DIVISION OF THE HUMANITIES AND SOCIAL SCIENCES

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA 91125

Market Barriers to Conservation: Are Implicit Discount Rates Too High?

Jeffrey A. Dubin

SOCIAL SCIENCE WORKING PAPER 802

July 1992

Market Barriers to Conservation: Are Implicit Discount Rates Too High?

Jeffrey A. Dubin

Abstract

This paper reconsiders whether implicit discount rates, generally cited as a market barrier to conservation, are really too high, and demonstrates that probabilistic choice studies of consumer durable purchases and hedonic housing price regression studies measure similar but non-identical discount factors. Four hedonic regression studies are reviewed which attempt to ascertain whether and to what extent the housing market capitalizes energy conservation investments. A theoretical model is presented which links the probabilistic choice and hedonic regression methods and shows how using results from both studies allows measurement of individual discount rates without bias. The paper identifies several factors which cause the degree of capitalization to differ from unity, resulting in consumer decisions which are rational from the individual perspective, but which can lead to low levels of social conservation.

Market Barriers to Conservation: Are Implicit Discount Rates Too High?*

Jeffrey A. Dubin†

1 Introduction

Ideally, an economy should operate so efficiently that all opportunities for cost-effective conservation are exhausted. In reality, however, most individuals fail to take advantage of opportunities to invest in energy efficiency. Conditions that discourage energy-efficient investments relative to cost-effective levels are known as "market barriers."

Investing in conservation involves making intertemporal consumption decisions. Many factors critically influence these decisions. Insofar as conservation requires the purchase of energy-saving capital, the amount of investment consumers choose will depend on its financial profitability. Since individuals' budgets are limited, the decision to purchase will also depend upon the opportunity cost of making the investment. It is also possible that consumers are simply irrational and cannot or will not take their medicine. Is it possible to tell whether consumer irrationality is the cause of the alleged underinvestment in conservation? Is it possible to demonstrate that there are "market barriers" to conservation which actually reside in the market rather than in the heads of the consumer?

Several studies have addressed these issues.[1] But to date all that has conclusively emerged is a taxonomy of potential barriers to conservation. These barriers include:

---

*This paper was presented at the Program on Workable Energy Regulation Conference on The Economics of Energy Conservation held at U.C. Berkeley on June 26, 1992. The comments of the discussants, Charles Lave and Steven Stoft, were greatly appreciated. I wish to acknowledge the research assistance of Kristina Sepetys and P. Scott Burton, and would like to thank Louis L. Wilde and Charles C. Cicchetti for their comments and suggestions.

†California Institute of Technology and Arthur Andersen Economic Consulting

[1]See, e.g., Sutherland(1991), Bates(1991), and Newlon and Weitzel (1991).

- Attitudes Towards Energy Efficiency—When fuel prices decline, consumers lose interest in conserving energy.
- Perceived Riskiness of Energy-Efficiency Investments—Energy-efficiency investments are made under uncertain conditions (changing fuel prices, technological development) and therefore are risky. Most investors are risk averse, resulting in fewer investments than would be made in a more certain world.
- Imperfect or Asymmetric Information—Much of the information related to energy efficiency is often asserted to be inadequate, expensive and difficult to obtain. As a result, conservation investment decisions must be made on the basis of incomplete or insufficient information.
- Moral Hazards or Misplaced Incentives—In the building sector, decisions regarding energy-efficient appliances and materials are generally made by the builder or architect and not by the consumer. The builder has no incentive to conserve energy or costs over time, but merely to undertake the minimum initial construction costs.
- Access to Capital or High Initial Costs—A homeowner may decide that an energy-efficiency investment is economically desirable, but may be precluded from undertaking such an investment by the high initial costs.

