 Observability

Observability, how visible and communicable the results of implementing an innovation are, affect its acceptance. If the advantages over the status quo in implementing an innovation are not obvious and tangible, it will not be accepted. Take for example, the hypothetical case of a builder who is considering adopting a 24" o.c. stud wall home framing system. He finds that he must take several hours on each project to negotiate with the carpenters and instruct them on the new method. After realizing a marginal reduction in the material costs for the job, not observably significant or undeniably attributable to the new framing technique, the builder decides not to adopt the 24" o.c. framing system. The innovation did not offer significant observable advantage. Observability and communicability tie into the other characteristics of innovation. If a new innovation is complex, it will be difficult to disseminate information about it. Similarly, if an innovation requires a large capital investment, few builders will be exposed to it through example, as most builders will reject the innovation as a possibility prior to the trial stage.

2.7 Conclusions

Innovations in home building represent developments in materials, products and processes which affect either the cost of construction of the quality of the home. Innovations may be incremental in nature or breakthroughs in technology.

The members of the home building industry social system; the builder, the home owner, the government, and the manufacturer, all play a role in the development and dissemination of innovation in home building.

Laying the ground work for developing a model of evaluation criteria for innovations in home building, the characteristics of innovation; relative advantage, compatibility, complexity, trialability, and observability were also presented.

ADOPTION PROCESS

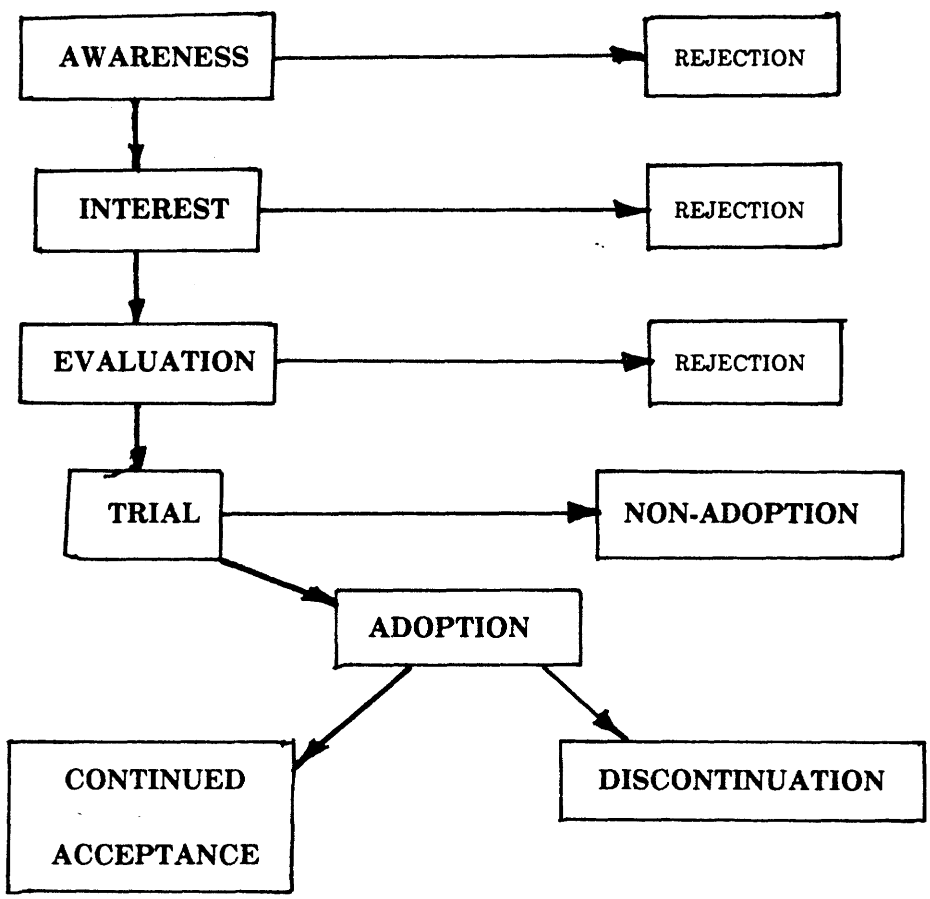

Figure 2-5: The Adoption Process

Chapter 3

Adoption and Dissemination

This chapter will address the adoption process and the dissemination of innovations in home building. The adoption process deals with the acceptance of innovation by the individual while dissemination relates to the adoption of innovation within the social structure. The adoption process is the steps taken by the individual in deciding whether or not to adopt a specific innovation. Issues involving the dissemination of innovation that apply to the adoption process will be integrated into the discussion of the adoption model. A discussion of the characteristics of dissemination that specifically apply to the larger social structure will follow.

3.1 Adoption Process

A builder or home owner, in deciding to adopt a specific innovation, moves through a cognitive process which can be approximated by the following steps: The *awareness* stage, the *interest* stage, the *evaluation*, the *trial*, and the *adoption* or non adoption [Rogers 62]. The primary focus of the discussion will be on the adoption process of the builder because the trial and adoption stages, representing decisions related to a repetitive process, are not applicable to the home owner.

3.1.1 Awareness Stage

The awareness stage is where the individual first becomes aware of the existence of an innovation. This is brought about by exposure to the innovation through information channels. Exposure to an innovation does not assure awareness. Some believe that a person exposed to an innovation will not become aware of it unless it fulfills a specific need. This seems plausible, considering that people are constantly engaging in selective recognition of external stimuli. In home building, as in most cases, awareness is first brought about by exposure to impersonal information sources, such as a magazine article or an advertisement. It has been found that, for the different stages of the adoption process, different types of information sources have varying influence. As in the case of awareness, a builder is far more likely to become aware of a new product repeatedly advertised in a national building magazine than to become aware of a new material a local builder is using.

3.1.2 Interest Stage

At the interest stage the individual actively seeks information about the innovation. The social system affects where he will seek information. In home building, the individual looks to the material and product distributors, trade magazines and organizations, and word of mouth from other builders for information on new ideas and products.

The social system also affects how the builder and home owner interprets the information they recieve. For example, a builder is much more likely to believe an article in *Progressive Builder* evaluating the relative merits of different insulation systems than comparable information provided by a product distributor. The builder is reluctant to base a decision on information offered by the distributor because the builder believes that the salesman, as a change agent[2] , will push for overadoption of the innovative insulation he represents.

3.1.3 Evaluation

In the evaluation, the innovator weighs the advantages and disadvantages of an innovation and decides whether or not to try it. In home building, this involves weighing the characteristics of the innovation discussed in the previous chapter. For example, the relative

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[2] a change agent is any individual or group that actively encourages or discourages the dissemination of an innovation

cost advantage of using on-site automated framing machinery must be weighed against the limitations in the trialability, complexity and in compatibility with existing building practices. The builder may decide that the cost savings outweighs the disadvantages, or he may decide that the lack of trial makes investment in the equipment too risky. Personal information sources are very important during this stage. The potential adopter will try to draw upon the experience of others when evaluating an innovation.

3.1.4 Trial

The trial stage involves applying the innovation on a limited basis. This allows the potential adopter an opportunity to test the innovation without major financial commitment. An innovation has a better chance of being accepted if the risk involved during the trial stage is minimized. The involvement of change agents, or product representatives has the greatest impact during this time, perhaps because the product representative can assure correct implementation of the innovation.

3.1.5 Adoption

"Adoption is a decision to continue full use of an innovation. ...The adoption decision is largely an individual one" [Rogers 62], the least influenced by outside sources. Adoption or nonadoption is primarily based on the success of the trial. It is important to realize that the incident of adoption is low. In fact, the Department of Commerce estimated that 90% of all new products in the United States fail in the marketplace within four years of their introduction.

3.2 Discontinuation

Discontinuation, which is the rejection of an innovation after complete adoption, is also very common. In the case of nearly half of all adoptions, the user will discontinue use of the innovation shortly after adoption. The later adopters of an innovation are the most likely to discontinue the use of the innovation. "Often a relatively late adopter may adopt a new idea but not the related ideas that must accompany it to achieve successful results" [Rogers 62]. A late adopter applying the Airtight Drywall Approach of air/vapor barrier to a home may fail to use the special paints associated with the technique which seal the surface of the wall. When the system fails the builder may choose to discontinue use of the innovation without determining the cause of failure.

Unfavorable economics can also discourage the continuance of an innovation. Encouraged by rising copper prices, aluminium electrical wiring systems for the home became a popular innovation during the 1970's. But as copper prices went down again the use of aluminium wiring tapered off. An added incentive for the discontinuation of aluminium wiring in homes was that after having "been given the standard available testing before introduction.... the connections of aluminium wiring were found to cause fires" [Comptroller 82]. Better connectors are available today, so perhaps aluminium wiring will again become popular if copper prices rise again.

3.3 Dissemination

Dissemination of innovation refers to how an innovation diffuses through the industry. The factors which have the greatest influence on the rate of dissemination are: the innovation itself, the individual and the social system, change agents, crisis and the information sources.

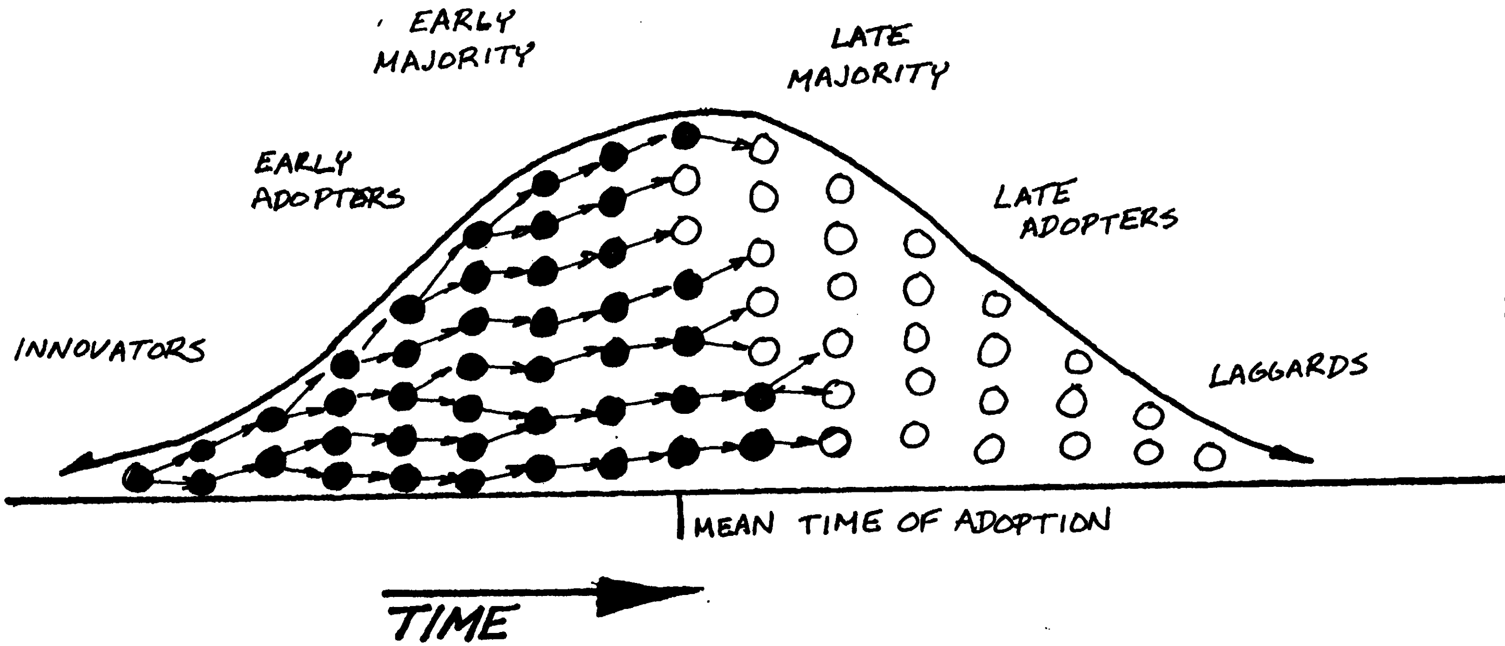

Figure 3-1: The Dissemination of Innovation

3.3.1 Adoption Period

> "Innovations with certain characteristics are generally adopted more quickly. For example, innovations that are relatively simple in nature, divisible for trial, and compatible with previous experience may have a shorter adoption period than innovations without these characteristics." [Rogers 62]

Innovations which have a relatively short adoption time disseminate more quickly than others. Bearing this in mind, it is understandable that pre-hung doors, which can be quickly evaluated, tried and adopted within the the course of one project, disseminated into the industry within three years, while truss roof systems, involving a much more complex, concept (prefabricating a major portion of the structure) and process (requiring the use of specialized equipment), took twenty years to disseminate [Comptroller 82]. David MacFadyen, president of the NAHB Research Center believes that "for a construction innovation, the mean time to adoption is typically 15 years" [MacFadyen 84].

Rogers found that the dissemination of an innovation within a social system follows an approximate bell shaped normal curve (Figure 3-1). Mr. MacFadyen also believes that the people involved in the marketing and dissemination of innovation would like to understand the process of acceptance of innovations in hopes of developing a mechanism which can compress this adoption curve for a new building product. In this way, the losses realized during research, development and marketing of the innovation could be recovered more quickly.

3.4 Factors Affecting the Process of Dissemination

3.4.1 Social System

The individual builder, manufacturer or home owner's innovativeness is linked to the innovativeness of their surroundings. Since the building industry is quite conservative as compared to society as a whole, it is not suprising to see that many of the recent innovations to disseminate in home building improve the quality of the home, reflecting consumer demands (thermal windows, home control systems, energy efficient appliances). A study by the National Association of Home Builders cited previously explains a cause for the difficulty in the dissemination of new building practices. It seems that the "expected savings from innovations were almost always modest and that the builders were most reluctant to experiment with new items which might lower costs a little if there was a possibility of poor performance" [NAHB 71]

3.4.2 Change Agent

A change agent is any individual or group that actively encourages or discourages the dissemination of an innovation. The NAHB, through their reports, research and display homes can be thought of as a change agent for economic building practices. Similarly, the plumbing unions acted as change agents in discouraging the dissemination of PVC piping products. "The use of Plastic pipe for plumbing has been opposed in many locations both by plumbers unions and by fire officials who point out that plastic pipe can help spread a fire and can emit toxic fumes when they burn" [California 77].

The extent of effort by the change agent can be directly related to the rate of adoption and dissemination of the innovation, as was exemplified in the case of energy crisis. The government and the utilities companies became change agents encouraging energy conservation by educating the public and by providing economic incentives through tax breaks and graduating energy rates. The American Plywood Association is another example of a change agent that speeds the dissemination of innovation. The APA engages in extensive and successful marketing campaigns to disseminate information on new developments in plywood technology, thereby encouraging the use of plywood in home building.

3.4.3 Crisis

The energy crisis not only left change agents in its wake, but it also created a catalyst for the speedy dissemination of energy efficient innovations. Although energy efficient appliances, and passive solar systems may have had advantages in their own right, the energy crisis served to multiply the relative advantage of energy saving technology, thereby speeding up the adoption and dissemination of innovative energy saving products.

A crisis provides fertile ground for the acceptance of innovation. During the energy crisis many of the barriers to innovations dissappeared or were side stepped in the frantic rush to cut energy costs. For once, the government invested heavily in research and development in building technology. The government also provided incentives for investment in energy saving construction through tax breaks and created rating systems for appliances. The government also launched an extensive program geared to educate Americans in energy conservation. Equipped with a vocabulary of "R" values, and an understanding of radiant and conductive heat losses, the consumer quickly realized the value of energy efficient home design, and subsequently demanded it of the builder.

3.5 Sources of Information

In home building, information about innovation is disseminated through magazine articles, advertisements, trade organization literature, and by word of mouth.

3.5.1 Articles

Because most of the building trade magazines do not actively disseminate information on innovations in home building, there is little literature on innovative products, materials and processes available to the builder and home owner. The articles that are written about innovations do not tend to be comprehensive in their evaluation of the innovation or in their comparison of innovations with existing techniques. A disproportionate amount of the articles that are written about innovation, are about energy saving innovations. Even now, ten years after the energy crisis, there is a relative ratio of ten to one articles involving energy saving innovations vs. other types of innovations.

Also, understandably, many articles on innovation are on glitzy or glamourous innovation which may not have a role in the building industry of the near future. It is not likely, for example, that tent structures and photovoltaics are likely to be in the home of the year 2000.

Another area for confusion is the tendency of test homes to overlap innovations. Many of the test homes discussed in literature and sponsored by organizations such as HUD and universities include a multitude of related innovations. A realistic evaluation of the impact of a specific innovation in one of these test homes would be impossible to determine.

3.5.2 Organizations

There is not one organization or sector within the industry to identify and evaluate innovations for the industry. Each builder or home owner must be convinced of the value of an innovation independently. The National Institute of Building Sciences was initially established to evaluate and encourage the use of innovation in building. Unfortunately, difficulties in the organization and funding have limited the impact of this program [Comptroller 82].

There have been some attempts made by various private and government organizations such as NAHB and HUD to disseminate information on energy and money saving building techniques. NAHB is currently piloting an educational program offering seminars locally in various subjects related to home building. The Graduate Builders Institute is a 54 hour certification program which was piloted in 1985-86. The NAHB hopes to keep participant costs well within the means of the average builder. The studies will cover twelve area related to home building including energy efficient and cost effective construction.

3.5.3 Advertisements

Since the impact of articles and organizations on the dissemination of innovations is small, manufacturers of innovations, carry the burden of exposing the merits of their innovation to the public. As described before, the consumer is interested in innovations which increase the value of the home while builders would like to cut the costs of building the home. Therefore, there are really two distinctly different target groups to consider when marketing a product.

3.5.4 Conclusion

The conclusion to be drawn here is that, without a comprehensive forum for the communication of innovation, the time rate of dissemination of innovation into home building remains low. Perhaps it will take a crisis, a real threat of foreign competition in the U.S. home building industry, to wake the sleeping giant.

Chapter 4

Evaluation Criteria for Innovation

The final two chapters of this thesis involve the development and application of a model for evaluating the success of an innovation in home building. In this chapter, Chapter 4, an evaluation criteria for innovations is presented, focusing on characteristics of 1) the product, 2) the market, and 3) the financial considerations. These evaluation criteria combine the influences of the four major factors discussed thusfar which influence the acceptance of innovation; the social structure of the home building industry, the characteristics of successful innovations, and the adoption and dissemination processes.

In each of the three areas evaluated; product, market, and finance, specific characteristics will be discussed with regard to the active participants in the social structure of the home building industry; the builder, the manufacturer, and the home owner/buyer. The influence of the government as a passive participant on the innovative process will be incorporated into the discussion of the evaluation characteristics.

In Chapter 5, five case studies of the development and dissemination of innovation will be presented. The five case studies are : innovations in the energy efficiency of appliances, low emmisivity glass coatings technology, the development of vinyl siding, the acceptance of performance rated structural paneling and the development and dissemination of all weather wood foundation systems. Concluding each case study will be a discussion identifying which evaluation criteria apply to each case.

In conclusion, the evaluation criteria presented here and applied to the case studies of Chapter 5 will be ranked by catagory based on their relative influence on the success of innovations in home building.

PRODUCT CRITERIA	MARKET CRITERIA	FINANCIAL CRITERIA
Newness	Market Size and Expected Company Share	Overall Profit Contribution
Manufacturer	Manufacturer	Manufacturer
Builder	Builder	Builder
Home Owner	Home Owner	Home Owner
Fit With Existing Facilities and Skills	Market Growth	Return on Investment Total Investment Requirement
....	....	....
....	....	....
....	....	....
Servicing Requirements	Market Positioning	Profit-Risk Ratio
Technical Feasibility	Effect on Existing Product Line	Effect on Cash Flow
Legal Considerations	Competative Status	
Organizational Support	Distribution Characteristics	

Source: Evaluating New-Product Proposals, *A Coference Board Report*, written by E. Patrick McGuire.

Figure 4-1: Evaluation Criteria for Innovations in Home Building

4.1 Comments on the Model

The framework of the following model is borrowed from the Conference Board Report, **Evlaluating New-Product Proposals**, writen by E. Patrick McGuire [McGuire 73] (Table 4-1).

This model is conceptual in nature, providing guidelines for evaluating the probability of success of an innovation by presenting the issues influencing its success. The breakdown of product, market and finance evaluation criteria simulate the movement of an innovation into the market.

An innovative material, product or process, whether originating from market pull or technology push, must meet product evaluation criteria before market evaluation criteria are considered. Similarly, an innovation must meet market evaluation criteria before financial characteristics are evaluated.

The conceptual nature of this model does not lend itself to becoming a report card evaluation system. It does not attempt to be a definitive, quantitative formula predicting the success of an innovation, but rather a tool to guide the individual in understanding the process of innovation acceptance.

Because of the exhaustive nature of this model, some characteristics do not involve some sectors of the social structure. When this is the case, it will mentioned in the discussion of the characteristic.

4.2 Product Criteria

"Among the factors frequently taken into acount in evaluating [McGuire 73]" the proposed development and use of an innovation are the following:

- Newness

- Fit with Existing Facilities and Skills
- Proprietary Position
- Servicing Requirements
- Technical Feasibility
- Legal Considerations
- Organizational Support

4.2.1 Newness

4.2.1.1 Definition

The newness of a product or process refers to how, and to what degree an innovation is different from existing products or processes. The newness is the relative advantage over existing alternatives and also the novelty and observability of the distinctive characteristics of the innovation.

4.2.1.2 Manufacturer

Manufacturers realize that to introduce a new product, some sense of advantage or novelty must be created. An innovation must be distinct in meeting or creating a market demand. In producing something for the conservative home builder, beyond a small threshold of novelty required for the recognition of the relative advantages of an innovation, excessive "newness" can be a detriment. In developing a product for the home owner, the novelty of the innovation can be created into a percieved relative advantage.

4.2.1.3 Builder

The builder, as a consumer, is skeptical of products that are novel or incredibly innovative. He is concerned with the degree to which an innovation provides an assured economic relative advantage. As a manufacturer, the builder is aware that the novelty of an innovation can create an economic advantage in selling the home.

4.2.1.4 Home Owner

Although not as skeptical as the builder, the home owner, who can be originally attracted to the novelty of an innovation, also requires that an innovation have advantages. Also, the "new" qualities of the new material or product must be easily communicated to the would-be users.

