Housing Market Capitalization of Energy Efficiency Revisited

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ABSTRACT

Whether and to what extent housing markets capitalize the value of energy efficiency in homes has been the subject of numerous studies published over the past twenty years. For various reasons the answer to this question is important to home builders and buyers, appraisers, and policymakers. But difficulties with measuring costs and benefits of energy efficiency in housing, as well as the fragmented and local nature of housing markets, have rendered the answer to this question elusive. This paper reviews published research on capitalization of energy efficiency, with a focus on studies that have applied the hedonic regression methodology, and presents a direction for future research.

Introduction

The notion that buyers are willing to pay a premium for energy efficiency in housing is consistent with economic theory, because they will anticipate savings in space conditioning expenditures over time. On the supply side, builders of new homes and sellers of existing homes will expect house sale price to reflect additional capital costs associated with energy efficiency beyond levels specified by building codes, such as added insulation, high performance windows, and highly efficient space conditioning equipment.

The issue is complicated by the temporal nature of investments in energy efficiency, with benefits in the form of utility expenditure savings occurring over time. The calculation of these benefit streams requires the application of an appropriate discount rate. Metcalf and Hassett (1997) have argued that technically derived estimates of energy savings are often overstated, and that knowledgeable consumers may rationally believe their realized savings will be far below these estimates and behave accordingly by applying high discount rates to benefit streams. At the same time, DeCanio and Laitner (1997) suggest that very high discount rates may indicate more than a pure financial perspective. Seemingly profitable investments may not be taken because of unobserved transaction costs, informational barriers, market failures, uncertainty about benefits, myopia, and other similar factors.

This multiplies the difficulty of considering a home buyer's discount rate estimate and an estimate of the change in house price due to energy efficiency, and it makes it seem unlikely that a discount rate estimate by itself could effectively be used to adjust the appraised value of a home. We have thus chosen to focus on studies that at least potentially could provide an appraiser or other interested party with a direct estimate of house price changes that result from improvements in energy efficiency. To establish the range of studies, we drew heavily on the literature review in Nevin and Watson (1998). This proved reasonably comprehensive, although we ultimately decided to supplement it with several items identified through computer searches of relevant databases or cited in the studies themselves, including related papers by the original authors that presented more details on the underlying work.

Hedonic Price Studies

In a study that attempted to gauge the impacts of rising fuel prices after the Arab oil embargo of 1973, Halvorsen and Pollakowski (1981) analyzed a sample of 269 homes that were sold in a single neighborhood in Seattle, Washington between 1970 and 1975. They chose to include only homes that used either gas or fuel oil for space heating. They reported that the marginal impact on market value of having natural gas heat rather than oil heat was $4,597 during the first half of 1975. While the fuel type variable ignores everything that is usually associated with energy efficient construction, it does relate to utility costs. But the focus on fuel type, and the finding that homes with gas heat were worth more than similar homes with oil heat during one six-month period out of five years studied, makes it hard to interpret the results of this study. It shows some evidence that oil-heated homes were less marketable than gas-heated homes during a period shortly after the oil embargo of 1973, but this effect disappeared after natural gas prices rose.

Corgel, Goebel, and Wade (1982) constructed a model using data from a sample of 100 single family residences sold in Lubbock, Texas during 1978 and 1979. Their regression model used selling price as a dependent variable and nine structural characteristic variables to which they added an indicator variable where energy efficiency was evaluated from aerial infrared photography. The infrared photography variable was significant in their regression, and these authors concluded that a home that was relatively energy efficient based on this information would sell for $3,416 more than a comparable structure with an inefficient rating. Although they did note that energy efficiency is capitalized into the sale price of a home, this study has several substantial limitations beyond its small data set: although the hedonic model did include structural characteristics and house age, locational and neighborhood variables were missing; the infrared flyover technology produces a crude measure of energy efficiency for a particular property; and the regression analysis produced results that are difficult to interpret.

Dinan and Miranowski (1989) used a sample of 234 single-family detached homes sold between January and June, 1982. They specified a hedonic model that included selling price, house structural characteristics, and neighborhood and locational variables. As a measure of energy efficiency, a proxy variable, F, was constructed by obtaining fuel expenditures of the houses in the sample and adjusting this information for differences in billing periods, degree days suring the 1982 heating season, internal temperature settings and heated floor space. Fuel expenses were obtained from Iowa Power, degree days from the Energy Extension Office at Iowa State University, and internal temperature settings through a survey of homeowners in the sample. F was then calculated from equations that considered different temperature setting preferences for homes in the sample and the above data. Dinan and Miranowski also considered alternate functional forms for the hedonic equation by using linear, semilog, log-linear, and Box-Cox models. From a likelihood ratio test they observed that the first three specifications differed significantly from the Box-Cox specification, which indicated an increase in house price of $11.63 for every $1 decrease in fuel expenditures. While these authors took a number of steps to calculate a value for F that would not include household lifestyle characteristics that could affect heating costs, they failed to describe these steps in enough detail to allow replication by a third party or independent evaluation of their adequacy. In addition, while Dinan and Miranowski are apparently aware of important issues that affect heating costs, internal heat gains from appliances are treated the same as provided heat from a furnace.