Some authors have attempted to argue that these barriers are illegitimate (see, e.g., Sutherland, 1991). But the evidence is inconclusive (see, e.g., Newlon and Weitzel, 1991). In fact with the exception of the extensive empirical literature which has demonstrated that individual discount rates[2] exceed social discount rates, the evidence is almost entirely anecdotal.[3] Policy analysts on both sides of the market barrier debate have tossed the discount figures back and forth and have *concluded* that either consumers must be irrational or that other factors must explain why implicit discount rates are so large. Chernoff (1983), for example, has argued that implicit discount rates may reflect the influences of risk, uncertainty, and ill-liquidity.[4] The evidence either way has relied on a set of empirical studies which have attempted to measure the discount rates implicit in

[2]We follow the literature (see, e.g., Hartman and Doane(1986)) and define the discount rate to be the change in operating costs for a unit change in capital cost. Discount rates are therefore real interest rates.

[3]Newlon and Weitzel cite interviews with 30 Michigan residents and a field experiment involving 18 stores in order to ascertain whether informational deficiencies preclude consumers from making informed decisions. Newlon and Weitzel find this *evidence* properly circumspect.

[4]Lowenstein and Prelec (1992) have recently reviewed several anomalies in intertemporal decision making. They find that many common intertemporal preference patterns deviate from the predictions of neoclassical discounted utility theory. In particular, they note the presence of framing effects, asymmetries in the treatment of gains and losses, and effects due solely to the magnitudes of the transactions (i.e., that large dollar amounts are discounted less than are small amounts). Their descriptive model of these phenomena is a combination of prospect theory (Kahneman and Tversky, 1979) and discount factors which decline over time but at less than exponential rates.

consumer tradeoffs between initial energy-efficiency investment costs, and the long-term savings from those investments. The methodologies used in these investigations divide into four categories:[5]

- Choice Models of Consumer Durable Goods—Multinomial logit or nested logit specifications for individuals' choices of alternative energy systems are used to reveal the tradeoffs between operating and capital costs.
- Engineering Models—Prices for alternative technologies (efficient or less efficient goods such as refrigerators or light-bulbs) are compared to access how changes in posted prices reflect alternative levels of stated efficiencies.
- Stated Preference—Surveys of individual consumers ascertain stated willingness to pay for alternative hypothetical payment streams.
- Hedonic price analysis—Regression analysis of home prices as a function of household characteristics, including relative annual fuel bills or the presence or absence of thermal integrity measures determine the implicit valuation of conservation investments.

In Tables 1 and 2, we present summaries of the results from a sampling of the studies. The basis for these tables is the compilation presented in Newlon and Weitzel. In addition, we have indicated the general approach used in each study (i.e., whether the study used a choice model or used stated preference, etc.). Notably absent from the summaries of either Train (1985) or Newlon and Weitzel is a similar compilation of studies based on the hedonic price method.

As discussed above, the purpose of the hedonic price studies is to determine whether or not the residential housing market capitalizes conservation investments. Hedonic price studies are important for at least two reasons. First, by reassessing the hedonic studies

---

Lowenstein and Prelec's model may partially explain why discount rates estimated from consumer durable purchases appear to be much larger than those obtained from the studies of intertemporal labor-leisure trade-offs. In the former case, the magnitude of the expected energy savings from the purchase of lower energy intensive capital is of a small magnitude as compared with the relatively large magnitudes considered in the latter case. However, this explanation of "high" discount rates calculated in the energy literature is at odds with the observed relationship between discount rates and individual incomes. Several studies (see, e.g., Train (1985)) have found that as income rises, implicit discount rates decline, leading researchers to conclude that a serious market barrier to energy conservation is ill-liquidity in the capital market. As income rises, however, the energy savings as a fraction of the households' budget declines, making their relative magnitudes appear even smaller to the consumer. Lowenstein and Prelec's model would predict that discount rates for such consumers should further increase (rather than decline, as has been observed).

[5] A survey of these methods and their findings is provided in Train (1985) and Cambridge Systematics, Inc. and Charles River Associates Inc. (1988).

and by standardizing their results, we can compare them amongst themselves to gauge whether the housing market does capitalize conservation investments and precisely to what degree. Second, the extent to which the housing market capitalizes investment will determine to a large extent the discount rate households employ in decision making.[6] We demonstrate below that it is not possible to determine individuals' discount rates from consumer choice models without making strong assumptions about the housing market. Conversely, it is not possible to separate the degree of capitalization and the implicit discount rate from a hedonic regression study without other identifying information. But by combining the results of two such studies, we show that it is possible to infer individual discount rates. Finally, the analysis will show that previously estimated discount rates may have been biased upwards.