4.2.2 Use of Existing Facilities and Skills

4.2.2.1 Definition

An innovation that utilizes existing facilities and skills focuses on compatibility, and therefore has a higher probability of success in the home building industry. For producers in home building, risk averseness and the high cost of capital investment are key in dicouraging non-compatible innovations.

4.2.2.2 Manufacturer

An innovation that utilizes existing production facilities or draws upon the existing skills of the research and sales staff is more likely to be developed. "Manufacturers prefer a proposed product that can be produced with existing plants and equipment. Many managements are ...reluctant to undertake new ventures that will move their companies into markets...which their sales organizations are unfamiliar with. [McGuire 73]"

4.2.2.3 Builder

The builder is more likely to adopt an innovation that is compatible with his existing building practices and equipment. The traditional, and competative nature of the industry and the limited skillfulness and innovativeness of construction workers discourages the acceptance of innovations that require new equipment or skills.

4.2.2.4 Home Owner

An innovation accepted by the home owner must be compatible with the home owner's percieved needs, preferences and lifestyles. Often it is difficult for builders and manufacturers to anticipate how the home owner percieves and evaluates an innovation because the home owner's criteria for compatablity include characteristics which cannot be quantified, such as comfort and personal preference.

4.2.3 Proprietary Position

4.2.3.1 Definition

Proprietary positioning refers to the goal of maintaining market share and the desire for market dominance.

4.2.3.2 Manufacturer

An innovation may create dominance in the market place through a "clearly superior product, a unique promotional appeal, an effective distribution system, or perhaps a strong patent position." Of these characteristics, a strong patent position is the most valuable because it protects the manufacturer from competitors producing the same product.

4.2.3.3 Builder

Builders also wish to maintain their market position. This interest in protecting market share affects the acceptance of innovation. The reputation of the builder directly affects his marketability. Therefore, a builder is not likely to adopt an innovation where the failure of the product might damage his reputation. Alternatively, a builder may be willing to adopt an innovation which increase his proprietary position by increasing productivity and production level.

4.2.3.4 Home Owner

For the home owner his proprietary position involves maintaining the value of the home for resale. Although not the exclusive concern of home owners, innovations which maintain or increase the value of the home are more likely to be accept.

4.2.4 Servicing Requirements

4.2.4.1 Definition

The servicing requirements of an innovation must be minimized for it to be successful. Adequate development of a product or process before marketing, and a complete understanding of the in-service use of the proposed product, decrease service requirements and aid in the success of the innovation. An innovation that increases the durability or dependability of a material, product or process has an important marketing advantage in the home building industry.

4.2.4.2 Manufacturer

"Manufacturers are inclined to reject product proposals that seem to present unusual servicing difficulties....An appliance manufacturer's ...analysis of its new-product failures during the past decade revealed several cases where a product had failed not because of an inherent weakness of the product itself, but because the company was unable to establish a satisfactory service network [McGuire 73]". In the home building industry, durability and dependability is of great importance to the builder and home owner. Innovations that provide either of these characteristics to a product may improve a companies proprietary position.

4.2.4.3 Builder

The builder does not want to service a home after construction is complete. In avoiding call backs and liabilty problems, a builder is often reluctant to take the risk of trying a new product if there is a chance that it may fail. Often, a manufacturer must offer excessive product assurance warrenties to convince the builder to try an innovative product, even in the case where one would expect the cost advantage alone to create demand for the new product.

4.2.4.4 Home Owner

The home owner prefers a product that is reliable and requires little or no maintenance. He is willing to pay more for these characteristics in a home or product.

4.2.5 Technical Feasibility

4.2.5.1 Definition

The technical feasibility refers to the ease of producing and implementing an innovation. The technical feasiblity of an innovation is dependent on its compatability with existing resources and technology.

4.2.5.2 Manufacturer

The technical feasibility of a market driven innovation is more probable than the technical feasability of a technology driven innovation [Mansfield 75]. "Anything is technically feasible given sufficient time and resources. But from a practical standpoint, when management asks whether or not a new product can be made, it has certain time and investment parameters in mind. [McGuire 73]"

4.2.5.3 Builder

For the builder, excessive complexity, which can often be resolved on the product manufacturers level, can be a great barrier to the acceptance of an innovation. For the builder, the technical feasability of an innovation is defined by its complexity as the skill and education level of his transient building crew is limited.

4.2.5.4 Home Owner

This criteria does not apply to the home owner.

4.2.6 Legal Considerations

4.2.6.1 Definition

Legal considerations, as they apply to innovations, include patent rights, government regulations, and insurance. Each of these have different implications on the success of an innovation.

4.2.6.2 Manufacturer

The legal consideration having the greatest impact on the the decision to manufacture an innovation is product liability. "Manufacturers are seeing their product-liability premiums rise anywhere from 200% to 500% .... some are going up 1000% and more. [Persinos 85]" Even if they are willing to pay very large sums for product liability insurance, manufacturers are often unable to locate a carrier willing to cover the new product [Jubak 86]. As an example of the impact of the rising cost of liability insurance, "18% of the price of a ladder was due to product liability costs [Barry 85]."

Patent rights to an innovative product or process encourage the manufacturer to develop an innovation. Although there may be ways for the competitor to work around the barriers created by patents, they often create propriatory positioning in the market for the developer.

Also, "government regulations (by local, state, or federal agencies- impinge on the [acceptance] of nearly any product. Increasingly, companies are forced to take into account whether a proposed product can meet these regulations) e.g. as to the size, weight, design, safety, physical features, modes of advertising, promotional claims [McGuire 73]" or warrenty requirements.

The manufacturer may also have to consider the costs of code acceptance of an innovative product in deciding whether or not to develope and market it.

4.2.6.3 Builder

The legal considerations that are of the greatest concern to the builder are building codes and liability in the event of a construction failure.

An innovation that does not require code approval will disseminate more quickly than one that must move through the hierarchy of code approval andadministration.

Many home builders do not carry liability insurance because they cannot afford it. Therefore, builders are especially averse to trying an innovation which might cause liability problems.

4.2.6.4 Home Owner

This criteria does not apply to the home owner.

4.2.7 Organizational Support

4.2.7.1 Definition

The organizational support of an innovation involves the acceptance or non-acceptance of an innovation by the members of a company or a building crew. The lack of organizational support for innovation in the home building social system as a whole is a detriment to the introduction of all types of innovation into the industry.

4.2.7.2 Manufacturer

The manufacturer must have organizational support for a new product for it to be successful. Most problems of this sort arise on the distribution level where the burden of disseminating the innovation is left to salesmen who may be unfamiliar with both the product and the market to which it is sold.

4.2.7.3 Builder

The builder must have organizational support from his building crew in order for an innovation to be successful. For many innovations, this support is very difficult to gain from crew members, partly because home building is very traditional, and partly because many construction workers see innovation as a threat to their proprietary building trade positions.

4.2.7.4 Home Owner

This criteria does not apply to the home owner.

4.3 Marketing Criteria

For any innovation to succeed, it must satisfy or create a market need. Understandably, market considerations are regarded as critical in judging innovations. The characteristics of marketing criteria are:

- Market Size and Expected Company Share
- Market Growth
- Market Positioning
- Effect on Existing Product Line
- Competative Status
- Distribution Characteristics

4.3.1 Market Size and Expected Company Share

4.3.1.1 Definition

Market size refers to the total annual demand for a type of material, product or process, ussually measured in dollar amounts. The expected company share is the anticipated percent of the market the company will capture.

4.3.1.2 Manufacturer

The market size and the expected company share of the market will help define whether a manufacturer will be willing to invest in the development of an innovation. If the volume production anticipated is less than is practically acceptable in terms of scales of production and return on investment over time, the manufacturer will decide not to produce the product.

4.3.1.3 Builder

The market size and expected company share of the market affects the acceptance of innovation by the builder. Because both the market share and size shift drastically with the cycles of the home building industry, builders are unlikely to adopt an innovation that requires a stable, predictable market to be cost effective. This discourages the acceptance of any innovation that requires a large capital investment.

4.3.1.4 Home Owner

This criteria does not apply to home owners

4.3.2 Market Growth

4.3.2.1 Definition

It is most logical to introduce a product into a growth industry. The market for an innovation should be growing at a rate at least equal to the growth of the economy [GNP] [McGuire 73], whether that growth is due to growth of the industry or due to the displacement of an older products.

4.3.2.2 Manufacturer and Builders

One of the reasons there are few innovations introduced to the home building industry is that the industry's cyclical nature make it difficult for builders and manufacturers to be sure of a sustained market for a new product.

4.3.2.3 Home Owner

The home owner owns a product that's value is increasing faster than the growth of the economy. The owner of the home can be fairly sure that in adopting of an innovation that increases the quality or value of the home, that the increase in value in terms of comfort and other attributes will be recoverable upon the sale of the home.

4.3.3 Marketing Position

4.3.3.1 Definition

Market position is how a producer defines the product and how the product is positioned within the segmentation of the market. In defining a product the producer defines the characteristics of the new product or process in terms of its advantages and price.

4.3.3.2 Manufacturer

A manufacturer is more willing to produce an innovative product or process if it fills a currently unfilled market niche. "Stratagists often seek out 'weak spots' where real or latent needs are not being met. [McGuire 73]"

4.3.3.3 Builder

For the builder, defining the market position of an innovation requires an understanding of the home owner's perceptions and expectations. A builder, in understanding what his market of home buyers is willing to pay for, can evaluate an innovation for the characteristics neccessary to create a successful market position.

4.3.3.4 Home Owner

Similar to the builder, the home owner, in understanding the perceptions and expectations of prospective home buyers, can evaluate an innovation for characteristics that might create a special market niche in the sale his home.

4.3.4 Effect on Existing Market

4.3.4.1 Definition

Unless a builder is moving into a totally new segment in housing construction, or the manufacturer into a new market, the introduction of an innovation will probably have an on impact the existing structure of their respective organizations.

4.3.4.2 Manufacturer

"Unless a company is moving into entirely new areas, it is seldom that a [innovation] introduction will be 'neutral' in its impact on the company's existing product line. [McGuire 73]"

The manufacturer must determine if the introduction of an innovative product or process will serve to 1) enhance the existing product line, perhaps "strengthening the firm's position as a supplier of first choice" or 2) 'cannibalize' the existing product line, "with the new product simply switching sales dollars from one of the company's standard products....In some reported instances, this situation has occured before a company has realized satisfactory return on its investment in the products made obsolete [McGuire 73]."

4.3.4.3 Builder

The builders acceptance of an innovation may redefine the structure of his market and crew. For example, an innovation that greatly increases production rates may cause the builder to redefine his target market from custom homes to subdivisional tract construction.

4.3.4.4 Home Owner

This criteria does not apply to home owners.

4.3.5 Competative Status

4.3.5.1 Definition

The competative status of a proposed innovation is defined by the characteristics of the direct and indirect competition in the market, relative to the competative advantages of the innovation.

4.3.5.2 Manufacturer

In the decision to market an innovation, the manufacturer must weigh the characteristics of the innovation against its prospective competition. "Some proposed products are disqualified because of the competition they would encounter from superior products already on the market, or because they would pit against competing suppliers already entrenched in the market [Mansfield 75]."

In the case of an truly new innovation, the manufacturer must access the "lead time" available before competative products appear on the market.

4.3.5.3 Builder

In manufacturing products for the builder, the manufacturer must look deeper than brand loyalty in evaluating the possible competative advantage that a product may have over an existing system or product. Home building is a traditional industry. The 'entrenchment' of existing building practices exist independent of brand loyalty making it difficult to evaluate the competative status for some products.

4.3.5.4 Home Owner

Often, when a manufacturer considers marketing a new product, marketing surveys help to define the competative status that the innovation will have.

4.3.6 Distribution Characteristics

4.3.6.1 Definition

Regardless of the positive attributes an innovation may posess, without an effective distribution system , the innovation will most likely fail. The dissemination of the innovation, or the distribution of the idea of an innovation, also affects its success.

4.3.6.2 Manufacturer

Most often, the appropriate method for distributing an innovation is already available to the manufacturer. The sophistication of the distribution system for an innovation defines its exposure, reflecting upon the speed of dissemination. Process innovations may represent the exception to this case. A process innovation in building often requires the distribution or dissemination of the concept along with, if not preceeding, the dissemination of the process. Often process innovations disseminate slowly because there aren't national producers encouraging the adoption of the innovation through advertisements and change agents.

4.3.6.3 Builder and Home Owner

The successful distribution of innovation to the builder and home owner requires the successful distribution of information about the innovation. After awareness, the responsibility of the distribution system is in making the innovation available to the consumer.

4.4 Financial Criteria

The financial criteria used in determining the innovations probability of success include:

- Overall Profit Contribution
- Return on Investment and Total Investment Requirements

- Profit-Risk Ratios

- Effect on Cash Flow

4.4.1 Overall Profit Contribution

4.4.1.1 Definition

The overall profit contribution is the potential impact the acceptance or development of an innovation will have on total profits.

4.4.1.2 Manufacturer

An innovation must represent an overall increase in profits for the manufacturer for investment in its development to be justified.

4.4.1.3 Builder

Similarly, the use of an innovation must represent an overall increase in profits for the builder to justify investment of time and money into adopting the innovation.

4.4.1.4 Home Owner

An innovation must represent overall profit on some level (e.g. increased comfort, value added to the home, etc.) for it to be adopted by the home owner.

4.4.2 Return on Investment and Total Investment Requirement

4.4.2.1 Definition

The return on investment is the "amount of income obtainable from a given investment" and the total investment requirement is the amount of investment required in the development of the innovation (e.g. investments in research and development, manufacturing, distribution and dissemination).

4.4.2.2 Manufacturer

Most manufacturers have policies relating to the minimum acceptable internal rate of return for a new product. These policies may require a specific yearly rate of return on investment, or they may require a minimum lifespan profit contribution. Also, companies often have policies relating to the maximum allowable investment requirements of a product, based on expected profits and other criteria.

4.4.2.3 Builder

Although most home builders do not develop a formalized approach for determining the probable return on investment created by the acceptance of an innovation, they do decide whether to adopt an innovation from the perspective of experience.

The total investment requirement for the adoption of an innovation by the builder must be low. More often than not, a builder does not have capital to invest. In the case where capital is available to the builder, he is often not willing to invest in a new product or system because the return on investment is not assured in the highly volatile home building market.

4.4.2.4 Home Owner

The home owner, in viewing the home as an investment, is interested in the total investment required in buying the home and the rate of return due to increases in the value of the home.

4.4.3 Profit Risk Ratio

4.4.3.1 Definition

There is inherent risk of failure associated with the introduction of every innovation. A profit risk ratio attempts to analyze and evaluate the probability of profit vs. the probability of failure.

4.4.3.2 Manufacturer

The profit risk ratio evaluation systems used by manufacturers varies greatly, although there is a trend toward risk averseness in producers of goods for the home building industry. This trend may be due either to increases in the cost of failure, or to the maturation of American industry. The maturation arguement is that, as a manufacturer and industry matures, it gradually shifts its focus to maintaining market share, away from the development of new products.

4.4.3.3 Builder

The level of risk a builder is willing to accept is very low. The home building market is very competative and the profit margin is very small. Builders are not willing to risk what little profit they can be assured of using the buiding practices and materials they are already familiar with.

4.4.3.4 Home Owner

This criteria does not apply to the home owner.

4.4.4 Effect on Cash Flow

4.4.4.1 Definition

High cash flow or liquid asset requirements of an innovation negatively affects its development and adoption during periods when the availability of money is low or the cost of money is high.

4.4.4.2 Manufacturer

During the seventies and early eighties cash shortages "compelled some managers to take a much closer look at the cash flow characteristics of new-product candidates. This, of course, tends to put increased emphasis on the 'quick winner'- the entry tht can soon reach its break even point. [McGuire 73]"

4.4.4.3 Builder

Builders are reluctant to adopt any product or process that might create problems with their project cash flow. The builder is ussually working within strict budget guidelines. Often these are defined by the nature of their construction loan.

4.4.4.4 Home Owner

It has become apparent in the last fifteen years that new home buyers are willing to forgo current cash flow in return for anticipated profits from the increased value of the home. Unfortunately for many perspective home owners, their current cash flow precludes them from qualifying for the loans needed to buy a home.

Chapter 5

Case Studies of Innovations in Home Building

5.1 The Energy Crisis

In 1973, an energy crisis began, driving up the cost of fuel oil. This increase in oil costs continued through the 1970's, eventually representing a fifteen fold increase in the price of oil from 1970 to 1981. Correspondingly, energy prices increased. "The average residential electricity bill has more than tripled during the past 15 years, an increase considerably greater than the general inflation rate [ESD 86b]." The difference in the relative increases in the cost of fuel oil and the average cost of electricity is due to the fact that 1) much of our electricity is generated with coal and natural gas and 2) that energy production represents the most capital intensive industry in the country. Exemplifying this, a spokesman of Cambridge Electric, which uses oil for 70% of their electricity production, claims that their rates have been constant during the 1980's in spite of a 50% drop in oil costs during this period because of increases in overhead costs,.

5.2 Response to the Energy Crisis

In response the energy crisis the country as a whole became acutely aware of the consumer's and the industry's dependence on energy and their vulnerability to fluctuations in the cost of oil on the world market. In the last fifteen years much has been done to increase the energy efficiency of America. A report by the American Council for an Energy Efficient Economy points out that "if we were still consuming at the rate of 1973 we would be spending an additional $150 billion per year for energy [in the U.S.] [American 86a]." The first two case studies on 1)energy efficient appliances and 2) low emmisivity coatings for windows are representative of the developments in technology encouraged by the energy crisis.

5.3 Case Study: Energy Efficient Appliances

The energy crisis created a catalyst for impressive increases in the energy efficiency of appliances. "For a number of [appliance] product catagories, today's best available technologies are at least twice as efficient as typical [appliances] in the [existing] housing stock [Geller 86a]." The impact of increased efficiencies is quite substantial when one considers that even today "residential appliances and heating and cooling equipment consume about one third of the electricity produced in the United States [American 86]." The premium paid for energy efficient appliances is ussually recovered within the first half of the expected service life of the appliance (Table 5-I).

5.3.1 Government Policies

Due to the energy crisis, the government adopted several policies geared toward increasing the energy efficiency of the home. Policies which encouraged the development of innovations in energy efficient appliances included 1) the Energy Policy and Conservation Act of 1975 and 2) the allocation of approximately $3 million a year for research and development of energy saving technologies for buildings [Geller 86b].

The Energy Policy and Conservation Act of 1975 called for the testing, rating and labeling of major appliances. These ratings were designed to provide the consumer with information about the operating costs of major appliances. The assumption was that an informed consumer would create a market pull for more efficient appliances. The labels also eliminated the possibility of unsubstantiated claims of energy efficiency by appliance manufacturers.

THE COST EFFECTIVENESS OF SOME HIGHLY EFFICIENT APPLIANCES(1)

MODEL	INCREASED FIRST COST (1985$)	SIMPLE PAYBACK PERIOD (YRS)	AVERAGE LIFETIME (GENERIC) (YRS)
ELECTRICAL EQUIPMENT			
Whirlpool ET17HK1M refrigerator/freezer	60	2.3	20
Protoype heat pump water heater(2)	100	3.7	13
Two-stage evapor-ative cooler(3)	400	6.4	12
Prototype heat pump clothes dryer	300	7.7	18
GAS-FIRED EQUIPMENT			
Condensing gas furnace(4)	1200	7.9	-
Prototype pulse combustion water heater(5)	550	6.0	15

Source: American Council for an Energy Efficient Economy (1) Based on the 1985 national average electricity and gas prices. (2) Assuming 60 gal/day of hot water consumption (family of 4). (3) Assuming a low cooling demand of 12 MBtu/yr. (4) Assuming a typical space heat load of about 60 MBtu/yr.

Table 5-I: The Cost Effectiveness of Some Highly Efficient Appliances

5.3.2 Rating System

According to the American Council for an Energy Efficient Economy (ACEEE):

"The energy ratings are based on the standardized product tests that manufacturers are required to conduct on their products. The same test ratings are used to derive the mandatory energy cost and/or efficiency labels now found on most home appliances. The list for "white goods" (refrigerators (r/f), freezers, clothes washers and dishwashers) include the estimated average annual energy cost appearing on the FTC [Federal Trade Commission] label, based on [the national average for energy costs during the previous year]....Only an efficiency rating is given for furnaces, boilers, water heaters, air conditioners and heat pumps", as the total operational costs of these appliances are lifestyle dependent.

"Appliances not rated are ranges, ovens, clothes driers, solar water heaters, wood stoves, tankless water heaters, portable space heaters and air to air heat exchangers [American 86]."

The appliance manufacturers responded to the labeling requirements by investing in the research and development of energy efficient appliances. According to Howard Geller, Associate Director of the ACEEE, there were "no fundamental discoveries or new patents" in the development of energy efficiency of appliances in the 1970's. Similarly, Mr. L.B. Metcalf of Whirlpool Corp. believes that the technologies for energy efficiency were available prior to the energy crisis. Mr. Metcalf also believes that the high energy costs and the mandatory rating system encouraged the development of efficiency where before, the minimal percent of the market gained through the introduction of efficient appliance design would not justify the research and devlopment dollars required to create the technology. Geller agrees that:

> "manufacturers have limited incentives to conducting research and development on their own due to 1) the risk of failure, 2)the cost, 3)the limited competative advantage they recieve in today's industrial world where successful innovations spread rapidly and 4) the fact that modest tax incentives provided for industrial research and development may be ineffective [Geller 86b]."

The government was also involved in the development of energy efficient appliances through its investment in the research and development of energy efficient technology for the home. As an example of the influence of government involvement in the timely development and dissemination of technology, the ACEEE cites between a 1000:1 to 13000:1 ratio of rate of return in consumer energy savings for the dollars invested in the DOE energy conservation research efforts.

5.3.3 Refrigeration Technology

One research project funded by the DOE helped in developing a more energy efficient condenser for refrigerators. This research benefitted both the consumer and the appliance manufacturer as the compressor, which represents 70-85% of the energy demand in the refrigerator [American 86b], are not normally produced by the appliance manufacturers. In some cases, according to an industry spokesman, appliance manufacturers bought compressor manufacturers in order to direct research for more efficient compressors. Working with the Oak Ridge National Laboratory which was funded by the Department of Energy, "Kelvinator was able to increase compressor efficiency by 44% [American1]." Other improvements in refrigerator technology include; 1) the use of humidity sensor on manual defrost refrigerators in place of timed cycles, 2) the use of poured foam insulation in place of fiberglass, and 3) improvements in the efficiency of the motor. The importance of these improvements becomes apparent when we consider that even today, refrigerators use 7% of all the electricity produced in the United States [American 86].