With an analytical framework that comprised both hedonics and capital theory, Johnson and Kaserman (1983) estimated capitalized values of energy efficiency from a sample of 1,317 houses sold in Knoxville, Tennessee. Their hedonic equation included an annual utility bill derived as an instrumental variable in a two-stage, least squares regression. From this estimation of implicit prices, the authors reported that an investment in an energy-saving durable good that results in a utility bill decrease of $1 per year increases the market value of a house by $20.73.

Although Johnson and Kaserman provided an adequate explanation for using two-stage least squares, like Dinan and Miranowski, they did not present results from the first stage of their model. While both papers employ an appropriate two-stage estimating procedure, they provide very little information about the first stage. This omission is important to note, because the economics literature provides significant examples of research results that were effectively overturned by demonstrating that problems existed in the first stage of a two-stage estimation procedure. In one case, Angrist and Krueger (1991) used Decennial Census data to estimate a wage equation with a relatively large number (28 to 30) of instruments including interaction terms. Subsequently, Bound, Jaeger, and Baker (1995) showed that the instruments were weak, that the Angrist and Krueger results consequently suffered from substantial finite sample bias even with a data set as large as the Census Public Use Microdata Sample, and that including interaction terms made the situation worse rather than better. Similarly, Hall (1990) introduced a set of instruments that were subsequently adopted by many others when estimating productivity equations. Burnside (1996), however, later demonstrated that these instruments were weak, and that other sets of instruments produced considerably different results. In both cases, instrumental variable estimates that appeared credible at first are now widely rejected within the profession due to the subsequently reported evidence that the instruments used to generate the estimates were weak. In the absence of information that would enable us to judge whether these models are free from weak instrument problems, we are reluctant to accept the estimated results at face value.

A further reason we suspect that the estimated value of energy efficiency in Dinan-Miranowski may be biased is that the paper ignores cooling season utility costs or savings in deriving the reported relationship between market value and energy efficiency. We do not find the authors' justification for doing so persuasive. They performed an *ad hoc* test for evidence of such a relationship and concluded it was not significant when viewed in isolation, so the final model attributed the entire difference in house value to savings in heating cost. If the efficient homes saved energy in both seasons then including cooling in the annual utility bill would reduce the impact of each dollar of utility savings on house value and utility bills, perhaps substantially, below the figure reported in the article.

Longstreth, Coveney and Bowers (1984) and Longstreth (1986) model energy efficiency as a collection of three to four specific attributes: inches of insulation in ceilings and walls (both continuous variables), presence or absence of storm windows/thermopane glass, and presence or absence of wood/vinyl window frames (both dummy variables). Separate coefficients represent the implicit prices of each of these attributes (e.g., an additional inch of ceiling insulation). Two of these variables are binary, which leads to problems with generalizability of results, while the other two (inches of wall and ceiling insulation) are potentially easier to generalize because they do not assign the same value to every house. Modeling market value as linear in inches of insulation is consistent with using product cost as the basis for market value, but not with energy savings (due to the diminishing marginal return of added insulation). Some findings reported in Longstreth *et al.* (1984) are that the marginal impact on market value of having specific energy saving features was \$528 for an added one inch of wall insulation; \$508 for an added inch of ceiling insulation; and \$407 for storm windows and/or thermopane glass. An alternative model in this paper omitted energy efficiency variables and used gas consumption instead. In attempting to relate natural gas consumption to market value, the authors conclude that "the relationship between sale price and consumption was negative, as expected." (p. 569) However, using unadjusted gas consumption as an independent variable introduces the same endogeneity problems as using total utility bills, which are not addressed in the paper. Furthermore, the underlying equation includes variables for both gas consumption and the square of gas consumption, and when the derivative of sale price with respect to gas consumption is evaluated at the mean level of gas consumption for the sample, the result is positive, not negative (i.e., sale price rises as gas consumption increases). In this respect the analysis based on gas consumption undermines rather than reinforces the overall conclusions of the article.

