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Housing market capitalization of energy-saving durable good investments

Ruth Crumley Johnson

To the Graduate Council:

I am submitting herewith a dissertation written by Ruth Crumley Johnson entitled "Housing market capitalization of energy-saving durable good investments." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Agricultural Economics.

Thomas H. Klindt, Major Professor

We have read this dissertation and recommend its acceptance:

David L. Kaserman, Joe A. Martin, Ben R. McManus

Accepted for the Council:

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(Original signatures are on file with official student records.)

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HOUSING MARKET CAPITALIZATION OF ENERGY-SAVING DURABLE GOOD INVESTMENTS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
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Ruth Crumley Johnson

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To the women

in

Agricultural Economics

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ABSTRACT

Rising energy prices provide an economic incentive to substitute capital for fuel in production processes, where the extent of substitution that is feasible is constrained by existing technologies. In the residential sector, such capital-fuel substitution depends upon the willingness of builders and homeowners to invest in the durable goods that make the house energy conserving. Since these durable goods become permanently attached to the dwelling unit and since ownership is likely to change over the lifetime of the house, the incentive to carry out an investment in energy conservation depends critically upon the efficiency of the housing market in capitalizing the financial benefits of future fuel savings.

In this study of the Knoxville housing market during 1978, an hedonic price equation of the form $P = f(U, X)$ was estimated, where P is the sale price of the house, U is the annual utility (fuel) bill, and X is a vector of structural, locational, and neighborhood attributes. The estimated hedonic price index reveals that, holding other influences constant, the marginal effect of a one-dollar savings in the annual fuel bill is to increase the sale price of the house by approximately $21. Estimates of implicit market discount rates, under various assumptions about fuel escalation rates and remaining lifetimes of the houses, indicate that the housing market performed in a manner consistent with a social discount rate of about 10 percent. The results of the study do not show whether or not investment in energy conservation is proceeding

at a socially optimum rate, only that the housing market, in this location and period of time, did operate efficiently in capitalizing the investments.

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CHAPTER 1

INTRODUCTION

The potential benefits of conservation in solving the national energy problem are widely recognized. Improved efficiency in energy usage, resulting from both behavioral changes and the implementation of new technology, can reduce the growth rate in the demand for energy, lessen the dependence on foreign oil, and curtail the construction of new power plants. The magnitude of benefits to be gained from conservation and the means for realizing the potential, however, are questions of public debate [26, 34]. Research efforts in conservation have concentrated primarily on new technology to improve energy efficiency in transportation, industrial processes, appliances, heating and cooling systems, and building construction. Policy means for implementing new and existing conservation technology have been less adequately researched, although various tax incentives, subsidy schemes, and direct regulation have been proposed and, in some cases, enacted. In a recent *Science* editorial, Hirst charges that, without needed data about energy usage and consumer behavior, policy decisions are being made on the basis of little more than intuition [15].

In the residential sector, changes in the capital stock of housing occur slowly as new houses are constructed and improvements are made to existing houses. Although some aspects of energy conservation require only changes in behavior, such as turning down the thermostat, the

implementation of new energy-saving technology requires, generally, a higher capital investment in durable goods. Therefore, realization of technologically feasible energy savings in housing depends upon the incentive of the individual homeowner to make the higher capital investment in constructing an energy-efficient house or to invest in retrofitting and replacing equipment in an existing house.

Rising fuel prices have provided an economic incentive for the consumer to substitute capital for fuel in the purchase of more energy-efficient appliances and in the household production process of providing heating and cooling. If the market were perfectly competitive, the consumer would have full knowledge of fuel prices, the effectiveness of various insulating materials, and the comparative energy efficiencies of all durable goods on the market. The consumer would, therefore, rationally invest in an energy-saving durable good or insulating material when the discounted value of future fuel savings exceeds, or at least covers, the incremental capital cost of the more energy-efficient good. Also, if the market were perfectly competitive, new houses would be built to incorporate the economically rational level of investment in energy efficiency, and the sale price of the house would incorporate the value of this investment. Furthermore, at the time of resale, the value of unrealized future fuel savings would be capitalized in the sale price of the house. In such a perfect market, both buyers and sellers could predict with certainty the level of fuel prices over the future planning horizon. In this situation, policymakers could focus entirely on research and development efforts to expand the available substitution possibilities.

In the real world the market is obviously less than perfect. Both buyers and sellers are faced with lack of information, misinformation, and uncertainties to some degree. Also, given the long lifetime of houses[a] and the short mean length of occupancy by U.S. families,[b] the incentive to invest in energy conservation depends critically upon the efficiency of the housing market in capitalizing the investment. Existing opinion seems to be that the housing market fails in this regard [10, 14, 19]. In a recently published article in the *Bell Journal*, Hausman [14, p. 51] states: "It is often claimed that capital improvements which lead to savings over time are not fully reflected in the sale price of the house." This claim or opinion as it affects the level of investment in energy conservation, however, has not been empirically tested and reported in the literature, although it has direct relevance to the formulation of policy measures intended to encourage the adoption of energy conservation measures in the residential sector. Research and empirical data are needed to identify the sources and the extent of market impediments and to determine the resulting effect on energy conservation investment. From these findings, specific policy recommendations can be formulated.

Statement of the Problem

This study undertakes an empirical investigation of the housing market for the purpose of determining the market valuation of energy

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[a]One-third of the housing stock is more than 40 years old [37].

[b]The mean length of occupancy is estimated at 5.8 years [36].

efficiency in the selling price of a house. The study addresses policy issues pertaining to the performance of the housing market, the information component of the market, and the discount rates that are implicit to energy conservation investment. The intent of the study is to provide empirical evidence that is necessary for the design and evaluation of energy conservation policies.

The objectives are:

1. To determine the efficiency of the housing market in capitalizing energy conservation investment in the sale price of the house.
2. To evaluate the availability and reliability of information upon which the buyer can judge future fuel costs of a particular house.
3. To calculate the implicit market discount rate at which future fuel savings are converted to a present value.

The study is a cross-sectional market analysis of houses sold through the Multiple Listing Services (MLS) of the Board of Realtors, Knoxville, Tennessee, during the time period of January 23, 1978, through January 24, 1979. Sources of data include the MLS files, utility billing records from Knoxville Utilities Board (KUB), census tract reports from the 1970 U.S. Census of Population and Housing, and property location information from the Knoxville Metropolitan Planning Commission. The statistical method of analysis is an hedonic price equation incorporating structural, neighborhood, location, and utility usage variables.

The present study is limited in scope to one location and one year in time. Hence, the empirical results must be interpreted and applied with due caution since housing markets are dynamic in nature, exhibiting changes and variations both spatially and temporally.

Importance of the Study

Despite the limitations of this study, the findings have implications for the formulation of policies which are designed to promote investment in energy conservation in the residential sector. If the housing market is found to operate efficiently in capitalizing future fuel savings, then policy should focus on technology to expand and improve the efficiency of insulating materials, housing designs, and durable goods. If, on the other hand, the market is found to exhibit imperfections, specific corrective policy measures are indicated, depending upon the source of market failure.

If the suboptimal market performance is due to insufficient or inaccurate information available to the homebuyer, labeling requirements in the form of past utility bills or an energy point index such as that initiated by the Florida Energy Office [8] are possible policy measures. Consumer education programs through agencies such as the Agricultural Extension Service also play a role in alerting the buyer to look for and make use of information that is available.

If high private discount rates, due to uncertainties in the market or individual time preferences for money, inhibit conservation investment, direct regulations such as building codes or mortgage insuror requirements

may be necessary. Various subsidy schemes or tax incentives are alternative policy strategies. If the discount rate for energy conservation investment is found to vary inversely with the price of the house, one implication is that low-income consumers lack the necessary capital or access to borrowing, indicating the need for special subsidies or loans. Another conclusion suggested by Hausman [14, pp. 52-53] is that low-income consumers exhibit higher discount rates because of the progressive nature of the income tax. Return on investment in stocks or savings accounts represents taxable income, whereas return on investment in the form of fuel savings is nontaxable, giving more conservation investment incentive to those persons in higher income brackets.

This study, which was funded by the U.S. Department of Energy, will be of value to researchers at Oak Ridge National Laboratory in their economic model for predicting energy demand in the residential sector. The empirical results will provide information for testing the validity of certain assumptions regarding consumer behavior, market penetration of new technology, and capitalization of conservation investment in the housing market.

Organization of the Study

An overview of the general problem has been given in Chapter 1. Chapter 2 presents a review of selected literature pertaining to the housing market, land values, and private investment decisions. This body of literature provides the foundation for the theoretical construct which is developed in Chapter 3. The third chapter also describes the

statistical techniques used, specification of the model, and the expected relationships of variables in the hedonic price equation.

Chapter 4 contains a description of the data collection procedures and characteristics of the houses in the sample. The results of the empirical analysis are reported in Chapter 5. Finally, the study is summarized in Chapter 6. Policy implications of the findings are suggested, and areas for further research are identified.

CHAPTER 2

REVIEW OF SELECTED LITERATURE

A study of the determinants of housing prices draws from economic theories pertaining to consumer behavior, the housing components that provide services, and the market interaction of supply and demand forces. The present study also includes theories of investment and relates the theories to investment in residential energy conservation.

Certain factors distinguish housing from other consumer goods, both as to its durability and the nature of services provided. Housing is not a single good, but a number of goods which can be constructed or assembled in various combinations. The goods or amenities that go into housing include the structural components and physical characteristics of the house, the size of the lot and its location, and the social and environmental qualities of a particular neighborhood. Traditional economic theory of consumer behavior, which distinguishes goods as to their substitutability or complimentarity, has lacked the means to handle quality differences or product differentiation [31] and to explain the complexities of combinations of goods such as those that exist in the housing market.

The work of Lancaster [24, 25] has given impetus to further development in consumer theory to include the concept of household production and the technique of hedonic pricing. These developments and their application to the housing market, as well as theories of

land values and investment in conservation, are reviewed in this chapter. This body of literature and empirical application of the theories provide the basic framework for the present study.

Theories of Hedonic Prices, Household Production, and Investment in Energy Conservation

Each of the components or characteristics of a house has its own implicit or hedonic price. The hedonic price approach is a technique for measuring the implicit prices of goods or characteristics that are not themselves explicitly traded in markets but which are characteristics of marketed goods. In empirical applications of the hedonic technique to the housing market, price is regressed on specified components or characteristics of houses. Thus, the marginal valuation of each component, found from the respective partial derivative, gives the implicit price of that component.

This technique was an outgrowth from Lancasterian theory in which it was recognized that consumers derive utility, not from goods themselves, but from the characteristics of goods. Lancaster [24] assumed that consumption is an activity in which goods, singly or in combination, are inputs, and the output is a collection of characteristics. In addition, a good will possess more than one characteristic, and many characteristics will be shared by more than one good. Goods in combination may possess characteristics that are quite different from those of separate goods. Therefore, consumers make choices, within the limits of available consumption technology and the budget constraint, among many goods or

combinations of goods to provide a desired characteristic. The rational consumer who wishes to maximize utility will choose the appropriate combination of goods to provide a given characteristic, based upon relative prices of the goods, as well as individual tastes and preferences.

The theory of household production is a logical consequence of consumption technology. In the household production function, goods are inputs into specified activities which, in turn, produce commodities as the output. The approach has been applied to a wide spectrum of problems and analyses ranging from allocation of time as an input in the household production process [30] to decisions regarding children and investment in human capital [28].

The theory of the household production function is relevant to the choices of the homeowner that affect the energy efficiency of the house. In this application of the theory, output is the heating and cooling necessary to maintain a desired indoor temperature. The homeowner has a number of options for combining inputs (insulating materials, equipment, and fuel) into several types of heating and cooling systems (activities) to achieve the desired output. The state of technology determines the number of options available to the consumer for combining inputs to produce a given output or service. An important part of the recent thrust in solving the problem of scarce energy resources has been the development of new technologies to expand the substitution possibilities for combining inputs that use less energy. Tastes and preferences of individuals are no doubt important in the household production process. For example, the homeowner may strongly prefer one fuel or a particular type of equipment

over another. Given these preferences and the budget constraint, the rational consumer's decision is then made on the basis of relative prices. Rising fuel prices provide an incentive for the consumer to become more energy efficient and to substitute the appropriate capital goods for fuel.

Generally, the initial capital cost of the energy-efficient durable good is higher than the cost of its less efficient counterpart. Room air conditioners with differing energy efficiency ratios provide a good example. Thus, there is a trade-off decision between first cost and energy use over the lifetime of the durable good. Under these conditions, the homeowner will rationally invest in conservation when the discounted value of future fuel savings covers the capital cost of the investment or the incremental cost of the more efficient durable good [3]. The appropriate discount rate in this situation is the opportunity cost of capital or the observed market interest rate.

If it is assumed that homeowners do indeed make rational investment decisions, an important question for empirical study is the discount rate implied in actual market transactions. A discount rate higher than the market rate of interest indicates the presence of market imperfections, whether they be uncertainties, insufficient information, lack of capital, financing problems, or other institutional constraints.

O'Neal and Corum [29], in a study of new home construction practices in effect during 1975-76, estimated the implied discount rate for consumers purchasing energy conservation in new residences. Their study included calculations for 10 cities in different regions of the United States,

with four types of fuel and differing assumptions as to future fuel prices and financing. The study concluded that the construction practices for 1975-76 implied discount rates that were high relative to historical real interest rates and which varied substantially with the heating fuel, location, and assumptions regarding financing arrangements and fuel price expectations. Possible causes of the high discount rates were not explained by the data. O'Neal and Corum suggested further research pertaining to institutional constraints affecting mortgage financing of extra costs of energy-efficient houses, the expectations of homebuyers regarding future fuel prices, and the efficiency of the residential housing market in capitalizing energy conservation investment.

Empirical Studies of Housing Markets

Housing markets have been studied for a variety of reasons: to evaluate methods of tax appraisals, to derive the demand for amenities such as clean air, to resolve questions of black-white price discrimination, and to determine the effect of location on the price of housing, to name a few of the many purposes. This review consists of a brief summary and examination of recent empirical work that is relevant to the techniques and the approach in the present study.[a] No attempt is made to be comprehensive, but rather the purpose of this review is to identify the empirical approaches used and the problems other researchers have encountered in studies of the housing market.

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[a]For a survey of earlier work, see the article by Ball [2].

Kain and Quigley [18], in a study of a sample of 1,500 households in St. Louis, attempted to measure the value of housing quality in the price of the house. The study had a particularly good data source, collected from two surveys, one of which included a household interview. In the first survey, interviewers made quality judgments about the interior of the house, while at the same time taking information from the interviewees. In the second survey, building inspectors evaluated the external quality of the houses and the environmental quality of the neighborhood. In all, 39 variables on quality attributes were collected. These were consolidated by factor analysis into five groupings which accounted for 60 percent of the variance among the 39 variables. The five factor groupings were: basic residential quality, interior dwelling unit quality, quality of proximate properties, nonresidential uses in the neighborhood, and average quality of the structures in the neighborhood. These five factors, plus other quantitative attributes of housing (age of house, number of rooms, etc.), were regressed on house price and monthly rent, respectively (estimated house prices and monthly rent were reported by households during the interview survey). A linear form, with R^2 of 0.72, for the renter equation, and a semilog form, with R^2 of 0.73, for the owner occupants, were found to give the best fit.

In the Kain and Quigley study, miles from the central business district (CBD), which was used as an accessibility measure, was insignificant for both tenure types. Since the result is contrary to most economic theories of residential location, the authors attributed the fault to "inadequate standardization, improper specification of the

equations, the measure of accessibility used, or existing theories that fail to consider effects of such important factors as stocks or housing market discrimination" [18, p. 540].

On the basis of tests of significance and the size of the coefficients for quality factors, Kain and Quigley concluded that the quality of the bundle of residential services had nearly as much effect on the price of housing as such objective aspects as number of rooms, number of bathrooms, and lot size.

Another study with a particularly good data base was that done by King [20] for the purpose of determining whether amenities, services, and taxes affect housing prices. The data were obtained from Multiple Listing Services (MLS) real estate transactions during 1967-69 for some 2,000 single-family homes in the New Haven, Connecticut, metropolitan region. A second set of data was obtained through a mail survey to the home purchasers. Of the 2,000 questionnaires mailed, approximately 45 percent were returned with complete and usable information. The major purpose of the mail survey was to determine the perceptions of the homebuyers regarding their neighborhoods and accompanying amenities. In addition, certain information such as sale price and date of sale provided a cross check for accuracy of the MLS data. From these tests, King concluded that the MLS provided a sufficient degree of accuracy and that errors were randomly distributed.