> "The most efficient mass produced two door refrigerator freezer with automatic defrost made in the United States in 1986 is a 17.2 cu. ft. model that consumes 750 kWh/ yr. according to the standard test proceedure. This model, the Whirlpool ET17HK1M features an improved motor compressor (made in Brazil), more efficient fan motors and 1.5-2.5 inches of foam insulation. It consumes 50-60% less electricity than the standard refrigerator/freezers built in the United States 10-15 years ago. [Geller 86a]"

These refrigerator/freezers (r/f) cost $60 to $100 dollars more than todays standard models but the simple pay back for the premium in energy savings should be realized within 2.3 to 4 years.

Ironically, according to Mr. L.B. Metcalf of Whirlpool Corp., the most efficient appliances recieve the most customer complaints. Companies recieve numerous calls complaining that the refrigerator "is on all the time and must be using too much energy". [3] This specific problem is a good example of how, sometimes, when the manufacturer/builder provides a product for the consumer with specific advantages or qualities deemed desirable, the consumer does not understan the mechanism which creates the quality or advantage.

Looking to the future: Japan and Denmark are producing refrigerators that require 2/3 the energy of our best available model using multiple compartments and compressors. Also, evacuated panel insulation, which would reduce heat gain through the walls, is being researched for future use. [Geller 86a]

5.3.4 Dishwashers

The second largest use of energy in the home is in the heating of water. Dishwashers use one seventh of the hot water in the home, and requires the highest temperature (140 degrees F.). To accommodate the need of the dishwasher, water heaters are often set at this temperature. Now, boosters within the dishwasher allow the incoming water temperature to be 110-120 degrees F. The booster heats the water as it comes into the dishwasher, much like the demand hot water heaters. This allows people to lower their hot water storage temperature and save money on their energy bills. Energy saving features such as an air dry option and energy saving wash for semi-dirty dishes, have also become available to the consumer since the energy crisis. [ESD 86b]

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[3] The most efficient compressor is one that is correctly sized for the refrigerator and runs all the time.

5.3.5 Heat Pumps

Heat pump technology works along the same lines as a refrigerator. It removes heat from the cooler side of the cycle through a gas expansion process and deposits the energy on the warmer side of the system as heat through compression. Heat pumps are now being developed and markets for space heating, water heating and clother drying. All heat pump systems appear to save 50% in electrical costs over standard electrical appliances. They are not selling well though, as their initial cost is high and their pay back period are from 3 to 6 years [Geller 86a].

5.3.6 Efficient Combustion Heaters

Improvements in the combustion space and water heaters, have brought the efficency of some appliances up to 97%. This technology is based on controlling the flow of air through the combustion systems. In the past, the air flow was left to natural venting, requiring a degree of safety which allowed 50% more air in the combustion chamber (and 50% more air to carry heat outside in loss) than was needed for the process. Now fans control the air flow, reducing heat losses and increasing the efficiency up to 30%. Air controls also decreases the venting requirements, sometimes allowing immediate return on investment in new construction by eliminating the requirement of a chiminey or flue. [Lewis 86]

5.3.7 Dryers

Although dryers do not come under the jurisdiction of the energy rating system, there have been some improvements in their energy efficiency. As mentioned previously, research is ongoing in the development of heat pump driers. Also, one major appliance manufacturer has invested in the development of microwave clothes drying systems. The producer anticipate that the microwave dryers will be cost competative with existing dryers while using half the energy and taking half the time to dry clothes as the standard clothes dryer [Geller 86a].

5.3.8 Air Conditioners

According to studies done by the appliance industry, air conditioner sales are the most effected by the energy rating system. One source speculates that this might be due to the observable increase in the electricity bill during the summer months. While refrigerators use more energy, their use of energy is constant, and therefore, not as observable.

Ironically, although there have been some improvements in the heat exchangers and the compressors on air conditioners, "The efficiency of top rated models have improved only slightly since 1983 [Geller2]."

5.3.9 Mandatory Requirements for Appliances

Recently, there has been legislation proposed in congress to create a mandatory minimum energy efficiency standard. There are two chief causes for this movement toward federal restrictions of appliance energy consumption; the consumer market has failed to drive the market toward higher energy efficiency, and since the implementation of the appliance rating and labeling in 1980, some states have created incongruous values for their mandatory minimum energy efficenct standards for appliances.

As stated earlier, it was thought that the consumer would continue to drive the market toward energy efficency in appliances after the energy efficency standards were implemented in 1980. This has not been the case for most appliances. Market research by Whirlpool Corp. found that the consumer is more concerned with features than with the energy ratings. Whirlpool has experienced limited success with even its most energy efficient refrigerator described above. Although, in a decision between two appliances with similar features, the lower energy rating of one might then influence the sales. The only market where the ET17HK1M seems to be selling well is in areas such as California, where the consumer recieves large rebates from the electric companies for purchasing energy efficient appliances.

Also, there is an increase in number of appliances bought by contractors for new homes. As stated in Chapter 1, the number of appliances included in the sales price of the home is steadily increasing. The contractor is generally more concerned with initial costs and probably would not be willing to pay a premium for an appliance that would pay back the extra initial cost in energy saving over time.

After the implementation of the appliance rating systems several states enacted their own mandatory minimum energy efficincy standards for appliances sold. Some of these standard are very stringent, as in California, precluding the market participation of smaller firms that cannot afford the research and development required to meet the standards. Differences, state by state, in the requirements of appliances is also hard on the industry as a whole. The eight major manufacturers of major appliances [working under 24 brand names], maintain national markets [Schultz 86]. Creating products differently for each state would be inefficient and costly.

If this proposal were to be adopted by congress, the government and the consumer would benifit at the expense of the product manufacturer. In requiring certain efficency standards, the government will shift the burden of research and development to the appliance manufacturer.

By 1990, the ACEEE anticipates that many appliances will require half the energy of those currently on the market [American 86b].

5.3.10 Application of Evaluation Criteria

5.3.10.1 Product Criteria

The relative advantage [*Newness*] of the rating system is that it made available to the consumer information on the energy consumption of most major appliances.

The technologies [*Technical Feasibility*] needed in developing energy efficient appliances were available to the appliance manufacturers prior to the energy crisis, but had not been pursued. Because the innovations represented improvements in an existing product, the production of the energy efficient appliances did not require many changes in the manufacturing process [*Fit with Existing Skills and Facilities*].

Legislation was passed legally requiring appliance manufacturers to rate and label their appliances for energy efficiency [*Legal Cosiderations*]. Because this legislation has been unsuccessful at creating market driven innovations in appliance efficiency the federal government is considering enacting legislation for minimum levels of efficiency.

5.3.10.2 Market Criteria

After the implementation of the rating system, manufacturers developed energy efficient appliances in response to an expected consumer demand [*Market Size*]. They believed that market demand would create a unique *Market Position* for energy efficient appliances. They believed that in order to maintain *Market Share* they would have to develop the technology available to them.

5.3.10.3 Financial Criteria

Because consumers have not responded to the energy rating system as expected, *Overall Profit* Contribution] offered by developing energy efficient appliances has been limited. Because of the high *Total Investment Requirement* associated with the development of the energy efficient appliances, it is doubtful that the industry will continue research without legislative mandate.

5.4 Case Study: Low Emissivity Technology

[4] As noted earlier, the energy crisis in the 1970's increased national awareness of the importance of energy conservation. The Department of Energy and local utility companies were active in educating the public in energy conservation practices. One of the areas of education emphasized through advertisements and pamphlets was in reducing the energy use in the home through insulative and window technologies. "One quarter of all energy used to heat and cool United States buildings is required to compensate for unwanted heat loss through windows. Windows are percieved as a weak thermal links relative to insulated walls and roofs [American 86b]."

The development of low emmisivity coatings, a passive solar technology, was initiated in the 1970's in hopes of developing the means to combat heat losses through windows.

Low emmisivity coatings are coatings applied to a transparent medium that exhibit selective transmission qualities. The basic qualities of the coatings are that they admit short wave solar energy and light while reflecting long wave radiant infra-red radiation [heat]. This allows light to come in through the window while reducing radiant heat losses. Short wave energy from the sun transforms to longwave radiation when it hits something non-transparent. The efficiency of these coatings is high. Soft low-e coatings incorporated into double paned window system are less expensive, lighter and more efficient than triple paned windows.

5.4.1 The Coating Processes

Currently there are two types of low emmisivity (low-e) coatings available, soft coats and hard coats.

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[4] Unless otherwise noted, information for this case study was provided by Tim Johnson, Research Associate, Dept. of Architecture, MIT.

Soft coats are silver based coatings applied to either glass or polyester using a sophisticated megatron sputtering process which produces uniform multilayer coatings. Sputtering involves placing the glass or film in a vacuum chamber that can be pumped down to "one millionth of a thousandth of an atmosphere [Smay 83]". The metal and the surface to be sputtered are put at different cathodes [electrical poles] in the machine. Then, a "gas or mixture of gases is admitted to the evacuated chamber". The gas is ionized by creating a potential between the cathodes, causing gas molecules to be shot against the metal cathode. Metal atoms are knocked off the metal cathode by these flying molecules and eventually condense onto the film or glass. Because the process involves technology at the atomic level, the system is highly controlled and accurate [Smay 83].

Hard coats are produced by a pyrolitic process. Using a tin oxide compound, the coating is mechanically sprayed "directly on the hot glass as it emerges from the float glass tank. This [process] has the potential of very low cost, but consistant control of the process parameters in the rapidly moving production line is difficult [American 86b]."

5.4.2 The History of Soft Coat Technology

The low-e soft coatings used today had their start during WWII. During the war metallic coatings for windows were developed, not for selective heat transmission, but to create a conductive surface on airplane cockpit windows. By passing an electrical current through the coating the window remained defrosted, unobscured by heating element bands. This original technology was called "Nissa" glass. It was originally available only in 18" squares, due to limitations in the production process which required that each piece be vacuum treated individually. The individual treatment of each piece made this a very expensive process.

In 1971, Tim Johnson and Day Chahroudi of MIT recieved limited funding from the National Science Foundation to investigate the selective transmission qualities of the Nissa glass.

5.4.3 The Development of an Economical Process

Independently, Day Chahroudi began work on developing an economical system for creating this low emmisivity coating. The process he developed was economical in that it was continuous. He placed a roll of mylar in a vacuum chamber, and slowly unrolling it during the sputtering process so that large volumes of the film could be produced in one production run. This technique had been used for other coating processes, but never with one where such a high degree of control was required.

5.4.4 The First Low-E on the Market

Meanwhile, in 1974 a European firm came out with the very first low emmisivity coating on architectural glass. This coating did not last long as it was too expensive to produce (gold coating) and was too reflective to be acceptable in the residential market.

5.4.5 Commercialization of Low-E Technology

In 1977, Day Chahroudi left MIT to form Suntech which was subsequently bought by Southwall Corp.. Southwall produced low emmisivity windows under the trade name of "heat mirror films". Shruddi's system involved suspending a coated sheet of mylar between sealed sheets of glass. Producing the film in house, Southwall contracts out propriatary rights to the use of coatings in windows to different window manufacturers. Although the original product had trouble with the suspension and sealing systems of the window, the current product line is durable and energy efficient.

5.4.6 Soft Coatings on Glass

In 1977, Southwall displayed the first prototype of the Heat Mirror windows in the MIT funded Solar Building on the MIT campus. In this same year, Airco, a company involved in producing welding supplies became interested in the low emmisivity coatings displayed in the Solar Building. Airco had already developed a continuous vacuum sputtering process [sputtering a continuous line of cooled glass sheets on a conveyer system] for another glass coating process and recognized the opportunity offered by the possible introduction of a low emmisivity coating on glass. Airco asked Tim Johnson of MIT to develop the architectural specifications for a low-e coating and within a year Airco had come out with their first glass coating low-e plant.

The first Airco sputtering plants to be used were in the United Kingdom and Sweden where energy prices were higher and energy technology more accepted than in the United States. The first large scale introduction of the Airco coated glass system to the U.S. was through a joint venture between Airco and Anderson windows, one of the largest window manufacturers in the United States [American 86b].

5.4.7 Large Scale Marketing

Anderson developed and implemented extensive testing of the low-e coating created by the Airco plant before marketting the product. Previous experience with coatings on windows were unsuccessful. There were problems with corrosion, peeling, splotching etc.. The testing techniques for the previous coatings were noncomprehensive leading to large losses for some coatings manufacturers whose products failed in the field. To avoid these historical problems with coatings, Anderson's testing methods were neccesarily rigorous and long term.

Finally, after three years of testing, Anderson put a low-e coated double paned window system on the market. Realizing that the public, too, was skeptical of window coatings, Anderson offered a 20 year warranty for the the low-e windows; ten years more than the warranty for its standard window line and four times the industrial average for a window warranty. Currently, the Airco glass coating system dominates the low-e window market. Although the glass coating systems are not quite as insulative as the heat mirror films, which create an extra air plenum by suspending the film between the glass surfaces [Gilmore

86], they are less expensive to produce than the Southwall system. Contributing to the preferential dissemination of the Airco system is the adoption of the continuous vacuum process by all the major window manufacturers.

5.4.8 Hard Coats Enter the Market

Within the last three years, hard coat low-e technology has been developed and is now being marketed. Untill recently, hard coats did not present a competative advantage over soft coats. Although the hard coats were sturdier than the soft coats, which require special handling, are hypersensitive to moisture, and corrode when exposed to the air [Best 85], they were less insulative and equivalent in price to the soft coats. The major market for hard coats had been in replacement/storm windows where the durability and ease of handling was put to best advantage.

Recently, a European firm, Sentinnel, has imported a hard coat process that is equally as insulative as the soft coat systems. Three large window manufacturers are now producing this new product and they anticipate that high volume production will bring down the cost, eclipsing the soft coat market share [Gilmore 86].

The major barrier to the adoption of the hard coats as seen by Tim Johnson of MIT, is related to the inherent limitations of the pyrolitic process. The pyrolitic process for applying coatings has been around for many years Mr. Johnson notes, and as long as the process has been around, there have been problems controlling the consistance of the application of the coatings. The process often leaves an unsightly oil like sheen on the glass. Mr. Johnson anticipates that it will take several years for the producers of hard coats to develop the technology to correct this characteristic of the pyrolitic process.

5.4.9 Boon in the Market

In 1980, a mere 1 million square feet of low-e windows were sold in the United States. Although statistics vary, the low-e market for 1986/87 is of the order 125 million square feet / per year. Following the current trend, low-e coating systems will have captured 50% of the window market within ten years of its full scale introduction in the United States.

5.4.10 Why Low-E Technology is So Successful

Low emmisivity technologies timely introduction to the market immediatly followed after the 1977 energy crisis, the second energy crisis of the decade. The involvement of the federal government in educating the public about energy saving technology during this period is thought to have cut five years off the dissemination process [American 86b].

Independent of its timeliness, the success of low emmisivity technology can be attributed to its effectiveness at creating comfort in the home at an affordable price, without condensation, while providing energy savings at the same time. It replaces movable insulation and shutters in cold climate markets at a cost savings. National marketing campaigns which focused on the the quality and comfort of the product, also encouraged its acceptance. Mr. Johnson believes that low-e coatings sell on comfort, not on energy savings, because the home owner is primarily interested in the comfort of the home.

5.4.11 Application of Evaluation Criteria

5.4.11.1 Product Criteria

The low-e coatings have a relative advantage [*Newness*] over other window products. They provide a comfortable environment in the home by reducing heat loss through the windows at a low cost.

Low-e windows are also compatible with existing building practices [*Fit with Existing practices and Skills*]. They can be installed in the same way as other pre-hung windows.

Ingenuity and existing technology has made the development of the low-e coatings *Technologically Feasible.*

The patent rights [*Legal Considerations*] to the various low-e coating systems assure a *Proprietary Position* for its producers.

5.4.11.2 Market Criteria

The low-e coatings created a unique *Market Position* by providing windows that fulfilled the market pull for lightweight, low cost, insulative windows.

The use of the existing window distribution systems [*Distribution Characteristics*] for the sale of the low-e window systems was instrumental in allowing low-e coatings to disseminate quickly into the market.

5.4.11.3 Financial Criteria

Without proprietary assurance, development of systems would have been discouraged. There would be a risk of competitors mimicking the idea, capturing market share before the development costs could be recovered through profits [*Return on Investment and Investment Requirements*].

The *Overall Profit Contribution* anticipated from the adoption of the low-e coatings influenced the acceptance of the processes and products. In the case of the glass soft coated product, Airco's financing of the successful application of the glass coating system by Anderson Windows provided proof of its overall profitability. The example of the success also reduced the risk [*Profit Risk Ratio*] percieved by prospective manufacturers in accepting the system.

5.5 Case Study: Vinyl Siding

The two previous case studies on energy efficient appliances and low emmisivity coatings technology, were representative of products responding to market pull. The following case study, vinyl siding, is representative of a product created in response to a technology push.

Polyvinyl Chloride, better known as PVC or vinyl, was first developed in the by B.F. Goodrich in the 1930's. Although today, vinyl producers have developed their own formulations, B.F. Goodrich still supplies the industry with the resins required for the production of vinyl.[5] The first vinyl produced was plastic in nature but within 10 years, rigid PVC, similar to that used in siding today was developed. The first large scale application of rigid PVC technology was in piping. By the late fifties/ early sixties B.F. Goodrich was casting about for a large tonnage use for their rigid PVC technology.

5.5.1 Creating A Market

Working from the precedent set by the asphalt [introduced in 1932] and aluminium [introduced in 1947] simulated siding products [Logay 87], Goodrich set about developing vinyl siding technology. According to Peter LLoyd of B.F. Goodrich, much time and money was invested in 1) developing a maufacturing process that could extrude the vinyl through thin slits to make the siding shape, and 2) in developing a weatherable vinyl formulation. Goodrich was farsighted in their invesment in PVC technology, as the manufacturing costs of PVC during the development of the siding product was extrememely high.

It was not until the early seventies, when aluminium siding costs began to increase, that vinyl siding became cost competative in the siding market [Logay 87].

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[5] Al Stoloff of M & T Chemicals

5.5.2 The First Marketing of Vinyl Siding

The first large scale production of vinyl siding employed the profile extrusion process developed by Goodrich and employed a formulation made up of "impact modifiers, pigment, resins, titanium dioxide, waxes and Ultra Violet inhibitors"[6] . The manufacturing process involved melting the ingredients into rotating cauldron, pushing out the semimolten mix into flat sheets which were then water cooled.

5.5.3 False Start

This first vinyl siding was of inconsistant thickness, subject of fading and unacceptably brittle. There was little choice in the number of colors and patterns available to the home owner. Dan Parks of Variform believes that vinyl siding industry suffered a bad reputation for many years because of the poor quality of the first vinyl siding product and the hard sale techniques employed by 'blue suede shoe' salesmen.

The false start described by Mr. Parks is characteristic of many innovations. Often innovations are marketed too early in their development process, or are subject to problems in service that were unanticipated during the product development stage [e.g. window films, poly butylene piping, prefabricated homes]. Sometimes the marketing blunder precludes the products reentry into the market [e.g. aluminium wiring systems].

5.5.4 Vinyl Siding Today

Now vinyl siding is made from improved compounds, utilizing improved pigments and resins. These products last longer (some offering lifetime gaurentees), with less fading. They are more flexible and impact resistant, important in both the installation of the product and during the service life, and are available in many shades and textures. It need never be painted and scratches do not show because the pigment is incorporated into the material.

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[6] Dan Parks of Variform, a manufacturer of vinyl siding.

Improvements in formulations have eliminated problems with the dents and puckers of earlier vinyl siding.[7] .

The manufacturing process has also been improved by the addition of a post-forming process, which has been adopted by 75% of the vinyl manufacturers. In this process, the material extrudes into hot flat sheets of controlled thickness onto a heated roller system which stretches the sheet to the correct tension. The hot sheet is then fed through a postforming system that produced uniform sheets 14" wide and from 37 to 45/1000 of an inch thick.

5.5.5 Technological Challenges

The major challange facing the vinyl industry today is in attempting to develop a darker tone product line. To date there have been several difficulties associated with the production and marketing of darker colors.

The largest barrier is the cost of the darker pigments. A darker vinyl siding produced by the conventional method and formulation would be outside the acceptable range of cost. Also, there are problems with the distortion of vinyl due to increased heat absorption of the darker pigments.

Darker vinyl sidings are now being produced that are cost competative through a production process called coextrusion. Coextrusion allows two similar or dissimilar pastics to be extruded together through a single die. The darker, and more expensive formulation, is coextruded onto a substrate of less expensive material.

The major problem with this system is that the lower layer of lighter colored material might show if the siding is scratched.

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[7] James McField of Variform

5.5.6 The Vinyl Siding Industry

Today, most producers of vinyl siding produce vinyl siding exclusively. Gone are the fly-by-night vinyl producers of the seventies. Today there are " 18 domestic vinyl siding manufacturers [Logay 87]" in control of the market. Dan Parks believes that vinyl producers must now produce a quality product in order to stay in the business because consumers choice in vinyl siding is now guided by brand name reputation.

This may be a sign of the maturity of the industry and the maturing of public expectations. New products that are complex, as in the case of vinyl siding with its varying formulations, tend to become brand name products rather than commodities.

5.5.7 The Success of Vinyl Siding

The success of vinyl siding is due to its cost competativeness. Vinyl has been decreasing in price relative to the price index of construction goods since the early seventies. Dan Parks of Variform states that over the last three years, the price of vinyl siding has actually gone down 10 to 15%! The impact of the low cost of vinyl is apparent when we compare the market share of 1971, 3.6%, to the market share of 1986, 16.5% (Table 5-II).

Regardless of the savings in cost, vinyl siding would not be successful if it did not meet the needs of the consumer.

The average homeowner, when surveyed by the NAHB, cited low exterior maintenance as the second most desired characteristic of their next home. Along the same lines, subscribers to Housing Magazine were surveyed in 1977 as to the most important factors in the selection of a siding material. In this survey, the three most important factors were found to be durability, price and weatherability. These indicators show that, if it were not for the general preference on the part of the consumer for traditional siding products, vinyl siding would gain a majority of the siding market share.