Longstreth (1986) used a sample of 505 single family detached homes sold between 1971 and 1978 in Columbus, Ohio. Data collection procedures included a mailed questionnaire that elicited demographic information, house structural characteristics, and energy consumption. Other data sources included the Multiple Listing Service, county tax and deed records, US Census, and the Ohio Dept. of Education. This paper reported the results of 13 hedonic regressions. One included the entire sample; the others were re-estimations of the model for different levels of demographic variables (age, education, income, and household size). Longstreth's reported findings included significant influences on house sale price from energy conserving house characteristics (ceiling and wall insulation). In the disaggregated samples, results differed depending on demographic characteristics. For example, extra inches of wall and/or ceiling insulation had a positive influence on prices of homes purchased by young and middle-aged buyers.

We noted some problems with Longstreth's results. The author reported the data were from a subset of homes sold between 1971 and 1980, yet data from 1979 and 1980 were dropped from the analysis with no explanation. In addition, the ceiling insulation variable in Equation 1 is reported as 3.37. This cannot be correct, since it is so far from the same variable in the other equations (0.31; 0.46; -0.11). This is likely to be a typographical error. The table which reports key results (Table 3) has additional errors. Variables that are not significant are reported as significant: W^2 (inches of wall insulation squared) in Equation 1 and W^2 in Equation 10.

Laquatra (1986) used a sample of 81 homes constructed through a government program in the state of Minnesota and sold in 1980. These were experimental homes that had varying levels of energy efficiency which were advertised during the marketing of the homes. These levels were quantified with Thermal Integrity Factors (TIF) that projected energy use in BTUs per degree day per square foot. Laquatra specified a hedonic price index with a TIF as an independent variable and found that house value increased by \$2,510 for every unit decrease in the TIF. The major limitation of this study was its restricted generalizability. The government subsidies for these homes were likely to distort the market. There was exceptionally high demand for the houses that necessitated the creation of a lottery to determine eligible buyers. The TIF would be expected to decrease for larger homes, but this was not considered in the regression. Because of the small number of houses in this data set, structural variables in the hedonic price index were limited to avoid a degrees of freedom problem. But Laquatra noted in his conclusions that in spite of the limitations of this study, findings were consistent with other studies that had been conducted up to that point, using different measures of energy efficiency, but observing that capitalization is occurring to some extent.

Horowitz and Haeri (1990) focused on Model Conservation Standards (MCS) and house prices. They used a sample of single-family, detached houses built in 1984 and 1985 in the Tacoma City Light service territory of Washington State. A house had to be sold at least once as of the final months of 1988 to be included in this sample; it had to be in subdivisions rather than in-filled lots; the resale date had to be separated by several months from the original sale; and the resale price had to be less than $170,000. The resulting sample size was 42 houses. To this number they added resales of 25 electrically heated single-family homes built before adoption of the MCS. The model includes an interaction variable, equal to floor area multiplied by the value of the MCS dummy variable, in order to let the incremental value of energy efficiency vary with size of house. This is more realistic and potentially easier to generalize across houses than the pure binary approach. Presumably the idea is that any house built to the Model Conservation Standards will command a premium, and larger homes will command a larger premium. Unfortunately, the model results give a different picture: the coefficient on the MCS dummy variable is extremely negative (-$29,333), and the coefficient on the interaction (MCS × square footage) variable is extremely positive ($19.94/square foot). While the reported net effect of a $1,315 addition in value for the average-sized house is not unreasonable on its face, the two coefficients used to generate it both appear implausible.

This observation leads directly to a further comment. The value of energy efficiency under the model is a linear combination of two terms, and both of the terms have statistically significant coefficients. However, the conclusions about market value rest not on either term but on the combination of the two terms, and the article never demonstrates that the overall impact on market value computed in this way is significantly greater than zero. Failure to include this straightforward test leaves the key finding of the paper without a statistical foundation. The significance test is of particular importance here because the two coefficients are opposite in sign and the magnitude of the sum is small compared to the individual terms. Uncertainty inherent in each term could easily make the sum of the two terms statistically nonsignificant, even if both individual coefficients are significant. Unfortunately, this cannot be tested without knowing the covariance of the two coefficients, which is not reported in the paper. Therefore, the published article does not demonstrate statistically that the MCS houses are worth more than non-MCS houses.