Observed market sales prices were regressed on structural, locational, and land area variables. Included in the vector of locational characteristics were accessibility, measured by distance

to the CBD and travel time to the CBD, neighborhood quality, property tax differentials, and certain public services. The conclusion of the study was that the analysis isolated reasonable prices for a number of structural characteristics, amenities, and public services. Tax differentials, however, were not fully capitalized, perhaps because the differentials were perceived as erratic or short lasting. The estimates of the coefficients for proximity to the CDB were questioned by King as being perhaps too low in value, although the coefficients were of the expected sign and statistically significant.

Straszheim [33] estimated the demand for urban housing services from household interviews in the San Francisco area. This study differs from others in that a separate hedonic price equation for each of 73 separate submarkets was used to estimate the price of various components in the housing bundle. Given these prices, demand functions for specified housing services were estimated. The rationale for this approach was that there are many housing submarkets within a single urban area, divided by social characteristics of the population and specific location. The price of housing was assumed to vary spatially because of travel distance to the work site. According to Straszheim's hypothesis, the household has the opportunity to choose the price at which it buys housing by altering the work trip. Assuming each housing attribute has a positive marginal utility, households will commute down the rent or price gradient until the additional disutility of a longer work trip offsets the savings in the price paid for housing. From the analysis of the data, Straszheim concluded that there was a substantial spatial variation in the price of

most attributes of housing services. While prices, in general, were negatively related to travel time required to commute to the CBD as hypothesized, there was additional spatial variation which Straszheim explained by suburban job-site concentrations and particular attributes of the stock of housing located in the suburbs.

Grether's and Mieszkowski's [13] study of the determinants of real estate values used a portion of the previously referenced data base from the New Haven metropolitan area [20]. Their analysis was limited to 830 transactions within the city of New Haven for the time period 1962-69. Grether and Mieszkowski postulated that the value of a house was an additive function of its structural characteristics, the characteristics of the lot, and the characteristics of the neighborhood in which the house was located. The authors noted the problem of heteroscedasticity with, not surprisingly, more variation associated with larger transactions. To correct for the problem, the sale price of each house was divided by the size of the house and the construction price index, thus transforming the dependent variable to real price per square foot. The problem of multicollinearity in the large number of independent variables was not discussed in the paper.

The reported multiple regression model in a linear form had an R^2 of 0.89. Nearly all the variables had the expected sign and the majority were statistically significant. Of particular relevance to the present study are the insulation and storm window dummy variables which had the expected sign but were not statistically significant. The explanation given for this result was that there were likely inconsistencies in the

reported data. Another probable factor, viewed from a present-day perspective, is that real fuel prices were low in the sixties; therefore, the economic incentive to invest in conservation was lacking at that time.

The measure of accessibility in the Grether and Meiszkowski study was distance from the New Haven Green (CBD). This variable had the expected negative sign but was not statistically significant. The result was explained by the fact that the city of New Haven was fairly compact with houses located on the boundary of the city being only three miles from the CBD.

The neighborhood variables were entered under three different assumptions: that they affected the price per square foot of the lot, that they changed the price per square foot of the house, and that neighborhood attributes had a fixed value that was independent of either house or lot size. The results showed that differing assumptions did not change the significance of the neighborhood variables. In the selected model, the researchers used the first assumption that neighborhood variables affected the price per square foot of the lot. The theoretical grounds for this choice were not discussed, however.

Finally, the study reported the results of a regression model using a restricted number of structural variables (size, age, bathrooms, average room size, and dummy variables for garage and stories). This model gave good overall results with an R^2 of 0.85. On this basis, Grether and Mieszkowski suggested for future housing studies that the necessary data are easily obtainable from local tax assessment records.

Berry and Bednarz [4] used hedonic models of prices and assessments for single-family homes in Chicago to identify ways in which the market and the assessor differed. A comparison of the ratio of property tax assessments to market values for single-family homes in Chicago in 1971 showed a variation in the average ratio ranging from less than 15 percent in certain neighborhoods to close to 30 percent in others. The sample for the study to explain this variation consisted of a geographically stratified random sample of 275 houses chosen from residential sales listings. Comprehensive data were obtained from the sales information, 1970 census reports, and tax assessment records. Separate equations to explain the factors that determine sale price and the factors that determine assessment were used with the same independent variables. The equations were of the log-log form and used independent variables of housing characteristics, housing improvements (structural characteristics), neighborhood characteristics, racial and ethnic variables, environmental pollution, and accessibility. These separate equations were each found to have good explanatory power, and many of the same variables, including age of the house, lot size, and neighborhood characteristics, were significant in both equations. The model for assessments, however, explained 62 percent of the variation while the model for sale price accounted for 79 percent.

As a direct means of comparison and to identify the specific variables on which the market and the assessor diverged, a third equation was formulated using the same independent variables as before but with the dependent variable being the assessment/price ratio rather than

price or assessed value. The logic behind this approach was that the same independent variables influenced both the numerator and denominator of the dependent variable and should, thus, to the extent that the market and the assessor agreed, cancel each other out. The results of this model showed that the assessor and the market agreed on most factors, with many of the most powerful variables in the earlier equations now becoming statistically insignificant. Two exceptions were size and age of the housing unit which were significant variables. The positive sign on the size coefficient indicated that assessments tended to run ahead of market prices for larger units, while the negative sign for age revealed that the assessor depreciated property more rapidly than did the market.

An interesting result of the study was the positive and significant coefficient on distance to the CBD. This result was explained by the amenity influence that increased with distance from the CBD and more than offset the effect of accessibility. A related and complicating influence was noted by the positive and significant coefficient for the pollution particulate variable in the assessment model. The authors pointed out the high degree of correlation between the pollution variable and distance from the CBD (simple correlation coefficient of -0.74) making the true relationship with the dependent variable difficult to isolate. However, the coefficient for the pollution variable remained positive and significant with or without distance in the equation. A plausible explanation was that this variable was serving as a proxy for access to industrial and commercial areas.

Little [27] used the hedonic technique to investigate preference rankings of housing characteristics, including structural, neighborhood, and local public service variables. A second purpose was to study the process of neighborhood filtering and neighborhood change. Neighborhood filtering was defined as a change in the ordering of neighborhoods as reflected by a change in relative housing prices among neighborhoods. The data consisted of more than 30,000 house sale observations in St. Louis city and county during the period 1961-71, with approximately 3,400 of them applicable to the 1970 cross-section analysis. The neighborhood unit was defined on the basis of census tracts.

Factor analysis was used to transform the variables into housing bundles that became the independent variables in the hedonic price equation. Assuming that households shared a common preference ranking over alternative housing bundles, the implicit prices derived from the price equation represented an ordering of alternatives. Neighborhood characteristics, including income class and racial change, were found to have a significant influence in the price equation. Comparisons of neighborhood rankings over time showed changes among certain neighborhoods but most were stable over time. However, in the short run, the change in rank of neighborhoods was found to be sensitive to racial change.

Yinger [40] studied the St. Louis housing market in an attempt to account for black-white price differentials. The data base was the same as that used by Kain and Quigley [18]. Yinger hypothesized two opposing effects that could cause differences in the black-white housing

markets. The first was actual price discrimination on the part of sellers, and the second was that racial composition was a neighborhood amenity characteristic in the hedonic price equation. Assuming that blacks were discriminately charged higher prices, Yinger hypothesized that the price for housing would be higher in all-black than in all-white neighborhoods. Further assuming that whites, constituting a majority, preferred to live in white neighborhoods, Yinger postulated that the unit price of housing declined as percent black increased in integrated neighborhoods. The issues and the relationships are complex, and in this study a further complicating factor was that house prices were estimated values made by homeowners rather than actual sale prices. The expected relationships were, in large part, borne out by the regression results. Yinger's conclusion was that careful specifications of models, including racial composition as an amenity, are needed in order to answer the issues regarding racial effects and price discrimination in the housing market.

Cho and Reichert [5] used multiple regression analysis to suggest a method for appraising single-family houses in Fort Wayne, Indiana. The data came from 1977 sales reported through real estate Multiple Listings. Only structural variables were used in the separate equations estimated for two geographic areas of the city. The authors stressed the need for proper selection of housing characteristics coupled with a reasonably homogeneous sample. This requirement would appear to be imperative in models where neighborhood and accessibility factors are not specified as was the case in the Cho and Reichert study.

The researchers used the stepwise regression technique to choose variables sequentially according to their relative explanatory power from among 15 selected housing characteristics. Only those variables with a level of statistical significance less than or equal to 10 percent were retained in the final models. Use of the stepwise technique might seem contradictory to the stated criterion of careful selection of housing characteristics or selection of variables on theoretical grounds. However, the models each had good explanatory power with R^2 of 0.87 and 0.89. The variables in the equations each had the expected signs, although the models differed in the selected variables and those variables common to both models had coefficients of significantly different size. Consequently, Cho and Reichert warned that undue significance should not be attached to the exact value of each coefficient. As an example, the inflated coefficient for the built-in dishwasher variable may more likely have reflected the value of a modernized kitchen.

The conclusion of the study was that multiple regression analysis is most effective when appraising houses with similar characteristics within a well-defined area. Furthermore, a statistical technique such as multiple regression analysis should be considered as an additional tool, not a substitute for the appraiser's judgment.

The importance of neighborhood amenities in the selling price of a house was investigated by Krumm [23]. The data base consisted of selling prices of 452 residences in Chicago and variables concerning structural and lot characteristics, together with data on characteristics of the block where the residence was located. Krumm hypothesized that

two markets exist, a housing market and an amenity market, and that the selling price of the house and the amenity level were both endogenous variables. In addition, a given level of amenity had two components, those which were fixed at a given location, such as accessibility, and those which can be varied by the neighborhood residents themselves, such as litter on the streets. The relationship was hypothesized to be two-way; the amenity level affected the selling price of the house and the price of the house affected the amenity level, as well.

Using the factor analysis approach, Krumm grouped neighborhood characteristics into an amenity variable. In his two-equation model, selling price (SP) and the amenity level (X_a) were determined by the two-stage least squares procedure. The coefficients of X_a and SP were significant in both equations. Krumm interpreted this result as support for the joint determination of equilibrium in the housing and amenity markets. Krumm further concluded that the effect of neighborhood amenities, as captured in X_a, was large and should not be ignored in analyses of housing markets.

The accessibility measure in the Chicago study was distance from the nearest freeway entrance to the CBD plus twice the distance to the nearest freeway entrance in thousands of feet. This variable had the expected negative sign and was statistically significant, indicating that the price of the house decreased, *ceteris paribus*, as one moved further from the CBD.

One of the more comprehensive recent studies of factors affecting the spatial distribution of land values was that done by Yeates [39] for

the city of Chicago covering the decades of 1910 through 1960. In this study, the logarithmic value of land per front-foot was regressed on the following independent variables (also in logarithmic form): distance from the CBD, distance from the nearest shopping center, distance from Lake Michigan, distance from the nearest elevated-subway system, population density, and the percent nonwhite population. The latter two variables were by census tract. This model explained decreasing percentages of the variation in land values, going from 77 percent in 1910 to 18 percent for 1960. In subsequent analyses, Yeates added dummy variables to represent six geographic sectors of the city and found that this addition increased the explanatory power of the 1960 model to 51 percent, indicating that sectoral differences at this period accounted for 33 percent of the variation in land values.

From these changes in the hypothesized relationship of factors associated with land values, Yeates concluded that the spatial distribution of land values has become more complex over time and cannot be accounted for with a single variable, as is commonly done with distance from the CBD. The hypothesis that land values decline with distance from the CBD was substantiated at each time period, but there appeared to be a continuous decline in strength of the association. Proximity to shopping centers had two opposite effects, depending upon the sector. Land values diminished with distance from shopping centers in the newer and more rapidly expanding, affluent areas of white population, whereas in old areas of manufacturing and commerce, occupied by a very large number of low-income nonwhite persons, proximity to shopping had a detrimental effect on land values.

The influence of recreational and physical amenities on land values, taken in this study to mean distance from Lake Michigan, appeared to have increased in relative importance during the past 50 years. This may have been due, in part, to the fact that distance from the lake measured accessibility to a major highway and rapid transit facilities which parallelled the lake for some distance. The variable for distance from rapid transit itself declined in importance as a determinant of land values since 1930.

The population density and nonwhite variables proved to be interrelated. In the early part of this century, higher land values were associated with high population densities. This relationship was not substantiated in later time periods, however. Yeates's analysis of both population density and nonwhite factors indicated that, as percentage nonwhite in an area increased, land values decreased, until such time as the population rose to a point where intense competition for living space caused land values to begin to increase.

The complexities of proper specification of factors influencing accessibility were handled in a different way by Jackson [16] who used a general accessibility measure consisting of a double power series in Cartesian coordinates. The term accessibility, as used in Jackson's study, referred to the locational advantage created by all trip destinations, including shopping, schools, churches, and recreation centers, as well as places of employment. Jackson hypothesized that the effects of all important accessibility influences were implicitly captured in the function $A = f(X, Y)$ where A is accessibility and X and Y are Cartesian coordinates. By taking a Taylor series expansion of $f(X, Y)$ around the

midpoint of the Cartesian coordinate system, the function is transformed into the polynomial form that constitutes the price surface of a geographic area. The double power series representation of a surface is generally known as trend-surface analysis and has been used extensively in geology [22].

Jackson incorporated this accessibility measure into an hedonic price equation using 1970 census tract data for the city of Milwaukee. The dependent variable was average census tract rent, and independent variables included structural and neighborhood characteristics, as well as characteristics of the land. The accessibility influence was assumed to depend upon the size of the lot; therefore, an interaction effect was specified rather than a lump sum treatment.

The selected model explained 97 percent of the variation in average census tract rent. The signs of the structural and neighborhood variables were as expected except the indicator of neighborhood stability (percent of population moved in last five years) which had a positive sign but was not significantly different from 0.

Two criteria were used to determine the preferred degree of the polynomial for the accessibility measure. The first criterion was to examine regression models of different polynomial degrees to determine the point at which the change in the sums of squares due to regression indicated that the additional polynomial terms did not add significantly to the explanatory power of the model. The second criterion had to do with examination of the residuals for spatial autocorrelation which occurs if a polynomial of too low a degree is estimated. On the basis

of these criteria, the quintic polynomial form was selected for the accessibility measure in Jackson's study.

Hedonic prices from the regression analysis were used to construct price indexes of the relative price of housing for different locations in Milwaukee. An analysis of the price contour map showed the effects of different manufacturing employment locations and the expressway system. Jackson found that, while the location of the CBD did appear to influence the price contours, the generally assumed predominance of the CBD location was not evident.

Issues and Problems in Application of the Hedonic Technique to Housing Markets

From the foregoing review of empirical studies of housing markets and two comprehensive survey articles, one by Ball [2] in 1973 and a recent one by Freeman [9] in 1979, certain problems and issues pertinent to the present study can be identified. These issues concern the theory and its assumptions, the availability and reliability of data, specification of the model, statistical problems, and judicial interpretation and application of the results.

Since the hedonic price equation is a reduced form of the demand and supply equations, one must assume that the housing market is in equilibrium in order to interpret the partial derivatives of the specific characteristics as implicit prices. The assumption means that each household is in equilibrium with respect to a given vector of housing prices and that the vector of housing prices is the one that just clears

the market for a given stock of housing and attributes [9, pp. 159-161]. In order for equilibrium to be fully achieved, two conditions are required: first, households must have full information on all housing prices and attributes with no moving and transactions costs and, second, the price vector must adjust instantaneously to changes in either demand or supply. Since such perfect markets do not exist, particularly with respect to housing, prevailing market conditions must be taken into account when using and interpreting the results of the hedonic technique. In the present study, it is recognized that there are time lags in changing fuel prices, response by consumers, and subsequent adjustment in the stock of housing. However, the four-year interval between the 1973-74 initial energy crisis and the 1978 housing market provides for a period of adjustment in conditions of demand and supply. The results of the study provide needed information concerning the extent of the housing market response to changing energy prices.

The data for the reviewed studies have come principally from MLS [4, 5, 13, 20, 23, 27], census tract reports [16, 23, 26, 29], property tax records [4, 5, 19], and household surveys and interviews [13, 18, 20, 33, 40]. Two data bases that have been used extensively in empirical studies over the past 10 years are from St. Louis [18, 40] and New Haven [11, 12, 13, 20, 21]. An important consideration in selection of the data is the accuracy of the data source and the necessary statistical assumption that errors are randomly distributed. A related question concerns the use of estimated or assessed value rather than actual sale price of the house. A theoretical assertion

is that only sale prices are valid and only those households that have moved are expressing their marginal willingness to pay.