RELATIVE DISTRIBUTION OF SHIPMENTS OF SELECTED RESIDENTIAL SIDING PRODUCTS, 1971-1985

<table>
<tr><th></th><th colspan="5">PERCENT DISTRIBUTION</th></tr>
<tr><th>YEAR</th><th>HARDBOARD (1)</th><th>PLYWOOD (2)</th><th>BRICK (3)</th><th>ALUMINIUM (4)</th><th>VINYL (4)</th></tr>
<tr><td>1971</td><td>20.5</td><td>17.3</td><td>31.0</td><td>24.0</td><td>3.6</td></tr>
<tr><td>1980</td><td>26.4</td><td>15.6</td><td>20.7</td><td>15.2</td><td>11.5</td></tr>
<tr><td>1985 (5)</td><td colspan="2">58.2</td><td>16.2</td><td>7.2</td><td>16.5</td></tr>
<tr><th></th><th colspan="5">PERCENT CHANGE</th></tr>
<tr><td>1971-85</td><td colspan="2">+54%</td><td>-48%</td><td>-70%</td><td>+358%</td></tr>
</table>

Source:

Data for 1971 and 1980 prepared by American Hardboard Association.

(1) American Hardboard Association's *Supplemental Statistical Reports.*

(2) Bureau of the Census, Current Industrial Reports, *Clay Construction Reports.*

(3) American Plywood Association's *Statistical Reports.*

(4) Architectural Aluminum Manufacturers Association's, *Architectural Aluminum Statistical Review.*

(5) Prepared by Sabre Associates, Inc.

Table 5-II: Vinyl Siding Production

5.5.8 Application of the Evaluation Criteria

The relative advantages [*Newness*] offered by vinyl siding are its low cost and durability [*Service Requirements*].

B.F. Goodrich's previous experience with the development of the technology for rigid PVC piping improved the *Technical Feasibility* of producing the vinyl siding.

The vinyl siding technology is compatible with current home building practices [*Fit with Existing Skills and Facilities*]. When vinyl first became available, the aluminium siding industry had already developed the technology for applying a siding product to the home.

5.5.8.1 Market Criteria

The *Competative Advantages* of vinyl siding have created an growing *Market Share* for vinyl siding, with low cost and durability outweighing consumer preference for wood and brick (natural) siding materials.

The low cost characteristics allowed vinyl to take over the *Market Position* of low cost durability from aluminum siding in the 1970's when the price of aluminium increased.

5.5.8.2 Financial Criteria

The anticipated *Overall Profit Contribution* was large enough to justify the sizable *Investment Requirement* for the development of the manufacturing technology.

The example set by the aluminium siding's acceptance reduced the percieved risk [*Profit Risk Ratio*] associated with the development and marketing of vinyl siding.

5.6 Case Study: Permanent Wood Foundation Systems

Permanent (or All-Weather) Wood Foundations are a pressure treated structural wood and plywood panel foundation system. It "was developed in 1969 in a joint industry-government effort involving the United States Department of Agriculture, the National Forest Products Association (NFPA) and the American Wood Preservers Institute (AWPI). [AWPI 80]"

5.6.1 Concept Development

According to Dr. King of the NFPA, the technology for the permanent wood foundations expanded from the original concept of gravel footings proposed by the National Association of Home Builders (NAHB) Research Foundation. The idea of a gravel footing stemmed from an attempt to develop some means of dealing with the problem of leaky basements. Currently, a majority of the homes with full size concrete foundations have leaky basements. The theory proposed by the NAHB research staff was that gravel footers would allow for drainage of water away from the foundation walls and floor. This would eliminate the problem of water pressure build up in the soil surrounding the foundation.

Members of the NFPA determined that the concept of gravel footings would be compatible with the development of a below ground wood foundation system. A feasibilty study, designed to determine if a wood foundation system would be economically competative with concrete foundation system, was done by the NAHB Research Center and sponsored by the joint venture participants.

5.6.2 Prototype Testing

In 1969, three prototype homes were built in Lexington Park, Maryland. These homes conformed to the style and design of the surrounding housing tract which was built on concrete foundations. Not one of the prototype basements leaked. In fact, "findings of a survey of 61 wood foundation homes in the Northern U.S. and Canada revealed that not one of the surveyed homes had failed to withstand severe water conditions over a period of years." Conversely, concrete foundation "control" homes in the same housing tract as the prototype wood foundations "commonly experienced leakage problems" [AWPI 80].

The concept of wood below ground was not new . For many years pressure treated wood has been used below ground for utility poles and railroad ties.

5.6.3 Discription of the System

After the site of the foundation has been excavated, a minimum of 4" of gravel, coarse sand, or crushed rock is laid as a base for the foundation. At this point the prefabricated, pre-numbered foundation panels can be installed without special equipment. The sections, and the plywood joints created by the joining of two sections are sealed with caulking compound. Prior to backfilling, a polyethelene barrier is draped over the below ground section of the foundation, redirecting the water down the wall to the gravel footing.

The panels themselves are made up of a footing plate, bottom plate, wood studs, plywood, and single top plate. The general design of the panels is nothing more than a standard wood construction framing system. All material going into the panel that will lie below a mark eight inches above the soil grade must be pressure treated with preservative salts. Any raw surfaces created by cutting the preserved lumber must be coated with a paint on preservative [APA 87].

5.6.4 Advantages the All Wood Foundations

There are several advantages to the wood foundation system. For the builder, the wood foundation system saves time (and often money) and avoids the scheduling hastles associated with concrete subcontractors. The foundation does not require "furring out" when finishing the basement.. Finally, plumbing and wiring can be installed as it would above ground.

Wood foundations also improve the quality of the structure by creating more living space in the home. An insulated wood foundation system is several times as efficent as concrete foundations at keeping heat in. Also, wood foundation walls are thinner than their concrete or masonry counterpart, creating more square footage in the home [WPPC 85] [APA 87].

5.6.5 Barriers to Technology

There have been only two significant barriers to this technology, as pointed out by Dr. King of NAFP who was involved in the initial development of the system.

Firstly, builders must be convinced of the durability of wood in underground applications. Dr. King sites great difficulty in convincing builders that the treated wood will not rot.

Secondly, concrete subcontractors are actively against the adoption of the technology. The concrete subcontractors and the concrete workers unions have engaged in "major promotion programs to deprecate the [wood foundation] program". Fortunately, historically, union objections to technology acceptance have not blocked the dissemination of technology, but merely slowed it down.

5.6.6 Lack of Dissemination

Although there are many advantages to the permanent wood foundation, it has been slow to disseminated into the industry. The specifications for the system were complete by 1970. By 1982, it had gained code acceptance in a healthy 80% of the local jurisdiction surveyed by the NAHB. Why then, thirteen years after its initial introduction, is this system used in only 3-5%[8] of all new homes built?

One possible explaination may lie in the fact that the system is not as compatible with

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[8] According to Jay Hutton of the APA Marketing Division

existing building practices as was originally hoped. The specialized nature of the panel systems and the pressure treatment of the wood tends to encourage prefabrication of the foundation system. Cost effective implementation of the system requires experience, as well as technical and design know how[9] , discouraging the adoption of the system by the individual builder for fabrication on the site. Therefore, permanent wood foundation systems may eliminate one trade, the concrete subcontractor, replacing it with a new subcontractor, the producer of the permanent wood foundation panels.

5.6.7 Identifying the Problem

Even given the fact that wood foundation systems require subcontrators; the wood systems are still more efficient and convenient to install than a concrete foundation system. The wood foundation panels are easy to transport and install. They can be pre-delivered to the site, avoiding the scheduling hang-ups that are associated with the concrete subcontractor. Wood foundations are also cost competative with concrete systems in the regions where they are available.

The problem with the dissemination of the permanent wood foundation systems lies in the marketing of the idea. Until recently, the three groups involved in the dissemination of this technology, the American Plywood Association (APA), the American Wood Council (AWC) and the Southern forest Products Association (SFPA), have concentrated their efforts on encouraging the individual builder to adopt the technology. According to Dr. King, it has now become apparent that the rate of dissemination for this system is directly dependent on the dissemination of sub-contractors qualified to offer the wood foundation system to local builders.

This problem of dependence on qualified subcontractors in the dissemination of an innovative system is not unique. Any system innovation, which requires special equipment

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[9] Dr. King, NFPA.

or knowledge, marketed to a local market by a subcontractor, will disseminate slowly into the industry. As an example, one could note the engineered roof truss systems which took twenty years to disseminate into the home building industry.

5.6.8 Application of the Evaluation Criteria

5.6.8.1 Product Criteria

As seen by most builders, the relative advantages [*Newness*] of the PWF system does not yet outweigh the disadvantages. Although the system offers a dry, insulated, inexpensive foundation, many builders are uncomfortable using wood below ground because they fear it will rot.

The PWF system is compatible [*Fit with Existing Facilities and Skills*] with wood frame building techniques. Although the successful implementation of the system requires some experience and technical knowledge, it can be installed quickly on the site. The system allows flexibility in scheduling not available when using concrete sub-contractors.

In general, the builder cannot adopt the wood system without a subcontractor first adopting the manufacturing techniques. Herein lies the greatest problem with the dissemination of PWF technology: subcontractors cannot be distributed to the local markets as easily as a product can be distributed by the manufacturer [*Distribution Characteristics*].

The PWFs have not recieved much *Organizational Support* from manufacturers. Wood treating plants, the wood products manufacturers most likley to benefit from the acceptance of the PWF, have not put much effort into disseminating the PWF technology to would-be users.

5.6.8.2 Market Criteria

PWF technology has not yet been accepted by a significant portion of the home building community despite the fact that it was originally introduced over 10 years ago [*Market Share*].

The advantages of compatability, dryness and competative cost create a unique *Market Position* for the Permanent Wood Foundations in the areas where it is available. This market position encourages the dissemination of the innovation. The unique market position defined by its advantages assure that the eventual success of the PWF system.

5.6.8.3 Financial Criteria

The lack of interest on the part of the pressure treatment plant may be due to the low anticipated *Overall Profit Contribution* offered through the dissemination of the PWF technology. Most of the large pressure treatment plants, work on large contracts producing such things as utility poles and railroad ties. They do not believe that the profit created by encouraging the use of AWF would justify the cost of disseminating the idea.

Also, builders perception of the risk [*Profit Risk Ratio*] of rot involved in using the wood below ground has discouraged the acceptance of the system.

5.7 Case Study: Performance Rated Structural Panels

[10] The performance rating of structural panels has opened up new markets to non-veneer wood based panels. The code acceptance of the American Plywood Association's performance rating system represents an innovation in material useage. This was made possible by the effective implementation of a system that judges products by their performance in specific applications rather than by their manufacturing process.

5.7.1 The History of Plywood, the First Structural Panel

The first soft wood plywood plant was started on the West Coast in 1905. Within 20 years, 12 plywood plants were producing 150 million square feet of plywood a year.[11] The producers of plywood, who at this point were mainly situated on the west coast, banded together to form the Douglas Fir Plywood Association in 1933. This organization developed industry standards for the production of plywood products. This first standard was prescriptive in nature. It "defined how a minimum standard product was to be manufactured. It specified bonding systems, materials, dimensional tolerances and the physical and mechanical properties of the panels [Montrey 82]."

Production quantities of plywood remained stable until WWII. During the war it was used by the military for the construction of airplanes and buildings. During this period,. plywood established itself as an acceptable structural panel material. By the 1950's, plywood was the "dominant structural panel used for light frame construction [Montrey 82]", and was busily gaining marketshare from the lumber industry.

In the 1960's, the price of the raw material that made up the original west coast

[10] Unless otherwise noted, the information for this case study was provided by Dr. M.R. O'Halloran and other employees of the American Plywood Association.

[11] The volume measurement of plywood is based on normalizing square footage values to a 3/8" thickness standard.

plywood, Douglas Fir, began to rise. One plywood manufacturer, Potlatch Forest Industries, after facing numerous technical difficulties, developed a system of manufacturing plywood using an alternative raw material, Southern Pine, which is abundent in the Southern portion of the United States. Other firms followed the example set by Potlatch Forest Industries, and in 1964, the DFPA became the American Plywood Association, incorporating western and southern plywood manufacturers into one of the first national manufacturing trade organizations.

5.7.2 The Development of the First Non-Veneer Structural Panel

The first alternative structural panel, waferboard, was first produced in Canada in 1966. In the early 1960's, the government of Alberta Canada in looking for some way to capitalize on its abundent, but previously valueless Aspen wood resource, encouraged the development of waferboard technology.

Aspen, a low density hard wood, flakes easily and its low density makes it suitable for compaction into the waferboard product. "The [waferboard] product is composed of rather large sqarish (2" X 2" to 3.5" X 3.5") wafers. These wafers are flaked from round wood and generally bonded together with powdered phenolic resin. Waferboards are typically produced in three random layers, with the largest flakes, possessing the best mechanical properties, laid on the faces of the panel, with the fines and other smaller flakes being utilized as the core material [APA 83]."

The government of Alberta further encouraged the use of the new waferboard product by accepting it into the building code immediately, bypassing the normal testing and review process.

5.7.3 Other Non-Veneer Structural Panels

Comply, Oriented Strand Board (OSB), and Structural Particleboard are three other non-veneer structural panels used today.

Comply, developed in 1976 is a hybrid panel that is composed of either an oriented stand or a waferboard core sandwiched between veneer face panels. This product looks like plywood, and is in fact, almost as expensive to produce due to the veneer material and the complicated production method.

Oriented Strand Board (OSB) is a relatively new technology, manufactured first in 1981. OSB is made up of wafers of wood whose length is much greater than their width. The strands of each layer of the board are oriented in one direction and are perpendicular to their adjacent layers, creating uniform strength and structural properties similar to plywood. There are several advantages to OSB.

> "Whereas powdered phenolic resins are used as adhesives in waferboard manufacturing, OSB is currently bonded with a phenolic resin which is applied in the liquid state during manufacturing. The liquid type of adhesive application technology has advantages over powdered technology in the area of product performance and process economics [Montrey 82]."

Also, OSB plants are highly industrialized, requiring half the staff of plywood facilities producing equal volumes of product.

Structural particleboard, although worth mentioning, is not economically competative with the other non-veneer structural panels. It is made of "the residue of other solid wood processing operations. Such products typically will gain their additional strength and stiffness from either higher resin content and/or additional product thickness along with increased density [APA 83]."

5.7.4 The Need for an Alternative Structural Panel

The development of performance standards for structural panels was encouraged by producers of plywood and non-veneer structural panel producers in response to the increases in the cost and decreases in the quality of plywood.

"The cost of timber throughout the seventies and into the eighties escalated beyond inflation rates [Montrey 82]", driving up the cost of timber products, such as plywood. Waferboard and Comply, and later Oriented Strand Board (OSB), offered savings to the manufacturer in raw material costs. Aspen and similar wood used in the production of these panels is an inexpensive raw material source. Also encouraging the use of alternative panels was the diminishing stock of timber suitable for producing quality veneer for the production of plywood.

Given these incentives, the APA began work on developing the performance standard in 1976.

The performance standard specified end use performance of panels used for specific applications in construction. The end uses applications analyzed in the original APA performance standards were single-layer flooring, sheathing with respects to roofs, subfloors and walls, exterior siding, and concrete forming. To date, only the flooring and sheathing standards have been accepted by the model codes. Research and development for the exterior siding and concrete forming standards are still under way [APA 87].

In the performance rating system, " the panel performance is evaluated through testing for structural adequecy, dimensional stability, and bond performance." A more rigorous description of these requirement is available in references [O'Halloran 84] and [APA 83].

5.7.5 Performance Panel Acceptance

Acceptance of the performance standards came in 1982. The Council of American Building Officials (CABO), " recognized the APA Performance Standard [for flooring and sheathing] under their National Research Report NRB-108 [O'Halloran 84]."

CABO represents a joint venture of the three major building code groups, the Southern Building Code Congress International (SBCC), the Building Officials and Code Administrators International, Inc. (BOCA), and the International Conference of Building Officials (ICBO). The NRB research report constitutes approval by CABO and the three major model code agencies. "Subsequent regional acceptances have since been secured by the APA technical staff [APA 83]."

Certification of the performance of a structural panel is approved following successful evaluation by the Amercan Plywood Association. The certification is symbolized by an APA Performance-Rating Registered Trademark which is printed on the panel. This Peformance rating involves the acceptance of the specific production system of a given panel being reviewed. "This individualized mill specification is unique to the mill and product qualified under the performance standard. .....The mill specification serves as the quality assurance document for future evaluation [APA 83]."

By 1985, over 150 panels had recieved performance rating from the APA. Waferboard and OSB sales have increased more than tenfold from 1980 to 1985 (Table 5-III). In March 1984 it was estimated that approximately 60% of the total sheathing production in the United States was produced under the APA Performance-Rated concept.

5.7.6 Application of the Evaluation Criteria

PRODUCTION OF STRUCTURAL WOOD PANELS IN THE UNITED STATES: 1980-1986

YEAR	OVERALL PROD.	WAFERBOARD & ORIENTED STRAND BOARD
	BILLIONS OF SQUARE FEET(1)	
1980	16.5	.2
1981	17.0	.3
1982	16.4	.6
1983	20.8	2.1
1984	22.0	2.1
1985	22.8	2.7
1986	25(est.)	3.5(est.)

Source: Jay Hutton, Marketing Division, American Plywood Association.

(1) The volume measurement of panels is based on normalizing square footage values to a 3/8" thickness standard.

Table 5-III: Plywood, Waferboard and Oriented Strand Board Production

5.7.6.1 Product Criteria

The advantage [*Newness*] of the performance rating system is that it legally redefines [*Legal Considerations*] wood panels production process to be more compatible with *Existing Facilities and Skills.*

The code acceptance allows the manufacturer to tailor his product to his manufacturing system [*Technical Feasibility*].

5.7.6.2 Market Criteria

The *Market Share* of non-veneer structural panels is now doubling each year which is significant in this 25 billion sq.ft./year industry.

The performance rating system defines a *Market Position* for non-veneer structural panels. These panels can now be used in applications previously reserved for plywood, at a savings of from $.50 to $1.00 per panel [*Competative Status*].

5.7.6.3 Financial Criteria

This system has created *Overall Profit Contributions* for both the manufacturer and the builder. The manufacturer can now develop the most cost effective way to produce the desired end use performance characteristics. This savings in production cost will be passed on, creating a cost advantage for the builder as well.

Chapter 6

Conclusions

The goal of this thesis has been to establish a criteria for evaluating innovations in the home building industry. In realizing this goal, this thesis has incorporated studies of the home building industry as a whole, its social systems, the characteristics of innovation, the adoption and dissemination processes, and case histories of innovations in the industry.

6.1 Synopsis

The American Dream is no longer affordable. The cost of the home has increased 51% in constant dollars over 19 years. Compounding problems for prospective home buyers, finance costs associated with the cost of the home have increased over 350% between 1970 and 1980. Interest rates are currently going down, but the gap between homeownership costs and household income continues to widen. Also contributing to the increase in the cost of the home, today's home has more floorspace, bathrooms and convenience oriented ameneties than ever before.

The home building industry is very volatile, experiencing increasingly severe swings in its economy approximately every seven years. In response to the cyclical nature of the industry, the home building firms are generally small and made up of a transient building crew that can easily move in and out of the industry. Although there has been discussion that increases in the cost of construction as whole are due to a 1.6% yearly decrease in productivity, there is good evidence that these statistics do not necessarily apply to the home building sector of the construction industry.

The social system of the home building industry is made up of the *home builder*, the *home owner*, the *government* and the *manufacturer.* The builder is interested in cutting the cost of construction while creating a product that the home owner will buy. The home owner is interested in the quality of the home he will recieve for a given amount of money. The manufacturer supplies goods for the home to both the builder and the home owner. The government regulates the industry through building codes and other local, state, and federal policies. Building codes are generally made up of both performance and prescriptive requirements, although the enforcement system preferentially accepts prescriptive building techniques. Although codes slow down the acceptance of innovation, they do not ussually prevent the eventual acceptance of a worthwhile innovation.

An innovation is an idea or product that is percieved as new by the individual. Innovations in home building can be innovations in products, materials or processes. They can be *breakthroughs* in technology or *incremental advances* affecting the *productivity* of the builder or the *quality* of the home. The impetus for the development of an innovation may be due either to a *market pull* or a *technology push.*

The characteristics of innovations are their *relative advantage*, *compatability*, *complexity*, *trialability*, and *observability*. Of these, the two most important characteristics are that an innovation must represent some relative advantage over the existing system or product, and that it be compatible with existing building practices and consumer lifestyles.

The adoption of innovation involves the movement through a series of steps or stages; the *awareness stage*, the *interest stage*, the *evaluation*, *trial*, and *adoption* or non-adoption. The most difficult and crucial step in the adoption process is the movement from evaluation to trial. The adoption of innovations is rare. Over 90% of new products released to the market are unsuccessful.

The dissemination of innovation refers to how an innovation diffuses through the industry. The factors which have the greatest impact on dissemination include; the length time it takes for the individual to move through the adoption process for the given innovation, the innovativeness of the social system, change agents and other personal and impersonal information sources. The mean time for dissemination of an innovation in home building industry is 15 years. The lack of innovativeness in the building industry's social system discourages the adoption and dissemination of innovations. The absence of a sector or organization within the industry to evaluate and encourage the adoption and use of innovation limits the acceptance of new products and systems. Because the industry is so disaggregated the manufacturer is generally dependent of his change agents and his efforts in advertising to disseminate innovations.

A criteria for the evaluation of innovation was presented and applied to five case studies. The five case studies included: innovations in the energy efficiency of appliances, low emmisivity coatings technology, the development of vinyl siding, the acceptance of performance rated structural panels and the development and dissemination of all weather wood foundation systems.

6.2 Rating of Criteria

Of the criteria presented in Chapter 4, those which have the greatest impact on the success of an innovation include:

- The Newness or Relative Advantage the innovation has over the existing system for the builder, the manufacturer, and the home owner.

- Fit with Existing Facilities and Skills for the builder and manufacturer, and compatability with consumer lifestyles.

- Market Size and Expected Company Share for the manufacturer to justify investment in the development of an innovation.

- Market Positioning for both the manufacturer and the builder, having the characteristics to create a market niche for the product or system.

- Distributional Characteristics of the innovation for the manufacturer.

- Overall Profit Contribution for builders and manufacturers, and comfort contribution for the home owner.

The criteria which are of the next level of importance include:

- Servicing Requirements must be minimized for acceptance by the builder, the manufacturer, and the home owner.

- Technical Feasability/ Complexity must be minimized for the builder.

- Legal Considerations, product liability insurance must be available to the manufacturer and code acceptance of the product must be available for both the builder and the manufacturer. Patent rights to the technology are important in creating proprietary positioning but not crucial to an innovation's success.