In Section 2, we review four hedonic regression studies which have attempted to ascertain whether and to what extent the housing market capitalizes energy conservation investment. In Section 3, we present a simple theoretical model which links the choice model and hedonic regression methods and shows how using results from both studies it is possible to measure individual discount rates without bias. In section 4, we present our conclusions.

2 Hedonic Price Analysis

Several authors have approached the question of market barriers to conservation through studies of the housing market. These studies attempt to determine whether the housing market capitalizes residential investments in efficiency attributes by estimating the contribution to home price of increases in thermal efficiency or decreases in annual fuel bills. The technique employed is the hedonic price method of estimating implicit prices of various housing attributes, including, for example, various levels of insulation, presence or absence of storm windows, and relative levels of energy consumption in addition to the more standard set of housing characteristics such as square footage, number of bedrooms, etc.

These studies consistently conclude that household energy efficiency investments are capitalized by the housing market, although they typically fail to investigate to what degree this is the case. With one exception, these studies have failed to link the implicit values of energy savings as reflected in the housing market to the revealed level of consumer discount rates. Following brief descriptions of four hedonic housing market capitalization studies, we calculate the discount rates implied by each study in an at-

[6]Chernoff (1983) has noted that "the possibility that the individual will not be able to internalize future benefits of the durable further raises the discount rate. Life cycle analysts evaluate costs and benefits over the physical life of the durable. Individuals, however, evaluate costs and benefits over the period they expect to own the durable."

tempt to standardize their quantitative implications. A summary of the key aspects of each study is given in Table 3.[7]

Johnson and Kaserman (1983) identified two plausible explanations for sub-optimal investment in household efficiency: high individual discount rates, and insufficient housing market capitalization of such investments.[8] Johnson and Kaserman estimate the marginal effect on home prices of a one-dollar reduction in the occupants' annual fuel bill. They then use the market's valuation of this energy savings to estimate an implicit market discount rate.

Johnson and Kaserman used 1978 house transactions data taken from the Knoxville, Tennessee multiple listing service (MLS). Their regression analysis used the household's annual fuel bill for the period beginning two months after the transaction as a proxy for thermal efficiency. Two-stage least squares was used to control for potential endogeneity of the household's fuel bill, but no evidence was provided on whether in fact behavioral variations in energy consumption were correlated with the purchase decision.

Johnson and Kaserman's model indicates that each dollar-reduction in the average household's annual fuel bill results in a house price increase of $20.73 (1978 dollars). Furthermore, Johnson and Kaserman estimate the implicit market discount rate for fuel savings to lie in the range 1.5 to 17 percent (assuming a remaining asset life of 15 to 50 years and an expected real percentage fuel price escalation rate of 0 to 12 percent). Johnson and Kaserman conclude that "the housing market appears to operate remarkably well in capitalizing future fuel savings."

Following Johnson and Kaserman, Longstreth, Coveney, and Bowers (1984) attempted to estimate the contribution of thermal efficiency to the market value of housing units, using two alternative surrogates for efficiency: consumption of natural gas, and the presence or absence of energy-conserving structural features. The primary data for their study came from the Columbus Gas of Ohio (CGO) 1973 natural gas consumption records of meters read monthly within the Columbus, Ohio standard metropolitan statistical area (SMSA). Self-reported information on structural attributes, including those affecting thermal efficiency (i.e., insulation, storm windows, and window frame type), were

[7]It is not the intention of the present paper to critique the existing hedonic housing market capitalization literature. Instead, we take the results of these studies at their face value. There are, however, serious questions about the way in which physical energy capital, local climatic conditions, and energy inputs should properly enter in hedonic regression studies. A recent attempt to integrate these factors, in a structural model, has appeared in Quigley and Rubinfeld (1989). One conclusion of their analysis is that total energy consumption may be a relatively weak substitute with other housing attributes in the production of overall household comfort. This finding could possibly confound the interpretation of discount factors obtained from standard hedonic regressions.