The use of census tract data imposes the assumption that the houses and neighborhoods within the census tract are reasonably homogeneous. Although the assumption of homogeneity does not hold strictly in each instance, most studies have accepted that the assumption holds, in general, and have used census tract data because it is the sole source or best source that is available. Ball [2] noted that the use of aggregate data, such as census tract data, results in an inflated R^2, as compared to studies that have used individual housing observations.

A further data limitation is that sources used within a single study may not be contemporary in time. Again, this limitation is generally accepted, and researchers use the best or most recent data source that is available for the purposes of the problem under study.

A majority of the reviewed studies have specified models of the general form

$$P = f(S, N, L)$$

where

P = price of the house,

S = vector of structural characteristics of the house,

N = vector of social and environmental attributes of the neighborhood, and

L = the lot and its accessibility to employment.

Only the Cho and Reichert study [5] limited the specification of the model to structural variables of the house. Since this study specified separate equations for each quadrant of the city of Fort Wayne, neighborhood and accessibility variables were implicitly assumed to be held constant.

Although the general specifications of the models in the reported studies have been similar, the specific variables used have varied considerably. This fact may be interpreted in several different ways: the purposes of the studies differed and, hence, different variables were selected; the studies used certain variables because of the availability of data; or housing markets varied from one city to another in the attributes that were important.

The reviewed literature offers no *a priori* theoretical justification for choice of functional form of the equation. The reported studies have used linear [5, 13, 16, 18], log-linear [18, 33], and log-log forms [4, 33, 39], with the choice being one of finding the functional form of the equation that gives the best fit.

A problem of model specification in many of the reported studies has been the choice of an accessibility measure or the locational advantage of a particular piece of property. Traditional theory dating back to von Thunen [3], and, more recently, Ely [7] and Alonzo [1], has hypothesized an inverse relationship between land values and distance from the CBD. The difficulty in applying traditional theory to contemporary housing markets is that, for a variety of reasons, urban and suburban land-use patterns have evolved in a manner more complex than

in von Thunen's model, with shopping centers, churches, schools, manufacturing and other places of employment spatially removed from the CBD. A further problem of model specification is that certain amenities and environmental qualities are strongly correlated with distance from the CBD. Therefore, it is not surprising that some empirical results have shown distance from the CBD to be statistically insignificant [13, 18, 39] or even of the wrong sign [4]. The general accessibility measure used by Jackson [16] to capture the effect of accessibility to all trip destinations, including employment, schools, shopping, recreation, and employment appears to be the most adequate of reported specifications.

The empirical studies have called attention to the statistical problems of multicollinearity [2, 9, 18], heteroscedasticity [13], and spatial autocorrelation [16]. The described data problems and the means for handling them provide the proper precautionary background information and insight necessary to the present study.

The review of literature of the hedonic technique and its application to the housing market shows that there are indeed many criticisms that can be raised about the validity of the assumptions, the adequacy of the data, and proper specifications of the models. Yet, in the words of Freeman ". . . all of these criticisms can be raised against virtually any empirical work in economics . . . but the question is not whether the model is perfect, but rather does it provide a usable vehicle for increasing our knowledge?" [9]. In this spirit, the present study was undertaken as a means for adding to the existing body of knowledge concerning the housing market and, more specifically, the response of the housing market to rising fuel prices.

CHAPTER 3

THEORY AND METHODOLOGY

The theoretical construct for the problem under study is developed from the previously reviewed body of literature on household production and housing markets, in general, and investment in energy conservation, in particular. This chapter describes the research methodology and the nature of the statistical problems that led to the choice of techniques used. The hedonic pricing model for the Knoxville housing market is specified, and expected relationships and effects of the specific variables are hypothesized.

Theoretical Construct

Investment theory provides the framework for analyzing the decision process through which energy conservation technology is implemented in the residential sector. In this context, the resale value of a house is equivalent to scrappage value in traditional investment theory. Given the relatively brief tenure of many homeowners in conjunction with the long lifetime of houses, the scrappage value and the marginal influence that energy efficiency has on this value can assume predominant importance in the homeowner's investment decision-making.

The criteria for optimal investment, both from a private investor's point of view and that which is socially optimal, are presented, using the following notation:

C = incremental capital cost of an energy-saving durable good,

T = expected lifetime of the durable good,

$U_1(t)$ = utility bill at time t with existing (or standard) equipment,

$U_2(t)$ = utility bill at time t with energy-saving durable good ($U_2(t) < U_1(t)$),

r_S = social discount rate,

r_I = individual discount rate,

P_1 = market price of house with existing (or standard) equipment, and

P_2 = market price of house with the energy-saving durable good installed.

Assuming there are no externalities, it will be socially optimal to undertake a given investment in an energy-saving durable good when

$$C \leqslant \int_0^T [U_1(t) - U_2(t)]e^{-r_S t}\, dt \,. \tag{1}$$

If the potential investor expects to sell the house after an interval of time length $n < T$, the private criterion for making the investment is

$$C \leqslant \int_0^n [U_1(t) - U_2(t)]e^{-r_I t}\, dt + (P_2 - P_1)e^{-r_I n} \,. \tag{2}$$

Therefore, if the housing market is to function in a manner consistent with the socially optimal investment policy, it is necessary that

$$P_2 - P_1 = \int_n^T [U_1(t) - u_2(t)]e^{-r_S(t-n)}\, dt \ . \qquad (3)$$

For builders, n = 0, so the investment criterion reduces to $C \leqslant P_2 - P_1$.

Notice that condition (3) is not a sufficient condition for the socially optimal investment policy to be realized. In addition to this criterion, a second requirement is that $r_I = r_S$. Previously cited studies [14, 29] indicated that $r_I > r_S$; therefore, an underinvestment in energy-saving durables may occur even if the housing market performs efficiently and condition (3) is thereby satisfied. These two potential sources of departure from the socially optimal level of investment each have implications for energy conservation policy. If $r_I > r_S$, corrective policy measures should be directed toward encouraging the retrofitting of existing houses, providing accurate information concerning fuel savings, removing institutional constraints, and reducing uncertainties concerning fuel price signals. If, on the other hand, the housing market fails to capitalize the investment so that condition (3) is not satisfied, direct regulation and performance standards may be required. Another option, as suggested by Hausman [14, p. 51], is that utilities purchase energy-saving equipment and offer it to homeowners under a lease-rental arrangement.

The two potential sources of departure from a socially optimum level of investment are not mutually exclusive, however. One of the causes of high individual discount rates is the perceived failure of

the housing market to capitalize the investment. Likewise, the performance of the housing market depends upon the willingness of home purchasers to make the investment in energy conservation.

A General Formulation of the Model

To investigate the issues regarding the performance of the housing market, the marginal impact of a one-dollar savings in the annual utility bill on the selling price of a house, holding other influences constant, must be determined. The statistical method is to estimate an hedonic price index of the form

$$P = f(U, S, N, L) \tag{4}$$

where P is the sale price of the house, U is the annual utility (fuel) bill, S is a vector of structural attributes, N is a vector of neighborhood characteristics, and L consists of the size and accessibility characteristics of the lot. Implicit or hedonic prices for each characteristic can be estimated from the respective partial derivative. Thus, $\partial P/\partial U$ is hypothesized to have a negative value, indicating that fuel savings are capitalized in the selling price of the house.

The method of trend-surface analysis is used in the specified model as a means of accounting for the locational value of land that is derived from overall accessibility to employment centers, schools, shopping, and other trip destinations. This method was used in the previously cited study by Jackson [16] and was found to yield results

that were superior to those from models using the commonly specified measures of accessibility.[a]

The functional equation (4) can be specified as

$$P = \beta_0 + \beta_1 U + \beta_2 S + \beta_3 N + \beta_4 (A)L + \mu \qquad (5)$$

where A represents the accessibility component of the value of the lot, β_0 is the intercept term, β_1 is the estimated coefficient, β_2-β_4 are vectors of coefficients, and μ is the stochastic disturbance term. Other variables are as previously defined. Under this specification, the contribution of accessibility is proportional to the quantity of land rather than a lump sum treatment.

The general relationship between location and accessibility can be represented as

$$A = f(X, Y) \qquad (6)$$

where X and Y are Cartesian coordinates that define a geographic location.

From the general relationship, the accessibility measure is derived by taking a Taylor series expansion of f(X, Y) around the midpoint of the Cartesian coordinate system. This gives

$$A = f(X, Y) = a_{0,0} + a_{1,0}X + a_{0,1}Y + a_{1,0}XY + a_{2,0}X^2$$

$$+ a_{0,2}Y^2 + \ldots + a_{n,0}X^n + a_{0,n}Y^n + R_n$$

$$= \sum_{k=0}^{n} \sum_{j=0}^{n} a_{k,j}X^kY^j + R_n \qquad k \leqslant n \;,\; j \leqslant n \qquad (7)$$

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[a] A difference between the Jackson study and the present study is that Jackson used aggregate data where the census tract was the unit of observation; here, the unit of observation is the individual house.

where a's represent the function and its partial derivatives evaluated at (0, 0), n represents the polynomial degree, and R_n is a remainder.

By substituting Eq. (7) into Eq. (5), the regression model becomes a double power series representation of the polynomial form

$$P = \beta_0 + \beta_1 U + \beta_2 S + \beta_3 N + \sum_{k=0}^{n} \sum_{j=0}^{n} a_{k,j} X^k Y^j \cdot L + \mu \tag{8}$$

Method of Analysis

The primary focus in this study is on the effect of annual fuel savings on the price of a house. The quantity of energy consumed by a given property, however, is not completely determined by the thermal characteristics of the structure and the energy efficiency of its attached appliances. The income and preferences of the occupants exert additional strong influences on energy consumption.

Since family income is positively correlated with both energy consumption[a] and housing consumption (energy and housing are normal goods), there is a two-way interaction between the price of the house and its fuel usage. As hypothesized, lowered utility bills that are attributable to energy efficiency should increase the sale price of the house. At the same time, certain components of the house which are associated with higher income and the overall quality of housing

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[a]In a survey article on the demand for electricity, Taylor [35, p. 101] reported estimated short-run income elasticities ranging from .02 to 1.16 and long-run income elasticities ranging from 0.20 to 1.94.

(uniformity of heating and cooling and number of labor-saving, energy-using appliances) will increase both the price of the house and the utility bill.

In the housing market sample under study, the correlation between sale price of the house and the annual utility bill is 0.51. Because of the strong positive correlation between these variables, the coefficient of U, estimated by ordinary least squares (OLS), will be both inconsistent and biased upward. In OLS estimation, the U variable will be strongly correlated with the disturbance term in the equation, thereby violating one of the classical assumptions of OLS. To obtain a consistent estimate of the coefficient it is necessary to employ a method to correct the variable U of the component associated primarily with income so that U is no longer correlated with the disturbance term.

The instrumental variable approach provides a means for making this correction [17]. In this method a new variable Z is created such that Z is uncorrelated with the error term but highly correlated with the independent variable. The difficulty in applying the instrumental variable approach, however, lies in choice of the instrument. Since the true disturbance is unobservable, it is difficult to be confident that the instrument is uncorrelated in the limit with the error term. Furthermore, different results will be obtained depending upon the choice of an instrument.

In this study the selection of the instrument was made on the basis of theoretical justification (the fact that both housing and energy consumption are correlated with income) and the limitation of data availability. Since demographic data on the occupants of the houses

were not available, the correction of U for that component of the utility bill which is associated with income could not be made directly. Therefore, the choice of an instrument was one that took into account all predetermined variables in Eq. (8) plus additional predetermined variables that are known to affect the utility bill, including the weather, a proxy variable for family size, and an indicator of the relative energy usage of the appliances in the house.

The procedure for estimation of the instrumental variable was to regress the annual utility bill (U) on all predetermined variables (the vectors of S, N, and L) in Eq. (8) plus the additional predetermined variables. The predicted values of U were subsequently used in the hedonic price equation. Thus, variable U was adjusted for those factors that directly influence the utility bill of a house, such as number of square feet, and the indirect effects associated with the income component of energy usage. For example, the neighborhood location of a house does not affect the utility bill of the house per se, but the location is indicative of the income of the occupants.

The instrumental variable approach leads to consistent estimators of the regression coefficients, although the estimates may not be asymptotically efficient or unbiased. Despite these limitations, the instrumental variable method was used for the problem under study for two principal reasons. First, the method corrects, at least in part, for the income and behavioral component in the utility bill to make variable U uncorrelated with the disturbance term. Second, the method permits estimation of the hedonic price equation when complete data are lacking.

Selection of Variables and Expected Relationships of Variables

The choice of variables used in Eq. (8) was constrained by the availability of data and, within the constraint, attempts were made to assure reliability and accuracy of the data used. Details concerning the data, their sources, and data procedures are contained in Chapter 4. In this section the theoretical justification for the selected variables and expected relationships are discussed.

Annual Utility (Fuel) Bill

Equation (3) of the investment criteria provides the theoretical basis for including the annual utility bill of a house as a variable in the hedonic price equation. Determination of the market valuation of a one-dollar annual fuel savings provides the necessary empirical test for meeting objectives 1 and 3 of the study.[a] The coefficient of U is hypothesized to have a negative value. An additional consideration in choice of the utility bill as a variable is that this item of information is included on the Knoxville MLS form (average monthly utility costs), and this information is available to prospective homebuyers in some cases.[b]

If the data were available, an alternative choice of variables would have been the durable goods and components that comprise an

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[a]See Chapter 1.

[b]A discussion of the availability and reliability of the utility bill information is reported in Chapter 5.

energy-efficient house. All such components, however, are not easily quantified, e.g., the siting of the house, shading from trees, weather stripping and caulking. Therefore, on the basis of theoretical justification and data considerations, the annual utility bill is the variable used in this study to determine the energy efficiency of a house.

Structural Variables

The structural and physical characteristics of the house that are used as variables in the model include age, size, number of bathrooms, and dummy variables for type of house (ranch, split-foyer, or two-story), brick exterior, carport, garage, patio, deck, paved driveway, fireplace, air conditioning, and built-in appliances. All structural variables, except age and type of house, are hypothesized to have a positive effect on the price of the house. The price of the house is hypothesized to decrease with age, whereas the effect of the type of house is not hypothesized.

Neighborhood Variables

The attributes of the neighborhood that are included in the model include three census tract variables: mean family income, percent black population, and population density. It is recognized that the geographic area defined by a census tract may not contain homogeneous neighborhoods and that the characteristics of the census tract have changed since the data were collected in 1970. However, despite the limitations, the census tract data represent the best of available sources.

The coefficient for income within the census tract is hypothesized to be positive, indicating that various neighborhood amenities are associated with higher incomes of the residents. This study makes no *a priori* prediction as to the relationship between percent black and the price of houses within a census tract. Reported studies suggest that this variable does have an impact on property values, but the direction of this impact varies from place to place, depending upon the market situation for nonwhite housing and the trend in neighborhood change. Neither can the effect of population density upon property values be ascertained *a priori*. Although low population density may be regarded as a neighborhood amenity contributing to the price of the house, competition for housing in highly populated areas may bid up the price.

Locational Variables

A dummy variable for location within the city limits is used as a means of accounting for differences between the city and the county in the property tax rate and services provided. An expected sign of the coefficient is not hypothesized.

The X, Y locational variables are used to determine the effect of accessibility upon the residential land values in the sample. This component is important to proper specification of the model. The results of the estimation will be interpreted *ex post* in relation to the Knoxville interstate system, centers of employment, and shopping centers, as well as proximity to the central business district.

Additional Predetermined Variables

Four predetermined variables in addition to those included in Eq. (8) are used in estimation of the instrumental variable ($\hat{U}$). These include heating degree days (HDD) and cooling degree days (CDD) for a twelve-month period, number of bedrooms as a proxy for family size, and a dummy variable indicating that a house has connections for both a washer and a dryer. The washer-dryer variable is hypothesized to have a positive effect on the utility bill. Furthermore, this variable is hypothesized to have a greater impact on utility usage than upon the price of the house. CDD are multiplied by the dummy variables for central and room air conditioning so that the variable enters the equation only for those houses having central or room cooling units. Individual housing observations in the sample differ slightly with respect to HDD and CDD because of variations in billing periods and the month in which the observed annual utility bill begins. HDD and CDD provide a means for measuring daily temperature extremities that are expected to have a positive effect upon heating and cooling requirements in the annual utility bill.