- Market Growth of the innovation, increasing profits for the builder and manufacturer.

- Competative Status an innovation may offer the builder and manufacturer and home owner.

- Return on Investment must meet the policies of the manufacturer and Total Investment Requirements must be low for the builder.

Those criteria which are important to the acceptance of innovation but not crucial include:

- Proprietary Position within the industry offered by the acceptance or development of the innovation.

- Organizational Support of the building crew and manufacturer's sales staff.

- Profit Risk Ratio in developing, manufacturing and using the innovation.

- Effect of Cash Flow , whether it meets policy requirements of the manufacturer or falls within the limits of the restricted cash flow of the builder and prospective home owner.

6.3 Conclusions

As illustrated by this thesis, innovations and the mechanism for the acceptance and dissemination of innovations in home building do exist. Although the model presented is not a definitive formula for evaluating the success of every innovation in the home building industry, it begins to illustrate the importance of the various criteria and their interplay in defining the success of an innovation.

Although there are many barriers to the success of innovation in home building, one can conclude that these barriers will not prevent the eventual acceptance of a worthwhile innovation.

The two largest barriers to the acceptance of innovation involve the home builder and the nature of the industry. These barriers are the lack of innovativeness on the part of the builder, and the need for a national forum for the identification, evaluation, and dissemination of innovations in home building.

One solution for dealing with these barriers might involve increased government interaction with the industry. The volatile nature of the industry is due to changes in interest rates and the availability of money. Other countries (Japan, Sweden), have successfully aided their home building industries by offering a buffer to the cycles of the economy through policies that stablize initial mortgages. These policies create a more constant housing demand, allowing builders to invest in innovation.

Effective government innvolvement in the evaluation, and dissemination of innovation may be the key to increasing the innovativeness of the builder. Organizations currently involved with the home building industry, the Department of Housing and Urban Development, the National Association of Home Builders, and the National Foundation for Building Sciences, do not adequately provide the builder a comprehensive forum in presenting innovations to the industry. Because the industry is fragmented and competative, and because each individual building company is small, builders are unable to organize their collective knowledge. For the health and future of the American home building industry, the government should take on the responsibility for organizing this collective knowledge, by providing the industry with resources for the effective identification, development, evaluation and dissemination of innovation.

Appendix A
Innovations in Home Building

The following is a list of innovations in materials, products and processes applicable to the home building industry.

- *Surface Bonded Masonry*; Stacked masonry blocks are surface bonded with a fiber reinforced cement mix [McClintock 86] [Cook 81].

- *Insul-Flex*; Stucco coating which can be applied to exterior insulation board [Cook 81].

- *Truss Framing*; Tilted up, complete profile, truss framing system [Cook 81].

- *Modified Stress Skin Panel*; This panel is foam and studs glued to exterior waferboad panels, allowing inspection of the interior of the panel [Hughes 85a] .

- *Polyurethane Panels*; These panels are a core of cellular polyurethane faced with fiberboard/plaster. These panels may be used as the structural system, eliminating the need for framing [Bliss 85] [Panelized 86] [Polyurethane 85].

- *Panelized Wall*; 4' by 8' wall panels made up of Polysyrene foam with integral steel studs [Martin 86].

- *Masonite I-Beam*; Structural panel used in Swedish factory built homes. Wood flanges and masonite web allow greater volume of wall cavity for insulation while creating a smaller thermal break [Schipper 85].

- *Ceramic Partitions*; Lightweight and sturdy, these interior partitions were developed in Japan where wood is a very limited resource [Japan 83].

- *Precast, Insulative Foundation Units*; This system uses concrete framing studs with precast holes for plumbing and electrical [Hughes 85a].

- *Structural, Lightweight, Insulative Concrete*; This type of concrete has a dryweight of less than 65 lb. per cu.ft. and a compressive strength of 1500-2000 psi. There are variations in innovation of lightweight concretes, including non-structural types [Concrete 86] [Walls 86].

- *Integral Siding and Insulation*; This is used for retro-fitting insulation [Layne 86a].

- *Spray-In Insulation*; This type of insulation provides insulation while creating a sealed air barrier [Brennan 85].

- *Freon Expanded Polystyrene Insulation*; This is a rigid board type of insulation that provides extra insulative value through the use of freon as the expansion gas [Hanke 86b].

- *Superinsulation*; Superinsulation is the concept and practice of producing a well insulated home. The "tight" construction creates a thoroughly insulated air barrier/envelope [Adams 86a] [Airtight 86] [ESD 86a].

- *Heat Recovering Ventilation Systems*; used in tight houses. These whole house ventilation systems are used with tight construction to insure safe indoor air quality. They recover heat from air leaving the home through heat exchangers [Schipper 85].

- *Thermal Wall System*; This type of wall system uses 'lego' type concrete wall form made of expanded polystyrene. It creates the forms and then remains in place to provide insulation [Hughes 85a].

- *Holographic Passive Solar Lighting*; By applying a holographic film to windows, light is redirected into the the interior of the building [Watts 84].

- *In Wall Active Solar Collectors*; These walls have heat light transmitting material on the exterior face. Particulate matter is blown around inside the wall during the day, passing heat to a storage system through a heat exchanger. At night the particulate matter acts as an insulator. This innovation is still in the development stage [Watts 84].

- *Photovoltaic Cells*; PV cells directly convert light to electricity [McCarney 86] [Baer 86] [Finneran 86].

- *Energy Efficient Home Appliances* [Geller 85a] [Geller 85b] [Geller 86a] [American 86a] [American 86b] [American 86] [Schultz 86] [Layne 86b] [ESD 86b]

- *Electric Heat Pumps for Home Heating* [Lewis 86] [Geller 86a] [Seisler 86] *Demand Hot Water Heaters*; These provide hot water when needed, saving energy lost through hot water storage tanks [Tankless 86] [Layne 86b].

- *Multiple Window Glazing*; There is market trend in the increased use of double and triple glazed window systems [Market 84].

- *Argon Window Insulation*, This window system seals argon, a clear insulative gas, in between the panes [Gaseous 86].

- *Low-Emmisivity Window Coatings*; These hard and soft window coatings restrict thermal conductivity [Best 85] [Better 85] [Gilmore 86].

- *Gaskets*; Gaskets between framing elements are a clean, easy to install method of creating air and vapor seals [Harr 86].

- *Polybutelene Piping*; This piping is bendable and inexpensive. It can be used for water and gas lines [Save 86] [Cook 81].

- *PVC/CPVC Piping*; PVC represents an innovation in code acceptance [Cook 81] [Extrude 84] [Save 86] [Code 86] [California 77].

- *Plastic Structural Elements*; Plastics as structural elements for construction have had limited use to date but it is important to recognize that the technology for the "all plastic home" has arrived [Wright 86] [Wigotsky 84].

- *Weatherable Plastics*; There is a new family of weatherable multipolymers that combine outdoor performance and economy [Wood 86].

- *Low Toxicity Plastics*; Low toxicity plastic technology may create new application for plastics in the home. These plastics have passed fire rating standards which define the fire characteristics of products safely used in the home [Lowering 85].

- *Sprinkler Systems*; Sprinkler systems are now cost effective in some residential construction [Ruegg 85] [Woodcock 86].

- *Rubber Roofing Membranes*; This is a rubber roofing membrane that is applied to the roof with adhesive and will last up to 100 years [Dupuis 85] [Rossiter 85].

- *Cordless Power Tools* [Cordless 86] [Smay 85a] [Hand 86]

- *Adobe Brick Equipment*; Produces over 600 adobe bricks per day on the site [Horst 86a] [Horst 86b].

- *On Site Framing Machinery*; Computerized, mechanized sytem for framing using truss plates. The framing machinery can be moved from site to site, incorporating the efficency of prefabrication and the convenience of on site construction [Adams 86b].

- *Industrialized Home Construction*; Automated, computerized, factory oriented prefabricated building techniques. There have been breakthroughs in the automation of custom home design in both Japan and Sweden. Some systems now offer the benefits of industrialized construction (quality control and cost efficiency), while allowing the consumer flexibility in design [Sackett 85] [Sweden 86] [Smay 85b] [Schipper 85] [Congress 86] [Cunningham 86] [Domestic 86] [Mathieu 86] [Precious 86]

- *Mechanized/Robotic Construction Systems Equipment*; "Robots" are currently being developed to do such tasks as building brick walls and lay sheetrock [Japan 83] [Slocum 86] [Whitney 86].

- *Home Control Systems*; Computerized systems that have the capacity to monitor and control energy use, lighting, security and more [Freifeld 86] [Hawkins 85] [Intelligent 86] [McLeister 86a].

- *Prefabricated Home Kits*; These are like adult "erector sets". They are delivered to the site in varying degrees of completion. Home kits reduce the on site construction time and offer the advantage of quality control that is characteristic of prefabrication [Ashley 86b] [Kindel 86] [Nutt-Powell 85].

- *Oriented Strand wood Board*; This type of waferboard orients the wafer fibers parallel to one axis [Ek 86] [Maloney 85].

- *Performance Rated Panels*; This rating system allows panels to be tested and rated for specific structural application. This system is replacing a prescriptive system which specifies the materials and production technique [APA 83] [O'Halloran 84] [APA 86] [Montrey 82].

- *Tent Structures*; PVC and Teflon coated polyester tent structures [Dietch 86].

New Construction Practices

- *Airtight Drywall Approach*; This system integrates gasketed interior paneling and air vapor coatings to create the air/vapor seal [McClintock 86].

- *Permanent Wood Foundation*; Pressure treated wood used to produce foundation which can be constructed in any weather condition [Cook 81] [APA 87] [AWPI 80] [WPPC 85].

- *Back-Up Clips*; Holds drywall in place for interior partitions [di Marne 86Marne].

- The following are cost saving innovations proposed by National Association of Home Builders in a report writen by Robert Stroh for the Dept. of Housing and Urban Development entitled "Regulation and Use of Innovation in Residential Construction [Stroh 84]". The innovations that I have selected to include here are innovations used by less than 25 percent of builders surveyed.

-
    - The use of in-line, off-center, splicing joists to increase allowable span.

    - The reduction in stairwell framing.

- The reduction in band joist dimensions.
- The adoption of pressure-treated wood foundations.
- The use of engineering foundation wall dimensions.
- The omission of sill plate on top of foundation.
- The use of 24" o.c. framing.
- The use of single top plate for wall framing.
- The reduction of the bottom plate dimension in wall framing.
- The use of two stud corners.
- The omission of the partition posts.
- The use of plywood box structural header.
- The use of 2X3, 24" o.c. interior partition studs.

Appendix B
Tables and Figures

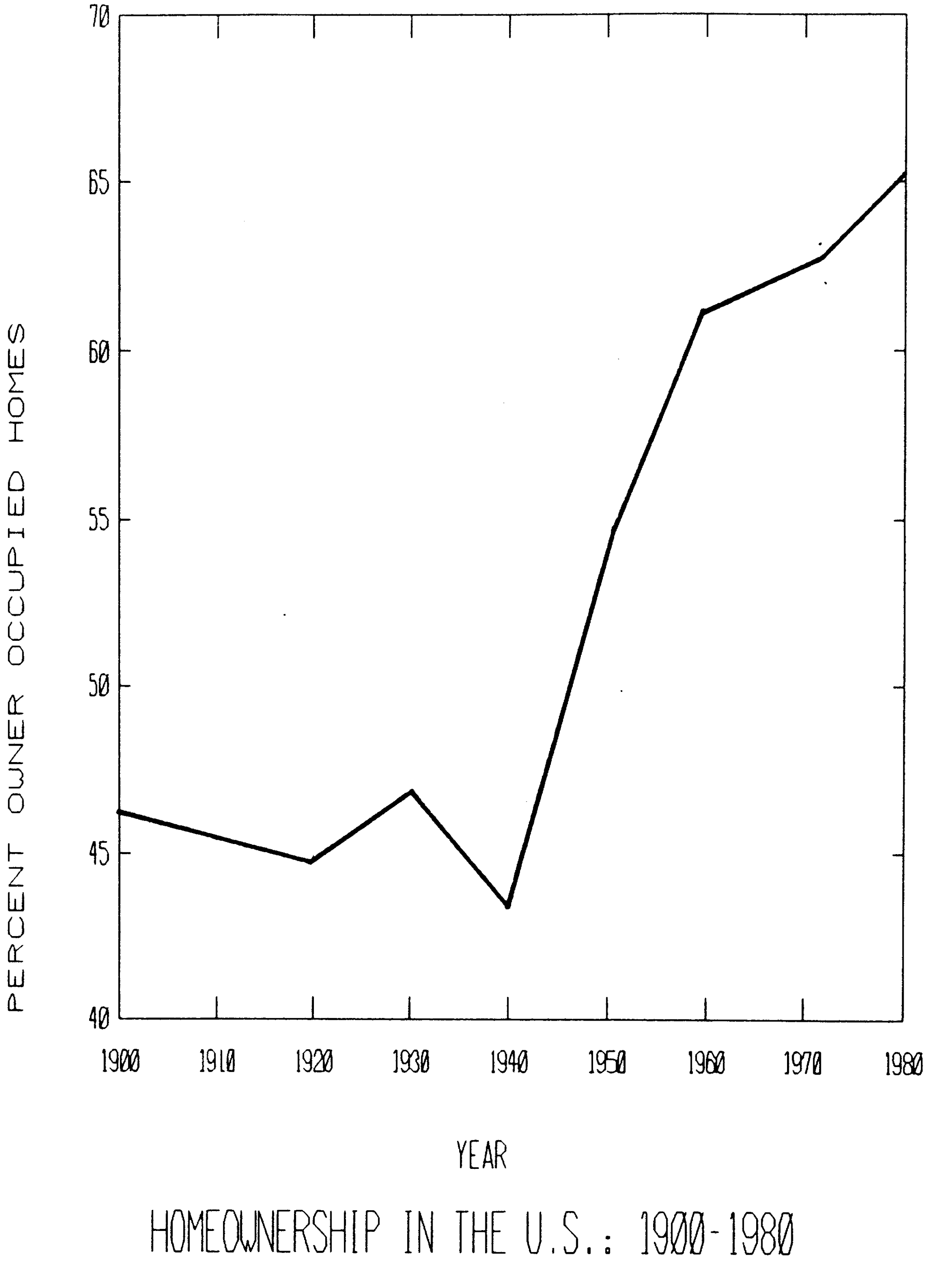


Figure B-1: Homeownership in the U.S., 1900-1980

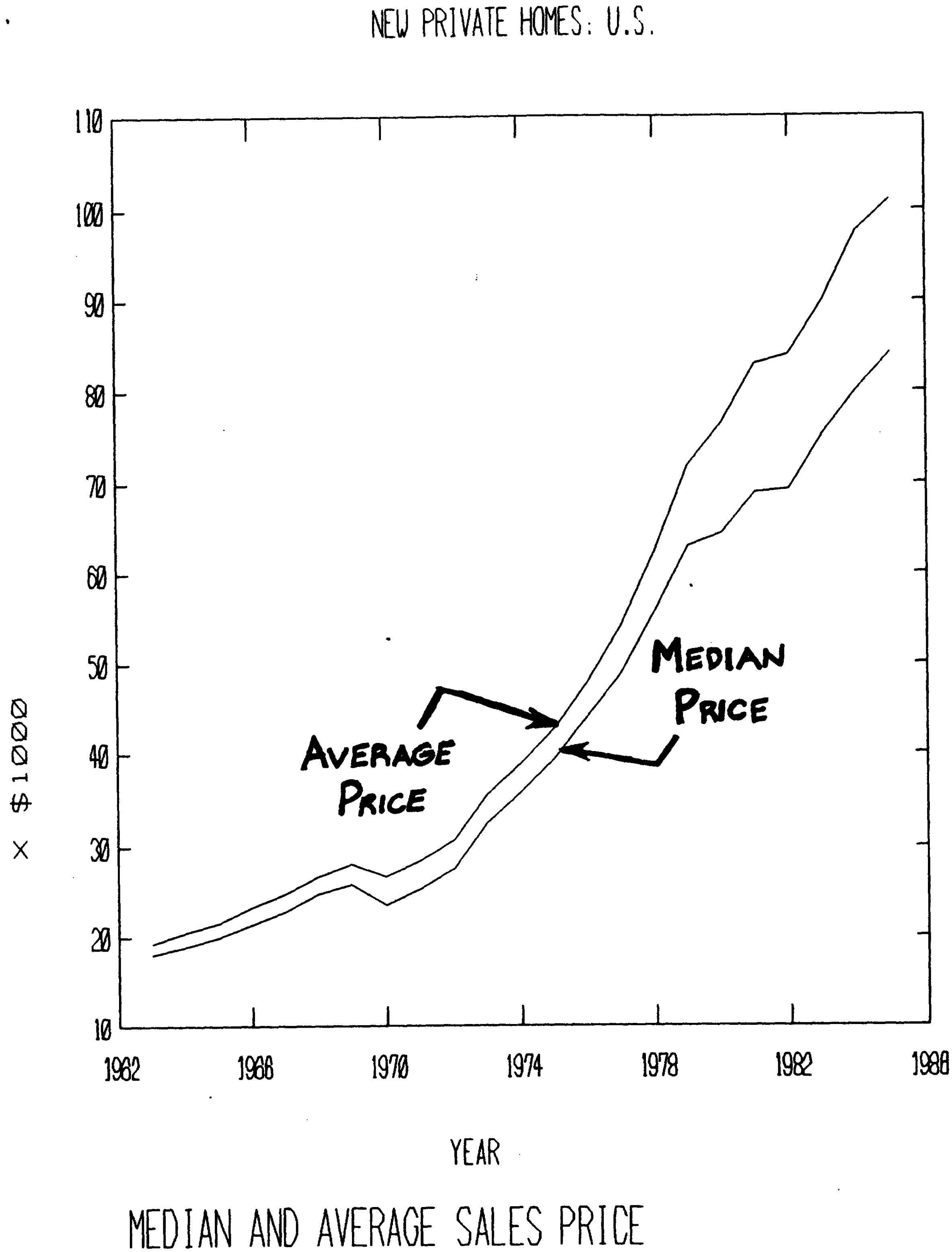


Figure B-2: Median and Average Price of New Private Homes

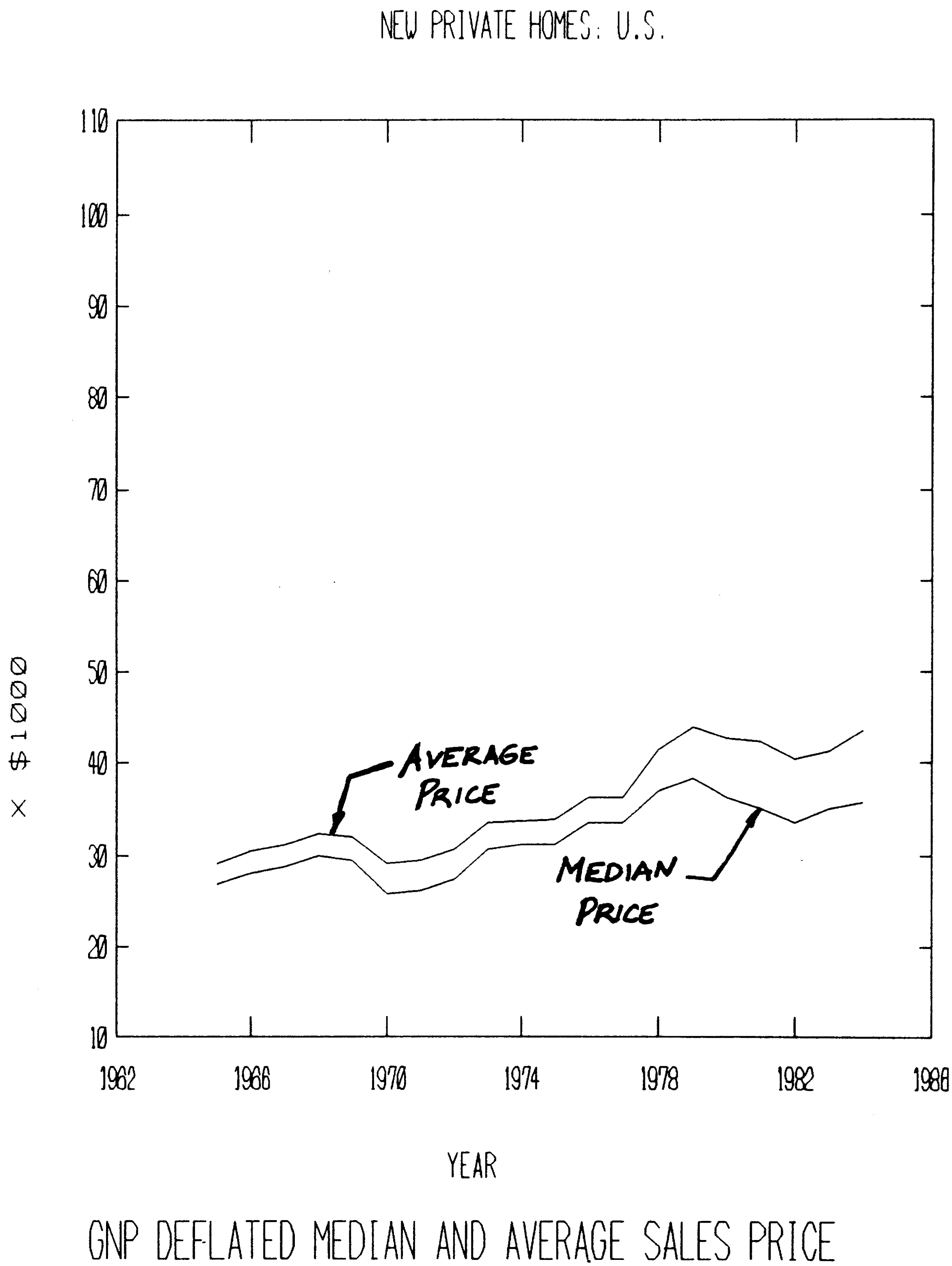


Figure B-3: GNP Deflated Price of New Private Homes

MEDIAN SALES PRICE OF NEW PRIVATE HOMES BY REGION IN CURRENT DOLLARS

YEAR	NO. EAST	MIDWEST X 1000$	SOUTH	WEST
1963	20.3	17.9	16.1	18.8
1965	21.5	21.6	17.5	21.6
1970	30.0	24.4	20.3	24.0
1971	30.6	27.2	22.5	25.5
1972	31.4	29.3	25.8	27.5
1973	37.1	32.9	30.9	32.4
1974	40.1	36.1	34.5	35.8
1975	44.0	39.6	37.3	40.6
1976	47.3	44.8	40.5	47.2
1977	51.6	51.5	44.1	53.5
1978	58.1	59.2	50.3	61.3
1979	65.5	63.9	57.3	69.8
1980	69.5	63.4	59.6	72.6
1981	76.0	65.9	64.4	77.8
1982	78.2	68.9	66.1	75.0
1983	82.2	79.5	70.9	80.1
1984	88.6	85.4	72.0	87.3
1985	103.3	80.3	75.0	92.6
		PERCENT CHANGE		
1963-85	409%	349%	366%	393%
ANNUALLY	18.6%	15.9%	16.6%	17.8%

Source:

International Trade Administration, U.S. Department of Commerce, *Construction Review*, (monthly).