[8]As we demonstrate below, there is a direct link between individual discount rates and housing market capitalization so that Johnson and Kaserman, in fact, identified only one possible explanation of household investment inefficiency.

obtained via a questionnaire mailed to the addresses of natural gas customers in the CGO records. The questionnaire yielded a 54 percent response, with approximately one fourth of the respondent's homes having changed ownership during the period 1971 to 1980 (n = 615 homes). All homes in the sample were therefore previously-owned, owner occupied single-family detached dwellings heated with natural gas which had sold between 1971 and 1980. The sample was biased due to the exclusion of new homes and under-representation of homes in the lowest and highest income groups.

Using a two-stage least squares method with correction for price heteroscedasticity, Longstreth, et al. found in their preferred specification that an increase in annual natural gas consumption of 100 cubic feet reduced home sale price by approximately $5.10 (1980 dollars), and that a savings of 11,500 cubic feet (approximately 10 percent of mean heating consumption for the sample) would add $548 to the market value of the house. They also found that wall and ceiling insulation added $528 and $508, respectively, to the sales price of the home.

Laquatra (1986) performed a cross-sectional analysis of high-efficiency homes constructed through the Energy Efficient Housing Demonstration Program (EEHDP) of the Minnesota Housing Finance Agency (MHFA) to derive estimates of efficiency values from a hedonic regression which incorporated a direct measure of thermal integrity. Under the EEHDP, the MHFA solicited bids from regional builders in June 1980 to construct 144 high efficiency units with a mean projected Thermal Integrity Factor (TIF), measured in BTUs per square foot per degree day, of 3. (Conventional Minnesota homes constructed during this period had average TIF values of 6-8.)

Units were constructed throughout the state, with 81 located in the Minneapolis-St. Paul SMSA. While small, this sample was selected by the author to investigate a market in which the thermal integrity of homes was measured and communicated accurately. The mean TIF for units in the sample was 1.81 , with a correlation coefficient between house sale price and TIF of 0.15, and average total cost for energy-conserving features (beyond those required by building codes) of $7,000.

Hedonic regressions were employed, with the TIF included as an endogenous explanatory variable. For this sample of homes, Laquatra found that energy efficiency is capitalized into house sale price, with a price increase of $2,510 for each one unit decline in the home's TIF. As shown below, this price increase is at the high end of those found in the hedonic studies and is almost surely due to the rules of the EEHDP program. In this demonstration project, builders received below-market interim financing for their first unit constructed. Further, the sale prices of the units were restricted and ownership was limited to moderate income first-time buyers, some of whom were also eligible for low interest, high loan-to-value 30 year loans.

More recently, Dinan and Miranowski (1989) have constructed a hedonic model to estimate the implicit price paid in the Des Moines housing market for an increase in energy efficiency. The primary data source for this study was the Greater Des Moines Board of Realtors MLS, from which information on price and structural attributes was obtained. This data was matched with that from various other sources, including a homeowner survey, and resulted in a final sample size of 234 single-family detached dwellings which sold during the period January through June 1982.

Dinan and Miranowski measured relative household efficiency using a proxy variable which is itself based in part on self-reported internal temperature settings, and which reflects per-square-foot expenditure necessary to maintain a particular house at 65 degrees Fahrenheit. This measure was constructed by adjusting actual winter energy expenditures for differences in internal temperature settings, billing periods, and heated floor space. A reduced form prediction of this measure was used in the analysis to control for potential endogeneity.

The preferred specification of Dinan and Miranowski showed that a one-dollar reduction in the energy expenditures required to maintain a home at 65 degrees during an average heating season raised the sales price by approximately $11.63.[9]

Each of the studies concludes that the housing market capitalizes household efficiency investments; in each case the relevant measure of thermal integrity or annual fuel bill was found to be statistically significant. This is by itself an important finding. However, the studies generally fail to corroborate whether the market valuations of these energy improvements were reasonable. To do this we have collected the relevant external information (such as the prevailing price of natural gas and location specific heating degree days) required to convert the estimates from each study into discount rates. For reasons of comparability, we present these implicit discount rates under a zero expected real fuel price increase assumption. Table 4 presents the details of the calculation as well as the estimated discount rates for three alternative known planning horizons (15, 25, and 50 years). Given the implicit prices, non-negative internal rates of return were not always determinate. These cases are not reported in the table.