CHAPTER 4

DATA COLLECTION AND CHARACTERISTICS OF THE SAMPLE

The collection, compilation, and management of data for this study, as in any empirical research, represented important and critical steps in the analysis. The reported work of King [20, 21] provided impetus and insight into the problems inherent in forming a data base for housing market analysis. The philosophy of King (and the one adopted for this study) is that elaborate or complicated econometric analysis will not compensate for deficiencies in the data or lack of painstaking time and effort in this phase of the research.

The principal data source for the study was the report of houses sold through the Multiple Listing Services (MLS) of the Knoxville Board of Realtors during 1978.[a] Additional data on the houses selected from the MLS report were obtained from the utility billing records of Knoxville Utilities Board (KUB), census tract reports from the 1970 U.S. Census of Population and Housing, and geographic information from the Knoxville Metropolitan Planning Commission (MPC). The selection of houses in the sample, the procedures for collecting data from each source, and the necessary assumptions are described. The specific variables used in the model, definitions of the variables, and their source are reported in Table 1.

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[a]See the Appendix for a copy of the MLS reporting form.

Table 1. Variable names and definitions in the hedonic price equation, sample from Knoxville Housing Market, 1978

Variable name	Definition	Source
P	Sale price of the house, 1978	1
U	Annual fuel bill, 1979	4
SIZE	Size of house, in square feet	1
AGE	Age of house, in years	1
BTHRMS	Number of bathrooms minus one	1
RANCH	Dummy variable for ranch style house	1
SFOYER	Dummy variable for split foyer house	1
2STORY	Dummy variable for two story house	1
BRICK	Dummy variable for brick exterior	1
CARPORT	Dummy variable for carport	1
GARAGE1	Dummy variable for one-car garage	1
GARAGE2	Dummy variable for two-car or larger garage	1
PATIO	Dummy variable for patio	1
DECK	Dummy variable for deck	1
PAVDRWAY	Dummy variable for paved driveway	1
FIREPL	Dummy variable for fireplace	1
UNITAIR	Dummy variable for one or more room air conditioners	1
CENTAIR	Dummy variable for central air conditioner	1
COMPAC	Dummy variable for trash compacter	1
DISHWSH	Dummy variable for dishwasher	1
DISPOS	Dummy variable for disposer	1
INTERCOM	Dummy variable for intercom	1
RANGE	Dummy variable for range	1
INC78	Estimated mean family income within census tract, 1978	2
BLACK	Percent black within census tract, 1970	2
POPDEN	Persons per acre within census tract, 1970	3
CITY	Dummy variable for inside city	1
LOT	Size of lot in square feet	1
X	Location variable, X coordinate value	3
Y	Location variable, Y coordinate value	3
Additional	Predetermined Variables:	
HDD	Annual heating degree days	4
UNITCDD	Annual cooling degree days × UNITAIR	4
CENTCDD	Annual cooling degree days × CENTAIR	4
WASHDRY	Dummy variable for washer-dryer connections	1
BEDRMS	Number of bedrooms	1

Sources:
1. Multiple Listing Service.
2. Census tract data.
3. Metropolitan Planning Commission.
4. Knoxville Utilities Board.

Sources of Data

Multiple Listing Services

An initial sample of 1,500 houses was selected from the approximately 3,400 houses sold through MLS in the Knoxville area during 1978. The criteria for selecting houses in the sample were:

1. single-family, detached dwelling unit;
2. located within Knox County;
3. heated by electricity or natural gas;
4. served by Knoxville Utilities Board; and
5. essential information about property: selling price, date of sale, identifiable address, age of house, total number of rooms, number of bedrooms, number of bathrooms, total area of house, and dimensions of lot.

The sample was limited to single-family, detached dwelling units for purposes of comparability and as a means of controlling for extraneous influences on the utility bill. The geographic area of Knoxville and surrounding Knox County was specified to define a particular housing market. The sample was limited to houses heated by electricity or natural gas and served by Knoxville Utilities Board because of the availability of data. In the KUB service area, approximately 70 percent of the homes are heated by electricity and 15 percent are heated by

natural gas, with the remaining 15 percent heated by oil, coal, wood and other fuels.[a,b]

All houses that met the above criteria were included in the sample. In some cases, particularly new houses, the address consisted of lot number and subdivision identification. Street addresses for these houses were located through the use of maps located at offices of the MPC. The geographic area of the housing market defined by criteria (2) and (4) as shown in Fig. 1 includes the City of Knoxville and all of Knox County except the western portion and a small area in the northwest.

In criterion (5) certain items of information from the MLS form were deemed essential in order to include the house in the sample. For other specific features of the house, such as garage, fireplace, or dishwasher, it was assumed that the feature, if present, would be checked on the form. The assumption is based on the rationale that a real estate agent and a homeowner wishing to sell a house will specify all positive attributes of that house. Therefore, a blank was coded as not having a particular feature rather than as missing data.

Knoxville Utilities Board

Addresses of the 1,500 houses were furnished to KUB personnel who, in turn, matched addresses with account numbers to supply the utility

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[a] Information from Rebecca Davis, Public Information Representative, Knoxville Utilities Board, October 15, 1980.

[b] Residential heating fuel types for the U.S. are: natural gas, 54 percent; oil, 22 percent; electricity, 16 percent; and other, 8 percent [37].

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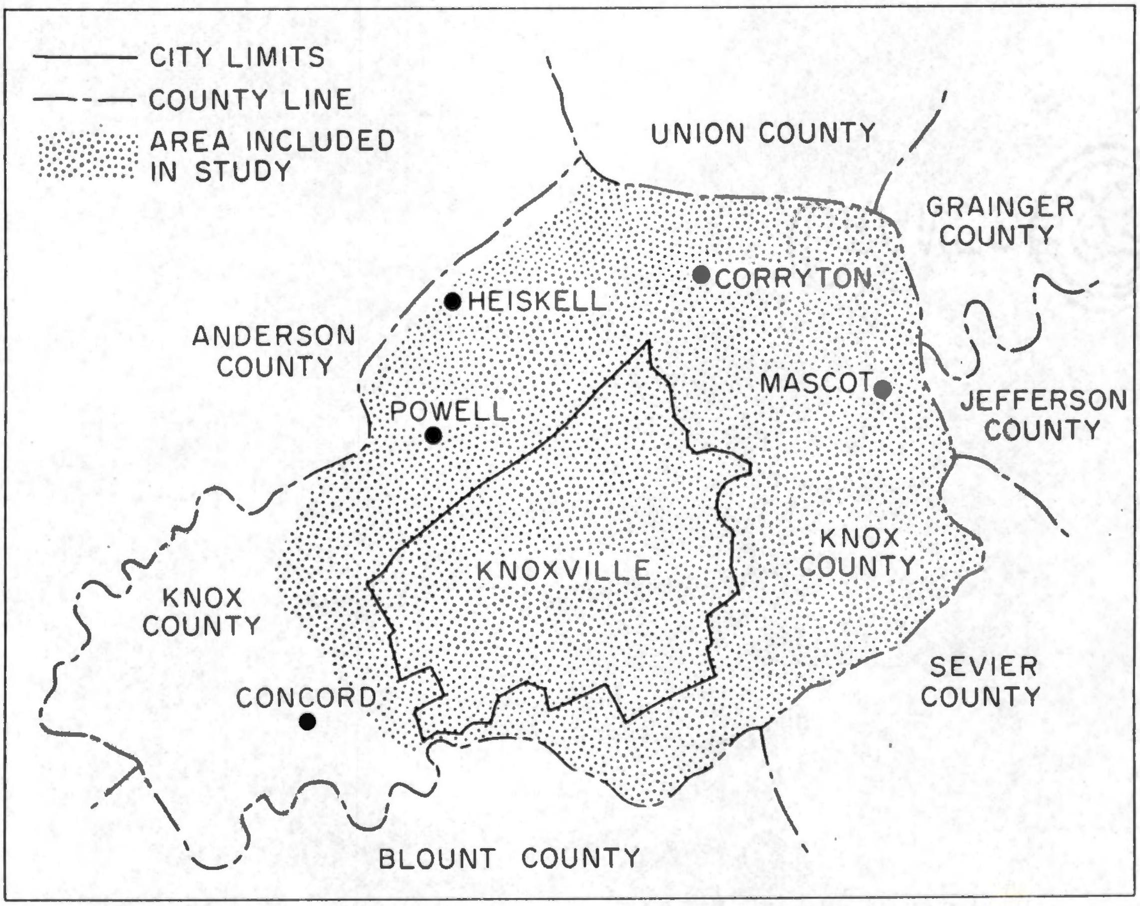

Fig. 1. Geographic area included in study of Knoxville housing market, 1978.

billing records for each house in the sample. Approximately 100 houses were eliminated from the sample at this point due to inability to match addresses with account numbers. This elimination was caused primarily by inclusion of houses in the MLS selection that were located in the fringe areas just outside the KUB service area and rural route addresses that could not be identified.

The period of time of the observed annual utility bill is the twelve-month period beginning two months after purchase of the house. The two-month interval was specified to allow for the transfer of ownership and change of occupancy. The choice of the time period was limited by the availability of data to that following sale of the house. The computer records of utility billings are maintained for a three-year period; hence, complete records for the year prior to sale were not available at the time of this study. Although the relevant time period may be debated from several standpoints, an argument in favor of the *ex post* time period is that occupancy and thus fuel consumption of the house are likely to have been more stable than in the year prior to the sale. Furthermore, the homebuyer, in making the investment decision, makes some projection of his future utility costs based upon considerations of family size and behavior that may differ from those of the previous owner, as well as observable characteristics of the house and past utility records.

The HDD and CDD variables for the time period corresponding to the utility billing of each house were supplied by KUB.

Census Tract Reports[a]

Published reports from the 1970 U.S. Census of Population and Housing were the source of neighborhood variables for percent black population and mean family income within each of 65 census tracts in Knox County. The income variable was inflated to the 1978 level by the Consumer Price Index.

Knoxville Metropolitan Planning Commission

The Geographic Base File/Dual Independent Map Encoding (GBF/DIME) system for the Knoxville-Knox County area is maintained by the MPC in conjunction with the U.S. Bureau of the Census. This computer system provided a beginning point for identifying each house in the sample by census tract and assigning X, Y coordinate values for the location variables. Since the computer files were not currently up to date, fewer than half the houses in the sample were matched in this manner.

The remainder of the locational data was obtained using the following procedure. The census tract in which the house was located was identified from MPC census tract maps. The relative X, Y coordinate values for each house were determined by overlaying a Knoxville area map on a computer screen. Each street address was then input as a point on the map, and the X, Y values were calculated on the same scale as that of the GBF/DIME system. If there was more than one house on a street in the sample, all houses were assigned the same X, Y values.

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[a] U.S. Bureau of the Census, Census of Population and Housing: 1970, *Census Tracts*, Final Report PHC(1)-101, Knoxville, Tennessee, SMSA.

Data furnished by the MPC were used to calculate the population density variables used as one of the indicators of neighborhood quality in the price equation. The data supplied were by traffic zones as the unit of observation. The traffic zones were regrouped into census tracts and calculations were made of persons per acre within a census tract. This variable was used as the measure of population density.

The Complete Data Set

Merger of the four data sets created a sample of 1,327 observations for the housing market study. Of this number ten contained missing values for one or more variables so that 1,317 observations were used in the regression analyses.

Efforts were undertaken to identify and correct coding errors by three methods. The first was to obtain computer printout for logically invalid coding; as, for example, a heat pump heating system having other than central air conditioning. A second verification was of maximum and minimum values and their reasonableness. A third check was of the outliers that appeared in examination of the residuals. In each case of a suspect variable, the data were checked and corrected with the original data source.

Characteristics of the Housing Market Sample

The housing market sample for this study is predominately urban and suburban in character due to the nature of the selection procedure.

The Knoxville, Tennessee, area is located within the region of the Tennessee Valley Authority where electric rates have been historically low in comparison with other parts of the country. As would be expected, a majority of homes in the area (70 percent) are heated with electricity.

During 1978, the year under study, the mean value of property sold through the Knoxville MLS was $47,441, whereas the mean price of houses in the sample is $39,529. However, the MLS figure includes some property other than residential. Another factor relevant to the comparison of the two values is that west Knox County, the area of rapid suburban development, was not included in the sample since that area is served by a utility company other than KUB. Mean values for the price and other variables descriptive of the sample are reported in Table 2.

The age distribution of houses in the sample is reported in Table 3. The majority of the houses (76 percent) were 20 years or below in age. The price distribution of the houses is reported in Table 4. The largest fraction (33 percent) are priced between $30,000 and $40,000.

Table 5 reports type of heating system and air conditioning. The distribution shows that the predominant heating-air conditioning system (35 percent) is that of electric resistance heating (other than a central system) and room air conditioners. The MLS data show that 545 (41 percent) of the houses have storm windows or windows with double glazing. Table 6 shows the distribution of storm windows by type of heating.

From the descriptive data of housing characteristics, one would expect that the Knoxville housing market in 1978 offered a wide range

Table 2. Selected characteristics of houses in the sample, Knoxville housing market, 1978

Variable	Mean	Standard deviation	Minimum value	Maximum value
Price	$39,529	$17,497	$6,700	$165,000
House size (sq. ft.)	1,560	616	631	4,851
Lot size (sq. ft.)	18,897	17,970	1,250	315,632
Rooms	6.5	1.4	3	14
Bedrooms	3.1	.7	1	6
Bathrooms	1.7	.6	1	4.5
Age (years)	14.1	13.1	0	99

Categorical variables[a]

Ranch style	58.5%	Fireplace	46.4%
Split foyer	18.5	Room air conditioners	38.6
Two story	8.5	Central air conditioning	44.2
Other house types	14.5	Garbage disposer	25.2
Brick exterior	11.8	Trash compactor	2.9
Carport	17.9	Dishwasher	54.4
Garage (one car)	35.6	Range	77.6
Garage (two car or larger)	29.5	Intercom system	12.5
Patio	47.2	Washer connection	96.5
Deck	29.0	Dryer connection	95.6
Paved driveway	85.0	Located within city limits	62.4

[a]Percent of houses in the sample having the characteristic.

Table 3. Age distribution of houses in the sample, Knoxville housing market, 1978

Age (years)	N	Percent
0 (new)	168	12.7
1-10	479	36.1
11-20	349	27.3
21-30	221	16.7
31-40	61	4.6
41-50	38	2.9
above 50	11	.8
Total	1,327	

Table 4. Price distribution of houses in the sample, Knoxville housing market, 1978

Price category	Number	Percent
$10,000 and below	10	.8
10,001-20,000	92	6.9
20,001-30,000	287	21.6
30,001-40,000	436	32.9
40,001-50,000	263	19.8
50,001-60,000	102	7.7
60,001-70,000	63	4.7
70,001-80,000	39	2.9
80,001-90,000	17	1.3
90,001-100,000	7	.5
above $100,000	11	.8
Total	1,327	

Table 5. Distribution of heating and air conditioning systems of houses in the sample, Knoxville housing market, 1978

Heating system	Air conditioning Frequency (percent) None	Central	Room	Total
Heat pump	0	201 (15.2)	0	201 (15.2)
Natural gas	35 (2.6)	152 (11.5)	43 (3.2)	230 (17.3)
Electric resistance/ central	8 (.6)	186 (14.0)	8 (.6)	202 (15.2)
Electric resistance/ other	186 (14.0)	47 (3.5)	461 (34.7)	694 (52.3)
Total	229 (17.3)	586 (44.2)	512 (38.6)	1,327

Table 6. Distribution of storm windows by heating type for houses in the sample, Knoxville housing market, 1978

Heating system	Frequency (percent) Without storm windows	With storm windows	Total
Heat pump	31 (2.3)	170 (12.8)	201 (15.2)
Natural gas	147 (11.1)	83 (6.3)	230 (17.3)
Electric resistance/ central	133 (10.0)	69 (5.2)	202 (15.2)
Electric resistance/ other	471 (35.5)	223 (16.8)	694 (52.3)
Total	782 (58.9)	545 (41.1)	1,327

of relative energy efficiencies as evidenced by the age distribution of houses, the price categories, the type of heating system, and the presence or absence of storm windows. The descriptive data provide background information that is useful in interpreting the empirical results presented in the next chapter.