Table B-I: Median Sales Price of New Private Homes by Region

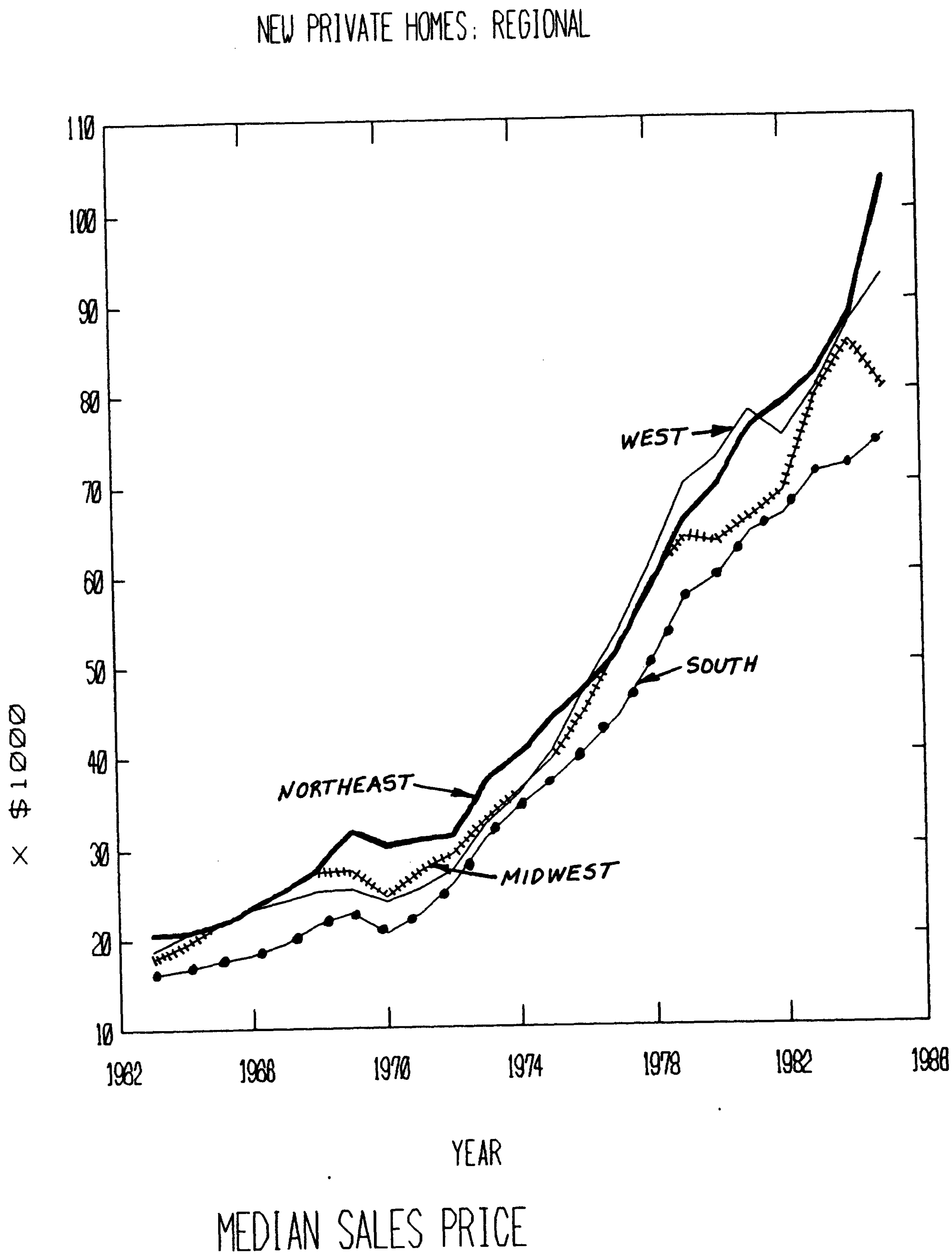


Figure B-4: Regional Median and Average Sales Price New Homes

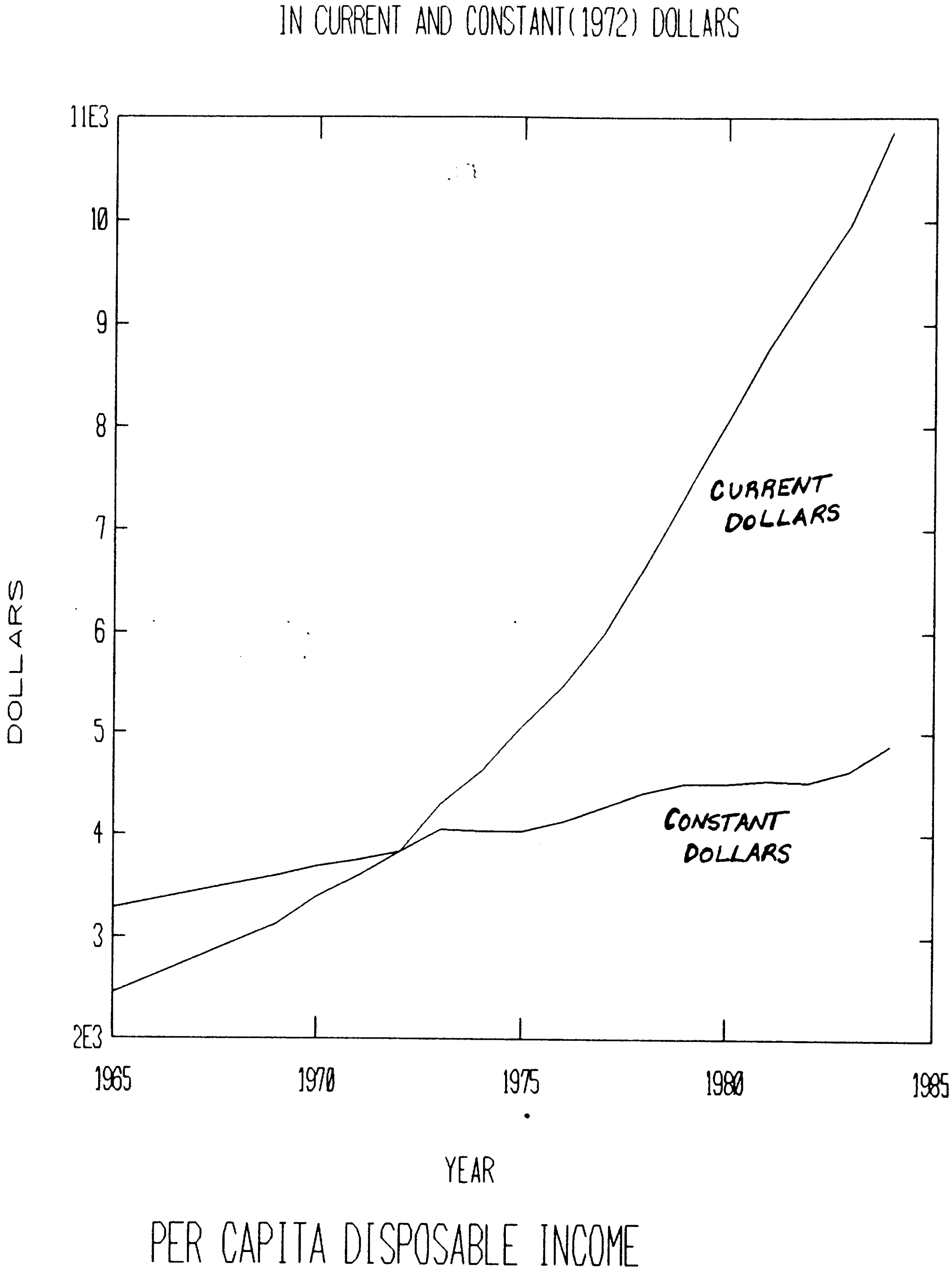


Figure B-5: Per Capita Disposable Income

COMPARISON OF PER CAPITA DISPOSABLE INCOME AND THE AVERAGE COST OF A NEW PRIVATE HOME 1965-1984

YEAR	PER CAPITA DISPOSABLE INCOME (1)	AVERAGE HOUSE COST (2)	DISPOSABLE INCOME / AVE. HOUSE COST
1965	$2436.00	$21,500.00	.113
1969	3130.00	27,900.00	.112
1970	3376.00	26,600.00	.127
1971	3605.00	28,300.00	.127
1972	3843.00	30,500.00	.126
1973	4295.00	35,500.00	.121
1974	4623.00	38,900.00	.119
1975	5075.00	42,600.00	.119
1976	5477.00	48,000.00	.114
1977	5965.00	54,200.00	.110
1978	6621.00	62,500.00	.106
1979	7331.00	71,800.00	.102
1980	8032.00	76,300.00	.105
1981	8774.00	83,000.00	.107
1982	9385.00	83,900.00	.112
1983	9977.00	89,800.00	.111
1984	10887.00	97,600.00	.112

Sources:

(1) U.S. Bureau of Economic Analysis, *The National Income and Products Accounts of the United States*, (yearly), and *Survey of Current Business*, (monthly).

(2) U.S. Bureau of the Census, Construction Reports, *Characteristics of New One-Family Homes*, (yearly).

Table B-II: Ratio of Per Capita Income to the Cost of the Home

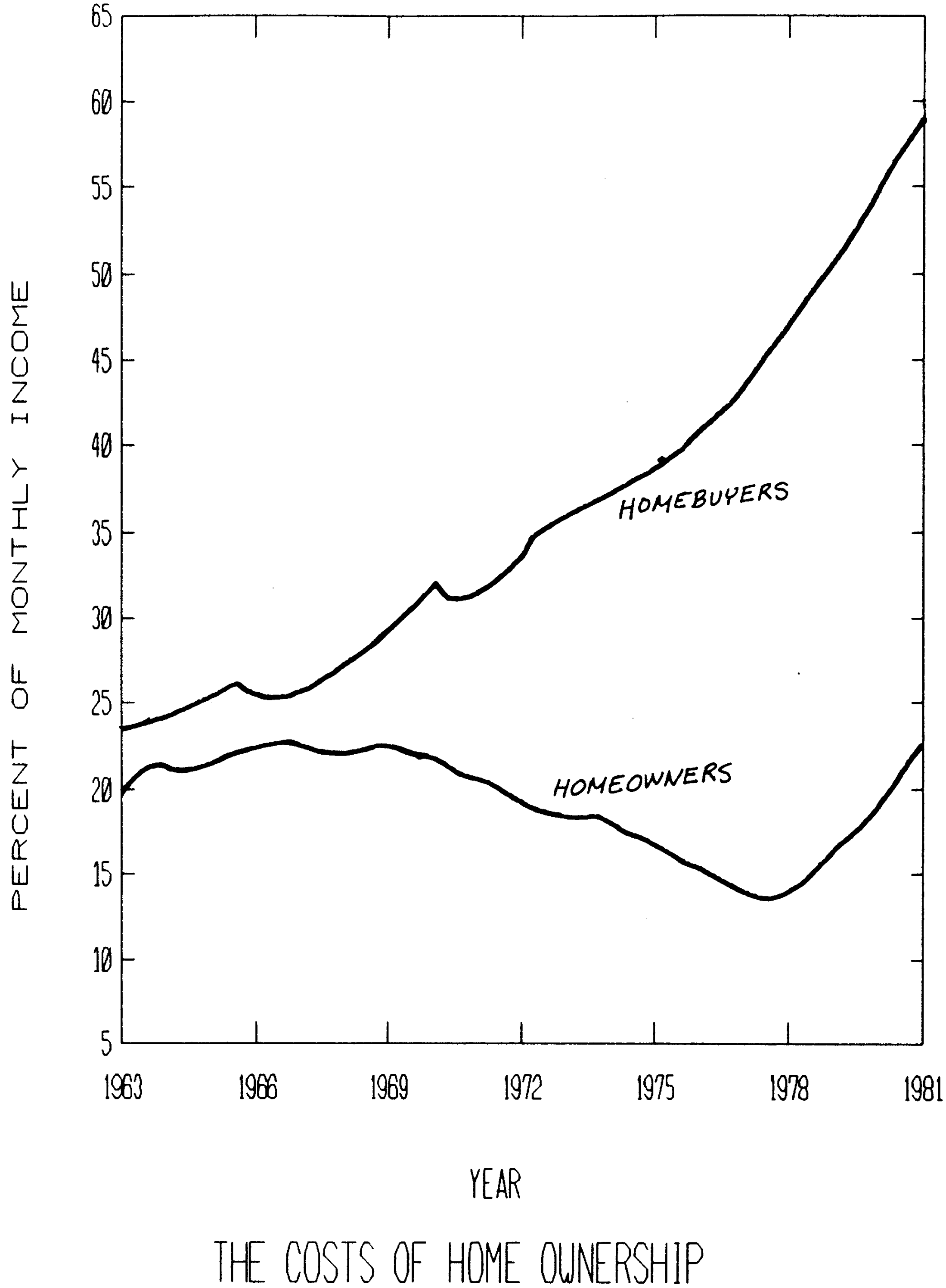


Figure B-6: The Costs of Homeownership

TRENDS IN THE HOME BUILDING INDUSTRY 1965-1985

YEAR	PRIME INTEREST RATE (EST.)	HOUSING STARTS X100,000
1973	8%	20.4
1974	10.5%	13.4
1975	7.5%	11.6
1976	6.7%	15.4
1977	6.7%	20.0
1978	8.5%	20.2
1979	11.5%	17.4
1980	15%	12.9
1981	19%	10.8
1982	15%	10.6
1983	11%	17.0
1984	12%	17.5
1985	9.5%	17.4

Source: See Table B-VII.

Table B-III: Trends in Home Construction

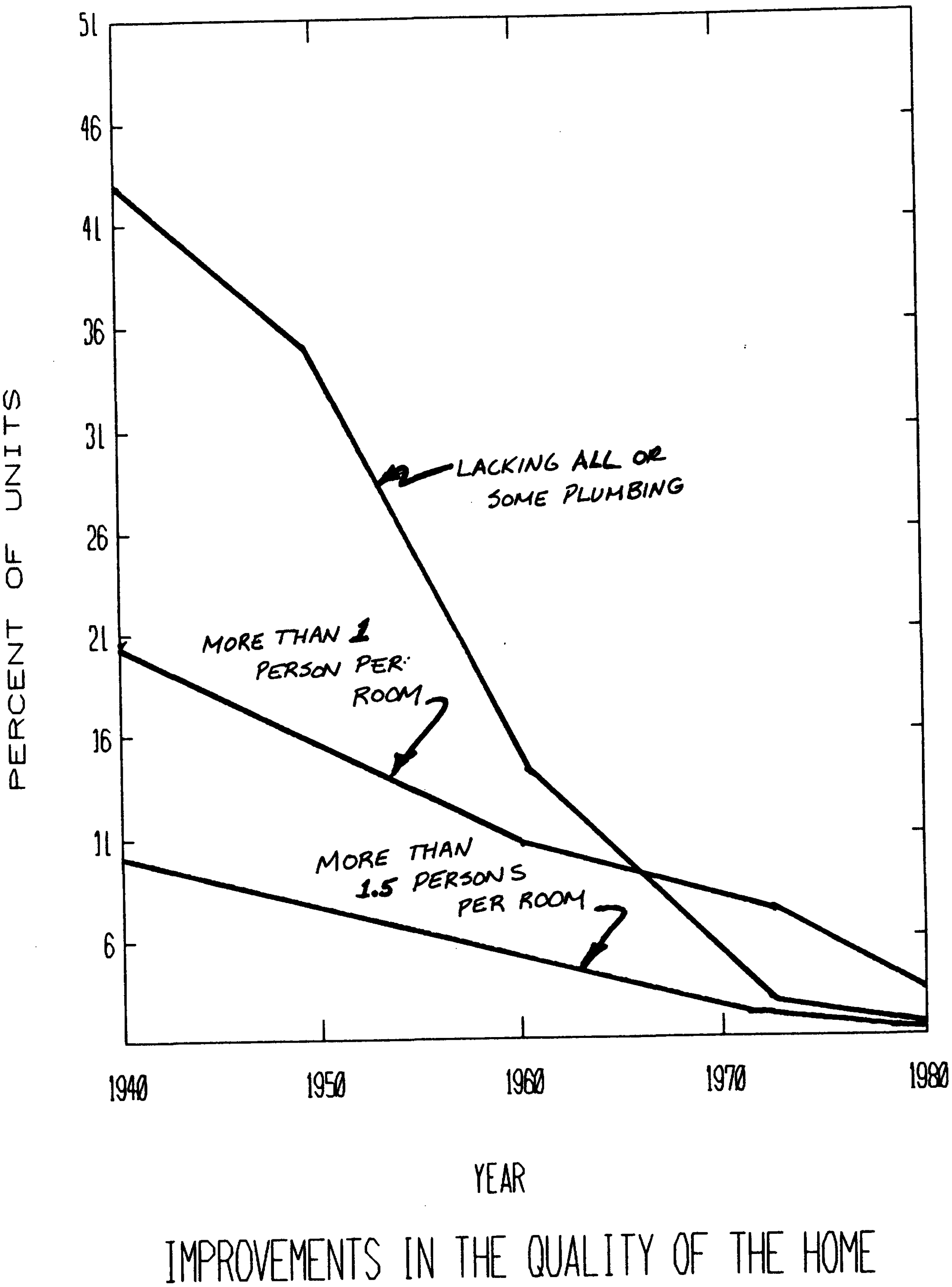


Figure B-7: Improvements in the Quality of America's Housing

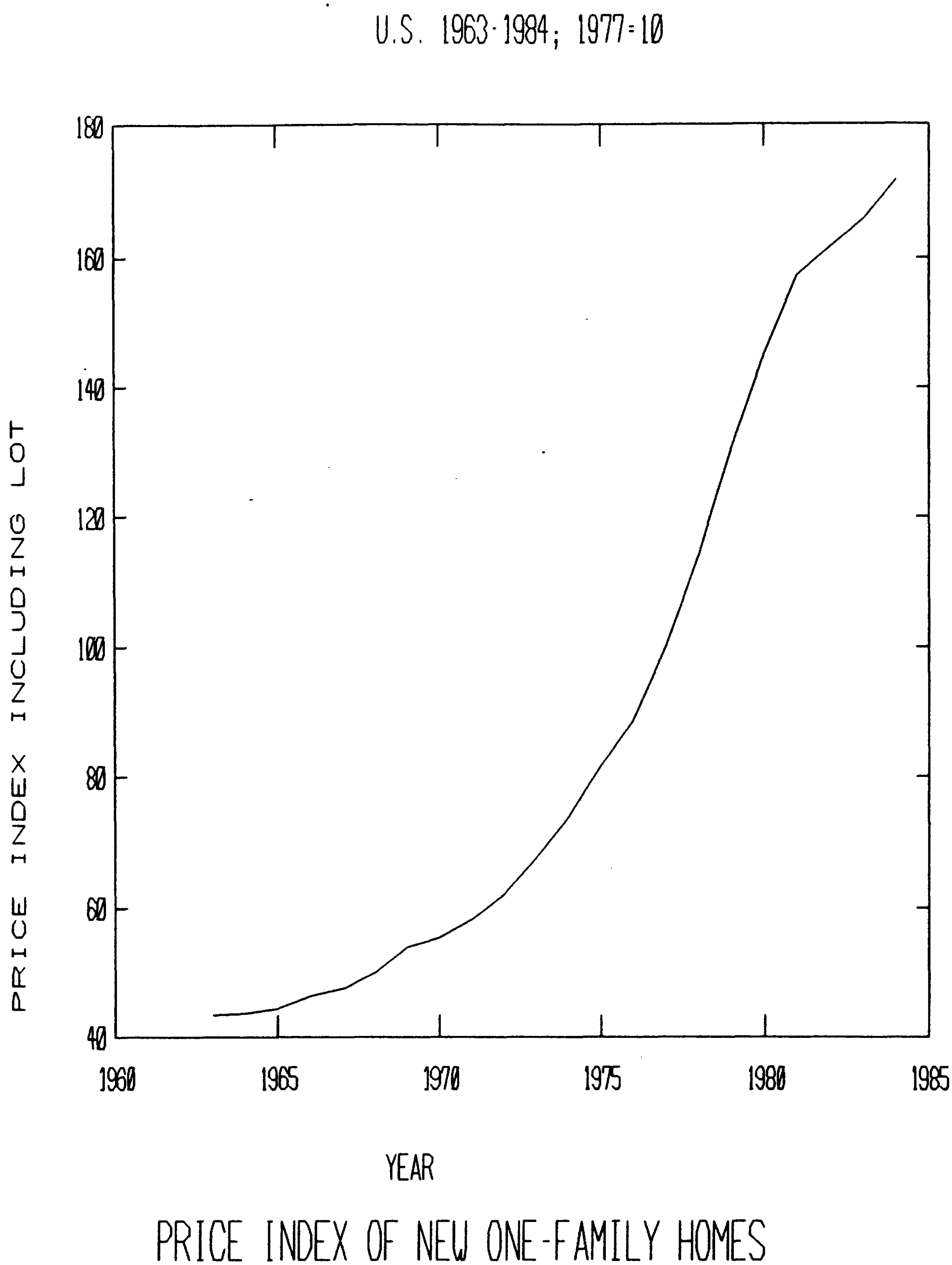


Figure B-8: Price Index of New One-Family Homes

MEDIAN AND AVERAGE SQUARE FEET PER HOUSE IN THE UNITED STATES 1965-1984

YEAR	MEDIAN SQUARE FEET PER HOUSE	AVERAGE SQUARE FEET PER HOUSE
1965	1495	
1970	1385	1500
1971	1400	1555
1972	1405	1555
1973	1525	1660
1974	1560	1695
1975	1535	1645
1976	1590	1700
1977	1610	1720
1978	1655	1755
1979	1650	1760
1980	1570	1700
1981	1560	1710
1982	1530	1690
1983	1580	1740
1984	1610	1790

Source:

U.S Bureau of the Census, Construction Reports, *Characteristics of New One-Family Homes*, (yearly).