Nevin and Watson (1998) used AHS national data from 1991, 1993, and 1995. They also used the AHS metro data from 1992, 1994, and 1996. In their hedonic model the dependent variable was occupant-estimated market value. Independent variables included lot size in square feet; property age; square feet of house; number of rooms; total fuel expenditures; lot size square feet squared; unit square feet multiplied by total utility expenditures; number of rooms multiplied by total utility expenditures; dummy variables for presence of a garage, porch and air conditioning; dummy variables for regional location in U.S.; and dummy variables for urban or rural location. The main finding of this paper was that house values increase about $20 for every $1 reduction in annual utility bills. Detailed regression results that were not published in this paper contradict this finding. The authors' error was to base all conclusions in the article entirely on the coefficient on the utility variable, even though the regression model included two interaction terms, based on the utility variable, which also change when the utility cost changes. The reported relationship between house value and utility bills as reported in the article actually applies only to homes with zero square feet and no rooms, since only under those conditions do the two interaction terms involving the utility bill variable effectively drop out. As square footage and room count rise, the impact of changes in utility expenditures on house value changes rapidly due to the interaction terms. This effect is so strong that for essentially any plausible house square footage and number of rooms, the regressions reported by the authors indicate a *decrease* in house value as utility bills drop, not an increase. For example, while the article interprets a utility coefficient of –23.41 in the 1995 national AHS detached home regression equation as indicating an increase in value of $23.41 for each $1 decrease in annual utility costs, the complete equation also includes statistically significant coefficients of +5.81 on the square footage interaction term and +4.41 on the number of rooms interaction term. Assuming the regression model is correct, this means the total impact of a $1 decrease in annual fuel bills on the value of a typical 1800 square foot house with six rooms would be a *decrease* of $13.51, far different than the increase of $23.41 reported in the article. In addition, drawing broad conclusions about market value based entirely on occupant estimates of house value rather than actual selling prices is a serious weakness of this study, but the failure to consider the whole regression equation in estimating the relationship between house value and utility costs is the greatest problem.

In a follow-up article, Nevin, Bender and Gazan (1999) compared regression results from Nevin and Watson (1998) with "cost vs. value" surveys of real estate agents conducted by Remodeling Magazine (RM). This study focused on effects of replacing existing 3-foot-by-5-foot windows with energy efficient windows. They specified model home energy use characteristics; estimated pre-project utility bills; and estimated post-project utility bills. Then they multiplied annual utility savings by model value for utility bill, and compared these window replacement value estimates with the RM survey value estimates. The authors repeated these steps for 25 MSAs in four US geographic regions. This analysis required assumptions regarding duct loss, heating and cooling efficiencies and infiltration rates, which were based on estimates from the Home Energy Rating Systems Council. The DOE2 energy analysis program was used to model home energy demand for different fuels in homes with and without air conditioning. They arrived at estimates of annual energy consumptions before and after window replacements. Energy savings depending on type of window varied from $200 per year to $424 per year. They then multiplied savings by $20, which was based on the Nevin and Watson (1998) result. While the RM value estimate for window replacement was $7,000, the result from this model was $5,500. The authors explained this disparity by assuming that the $1,500 difference represented value attributed to ease of maintenance. The major weakness of this paper is that the analysis relies on a questionable result from the Nevin and Watson (1998) paper. The authors also offer a confusing explanation for the validity of their model, by discussing RM survey value estimates for a large master bedroom with a number of amenities and their regression model for home value estimates. The discussion only raises questions about the appropriateness of using subjective estimates from real estate brokers and applying it to a model based on questionable assumptions.

Opportunities for Future Research

Although economic theory suggests that the value of a house should rise as it becomes more energy efficient, the magnitude of the increase is an empirical question. The studies we reviewed in the previous section used a variety of approaches to answer that question, and we highlighted some of the problems inherent to those approaches. Each of the hedonic regression papers we reviewed has a substantial section of exposition that is interesting and elucidates important aspects of important issues. We recommend reading them for that reason. However, the empirical task they undertake is quite difficult, and they do not always deal with the formidable measurement and statistical difficulties in a completely satisfactory fashion. Moreover, the data they employ are often quite limited. Some of the studies rely on oversimplified models that cannot support general conclusions about the relationship between value and energy efficiency or fuel prices (Halvorsen and Pollakowski 1981; Corgel *et al.*, 1982). In two cases the key published findings cannot be supported by data in the studies themselves (Horowitz and Haeri, 1990; Nevin and Watson, 1998). Two other papers present mixed results (Longstreth *et al.,* 1984; Longstreth, 1986). In another case the results, while interesting, are based on data from a subsidized government demonstration program in an artificial market environment and cannot be generalized (Laquatra, 1986). The two most sophisticated studies avoid these problems, but both fail to provide enough information about critical intermediate results to allow the validity of their conclusions to be assessed (Johnson and Kaserman, 1983; Dinan and Miranowski, 1989). For these reasons, we do not believe the studies produce a single result, or range of results, for the implicit price associated with a measure of energy efficiency that could be effectively used by builders or consumers to impute value, or by appraisers to adjust the prices of otherwise comparable housing units.