CHAPTER 5

THE EMPIRICAL RESULTS

The empirical results of the housing market study and an analysis of the results are presented in this chapter. The overall model and the calculated market discount rates provide the necessary tests for determining the efficiency of the housing market in capitalizing the benefits of future fuel savings. The disaggregated models facilitate comparison of new versus existing houses, gas- and electric-heated houses, and houses of differing price ranges within the housing market. The market information component with respect to the reported utility bills in the MLS listings is analyzed. Together these empirical tests and their interpretation provide the basis for meeting the objectives of the study as outlined in Chapter 1.

The Hedonic Price Index

The estimated coefficients for the specific variables in the hedonic price index are reported in Table 7. The results of the model show, first, that of the 18 coefficients for which a sign is hypothesized, all estimates have the expected sign. Next, of the 33 parameters estimated, 24 attain significance at the .01 level and three are significant at the .05 level. In general, the coefficient estimates for each housing component are of reasonable magnitudes. The signs and estimates of the neighborhood attributes (INC78 and BLACK) are consistent with those of previous housing studies, although it is recognized that

Table 7. Estimated hedonic price index, sample from Knoxville housing market, 1978

Variable[a]	Expected sign	Coefficient	*t* statistic
U[b]	(-)	-20.73	-2.27**
SIZE	(+)	13.90	10.38*
AGE	(-)	-233.33	-7.43*
BTHRMS	(+)	3682.95	4.95*
RANCH	(?)	-1064.49	-1.35
SFOYER	(?)	-4435.12	-4.53*
2STORY	(?)	3527.06	3.22*
BRICK	(+)	2075.99	2.72*
CARPORT	(+)	1604.50	2.20**
GARAGE1	(+)	1580.83	2.35**
GARAGE2	(+)	5505.53	6.44*
PATIO	(+)	1026.05	2.03**
DECK	(+)	598.38	1.01
PAVDRWAY	(+)	1776.53	2.22**
FIREPL	(+)	2075.63	3.44*
UNITAIR	(+)	1152.92	1.63
CENTAIR	(+)	5579.73	6.63*
AINDEX	(+)	3948.42	2.86*
INC78	(+)	0.46	9.82*
BLACK	(?)	-88.41	-4.16*
POPDEN	(?)	-44.49	-0.31
CITY	(+)	1767.08	2.54*
LOT	(+)	0.07964	4.50*
X • LOT	(?)	0.01430	4.07*
Y • LOT	(?)	-0.02461	-5.93*
X^2 • LOT	(?)	-0.00084	-2.51*
X • Y • LOT	(?)	-0.00107	-2.66*
Y^2 • LOT	(?)	0.00242	4.98*
X^3 • LOT	(?)	-0.00011	-2.73*
X^2 • Y • LOT	(?)	0.00033	5.87*
X • Y^2 • LOT	(?)	-0.00002	-0.41
Y^3 • LOT	(?)	-0.00004	-0.84
Intercept	(?)	12747.37	2.77*

$F_{32,1284} = 160.10$ $R^2 = 0.80$ $n = 1317$

[a]AINDEX is appliance index. Other variables are defined in Table 1, page 45.

[b]Instrumental variable.

*Significant at .01 level.

**Significant at .05 level.

the variable BLACK is correlated with other factors of neighborhood and housing quality. The variable POPDEN has a negative sign but is not significant. As found in previous studies [9, 39], opposing factors (low population density as an amenity and more competition for housing in high-density areas) cause difficulty in estimating this coefficient.

Of the three dummy variables for house types,[a] RANCH is negative but not significant. The negative price for the SFOYER is reasonable, since this type of construction is generally a low-cost means for adding floor area. The valuation for 2STORY also seems reasonable in that this type of construction is associated with the upper-price category.

The estimated coefficients of the variables SIZE, AGE, BTHRMS, GARAGE2, and CENTAIR are of reasonable magnitudes and highly significant. The variables BRICK, PATIO, PAVDRWAY, and FIREPL add to the price of the house as would be expected, while the variables DECK and UNITAIR are not significant. The lack of significance for UNITAIR is not surprising, since the variable as reported and coded could indicate cooling of one room only or the entire house.

The estimated coefficient of the dummy variable for CITY (accounting for differences in both services and property taxes) shows a market valuation for houses located inside the city limits. Eight of the ten coefficients of the third-degree locational polynomial for lot size and the X, Y coordinate system (used to measure accessibility) are significant

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[a]The omitted category for other construction types includes tri-level, A-frame, bungalows, and all that could not be identified in the three main types.

at the .01 level. Thus, the land-price surface for the housing market area appears to be adequately represented by the trend-surface analysis approach.[a]

As was anticipated, due to the nature of housing characteristics, multicollinearity caused difficulty in obtaining statistically significant and unbiased estimates of certain parameters, particularly the five appliances (dishwasher, range, garbage disposer, trash compactor, and intercom, as listed in Table 1, page 45) and the utility bill. Deletion of the appliances from the equation created underspecification bias in the utility bill coefficient estimate, whereas their inclusion caused loss of significance in some estimates and an unreasonably large estimate for the garbage disposer. The utility bill coefficient was highly sensitive to changes in the appliances included in the equation, since the appliances are positively correlated with both the price of the house and the utility bill. The solution to the problem was to create one new variable, an appliance index (AINDEX) based upon the relative prices of the five appliances. The estimated price and respective weight for each appliance are reported in Table 8. Thus, if all five appliances are installed in the house, the coefficient gives an hedonic price of $3,948.42. This estimate is approximately 2.5 times the total cost of the appliances as reported in Table 8. However, the estimate seems reasonable when installation costs and the effect of omitted

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[a]An interpretation and geographic representation of the price surface are reported in the fourth section of this chapter.

Table 8. Calculations of the appliance index[a] and the energy index[b] of appliances in the hedonic price equation, Knoxville housing market, 1978

Appliance	Price[c]	Appliance index	Kilowatt hours[d]	Energy index
Range	$ 550	.35	1,200	.21
Dishwasher	330	.21	1,560	.26
Garbage disposer	80	.05	30	.01
Trash compactor	260	.16	50	.01
Intercom	370	.23	110	.02
Washer connection			1,900	.32
Dryer connection			1,000	.17
Totals	$1,590	1.00	5,850	1.00

[a]To measure relative prices.

[b]To measure relative energy usage.

[c]Sears Fall-Winter Catalog, 1978 (midline priced appliances).

[d]Tennessee Valley Authority, Electric Energy Use and Cost (estimates of annual usage).

variables that are associated with overall housing quality and modernization (and correlated with the appliances) are taken into account. The AINDEX variable attains significance at the .01 level, while the estimate of the utility bill coefficient is significant at the .02 level (compared to the .08 level in earlier estimates).

In the instrumental variable estimation, an energy usage index (EINDEX in Table 8) was created as a means of handling the multicollinearity of the five appliances. In EINDEX each appliance is assigned a weight based upon estimated relative energy consumption of the appliances. Also included in EINDEX are weights for washer and dryer connections which are hypothesized to have a more direct and greater effect upon the utility bill than on the price of the house. The creation of the two variables AINDEX and EINDEX appears to have been an adequate means for handling the problems associated with multicollinearity in the model.

The coefficient of determination, $R^2 = 0.80$, and an examination of the pattern of residuals indicate a good fit to the data. The plot of residuals against price shows the desired random distribution of positive and negative values except for those houses priced above $100,000. Of the 11 houses in this price category, eight exhibit positive residuals that are greater than those in the rest of the model. As would be expected, examination of the MLS data revealed that these houses possess unique characteristics such as a swimming pool, burglar alarm, boat dock, etc., that are not included in the model. Since these eight houses constitute less than 1 percent of the sample, however, neither the specification of the model nor the linear functional form were modified.

The estimated coefficient of primary interest in the hedonic price index is that of the utility bill, $\hat{\beta}_u$. The negative sign of the coefficient indicates that $\partial P/\partial U < 0$, and the *t* ratio shows a level of significance of .02. These tests provide statistical evidence that the housing market does indeed capitalize the benefits of fuel savings in the price of the house. The estimate of $\hat{\beta}_u$ indicates that an investment in an energy-saving durable good resulting in a one-dollar reduction in the annual fuel bill of the house will increase the market value of the house by \$20.73, *ceteris paribus*.

The standardized parameter estimates, reported in Table 9, provide a means for comparing the relative importance of variables in their contribution to the price of the house. The relation is

$$\beta_s = \frac{\hat{\beta}_x S_x}{S_y}$$

where β_s is the standardized parameter estimate, $\hat{\beta}_x$ is the estimated parameter, S_x is the standard deviation of the respective variable, and S_y is the standard deviation of the dependent variable. By ranking the variables in order of importance, the U parameter is fifth, following SIZE, the set of variables associated with the lot, AGE, and CENTAIR.

An alternative approach to the problem under study would have been to estimate the market valuation of the durable good components of energy efficiency directly. This approach was not chosen for the focus of this study for both theoretical reasons and data limitations, as discussed in Chapter 3. However, as a partial test for substantiating the results

Table 9. Standardized parameter estimates for the hedonic price index, Knoxville housing market, 1978

Variable	Standardized estimate
1. SIZE	0.4906
2. LOT	0.0821
$X \cdot$ LOT	0.1317
$Y \cdot$ LOT	-0.1734
$X^2 \cdot$ LOT	-0.0575
$X \cdot Y \cdot$ LOT	-0.0472
$Y^2 \cdot$ LOT	0.1187
$Y^3 \cdot$ LOT	-0.0889
$X^2 \cdot Y \cdot$ LOT	0.1342
$X \cdot Y^2 \cdot$ LOT	-0.0089
$Y^3 \cdot$ LOT	-0.0227
INC78	0.1571
BLACK	-0.0630
POPDEN	-0.0059
CITY	0.0491
3. AGE	-0.1757
4. CENTAIR	0.1588
5. U	-0.1552
6. GARAGE2	0.1440
7. BTHRMS	0.1371
8. SFOYER	-0.0981
9. FIREPL	0.0593
10. AINDEX	0.0579
11. 2STORY	0.0561
12. GARAGE1	0.0434
13. BRICK	0.0383
14. PAVDRWAY	0.0361
15. CARPORT	0.0355
16. UNITAIR	0.0321
17. RANCH	-0.0300
18. PATIO	0.0293
19. DECK	0.0156

of the hedonic price index, the regression analysis was estimated using OLS with the storm window dummy variable (STWNDO) in place of U. The results of this model are reported in Table 10. Estimates of the coefficients, their signs, levels of significance, and magnitudes of the estimates are similar to the hedonic price index reported in Table 7, page 58. STWNDO must be interpreted as a proxy for a relatively energy efficient house due to the exclusion of other variables (insulation, etc.) that influence U. The STWNDO coefficient is highly significant and gives a market valuation of $2,021.39 for this component of energy efficiency. Assuming an incremental cost of storm windows and other energy-saving features, C $\leqslant$ $2,021.39, the housing market does operate efficiently in capitalizing the investment. Thus, the models, using two different approaches, give consistent results.

The Disaggregated Models

For further analysis of the housing market and its efficiency in capitalizing energy conservation investment, the overall model was disaggregated into submodels by price category, type of heating fuel, and new and existing houses. The results of each set of submodels were first compared by calculating the F statistic from the Chow test [6]. The null hypothesis is that the groups are from the same population. The test proved to be invalid, however, because in regressions involving the instrumental variable, the total sums of squares due to error are not necessarily less for the submodels than for the overall model. Therefore, a negative F statistic (invalid) in the Chow test may result.

Table 10. Estimated hedonic price index using storm windows (STWNDO) as variable, sample from Knoxville housing market, 1978

Variable	Expected sign	Coefficient	*t* statistic
STWNDO	(+)	2021.39	5.07*
SIZE	(+)	11.68	20.30*
AGE	(-)	-198.23	-8.43*
BTHRMS	(+)	2929.80	5.37*
RANCH	(?)	-43.41	-0.07
SFOYER	(?)	-3156.79	-4.14*
2STORY	(?)	2797.28	3.16*
BRICK	(+)	1896.92	3.04*
CARPORT	(+)	979.17	1.68
GARAGE1	(+)	1002.81	1.92
GARAGE2	(+)	4627.55	6.82*
PATIO	(+)	885.75	2.15**
DECK	(+)	786.45	1.64
PAVDRWAY	(+)	1982.53	3.01*
FIREPL	(+)	1529.31	3.22*
UNITAIR	(+)	1082.47	1.86
CENTAIR	(+)	4664.57	6.73*
AINDEX	(+)	4375.21	3.98*
INC78	(+)	0.46	11.88*
BLACK	(?)	-80.67	-4.64*
POPDEN	(?)	-113.13	-0.96
CITY	(+)	1453.57	2.53*
LOT	(+)	0.07634	5.29*
$X \cdot LOT$	(?)	0.01164	4.15*
$Y \cdot LOT$	(?)	-0.02483	-7.55*
$X^2 \cdot LOT$	(?)	-0.00112	-4.35*
$X \cdot Y \cdot LOT$	(?)	-0.00078	-2.49*
$Y^2 \cdot LOT$	(?)	0.00172	5.14*
$X^3 \cdot LOT$	(?)	-0.00010	-3.19*
$X^2 \cdot Y \cdot LOT$	(?)	0.00030	6.89*
$X \cdot Y^2 \cdot LOT$	(?)	0.000006	0.13
$Y^3 \cdot LOT$	(?)	-0.00003	-0.71
Intercept	(?)	1746.49	1.31

$F_{32,1292} = 236.80$ $R^2 = 0.85$ $n = 1325$

*Significant at .01 level.

**Significant at .05 level.

The statistical test as defined by Chow is appropriate only for regressions estimated by ordinary least squares. In the problem under study, the respective submodels were compared as to the general criteria of goodness of fit and tests of significance, with emphasis on the estimated coefficients of U, in particular.

New versus Existing Houses

New houses on the market would be expected, in general, to utilize up-to-date technology in building construction and to include more energy-saving features relative to houses for resale. Existing houses obviously encompass a range of energy efficiencies, including those houses that have been retrofitted as well as houses with minimal or no insulation. The sample was first disaggregated into new and existing housing categories and separate regressions were run. The regression for new houses gave poor results, both in R^2 and tests of significance, while the regression for existing houses gave reasonable results as compared to the model for the overall sample. The tentative conclusion was that new houses on the market differ significantly from existing houses as one would expect under dynamic circumstances.

An important difference between the two groups of houses is their spatial distribution with new houses located in clusters of newly developed subdivisions. Therefore, the trend-surface analysis does not adequately control for the price of land in the disaggregated model; the land-price surface is best represented in the overall model. As a means of controlling for the price of land, disaggregated models were estimated using ADJPR (adjusted price) as the dependent variable where

ADJPR = PRICE - LOTPR

with LOTPR (lot price) calculated from the estimated coefficients of the X, Y coordinates, lot size, and neighborhood variables from the overall model.[a] The results of the estimated submodels are reported in Table 11.

The model for existing houses performs in much the same manner as the overall model with the expected signs, statistical significance, and reasonable magnitudes of the coefficients. The model for new houses, however, has only 166 observations and exhibits both changes in sign and loss of significance of certain coefficients. The dummy variable for PAVDRWAY (as well as the AGE variable) had to be deleted to avoid singularity of the matrix, because all new houses in the sample have paved driveways.

Table 12 reports descriptive statistics of the two groups of houses. Comparing the means of the two groups, the new houses are higher priced, of approximately the same size, and have more appliances installed (AINDEX). The majority of the new houses are heated by heat pumps (72 percent), and a majority have storm windows (84.5 percent). Of the existing houses, the majority (59.4 percent) are heated by electric resistance units (rather than central) and only 34.9 percent have storm windows.

In comparing the coefficients of primary interest to this study, $\hat{\beta}_u$ = -\$19.75 for new houses and $\hat{\beta}_u$ = -\$16.64 for existing houses. The

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[a]The estimated lot prices are discussed in the fourth section of this chapter.