Table B-IV: Median and Average Square Feet per House

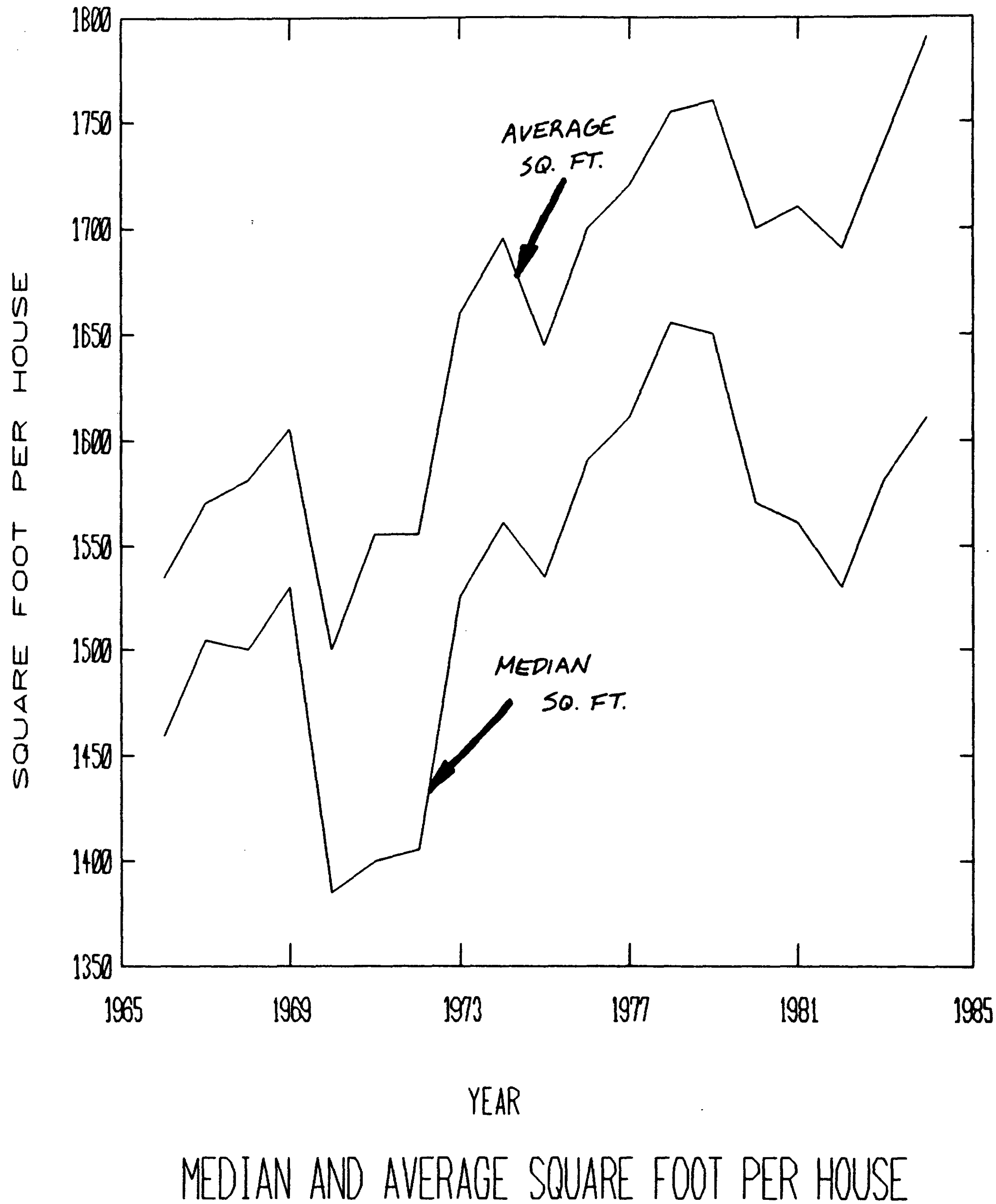


Figure B-9: Median and Average Square Feet per House

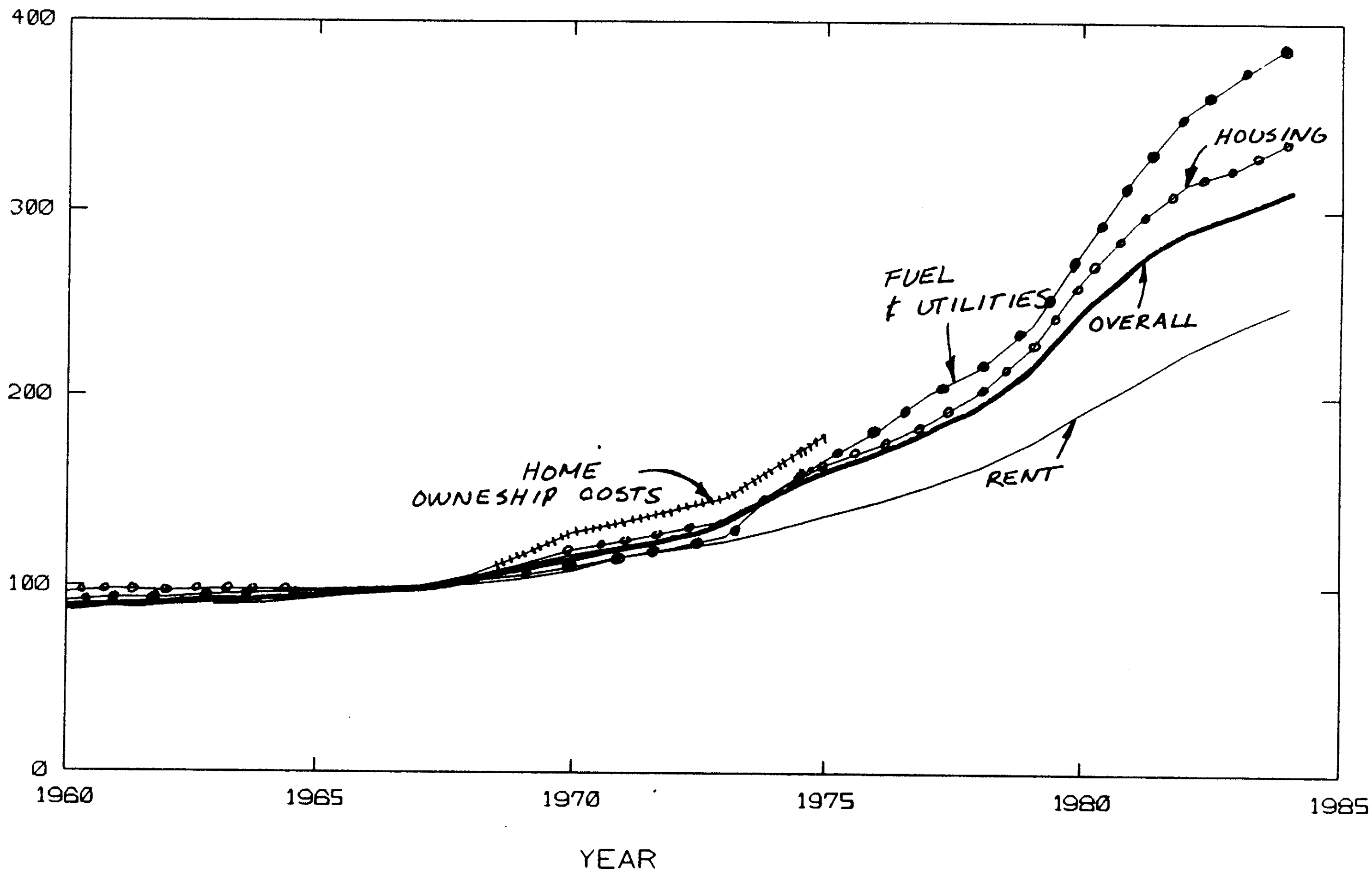
CONSUMER PRICE INDEXES
1967 = 100

YEAR	CPI ALL ITEMS	HOUSING TOTAL	RENT	FUEL & UTILITIES	HOME OWNERSHIP
1960	88.7	90.2	91.7	95.9	86.3
1961	89.6	90.9	92.9	98.1	
1962	90.6	91.7	94.0	97.3	
1963	91.7	92.7	95.0	98.2	89.0
1964	92.9	93.8	95.9	98.4	90.8
1965	94.9	94.9	96.9	98.3	92.7
1966	97.2	97.2	98.2	98.8	96.3
1967	100.0	100.0	100.0	100.0	100.0
1968	104.2	104.2	102.4	101.3	105.7
1969	109.8	110.8	105.7	103.6	116.0
1970	116.3	118.9	110.1	107.6	128.5
1971	121.3	124.3	115.2	115.0	133.7
1972	125.3	129.2	119.2	120.1	140.1
1973	133.1	135.0	124.3	126.9	146.7
1974	147.7	150.6	130.6	150.2	163.2
1975	161.2	164.5	137.3	167.8	180.1
1976	170.5	174.6	144.7	182.7	
1977	181.5	186.5	153.5	202.2	
1978	195.4	202.8	164.0	216.0	
1979	217.4	227.6	176.0	239.3	
1980	246.8	263.3	191.6	278.6	
1981	272.4	293.5	208.2	319.2	
1982	289.1	314.7	224.0	350.8	
1983	298.4	323.1	236.9	370.3	
1984	311.1	336.5	249.3	387.3	

Source: U.S. Bureau of Labor Statistics, *Monthly Labor Review.*

Table B-V: Consumer Price Indexes

Figure B-10: Consumer Price Indexes



CONSUMER PRICE INDEXES 1967 = 100

YEAR	GNP BILLION $ (1)	1972 GNP DEFLATOR (2)	HOUSING AS % OF GNP CURRENT DOLLARS (3)
1960	503.7	68.7	3.24%
1965	684.9	74.4	3.04
1970	977.1	91.5	2.46
1971	1054.9	96.0	3.29
1972	1158.0	100.0	3.83
1973	1294.9	105.8	3.66
1974	1434	115.1	2.62
1975	1549	125.8	2.25
1976	1718	132.3	2.78
1977	1918	140.1	3.46
1978	2164	150.4	3.56
1979	2418	163.4	3.26
1980	2632	178.4	2.40
1981	2958	195.6	2.12
1982	3069	207.4	1.88
1983	3305	215.3	2.90
1984	3663	223.4	3.14

Sources:

(1) U.S. Bureau of Economic Analysis, *The National Income and Products Accounts of the United States, 1929-1986* and *Survey of Current Business.*

(2) U.S. Bureau fo Economic Analysis

(3) International Trade Administration, U.S. Department of Commerce, *Construction Review,* (monthly). Value of new, privately built, housing units as a percent of the total value of new construction put in place in the United States. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States,*(yearly). Total construction as a percentage of the Gross National Product.

Table B-VI: Housing Construction as a Percent of the Gross National Product

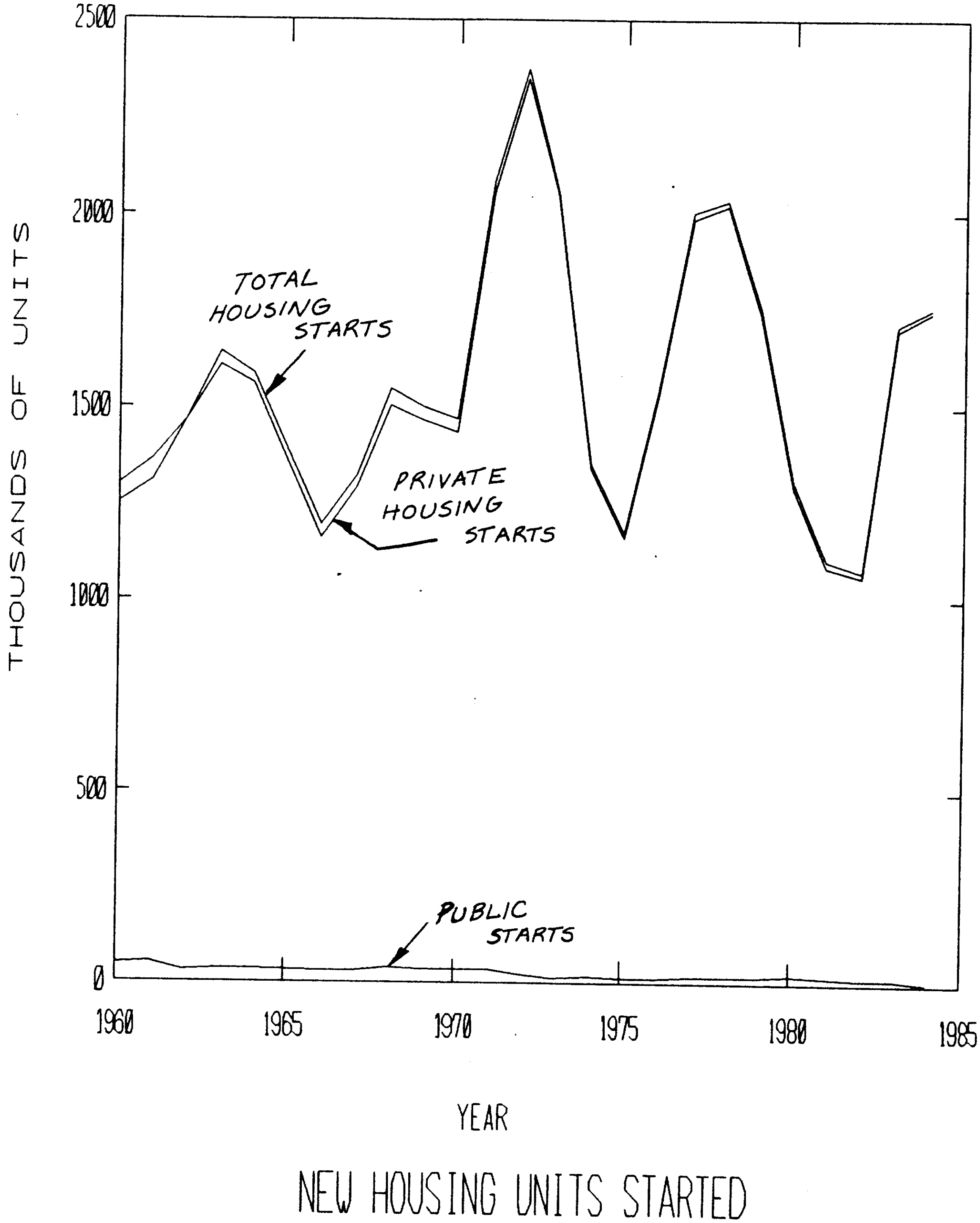


Figure B-11: Public and Private Housing Units Started

NEW HOUSING UNITS STARTED BY NUMBER OF UNITS, PRIVATE CONSTRUCTION X1000

YEAR	TOTAL UNITS	1 UNIT	2 UNITS	3 AND 4 UNITS	5 + UNITS
1960	1252.1	994.8	44.0	213.4	
1964	1557.4	971.5	53.5	532.4	
1966	1164.9	778.6	34.6	26.5	325.1
1967	1291.6	843.9	41.4	30.2	376.1
1968	1507.6	899.4	46.0	34.9	527.3
1969	1466.8	810.6	43.0	42.0	571.2
1970	1433.6	812.9	42.4	42.4	535.9
1971	2052.2	1151.0	55.1	65.2	780.9
1972	2356.6	1309.2	67.1	74.2	906.0
1973	2045.3	1132.0	54.2	64.1	795.0
1974	1337.7	888.1	33.2	34.9	381.6
1975	1160.4	892.2	34.5	29.5	204.3
1976	1537.5	1162.4	44.0	41.9	289.2
1977	1987.1	1450.9	60.7	61.0	414.4
1978	2020.3	1433.3	62.2	62.8	462.0
1979	1745.1	1194.1	56.1	65.9	429.0
1980	1292.2	852.2	48.8	60.7	330.5
1981	1084.2	705.4	38.2	52.9	287.7
1982	1062.2	662.6	31.9	48.1	319.6
1983	1703.0	1067.6	41.8	71.7	522.0
1984	1749.5	1084.2	38.6	82.8	544.0
1985	1741.8	1072.4	37.0	56.4	576.1

Source:

International Trade Administration, U.S. Department of Commerce, *Construction Review*, (monthly).

Table B-VII: New Housing Units Started in Private Construction

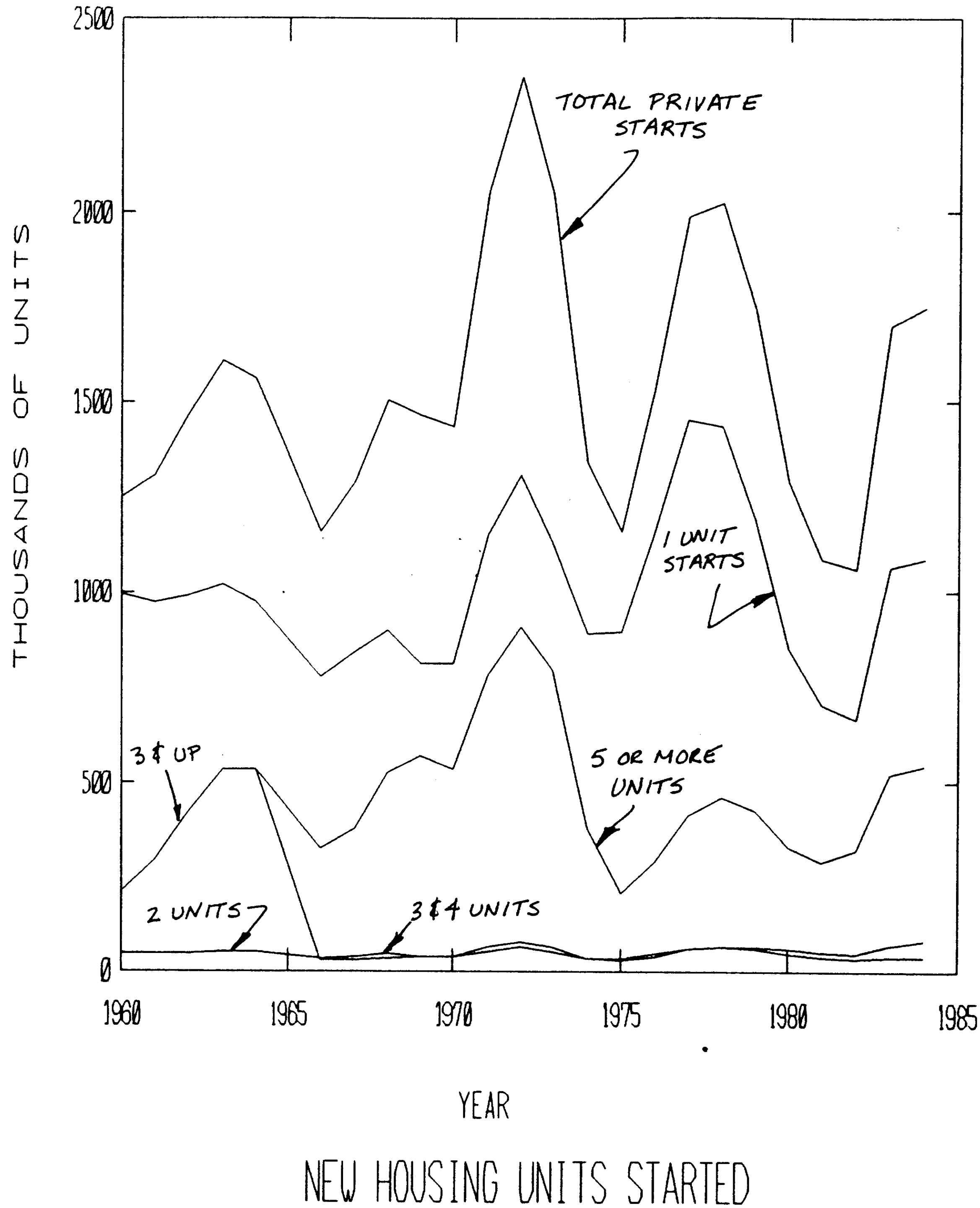


Figure B-12: New Housing Units Started in Private Construction

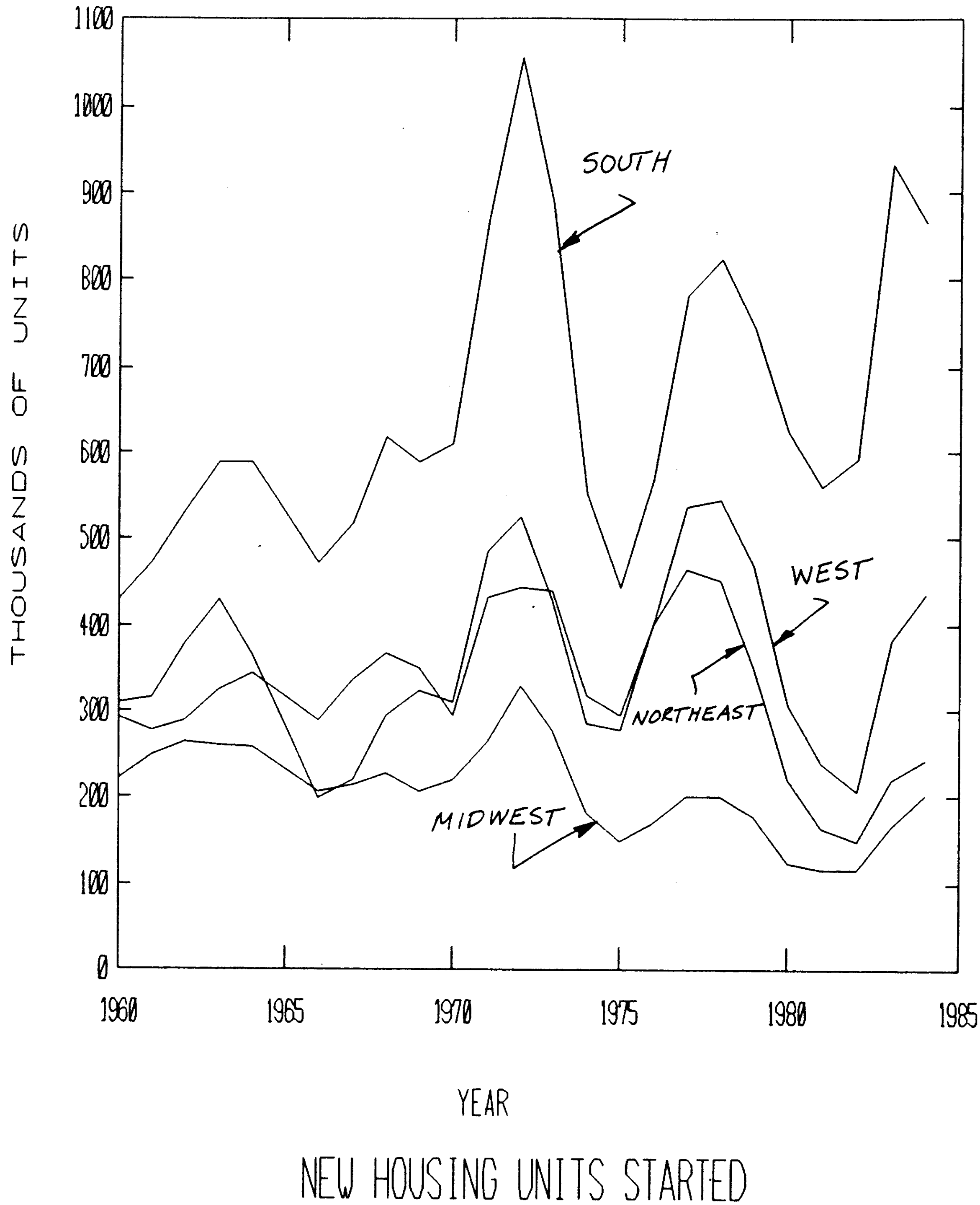


Figure B-13: Regional Private Housing Starts

CALCULATION OF INDEX OF UNIT LABOR COSTS FOR U.S. CONSTRUCTION WORKERS 1965-1980, (1965=100)

YEAR	INDEX OF AVE. HOURLY EARNINGS	INDEX OF OUTPUT PER HR. WORKED	INDEX OF UNIT LABOR COSTS COL.1/COL.2
1965	100	100.0	100
1966	103	97.0	106
1967	111	95.9	116
1968	119	99.5	120
1969	129	92.0	140
1970	141	90.5	156
1971	180	96.7	186
1972	163	96.3	169
1973	173	91.0	190
1974	184	83.0	222
1975	197	85.5	130
1976	208	86.3	241
1977	218	89.8	243
1978	233	85.9	271
1979	250	79.9	313
1980		268	
PERCENT CHANGE			
1965-1979	+150	-20	+213

Source:

Calculated by Bureau of Industrial Economics (BIE) from data developed by the Bureau of Labor Statistics and the Bureau of Economic Analysis.