One possibility for constructing a hedonic model with improved specification would be to explore the use of two-stage least squares in analyzing the American Housing Survey data, effectively combining the Johnson and Kaserman methodology with the Nevin and Watson data set. Although this would represent an advance in methodology, there is no guarantee it would produce satisfactory results. Ultimately, the lack of a true energy efficiency variable in the AHS and the difficulty of constructing one from the available data could prove to be an insurmountable obstacle. Moreover, there doesn't seem any way the AHS methodology of using computer-assisted telephone interviews of the housing unit's occupant could be easily or cost-effectively modified to provide such a variable.

Another possibility would be to adapt Laquatra's methodology of including a continuous independent variable for energy efficiency in the hedonic regression. This method has several advantages. It avoids problems associated with two-stage models that rely on utility expenditures, which at best can only crudely approximate energy efficiency. It uses an overall measure of energy efficiency that captures accuracy in a way that structural variables cannot (i.e., inches of wall insulation). And its continuous form allows comparisons among different levels of energy efficiency. Since Laquatra's study, better measures of thermal integrity have become available, through Home Energy Rating Systems programs and the Environmental Protection Agency's ENERGY STAR program. The latter program is particularly suited to this approach, as the ENERGY STAR label represents a standard indicator of energy efficiency that is recognizable to consumers and could be used by appraisers as well as by economists in a hedonic regression model.

In order to fulfill this possibility, an acceptable hedonic model would need to be developed and estimated. To this end, we recommend that an underlying data base be developed that contains homes with varying levels of energy efficiency, so that a statistical model applied to the data can distinguish variation in levels of thermal integrity. In addition, such a data base should include information about a large number of home, neighborhood, and locational characteristics, so that a statistical model can do a reasonable job of isolating the marginal impact of energy efficiency on house price. Although possibly time consuming and costly, this is necessary because housing is such a complex commodity. We therefore further recommend that a data base compiled for such a study contain information about as many structural, neighborhood and locational variables as possible.

Other Lessons Learned About Hedonic Models

Since the studies reviewed in this paper were undertaken, significant advances have occurred in the use of hedonic models. Goodman and Thibodeau (1997) examined the issue of heteroskedasticity in hedonic indices. They observed a systematic relationship between the residual variance and house age, which results from the variance in renovations and maintenance as a house gets older. Variables based on these data are difficult to include in hedonic models, because such information is not available in publicly accessible data sets. For this reason, an iterative generalized least squares procedure that models residual variance is recommended for more accurate parameter estimates.

Basu and Thibodeau (1998) discussed the problem of spatial autocorrelation (correlation between prices of neighboring houses) and demonstrated a method that analyzes submarkets through estimated generalized least squares and kriging, a geostatistical estimation procedure. This method recognizes that houses in neighborhoods developed at the same time tend to have similar physical characteristics and that neighboring houses share locational amenities. Dubin (1998) recognized these issues and compared both OLS with maximum likelihood (ML) with kriging terms and concluded that when ML is used in this way, predictions are improved but still prone to large errors. For this reason she recommends the technique be augmented with standard appraisal techniques.

Gatzlaff and Haurin (1998) discussed a problem inherent to using the hedonic price model: a sample of sold houses may not be a random sample that is representative of the entire stock in a housing market, which would result in selection bias. To correct for this bias, they demonstrate the use of censored regression, which uses tax assessment appraisal data from unsold properties and simulation to generate a sample of sold properties. They concluded that their censored hedonic price index for homes in Miami followed the housing market's typical cyclical pattern, as opposed to the smoother results obtained from OLS hedonic regression.

These recent studies of the hedonic price method indicate that the construction of a model to analyze capitalization effects of energy efficiency should consider additional issues that relate to the reliability of a model's estimates. These issues may be pertinent to the sample we recommend developing and could be investigated further as data become available.

Conclusions

Consistent with expectations based on economic theory, the empirical studies reviewed in this paper suggest that energy efficiency improvements in housing are capitalized to some degree. However, the weaknesses and limitations of the studies reviewed make it impossible to draw reliable conclusions about the magnitude of that capitalization in typical market environments. There is reason to believe much more could be learned with additional research using an improved methodology, drawing on the strengths of work performed to date and suggestions made in this article. The importance of the capitalization issue to so many different interest groups underscores the need for continuing work in this area.

We recommend the assembly of a large data set and acknowledge the effort and expense involved with such a venture. The benefits of doing so, however, extend far beyond research opportunities that will be created to the practical application of tools that will be useful to appraisers, builders, and consumers.

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