Table 11. Estimated hedonic price indexes, new and existing houses, sample from Knoxville housing market, 1978

Variable	Expected sign	Coefficient	*t* statistic
		New Houses	
U[a]	(-)	-19.75	-0.93
SIZE	(+)	10.89	4.53*
BTHRMS	(+)	3354.92	1.87
RANCH	(?)	-2105.93	-1.06
SFOYER	(?)	-2189.04	-1.20
2STORY	(?)	7635.78	2.16**
BRICK	(+)	1682.61	0.42
CARPORT	(+)	-1031.08	-0.26
GARAGE1	(+)	-5874.27	-2.10**
GARAGE2	(+)	563.27	0.17
PATIO	(+)	-121.37	-0.09
DECK	(+)	-2289.22	-1.28
FIREPL	(+)	5322.84	3.12*
UNITAIR	(+)	3749.33	0.53
CENTAIR	(+)	8066.68	2.67*
AINDEX	(+)	8908.19	2.34**
Intercept	(?)	19,041.71	1.77
	$F_{16,149} = 35.06$	$R^2 = 0.79$	$n = 166$
		Existing Houses	
U[a]	(-)	-16.64	-1.86
SIZE	(+)	14.14	10.20*
AGE	(-)	-220.63	-7.43*
BTHRMS	(+)	3436.66	4.67*
RANCH	(?)	-1050.24	-1.36
SFOYER	(?)	-4873.29	-4.60*
2STORY	(?)	2562.17	2.30**
BRICK	(+)	2099.01	2.79*
CARPORT	(+)	1636.67	2.31**
GARAGE1	(+)	1774.69	2.64*
GARAGE2	(+)	5043.44	5.69*
PATIO	(+)	1295.56	2.51*
DECK	(+)	845.14	1.40
PAVDRWAY	(+)	1878.08	2.43**
FIREPL	(+)	1562.58	2.54*
UNITAIR	(+)	1107.41	1.60
CENTAIR	(+)	5335.39	6.17*
AINDEX	(+)	3589.28	2.65*
Intercept	(?)	9588.00	2.08**
	$F_{18,1132} = 186.80$	$R^2 = 0.75$	$n = 1151$

[a] Instrumental variable.

*Significant at .01 level.

**Significant at .05 level.

Table 12. Selected characteristics of houses in the sample, new and existing houses, Knoxville housing market, 1978

Variable	Mean	Standard deviation	Minimum value	Maximum value
	New Houses[a]			
Price	$47,907	$13,075	$28,200	$80,000
House size (sq. ft.)	1,575	557	821	3,208
Lot size (sq. ft.)	16,409	7,711	7,500	51,742
Appliance index	0.61	0.17	0	1
Rooms	6.6	1.2	5	11
Bedrooms	3.2	0.44	3	5
Bathrooms	2.0	0.55	1	3.5
Annual utility bill	$706.77	$197.78	$275.42	$1313.39
	Existing Houses[b]			
Price	$38,315	$17,727	$6,700	$165,000
House size (sq. ft.)	1,558	624	631	4,851
Lot size (sq. ft.)	19,258	18,978	1,250	315,632
Appliance index	.41	0.26	0	1
Rooms	6.5	1.5	2	14
Bedrooms	3.1	0.70	1	6
Bathrooms	1.7	0.65	1	4.5
Age (years)	16.2	12.8	1	99
Annual utility bill	$707.92	$225.29	$157.95	$2028.56

[a] Heating system:

Heat pump	72.0%
Natural gas	1.2
Electric (central)	23.2
Electric (units)	3.6
Storm windows	84.5

[b] Heating system:

Heat pump	6.9%
Natural gas	19.7
Electric (central)	14.0
Electric (units)	59.4
Storm windows	34.9

estimate for new houses is not statistically significant, however, and the estimate for existing houses has a lower *t* value than that of the overall model. This result must be interpreted in terms of the relatively smaller number of new houses in the sample. Furthermore, if new houses, relative to the group of existing houses, are more homogeneous in energy efficiency, having less variation in U, the coefficient of $\hat{\beta}_u$ loses statistical significance. In the overall model, the new houses increase both the level of significance of $\hat{\beta}_u$ and its absolute value.

<u>Low-, Medium-, and High-Priced Houses</u>

The houses in the sample were divided into three price categories

Low ($P \leq \$30,000$)	29 percent
Medium ($\$30,000 < P \leq \$50,000$)	53 percent
High ($P > \$50,000$)	18 percent

and regression models were estimated for each category.

Since the spatial distribution of houses by price differs, as it does with new houses, the estimated price of the lot was subtracted and the models were estimated with ADJPR as the dependent variable. The results are reported in Table 13.

Based on R^2 statistics, changes in signs, and the *t* values, none of the three models performs particularly well, compared with the overall model. The explanation would appear to be, again, that smaller sample size and greater homogeneity make within group variation more difficult to explain than is the variation across the total sample.

Estimates of $\hat{\beta}_u$ are \$6.05, -\$19.86, and -\$13.64 for the low-, medium-, and high-priced categories, respectively. The estimate for the

Table 13. Estimated hedonic price indexes by price category, sample from Knoxville housing market, 1978

Variable	Expected sign	Coefficient	*t* statistic
		Low (P ⩽ $30,000)	
U	(-)	6.04	0.92
SIZE	(+)	2.63	1.87
AGE	(-)	-73.93	-3.40*
BTHRMS	(+)	2819.36	3.27*
RANCH	(?)	1960.54	3.40*
SFOYER	(?)	2326.74	1.67
2STORY	(?)	747.20	0.59
BRICK	(+)	1710.70	1.49
CARPORT	(+)	213.55	0.38
GARAGE1	(+)	821.14	1.34
GARAGE2	(+)	-204.61	-0.16
PATIO	(+)	1083.02	2.32**
DECK	(+)	-230.91	-0.33
PAVDRWAY	(+)	1520.70	3.05*
FIREPL	(+)	963.92	1.49
UNITAIR	(+)	1542.50	3.30*
CENTAIR	(+)	2096.26	2.59*
AINDEX	(+)	1535.57	1.42
Intercept	(?)	4652.91	1.55
	$F_{18,363} = 13.29$	$R^2 = 0.40$	n = 382
		Medium ($30,000 < P ⩽ $50,000)	
U	(-)	-19.86	-2.69*
SIZE	(+)	5.73	5.13*
AGE	(-)	-123.62	-4.02*
BTHRMS	(+)	3230.33	5.18*
RANCH	(?)	-2157.25	-2.94*
SFOYER	(?)	-2302.93	-2.74*
2STORY	(?)	-416.89	-0.27
BRICK	(+)	3342.92	4.88*
CARPORT	(+)	1720.16	2.52*
GARAGE1	(+)	885.72	1.44
GARAGE2	(+)	4425.11	6.05*
PATIO	(+)	672.93	1.54
DECK	(+)	674.80	1.35
PAVDRWAY	(+)	1540.22	1.50
FIREPL	(+)	1516.68	3.32*
UNITAIR	(+)	-459.74	-0.60
CENTAIR	(+)	2373.16	3.07*
AINDEX	(+)	4527.54	3.77*
Intercept	(?)	25,718.28	6.41*
	$F_{18,677} = 34.62$	$R^2 = 0.48$	n = 696

Table 13 (continued)

Variable	Expected sign	Coefficient	*t* statistic
		High (P > $50,000)	
U	(-)	-13.64	-0.73
SIZE	(+)	15.77	5.36*
AGE	(-)	-31.63	-0.30
BTHRMS	(+)	1193.21	0.49
RANCH	(?)	1471.74	0.51
SFOYER	(?)	-2270.08	-0.72
2STORY	(?)	5749.88	1.93
BRICK	(+)	-2599.36	-1.22
CARPORT	(+)	1747.62	0.53
GARAGE1	(+)	-915.33	-0.26
GARAGE2	(+)	5508.21	1.81
PATIO	(+)	2215.39	1.14
DECK	(+)	960.55	0.50
PAVDRWAY	(+)	-1693.70	-0.26
FIREPL	(+)	5454.38	1.14
UNITAIR	(+)	7730.49	0.91
CENTAIR	(+)	14,085.43	1.78
AINDEX	(+)	6796.03	-0.27
Intercept	(?)	1929.80	0.13
	$F_{18,220}$ = 10.69	R^2 = 0.47	n = 239

*Significant at .01 level.

**Significant at .05 level.

low-priced group has the wrong (positive) sign but is not statistically significant. The estimate for the high-priced group also is not significant, whereas the estimate for the medium-priced category is significant at the .01 level. Compared with the estimate of $\hat{\beta}_u$ from the overall model, the coefficient from the medium-priced group estimation has a higher level of significance and a decrease of $0.87 in absolute value.

Other combinations of price categories were attempted but these regression results were found to yield estimates that did not differ significantly from those reported. In the lower-priced category, however, deletion of the houses with $P < \$18,000$ gave the hypothesized (negative), although not significant, sign for $\hat{\beta}_u$.

The comparison of price categories with respect to estimates of $\hat{\beta}_u$ and the respective level of significance gives several possible interpretations about the capitalization of energy conservation investment. One is that the market operates efficiently in the midprice range but is less so at either the upper or lower extreme. A second tentative, but plausible, explanation is that the higher-priced houses are relatively more energy efficient as a group, and the model does not perform well in differentiating. In the lower-priced houses, homebuyers likely have fewer options for investing in conservation due to lack of capital and access to borrowing. This explanation is consistent with Hausman's finding [14] of higher implicit discount rates for low-income buyers of room air conditioners. A second possible market imperfection is in the rental market. The data for houses in the sample do not show

whether the houses are owner-occupied or rental. If the lower-priced houses are relatively more often rental property, the incentive to invest in conservation depends upon the efficiency of both the housing market and the rental market in capitalizing the investment.

Descriptive data for the three price categories are reported in Table 14. The data show that a majority of the houses in the low- and medium-priced categories are heated with electric resistance units (other than central electric systems), while a majority of the houses in the upper-priced category are heated by gas, followed by heat pumps. Surprisingly, a higher percentage of low-priced houses (40.4 percent) have storm windows than the medium-priced houses (37.2 percent).

Gas- versus Electric-Heated Houses

In this study there were no *a priori* expectations concerning differences between gas- and electric-heated houses and the market performance with respect to energy conservation investment. Separate regression models were estimated for each fuel type. The results of the the models are reported in Table 15. The R^2 and signs of the coefficients show good results, although many of the coefficients are not statistically significant. The model for electric-heated houses performs better in attaining significance of the coefficients due perhaps, in part, to the larger sample size.

The estimates of $\hat{\beta}_u$ for the two groups are \$3.37 (not statistically significant) for gas-heated homes and -\$32.37 (significant at the .01 level) for electric-heated homes. This result implies that fuel bill

Table 14. Selected characteristics of houses in the sample, by price category, Knoxville housing market, 1978

Variable	Mean	Standard deviation	Minimum value	Maximum value
Low (P ≤ $30,000)[a]				
Price	$23,347	$5,616	$6,700	$30,000
House size (sq. ft.)	1,125	349	631	3,400
Lot size (sq. ft.)	13,048	10,756	1,250	139,392
Appliance index	0.21	0.22	0	0.84
Rooms	5.5	1.1	2	10
Bedrooms	2.7	0.7	1	6
Bathrooms	1.1	0.3	1	3
Age (years)	24.3	14.0	0	99
Annual utility bill	$606.49	$178.27	$238.84	$1401.60
Medium ($30,000 < P ≤ $50,000)[b]				
Price	$38,840	$5,350	$30,200	$50,000
House size (sq. ft.)	1,491	370	664	3,163
Lot size (sq. ft.)	18,958	17,619	5,275	315,632
Appliance index	0.46	0.19	0	1
Rooms	6.5	1.1		13
Bedrooms	3.1	0.5	2	6
Bathrooms	1.7	0.5	1	4
Age (years)	10.1	10.0	0	70
Annual utility bill	$693.45	$178.34	$157.95	$1409.66
High (P > $50,000)[c]				
Price	$67,882	$18,270	$50,400	$165,000
House size (sq. ft.)	2,470	598	1,135	4,851
Lot size (sq. ft.)	28,238	23,592	6,664	174,240
Appliance index	.70	0.16	0.21	1
Rooms	8.2	1.3	5	14
Bedrooms	3.8	0.7	2	6
Bathrooms	2.6	0.5	1	4.5
Age (years)	9.2	10.4	0	50
Annual utility bill	$909.70	$263.97	$420.20	$2028.56

[a]Heating system:

Heat pump	1.3%
Natural gas	18.5
Electric (central)	4.6
Electric (units)	75.6
Storm windows	40.4

[b]Heating system:

Heat pump	16.2%
Natural gas	9.7
Electric (central)	22.3
Electric (units)	51.7
Storm windows	37.2

[c]Heating system:

Heat pump	34.7
Natural gas	37.7
Electric (central)	11.7
Electric (units)	15.9
Storm windows	54.0

Table 15. Estimated hedonic price indexes, gas- and electric-heated houses, sample from Knoxville housing market, 1978

Variable	Expected sign	Coefficient	*t* statistic
		Gas-Heated Houses	
U[a]	(-)	-3.37	-0.16
SIZE	(+)	11.32	3.49*
AGE	(-)	-245.26	-2.09**
BTHRMS	(+)	4049.29	1.95**
RANCH	(?)	-779.02	-0.30
SFOYER	(?)	-4587.92	-1.40
2STORY	(?)	1699.80	0.68
BRICK	(+)	918.68	0.43
CARPORT	(+)	-1901.14	-0.58
GARAGE1	(+)	870.09	0.25
GARAGE2	(+)	6397.83	2.10**
PATIO	(+)	1565.57	0.92
DECK	(+)	1842.30	0.98
PAVDRWAY	(+)	2808.67	1.18
FIREPL	(+)	1088.63	0.51
UNITAIR	(+)	2858.97	1.08
CENTAIR	(+)	4340.70	1.27
AINDEX	(+)	6937.95	1.19
INC78	(+)	0.46	3.68*
BLACK	(?)	-90.24	-1.30
POPDEN	(?)	-387.61	-0.84
CITY	(+)	5112.45	1.57
LOT	(+)	0.26	2.49*
X • LOT	(?)	0.05279	1.79
Y • LOT	(?)	-0.04207	-2.04**
X^2 • LOT	(?)	-0.00192	-1.76
X • Y • LOT	(?)	-0.00254	-1.39
Y^2 • LOT	(?)	0.00139	0.99
X^3 • LOT	(?)	-0.00041	-1.60
X^2 • Y • LOT	(?)	0.00017	0.71
X • Y^2 • LOT	(?)	-0.00038	-1.01
Y^3 • LOT	(?)	0.00011	0.51
Intercept	(?)	-207.98	-0.02

$F_{32,197} = 35.24$ $R^2 = 0.85$ $n = 230$

Table 15 (continued)

Variable	Expected sign	Coefficient	*t* statistic
	Electric-Heated Houses		
U[a]	(-)	-32.38	-2.62*
SIZE	(+)	16.19	7.63*
AGE	(-)	-201.05	-5.40*
BTHRMS	(+)	3546.51	3.92*
RANCH	(?)	-1145.19	-1.28
SFOYER	(?)	-4188.20	-3.73*
2STORY	(?)	4889.27	2.96*
BRICK	(+)	2278.94	2.44*
CARPORT	(+)	2164.69	2.62*
GARAGE1	(+)	1506.44	2.01**
GARAGE2	(+)	5140.12	5.16*
PATIO	(+)	1003.30	1.69
DECK	(+)	32.19	0.04
PAVDRWAY	(+)	1761.30	1.83
FIREPL	(+)	2531.85	3.74*
UNITAIR	(+)	431.28	0.53
CENTAIR	(+)	5337.17	5.39*
AINDEX	(+)	4014.47	2.56
INC78	(+)	0.41	6.72
BLACK	(?)	-86.98	-3.54
POPDEN	(?)	154.13	0.89
CITY	(+)	820.99	1.03
LOT	(+)	0.07	3.78*
X • LOT	(?)	0.00669	1.58
Y • LOT	(?)	-0.01912	-4.13*
X^2 • LOT	(?)	-0.00038	-0.88
X • Y • LOT	(?)	-0.00129	-2.53*
Y^2 • LOT	(?)	0.00224	3.04*
X^3 • LOT	(?)	-0.00004	-0.80
X^2 • Y • LOT	(?)	0.00024	3.25*
X • Y^2 • LOT	(?)	0.000003	0.05
Y^3 • LOT	(?)	-0.000004	-0.07
Intercept	(?)	18477.47	3.28*
	$F_{32,1054} = 85.35$	$R^2 = 0.72$	n = 1087

[a]Instrumental variable.

*Significant at .01 level.

**Significant at .05 level.

savings are capitalized in the sale price of the electric-heated houses, whereas the market for gas-heated homes operates less efficiently. The implication, however, warranted further analysis of the data.

Selected characteristics of the two groups of houses are reported in Table 16. The mean values show that the gas-heated homes in the sample are more expensive, larger, more energy intensive (AINDEX), and older than the electric-heated homes. The minimum and maximum prices for the two groups reveal a wider price range for gas-heated homes. In comparing standard deviations of all five variables for the two groups, all values are smaller for the electric-heated houses, indicating greater homogeneity within this subsample. Table 5 (page 54) shows that 85 percent of the gas-heated houses have air conditioning, compared to 83 percent of the electric-heated houses. In the distribution of storm windows, 36 percent of gas-heated houses have storm windows, compared to 43 percent of the electric-heated houses.