Table B-VIII: Unit Labor Costs

TRENDS IN PRODUCTIVITY IN THE UNITED STATES CONSTRUCTION INDUSTRY: 1965-1979

YEAR	PRODUCTIVITY (OUTPUT PER HOUR) (1972 DOLLARS)	ANNUAL % CHANGE IN PRODUCTIVITY (FROM PREVIOUS YR.)
1965	8.46	
1966	8.21	-3.0
1967	8.11	-1.2
1968	8.24	+3.8
1969	7.78	-7.6
1970	7.66	-1.5
1971	8.18	+6.8
1972	8.15	-0.4
1973	7.70	-5.5
1974	7.02	-8.8
1975	7.23	+3.0
1976	7.30	+1.0
1977	7.60	+4.1
1978	7.27	-4.3
1979	6.67	-7.0
	PERCENT CHANGE	
1965-1979	-20	-1.6

Source: Unpublished data from Bureau of Economic Analysis.

Table B-IX: Trends in Construction Productivity

Appendix C
Related Tables and Figures

AVERAGE AND MEDIAN PRICE PER SQUARE FOOT RESIDENTIAL CONSTRUCTION EXCLUDING VALUE OF LOT IN CURRENT AND CONSTANT(1972) DOLLARS

YEAR	AVE. PRICE PER SQ. FT.	MEDIAN PRICE PER SQ. FT.	ADJUSTED AVE. PRICE	ADJUSTED MEDIAN PRICE
1965	$14.10	$13.69	$18.95	$18.40
1970	14.00	13.95	15.30	15.25
1974	19.00	19.00	16.52	16.52
1975	21.10	21.75	16.77	16.49
1976	22.70	22.35	17.16	16.89
1977	25.35	24.75	18.08	17.66
1978	28.50	27.80	18.95	18.48
1979	32.40	31.35	19.83	19.19
1980	35.20	33.50	19.73	18.78
1981	38.20	36.20	19.53	18.51
1982	39.75	37.70	19.17	18.18
1983	40.70	38.85	18.93	18.04
1984	42.90	40.55	19.20	18.15

Source:

U.S. Bureau of the Census, Construction Reports, *Characteristics of New One-Family Homes*, (yearly).

Note: Adjusted values calculated with 1972 GNP deflator as defined by the U.S. Bureau of Economic Analysis.

Table C-I: Price per Square Foot Residential Construction

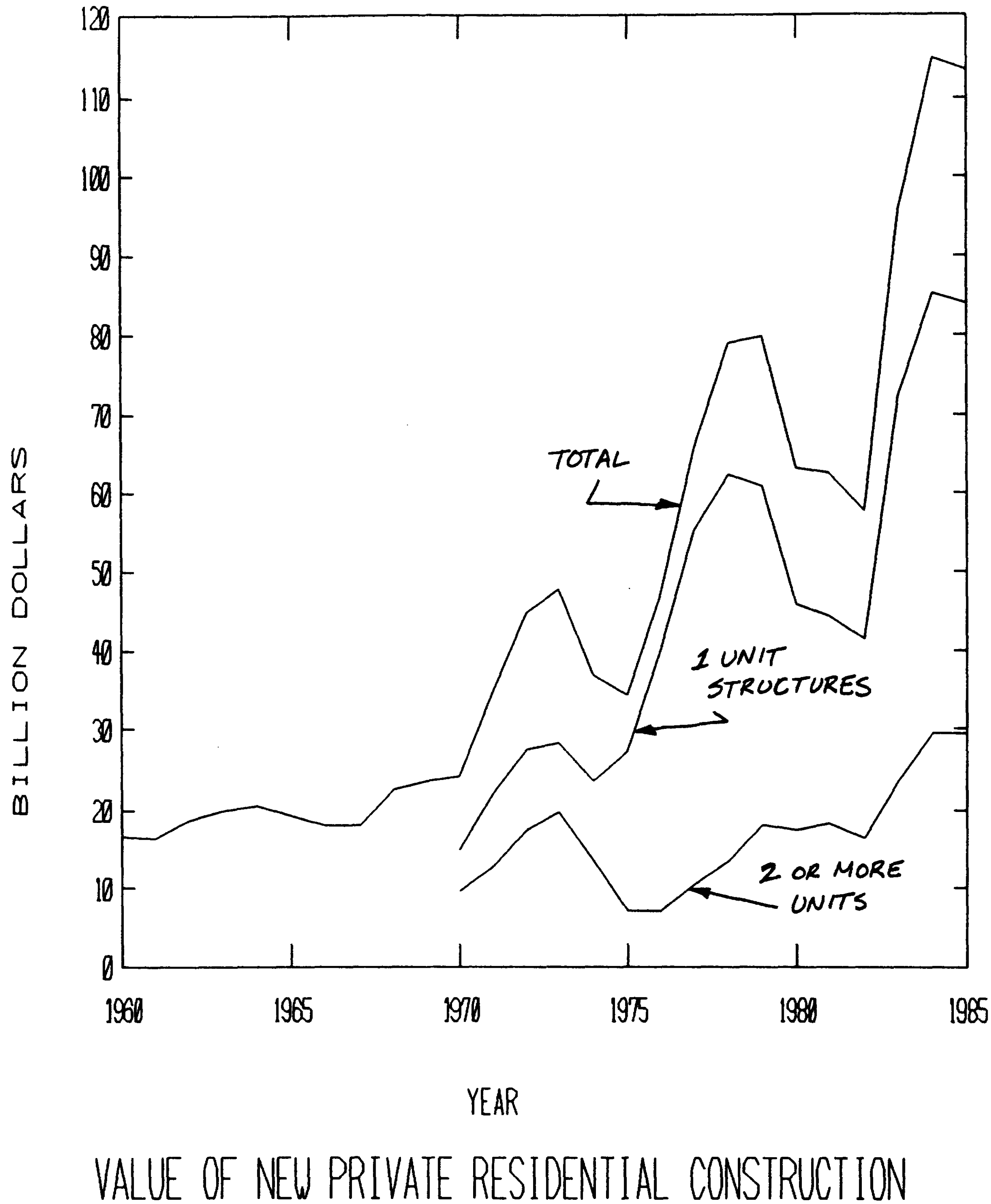


Figure C-1: Value of New Private Residential Construction, U.S. Department of Commerce

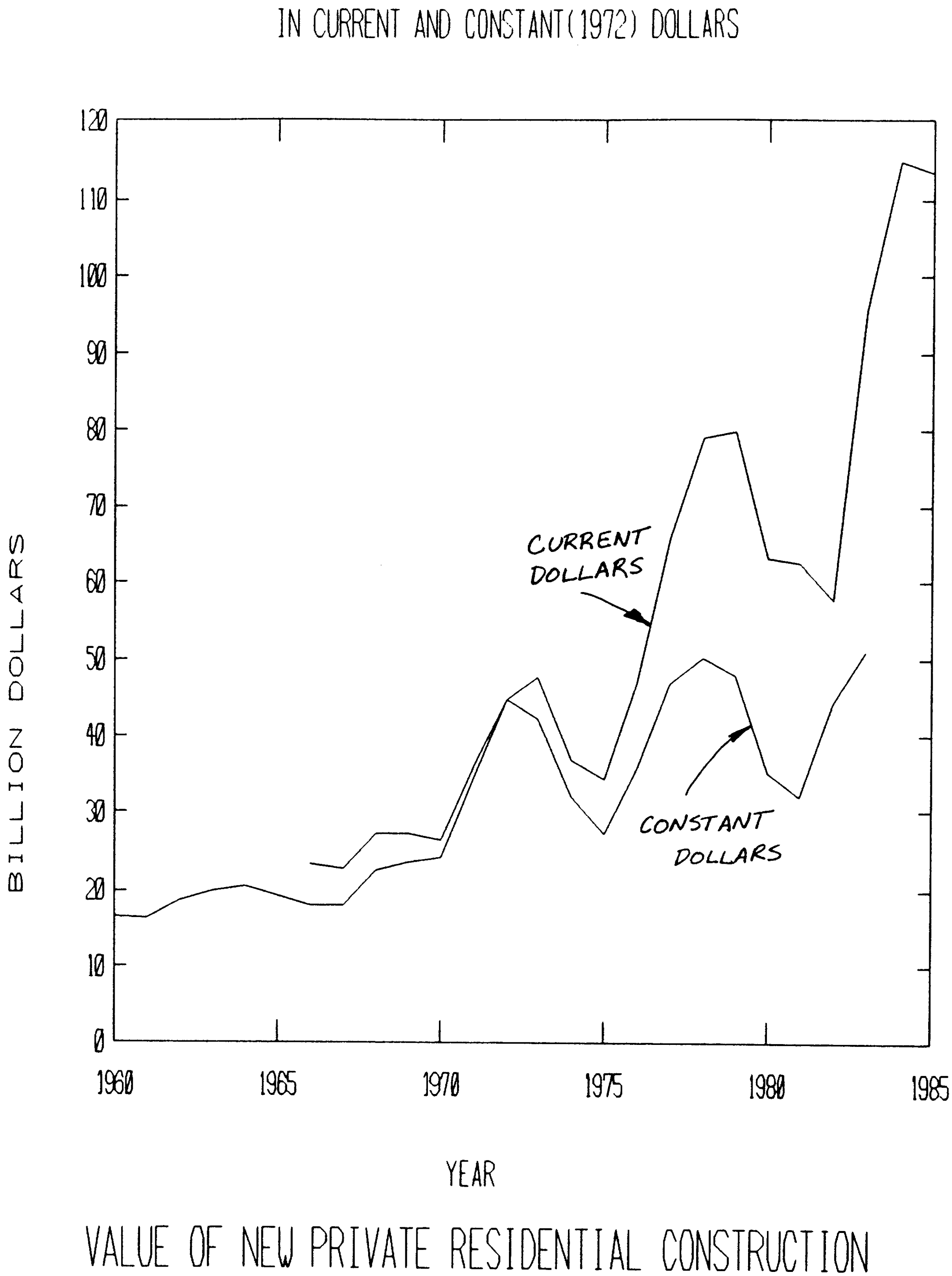


Figure C-2: Value of New Private Residential Construction, in Current and Constant Dollars

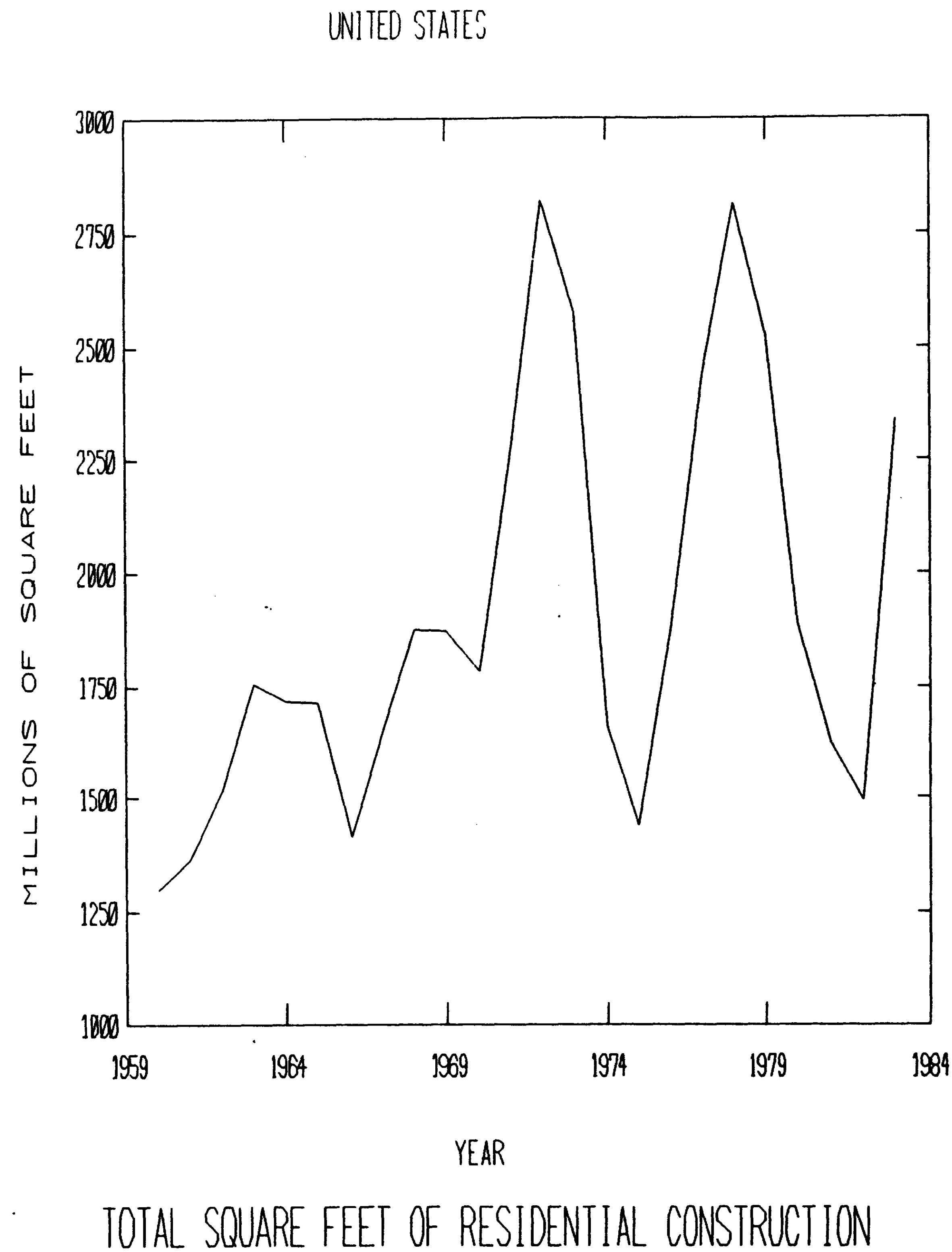


Figure C-3: **Total Square Feet of Residential Construction, Dodge Construction Potentials**

AVERAGE ANNUAL RATE OF INCREASE IN BUILDING LABOR COSTS IN SELECTED COUNTRIES 1970-1977, 1977-1985, IN CURRENT MONEY UNITS

COUNTRY	AVERAGE ANNUAL RATE OF INCR. LABOR COSTS 1970-1977	AVERAGE ANNUAL RATE OF INCR. LABOR COSTS 1977-1985
UNITED STATES	6.0	6.8[1]
SWEDEN	9.7	5.5
SWITZERLAND	9.9	5.5[2]
FINLAND	11.3	8.1
DENMARK	11.4	8.4
CANADA	11.7[3]	6.5
PORTUGAL	14.5	12.2
U.K.	15.0	12.2
IRELAND	16.3[4]	14.2[2]
AUSTRIA	17.1	7.6

Source:

United Nations Economic Commission for Europe, Annual Bulletin of Housing and Building Statistics for Europe, (New York, 1978, 1980, 1983, 1986).

[1] 1977-1984, U.S. Department of Labor, Bureau of Labor Statistics

[2] 1977-1983

[3] 1971-1977

[4] 1970-1976

Table C-II: Rate of Increase in Building Labor Costs in Selected Countries

AVERAGE ANNUAL INCREASE IN PER CAPITA DISPOSABLE INCOME FOR SELECTED COUNTRIES 1970-1977, 1977-1984, IN CURRENT MONEY UNITS

COUNTRY	AVERAGE ANNUAL RATE OF INCR. DISP. INCOME 1970-1977	AVERAGE ANNUAL RATE OF INCR. DISP. INCOME 1977-1984
BELGIUM	10.7	7.8
AUSTRIA	13.5	8.8
SWEDEN	9.7	14.5
U.K.	14.7	17.5
IRELAND	11.6	19.5
UNITED STATES	8.8	10.8
JAPAN	11.0	7.3
NETHERLANDS	11.2	4.9
NORWAY	11.7	19.1
DENMARK	12.0	13.2
WEST GERMANY	8.1	6.3
FINLAND	15.4	19.0
SWITZERLAND	7.5	6.6
CANADA	12.8	12.3
FRANCE	13.3	16.6

Source:

Organization for Economic Cooperation and Development, National Accounts of OECD Countries, 1952-1977 and 1960-1984, [Paris, 1979, 1986], Vols. 1.

Table C-III: Average Increase in Per Capita Disposable Income in Selected Countries

AVERAGE ANNUAL RATE OF INCREASE IN BUILDING MATERIALS COSTS IN SELECTED COUNTRIES 1970-1977, 1977-1985, IN CURRENT MONEY UNITS

COUNTRY	AVERAGE ANNUAL RATE OF INCR. MATL. COSTS 1970-1977	AVERAGE ANNUAL RATE OF INCR. MATL. COSTS 1977-1985
WEST GERMANY	4.6	4.4[1]
AUSTRIA	7.5	6.5
JAPAN	8.2[2]	-7.2[1]
UNITED STATES	9.0	6.4[1]
FRANCE	9.0	17.4[1]
CANADA	9.4[3]	8.2
DENMARK	10.4	10.2
SWEDEN	11.0	11.3
AUSTRALIA	11.7	12.6[1]
FINLAND	13.9	9.0
U.K.	17.1	10.8
BELGIUM	15.6[2]	4.8[1]
IRELAND	17.8[2]	10.9[1]

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[2] 1970-1976

[3] 1971-1977

Table C-IV: Rate of Increase in Building Materials Costs in Selected Countries

AVERAGE ANNUAL RATES OF INCREASE IN RENTS IN SELECTED COUNTRIES 1970-1977, 1977-1985, IN CURRENT MONEY UNITS

COUNTRY	AVERAGE ANNUAL RATE OF INCR. 1970-1977	AVERAGE ANNUAL RATE OF INCR. 1977-1985
UNITED STATES	4.9%	7.4%
WEST GERMANY	5.5	4.2
SWITZERLAND	6.6	3.0
SWEDEN	7.4	9.8
NORWAY	7.4	8.4
CANADA	7.8	6.0
FRANCE	8.3	15.8
NETHERLANDS	9.0	7.0
ITALY	9.6	22.4
DENMARK	9.7	7.7
GREECE	9.9	21.8
SPAIN	10.3	17.2
IRELAND	10.3	7.0
FINLAND	11.0	8.8
AUSTRIA	11.9	6.7
U.K.	12.6	16.7

Source:

United Nations Economic Commission for Europe, Annual Bulletin for Housing and Building Statistics for Europe, [New York, 1978, 1980, 1982, 1986].

Note: Some of the rent indices relate to rent both in old and new dwellings; some others are limited to rents in old dwellings only; others refer to rents including rates and water charges for even fuel and light and charges for repair and maintenance, i.e. sometimes the rent indices comprise what is generally termed as "Housing".

Table C-V: Rates of Increase in Rents in Selected Countries

AVERAGE ANNUAL RATES OF INCREASE IN THE CONSUMER PRICE INDEX OF SELECTED COUNTRIES 1970-1977, 1977-1985, IN CURRENT MONEY UNITS

COUNTRY	AVERAGE ANNUAL RATE OF INCR. IN THE C.P.I. 1970-1977	AVERAGE ANNUAL RATE OF INCR. IN THE C.P.I. 1977-1985
FINLAND	12.4%	11.1%
WEST GERMANY	5.7	4.0
DENMARK	9.5	8.8
FRANCE	9.0	11.2
SWEDEN	9.1	11.2
UNITED STATES	8.5	8.0
NORWAY	8.7	8.3
NETHERLANDS	8.7	4.7
CANADA	7.4	8.7
U.K.	14.1	9.9
AUSTRIA	6.6	4.8
JAPAN	11.1	5.7[1]
SWITERLAND	5.7	4.5

Source:

United Nations Economic Commission for Europe, Annual Bulletin for Housing and Building Statistics for Europe, [New York, 1978, 1980, 1983, 1986].

Note: Values exclude rent.

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Table C-VI: Rates of Increase in Consumer Price Index of Selected Countries

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