The two submodels were further evaluated by several different approaches: (1) using ADJPR as the dependent variable; (2) deleting houses where $P \geqslant \$100,000$; (3) deleting houses where $P \leqslant \$10,000$; and (4) removing one or more outliers. In these estimations, the model for electric-heated homes did not change appreciably; $\hat{\beta}_u$ remained relatively stable both in value and level of significance. In the model for gas-heated homes, the estimates did exhibit changes but none of the regression models gave results considered to be superior to those reported in Table 15. $\hat{\beta}_u$ tended toward zero, giving both positive and

Table 16. Selected characteristics of houses in the sample, by type of heating fuel, Knoxville housing market, 1978

Variable	Mean	Standard deviation	Minimum value	Maximum value
	Gas-Heated[a]			
Price	$47,459	$25,564	$7,500	$165,000
House size (sq. ft.)	2,004	784	768	4,851
Lot size (sq. ft.)	20,434	14,290	2,800	88,800
Appliance index	0.49	0.29	0	1
Rooms	7.3	1.7	4	14
Bedrooms	3.4	0.91	2	6
Bathrooms	2.0	0.76	1	4
Age (years)	21.0	17.6	0	97
Annual utility bill	$753.56	$241.18	$253.08	$1565.56
	Electric-Heated[b]			
Price	$37,867	$14,761	$6,700	$135,000
House size (sq. ft.)	1,467	530	631	4,700
Lot size (sq. ft.)	18,575	18,639	1,250	315,632
Appliance index	0.42	0.25	0	
Rooms	6.3	1.3	2	13
Bedrooms	3.1	0.59	1	6
Bathrooms	1.7	0.61	1	4.5
Age (years)	12.7	11.5	0	99
Annual utility bill	$697.63	$215.96	$157.95	$2028.56

[a]Storm windows 36.1%

[b]Heating system:

Heat pump	18.3%
Electric (central)	18.4
Electric (units)	63.3
Storm windows	42.2

negative signs, but was not significant in any of the regressions for the gas-heated homes.

The statistics from Table 16, the further attempts at evaluating the models, and comparison with the price category models provide a basis for interpretation of the differences in $\hat{\beta}_u$ between the two models. The estimate of $\hat{\beta}_u$ (negative but not significant) for gas-heated homes is consistent with the estimate obtained for higher-priced houses, since the gas-heated houses are, on the average, larger and more expensive than the electric-heated houses. The gas-heated houses are older (mean of 21 compared to 13 years), and it is reasonable to expect older houses to have less insulation and other energy-conserving features. The reported distribution of storm windows confirms this expectation with 7 percent more of the electric-heated houses having storm windows.

Other market constraints may account, in part, for the apparent difference between gas- and electric-heated homes. In the Knoxville area, as part of the region of the Tennessee Valley Authority, a majority of houses are heated by electricity. Natural gas is not available in all areas, particularly the new subdivisions, and there is some uncertainty as to the future availability and price. At the present time, the relative prices of electricity and natural gas make the price of electricity per unit of output (measured in British thermal units) higher than that of natural gas. If the housing market were fully efficient in capitalizing cost savings in fuel, the advantages of a

gas-heating system would be capitalized in the sale price of the house. If this does not occur, the predominant influence may be that purchasers of gas-heated homes, because of uncertainties about the future, have less incentive to make such investment.

The estimate of $\hat{\beta}_u$ = -\$32.38 for electric-heated homes may reflect both the market valuation of quality differences in heating systems and the problems of converting an existing house to a more efficient system, as well as the benefit of annual fuel savings. A majority (63 percent) of the electric-heated houses in the sample have electric resistance units (wall heaters, baseboard heaters, or ceiling heat) that lack the amenities associated with central heating and cooling and the necessary ductwork for converting to a more efficient (heat pump) system. Therefore, one would expect the market to show a premium valuation on houses with the more efficient electric heating systems.

Comparison of Fuel Costs by Categories

In Table 17 annual fuel costs and the index of installed equipment (AINDEX) are shown for each housing category analyzed. The cost per square foot is not a direct measure of energy efficiency, since family size and behavior, type of heating fuel, and other factors have an influence. The comparison does, however, provide some additional insight to the preceding analyses. In this comparison AINDEX may be interpreted as a proxy for that part of energy consumption which is associated with income.

Table 17. Comparison of houses in the sample by category, annual fuel costs and appliance index, Knoxville housing market, 1978

House category	Annual fuel cost/sq. ft. (mean value)	Appliance index[a] (mean value)
(1) New	44.9¢	.61
Existing	45.4	.41
(2) Electrically heated	47.6	.42
Gas-heated	37.6	.49
(3) Low-priced	53.9	.21
Medium-priced	46.5	.46
High-priced	36.8	.70

[a]Maximum value of 1.

The annual costs per square foot are only slightly higher in existing houses, although new houses have a higher AINDEX. In comparing houses by price categories, there is an inverse relationship between price of the house and costs per square foot. AINDEX, however, increases from the low- to high-priced categories.

The cost per square foot of electric-heated houses is 10 cents higher than that of gas-heated houses. The difference may be due to a number of factors, as well as relative energy efficiencies.

The Discount Rates

The estimated coefficient, $\hat{\beta}_u$ in the hedonic price index, provides a means for calculating discount rates and further evaluating the performance of the housing market in capitalizing investment in energy-saving durable goods. Since the estimated function is linear, the partial derivative of price with respect to the utility bill is equal to $\hat{\beta}_u$. Since both P and U are measured in dollars, $\hat{\beta}_u$ provides an estimate of the present value of a one-dollar savings (at current fuel prices) in the utility bill discounted over the remaining life of the house. Letting this one-dollar savings escalate at a rate g (percent/100) to reflect increasing fuel prices and letting r_H (percent/100) represent the housing market's implicit discount rate, the relationship is

$$\hat{\beta}_u = \sum_{i=1}^{R} \left(\frac{1 + g}{1 + r_H} \right)^i \qquad (1)$$

where R is the number of years remaining in the life of the house.

Equation (1) can be manipulated to yield

$$\hat{\beta}_u = \frac{1 + g}{r_H - g}\left[1 - \left(\frac{1 + g}{1 + r_H}\right)^R\right] . \qquad (2)$$

Given $\hat{\beta}_u$ and assumed values for g and R, Eq. (2) may be solved numerically for r_H.

In the model for the entire housing sample, the estimate of $\hat{\beta}_u$ is -\$20.73 and is significant at the .02 level. In the disaggregated models reported in the second section of this chapter, the estimates of $\hat{\beta}_u$ range from \$6.05 to -\$32.37. Of the eight disaggregated models, two give estimates of $\hat{\beta}_u$ that are significant at the .01 level or higher: -\$32.37 for electric-heated houses and -\$19.86 for houses in the medium-priced category. A third estimate of -\$16.64 for the existing houses category is marginally significant at the .06 level.

From the estimates of $\hat{\beta}_u$ that are statistically significant and assumed values for g and R, Eq. (2) was solved numerically to yield the implicit market discount rates reported in Tables 18-21. Since g is real, the rates are real, rather than nominal, values. The calculated rates range from lows that are zero or negative (not reported in the tables) to a high of 17.9 percent. The discount rates for each of the disaggregated submodels cannot be meaningfully compared with one another since they are not counterparts. Each table of estimates can, however,

Table 18. Implicit market discount rates[a] for the overall sample, Knoxville housing market, 1978

Years	Fuel escalation rates (percent)						
	0	2	4	6	8	10	12
15	—	—	—	2.0	3.9	5.8	7.7
20	—	1.7	3.6	5.6	7.6	9.6	11.6
25	1.5	3.5	5.6	7.6	9.6	11.6	13.7
30	2.6	4.6	6.7	8.7	10.8	12.8	14.9
35	3.2	5.3	7.4	9.4	11.5	13.6	15.6
40	3.7	5.8	7.8	9.9	12.0	14.1	16.1

[a]Negative or zero discount rates are not reported.

Table 19. Implicit market discount rates[a] for electric-heated houses in the sample, Knoxville housing market, 1978

Years	Fuel escalation rates (percent)						
	0	2	4	6	8	10	12
15	—	—	—	—	—	.1	2.6
20	—	—	—	1.5	3.5	5.4	7.3
25	—	.1	2.0	4.0	6.0	7.9	9.9
30	—	1.5	3.5	5.5	7.5	9.5	11.5
35	.1	2.3	4.5	6.0	8.5	10.5	12.0
40	1.1	3.1	5.1	7.1	9.2	11.2	13.2

[a]Negative or zero discount rates are not reported.

Table 20. Implicit market discount rates[a] for houses in the medium-priced category, Knoxville housing market, 1978

Years	Fuel escalation rates (percent)						
	0	2	4	6	8	10	12
15	—	—	.5	2.5	4.4	6.3	8.3
20	—	2.0	4.1	6.0	8.1	10.1	12.1
25	1.9	3.9	5.9	8.0	10.0	12.0	14.1
30	2.9	5.0	7.0	9.1	11.1	13.2	15.2
35	3.5	5.6	7.7	9.8	11.8	13.9	16.0
40	4.0	6.1	8.1	10.2	12.3	14.4	16.5

[a]Negative or zero discount rates are not reported.

Table 21. Implicit market discount rates[a] for resale houses in the sample, Knoxville housing market, 1978

Years	Fuel escalation rates (percent)						
	0	2	4	6	8	10	12
15	—	.1	2.7	4.7	6.6	8.6	10.6
20	1.8	3.6	5.9	7.9	10.0	12.0	14.0
25	3.4	5.5	7.5	9.6	11.7	13.6	15.8
30	4.3	6.4	8.5	10.6	12.7	14.8	16.8
35	4.9	7.0	9.1	11.2	13.3	15.4	17.5
40	5.2	7.3	9.4	11.5	13.6	15.7	17.9

[a]Negative or zero discount rates are not reported.

be compared with the discount rates reported in Table 18 for the overall model.

As an example in interpreting the calculated discount rates for the entire sample, consider a 14-year-old house (the mean age of houses in the sample). If the projected remaining lifetime of the house is 30 years (although the lifetime of the equipment may be less) and fuel prices are expected to escalate at an annual rate of 4 percent,[a] the implicit housing market discount rate is 6.7 percent. If the homebuyer instead expects fuel prices to rise no faster than the rate of inflation (a 0 escalation rate), the discount rate is only 2.6 percent. For the homebuyer who expects fuel prices to increase at an annual rate of 12 percent, the discount rate is 14.9 percent.

In Table 19, the discount rates for buyers of homes heated by electricity, the estimates are lower than those for the overall model. There are three tentative conclusions: (1) buyers of electric-heated homes expect escalation rates in the range of 10 to 12 percent per year; (2) they have relatively long planning horizons; or (3) some combination of these two factors.

Table 20 shows discount rates for purchasers of homes in the $30,000-$50,000 price range that are slightly higher than in the overall sample. No particular comparison or conclusion as to the reason is

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[a]This rate is consistent with 15-year projections by the U.S. Department of Energy [38] for this region of the country.

possible except to note that the level of significance of $\hat{\beta}_u$ increased from .02 in the overall model to .01 for this subsample.

The discount rates for purchasers of existing houses, reported in Table 21, are only slightly higher than for the overall model. The result of removing new houses from the sample is to lower the estimate of $\hat{\beta}_u$ (in absolute value) and to lower the *t* ratio to a marginal (.06) level of significance.

Thus, the general conclusion concerning the discount rates calculated for the entire sample and the three subsamples is that they are surprisingly low when compared with reported discount rates from recent studies.[a] The discount rates from this study, however, are compatible with those that are currently in use as social discount rates,[b] indicating that the housing market operates efficiently in capitalizing energy conservation investment.

There are important differences between this study and the previously cited studies that should be noted when interpreting and comparing the results. First, the objective of this study is to determine the efficiency of the housing market in capitalizing future fuel savings. The study does not answer the question of whether or not the socially optimum level of investment in conservation is taking place. A further condition is that the individual discount rate must be equal to the social discount rate.

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[a] Recent studies are reported in the review of literature [14, 29].

[b] The U.S. Department of Energy [38] currently recommends a discount rate of 10 percent for cost-benefit analysis.

Second, in the present study the durable goods are part of the overall housing package, whereas the earlier studies have considered market purchases of room air conditioners, and levels of insulation and window glazing in construction of new houses as single investment components. Although the data do not provide a means for testing the hypothesis, it is feasible that the total package of efficient equipment and insulation already installed in a house would have a higher market valuation than would the same components as single purchases. Savings in search costs and the costs of time and inconvenience in installing the equipment provide an economic rationale for a price premium on the existing fuel efficiency of an individual house. In addition, long-term mortgage financing may offer an incentive for investment in conservation at the time the house is purchased.

A further consideration is that there are amenities other than fuel savings associated with certain equipment and thermal properties of a house. As an example, compare two houses each having a different type of heating and cooling system: a house heated and cooled by a heat pump and a house with electric resistance heating units and room-size air conditioners. The house with the heat pump not only has a more fuel-efficient system, but greater aesthetic appeal and the potential for more uniform temperature and a higher level of comfort for the occupants. Also, insulation and storm windows may have a market valuation for their sound insulating properties as well as their thermal insulating properties.

In comparing the implicit discount rates from this study of the housing market with those calculated from purchases of room air conditioners, one would expect to find differing income distributions of the two groups of purchasers. In effect, the income distribution of homebuyers may be truncated, making the lower discount rates from this study consistent with Hausman's finding that discount rates vary inversely with income.

Thus, the low discount rates calculated in this study may be capturing several effects: (1) expected savings in the fuel bill, (2) the convenience of purchasing and financing energy efficiency as part of the housing package, (3) extra amenities that are inherent in certain equipment and thermal characteristics, and (4) the income distribution of homebuyers.

The Land-Price Surface

The selling price of a house can be partitioned into components associated primarily with the capital investment in the structure and those associated with the building site. The price of residential building sites is expected to vary with the size of the lot, the characteristics of the neighborhood, the property tax rate and public services provided, and accessibility to centers of employment, shopping, recreation, and other trip destinations. In this study the factors associated with land values are census tract variables (INC78, BLACK, and POPDEN), a dummy variable (CITY) for within city limits, and X, Y Cartesian coordinates to define each location. Under the specification

of Eq. (8) in Chapter 3, the effect of each neighborhood characteristic is a lump-sum treatment, whereas the effect of accessibility is directly proportional to the size of the lot. Of the 14 variables associated with the price of land in the hedonic price index (Table 7, page 58), 11 are significant at the .01 level (POPDEN and two of the polynomial terms are not significant).

In the disaggregated models reported in the second section of this chapter, the adjusted price of the house (with the price of land subtracted) was used as the dependent variable. Predicted lot prices for houses in the sample were calculated from the estimated coefficients in the hedonic price index. The calculated lot prices were found to be of reasonable magnitudes.

The accessibility component of land values in this study is represented by the third degree polynomial. This form was found to give the best fit to the data using the F test and spatial autocorrelation criteria reported by Jackson [16]. First, the F test indicated that the sums of squares for regression was not significantly improved by a higher degree polynomial. Second, the plot of the residuals against X and Y showed the desired random distribution of positive and negative values, indicating the absence of strong spatial autocorrelation. Therefore, the third degree polynomial form of the X, Y coordinate system was used for the accessibility component of land values in the hedonic price equation.

The geographic representation of the land-price surface (estimated from the ten polynomial terms in the estimated hedonic price index) is

presented in Fig. 2. This shows a central valley (low point) that extends east and west and then runs southeast. Land values increase in the contour that includes the CBD, Westown shopping center, and The University of Tennessee. Land values continue to increase going from Sequoyah Hills, Lakemoor Hills, and Riverbend residential areas. The predominant influences in this area appear to be the Tennessee River, offering aesthetic beauty and recreation, and Alcoa Highway, providing easy accessibility to the interstate system, The University of Tennessee, the CBD, Alcoa Aluminum Company, and the airport. In the northern portion of the area, land values increase around the periphery of the valley. This may be attributed, in part, to the development of new subdivisions and the improved accessibility to these areas provided by Interstate-75 in the north and northwest portion and by Interstate-40 in the northeast portion.

The decline in land values in the contours extending west is contrary to what would be expected, since these areas are in close proximity to the interstate system, shopping centers, and places of employment. A possible explanation of this result is that the variable POPDEN (population density) was not adequately controlled in the estimated hedonic price index. Since the western portion of the county has been one of rapid suburban growth, the 1970 estimates of population density (the data used for this variable) are low for the area in 1978. Therefore, the estimated coefficient for POPDEN was not significant in the model and the accessibility price contours for the western portion of the county may be inconclusive relative to the entire housing market area included in the study.

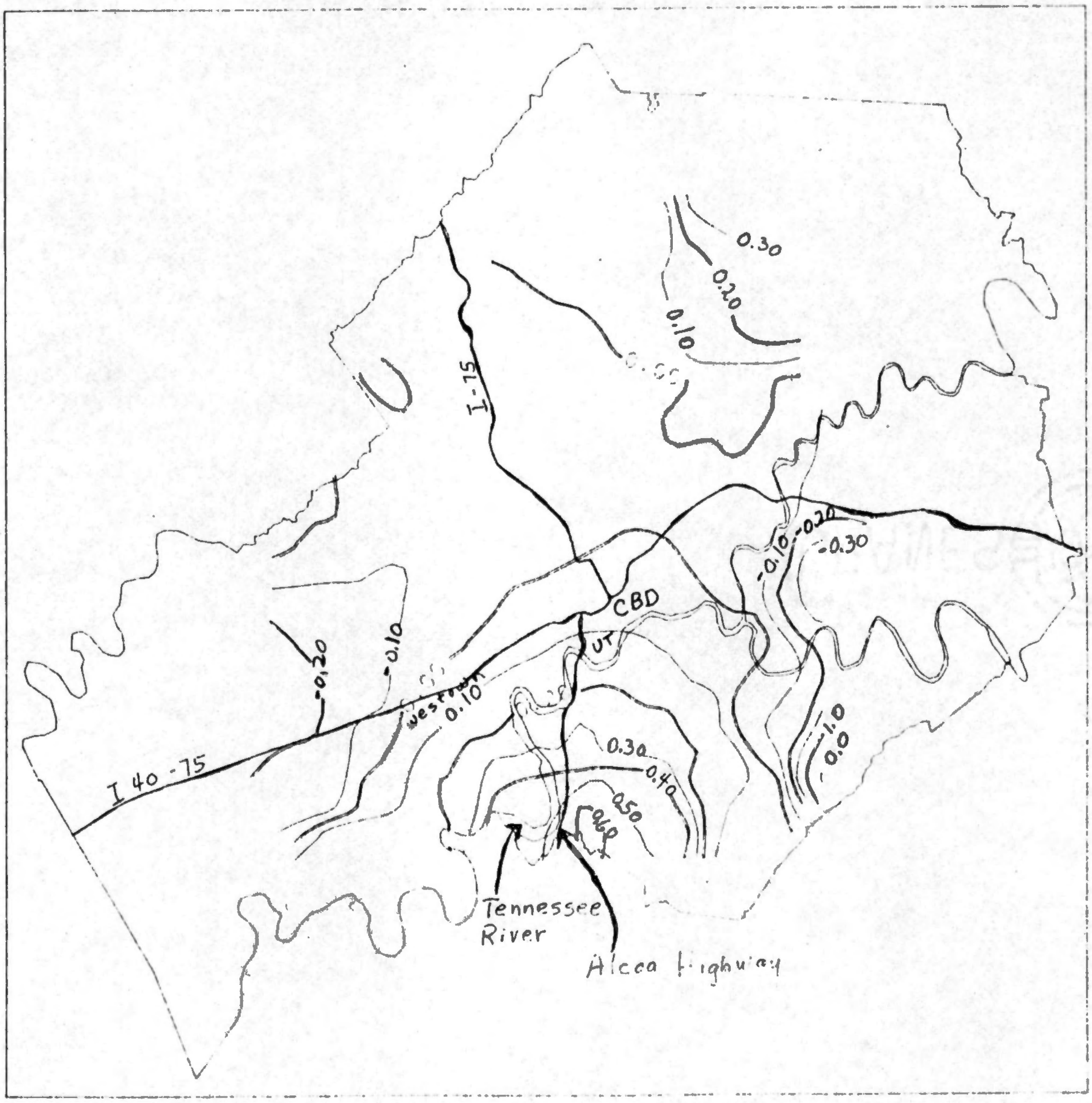

Fig. 2. Land-price surface for Knoxville housing market, 1978.

The overall results of the land-price surface, however, show that the CBD is not a single predominant influence in determining land values in the Knoxville housing market. Under a location variable specification of distance to the CBD, one would expect to obtain the wrong sign and, possibly, other problems attributable to specification error in the model.

The Information Component

One of the assumptions of the perfectly competitive market is that both buyers and sellers have full and accurate information. A question of importance to the present study is the extent to which the housing market falls short of this perfect norm. Can a homebuyer accurately judge the energy efficiency of a house on the basis of the information provided and make the appropriate level of investment? The MLS form (see Appendix) provides a space for reporting average monthly utility costs. One of the objectives of this study is to evaluate the usefulness of this information to the prospective homebuyer. The information on monthly utility costs was analyzed as to its availability and its accuracy.

Of the 1,159 existing houses (those with a past utility billing history), 665 (57 percent) reported average monthly utility costs on the MLS form. This percentage is biased to some extent by the fact that houses with missing items of information considered essential to the study (size and age of house, dimensions of lot, number of rooms, and type of heating system) were eliminated from the sample in the selection process.

In the coding and analysis of the data, if the reported information separated the bill into components of electricity, gas, and water, only electricity and gas were recorded. Otherwise, if a single figure was reported, it was adjusted by subtracting the average cost (in the Knoxville area) for water and sewer fees to make the utility bills comparable.

Of the 665 houses for which there was a reported average utility bill, the data file from the utility company contained a one-year history for the corresponding period of time (one year prior to sale of the house) for 507 houses. These 507 houses provided the sample for statistically comparing the reported bill with the actual. For the analysis, the reported monthly average was converted to an annual figure. Mean values, standard deviations, and the ranges for reported and actual bills are reported in Table 22. Table 23 shows the distribution of error due to both underestimation and overestimation. Approximately half (49 percent) of the reported bills were within 15 percent of the actual.

The paired t test [32] provided the statistical means for evaluating the accuracy of the reported information. The ordinary t test is not designed for paired comparisons. Instead, for paired comparisons, a new variable containing the differences between the paired variables is created, and the statistical test is whether the mean difference is significantly different from zero. The null hypothesis in this case is that the difference between the actual and reported utility bills is equal to zero. The t value of $1.78 < 1.96$ at the .05 level of

Table 22. Comparison of reported with actual annual utility bill for subsample of houses, Knoxville housing market, 1978

Utility bill	Mean	Standard deviation	Minimum value	Maximum value
Reported	$685.99	$207.84	$276.00	$1,896.00
Actual	700.19	190.88	300.63	1,850.27

Table 23. Error distribution in comparison of actual utility bill with reported, Knoxville housing market, 1978

Percent error	Overestimated	Underestimated	Total	
			Number	Percent
5	32	33	65	13
10	34	51	85	17
15	19	55	74	15
20	28	53	81	16
25	14	57	71	14
30	9	44	53	10
40	14	35	49	9
50	4	8	12	2
>50	12	5	17	3
Total	166	341	507	

significance indicates accepting the null hypothesis. Therefore, the conclusion is that the utility bills as reported on the MLS forms are reasonably accurate.

In this study, the principal information problem was that 43 percent of the sellers did not report utility costs. The buyers of these houses apparently relied upon other sources of information or their own judgments in evaluating and comparing the energy efficiencies of houses on the market.

CHAPTER 6

SUMMARY AND CONCLUSIONS

This study investigated the Knoxville housing market during 1978 for the purpose of determining the effect of fuel savings on the sale price of the house. The need for the study is evident both in the economic literature and analyses of energy conservation programs and in policies where assumptions are made about the housing market often without empirical investigation. The specific objectives of this study are: to determine the efficiency of the housing market in capitalizing investment in energy-saving durables, to calculate the implicit market discount rates, and to evaluate the information about fuel costs that was available to the homebuyer.

The theoretical construct of the model is based upon principles of the household production function and investment theory. The rising energy prices of recent years provide an economic incentive for households to substitute capital for fuel in the production of heating, cooling, and other commodities, where the extent of substitution that is feasible is constrained by existing technology. Such capital-fuel substitution requires that builders and homeowners invest in the durable goods that make the house energy efficient. Since these durable goods become permanently attached to the dwelling unit and since ownership of the unit is likely to change within the lifetime of the installed equipment, the incentive to carry out this investment depends critically upon the efficiency of the housing market in capitalizing the financial

benefits of future fuel savings. In this context, the resale value of the house is equivalent to scrappage value in traditional investment theory. Given the relatively brief tenure of many homeowners in conjunction with the long lifetime of houses, the scrappage value and the marginal influence that energy efficiency has on this value can assume predominant importance in the homeowner's investment decision calculus.

The statistical technique of the study is to estimate an hedonic price index of the form P = f(U, S, N, L) where P is the sale price of the house, U is the annual utility (fuel) bill, S is a vector of structural attributes, N is a vector of neighborhood characteristics, and L consists of the size and accessibility characteristics of the lot. The estimated hedonic price index reveals that, holding other influences constant, the marginal effect of a one-dollar savings in the annual fuel bill is an increase of approximately $21 in the sale price of the house. From the estimated coefficient ($\hat{\beta}_u < 0$) and the statistical test of significance (significant at .02 level), the conclusion is that the housing market does capitalize the investments that result in fuel savings.

Estimates of the implicit market discount rates, under various assumptions about fuel escalation rates and remaining lifetimes of the houses, indicate that the housing market performs in a manner consistent with a social discount rate of about 10 percent.[a] Factors other than

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[a]This rate is currently used in analyses by the U.S. Department of Energy [38].

fuel savings that may have contributed to the low discount rates found in this study were discussed in Chapter 5. An additional question, not answered by the data, is whether or not the estimated hedonic price index represents a market equilibrium? If, during 1978, there was excess demand for houses with energy-efficient durable goods installed, the price would have been bid upward. A study of 1979 or 1980 could represent a changed demand and supply situation with differing discount rates. In either case (a market equilibrium or disequilibrium), the results of the study indicate that the market system is functioning, although the calculated discount rates may be of a transitory nature.

The results of the study do not indicate whether or not investment in energy conservation is proceeding at a socially optimum rate, only that the housing market in this location and period of time, did operate efficiently in capitalizing the investments. In order to have a socially optimum level of investment, both the individual discount rate (r_I) and the housing market discount rate (r_H) must be equal to the social discount rate (r_S); that is, $r_I = r_H = r_S$.

The disaggregated models reveal differences (sizes, equipment, spatial distribution, etc.) between new and existing houses, gas- versus electric-heated houses, and variations across price categories. No firm conclusions can be reached, however, with respect to the relative energy efficiencies of the houses or the market performance within a particular category.

Evaluation of the information component of market performance indicates that the utility costs as reported on the MLS form are

deficient in number reporting, but reasonably accurate for the cases that were reported.

Policy Implications

The results of this study apply to one housing market at one point in time. Therefore, the implications for policy, although direct and important, must be tempered with due caution. The broad implication for public policy is that the housing market does operate in an efficient manner and that policy strategies be directed toward reinforcing, rather than negating, the market system. An example of a negative policy would be that of controlling fuel prices at an artificially low level, whereas a policy that improves the information component of the market would be reinforcing.

The results of this and similar studies would enable builders, homebuyers, homeowners, and those persons who are planning to sell a house in making appropriate investment decisions. The information would also be of interest and value to real estate appraisers. Evidence of the performance of the housing market will help in overcoming one of the perceived obstacles to investing in energy-saving durable goods. This type of economic information is needed along with the dissemination of information on new technology. If individuals are aware of the performance of the housing market, high individual discount rates may be lowered to a level more in keeping with the housing market's discount rate and the social discount rate.

The need for special subsidies for retrofitting would appear to be greatest in the lower-priced houses. In this study a majority of houses in the low-priced category have electric resistance heating (a relatively less efficient system) and would have a larger marginal benefit from improving the thermal integrity of the house. For low-income rental housing, direct regulation, subsidies, or a combination of the two may be necessary for insuring the investment in insulation and other energy-saving durable goods.

The evaluation of market information implies a need for the requirement of labeling or the actual utility records from the seller. A uniform energy-rating index, efficiency ratings of the heating system, and R-values of the insulation are examples of types of labeling requirements that would improve market information. A relevant question pertaining to the information component is how well past utility records serve in predicting the future fuel usage of the new owners. Further study and analysis are needed for developing a policy proposal in this area.

Needs for Further Research

One of the accomplishments of this study has been the compilation of the large and detailed data base. There are plans for further use of the data at Oak Ridge National Laboratory, and perhaps the outgrowth of studies can become important and significant in the housing and energy conservation literature. Some proposals include: a study of the household production process to include the elasticity of substitution

of capital for fuel; use of the trend-surface analysis to determine the elasticity of substitution of land for capital in the production of housing services; a survey of the owners of houses in the sample to obtain in-depth information for further analysis; matching of sample data with TVA energy audits to facilitate additional study; and a study of the behavioral component of energy consumption, perhaps through paired comparisons of different occupants through utility records (available for a portion of the sample) prior to and after sale of the house.

Other proposals include one or more studies of housing markets in different regions of the country. The comparison of market performance with differing climatic conditions will provide additional information needed for policy analysis and recommendations. Another study of interest would be the comparative energy efficiencies and level of investment of custom-built versus speculative-built houses. The performance of the rental housing market and investment in energy-saving durables is a needed area of study.

Further research and analysis are necessary to distinguish the performance of the housing market in the disaggregated models by fuel type, price category, and new and existing houses. One of the challenges in this area of research is to find an improved means for measuring the actual energy efficiency of a house, while controlling for the demographic and behavioral characteristics of the occupants.

The problems of energy shortages and the public interest in conserving energy will provide continued issues and questions for

further research. Present studies, it is hoped, provide an important beginning for what will become a new and significant body of literature.

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Reporting Form Used by Knoxville Multiple Listing Services

PRICE	ADDRESS	TYPE	ROOMS	BDRMS	BATHS	AREA-GRID	MLS NO.

Lot Size Legal Descrp. Sq. Ft. Apprx.
Up
Listing Realtor Realtor No. Phone Main
Listing Salesperson Phone Down
Owner's Full Name Phone Total

Style Dishwasher
Const. Range
Age Disposal
Sewer Compactor
Septic Pantry
Driveway Intercom
Roof Washer Conn
Garage Dryer Conn
Carport HW Floors
Patio Frpl.
Deck Bar
Windows Heat
City Bus Air Cond.

ROOM SIZES CRPT DRPS
Entry x
Liv. x
Din. x
Kit. x
Den x
Rec. x
Bdrm. x
Bdrm. x
Bdrm. x
Bdrm. x
x
Utility Basement

Possession
Mortgagee
Mort. Bal.
Equity
Payments Maturity
Int. Rate
Type
City Tax
County Tax
Av. Utility Costs
El. Company
Water Co.
Gas Co.

School: GR. BUS JR BUS HI BUS
REMARKS:

DIRECTIONS:

VITA

Ruth Crumley Johnson is a native of Sullivan County, Tennessee, where she grew up on a farm and actively participated in 4-H Club work. She is the daughter of Mr. and Mrs. Glenn F. Crumley of Bristol, Tennessee. She received the B.S. in home economics in 1970 and the M.S. in family economics and economics in 1971 from The University of Tennessee, Knoxville. She was employed as a social worker by the Anderson County Day Care Program during 1972 and as home economist for the City of Oak Ridge from 1973 through 1977. During this time she served on the Boards of Anderson County Community Action Commission and Anderson County Health Council and was chairperson of the Youth Workers Council.

In 1978 Ruth Johnson entered the Ph.D. program in the Department of Agricultural Economics and Rural Sociology at The University of Tennessee, Knoxville, where she worked as a graduate research assistant. In 1979 she began her dissertation research at Oak Ridge National Laboratory under funding by the U.S. Department of Energy. She has published a paper in the *Southern Journal of Agricultural Economics* and has presented papers at professional meetings. She is a member of Gamma Sigma Delta, Omicron Nu, and Phi Kappa Phi honor societies. She is a member of several professional organizations, including the American Agricultural Economics Association, the American Association for the Advancement of Science, the Association of Environmental and Resource Economists, and the American Home Economics Association. She

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She is married to Robert William Johnson, a chemist with Union Carbide Corporation, and they live in Oak Ridge, Tennessee.