With the exception of the Laquatra study (which was based on the subsidized demonstration housing project), the range of discount rates is remarkably small: from 4.2 to 8.4 percent. Moreover, these values are not remarkably different from those found in the

[9]Dinan and Miranowski's analysis also revealed that the relationship between price and required fuel expenditures was decreasing at a decreasing rate. This implies that efficiency is valued more highly in relatively efficient homes. Furthermore, the contribution to home price of changes in the thermal integrity measure was greater in newer than in older dwellings. Dinan and Miranowski speculate that these results may be caused by higher visibility and aesthetic appeal of efficiency attributes, in the former case, and by differences in the expected remaining life of conservation assets, in the latter case. Alternatively, they may reflect differences in income levels which lead less wealthy buyers to buy homes with lower thermal efficiency. For a more complete discussion of this point see Dubin and Henson (1988a and 1988b).

durable purchase literature. However, the estimated discount rates should themselves depend on the degree of housing market capitalization, and nothing in the hedonic studies has measured this important factor. Indeed, as shown in the next section, it is not possible to determine the degree of housing market capitalization from hedonic studies alone.

3 The Degree of Housing Market Capitalization

It is a fundamental property of the residential housing market that not all improvements or capital expenditures undertaken by owners are ultimately rewarded to the same degree by buyers. The common wisdom from realtors is that adding a bathroom or remodeling a kitchen are more worthwhile in terms of resale value than are most other forms of home improvement. Some hedonic studies have in fact shown that the dollar value of many improvements can have no statistically discernable effect on the sales price of the home. Grether and Mieszkowski (1974), for example, included the dollar value of recent home improvements (including painting, putting-on new siding, roof repair) in their hedonic analysis but found that such improvements were not significant. While it can be argued that many of these "improvements" were simply an attempt by the owner to bring his home up to the average quality of properly maintained homes in the neighborhood, other hedonic studies have repeatedly demonstrated that homes with swimming pools will often sell for no more than homes without swimming pools even if the owner has gone to considerable expense to add this "amenity."

If consumers do not expect that dollars spent on home improvements will be returned at the time they sell their dwelling, then implicit discount rates will also reflect this form of capital price depreciation. The capitalization of energy efficiency improvements should certainly be at issue for that segment of the market that will ultimately sell their homes. On the other hand, households that do not expect to sell their homes quickly should not be acutely sensitive to the recapture of their capital investment. A simple theoretical model illustrates these points.

Suppose consumers consider the value V of a capital improvement which will reduce energy consumption by one dollar in perpetuity. If the consumer does not sell his home, he enjoys the benefits of the reduced energy savings forever. The value of the capital improvement is, in this case, $1 + 1/r$ (i.e., the current period's savings plus the present discounted value of the stream of one dollar savings received in future periods). The discount rate r can be determined from the equation $r = 1/(V - 1)$ and is given by the ratio of the expected annual energy savings to the initial net capital expenditure. If, on the other hand, consumers do sell their homes, then the capital investment's recaptured value becomes relevant.[10]

[10]Our model assumes, for simplicity, that the durable good has an infinite lifetime. In fact, most

Suppose that consumers face an exogenous probability p in any period of moving from their homes. In the event that the consumer moves, he sells his home to a willing buyer. In addition we assume that buyers are only willing to pay a fraction γ of the real cost of the capital good. Provided the probability of moving occurs independently across periods, the optimality principle shows that V satisfies:

$$V = 1 + \frac{1}{1+r}[(1-p)V + p\gamma V]. \tag{1}$$

Equation (1) simply says that V is that value which returns one dollar in the current period plus the present discounted value of the expected future value where expectations are taken with respect to the exogenous probability of moving. With probability $(1-p)$, the consumer does not move and therefore has an asset with present value V; but with probability p, the consumer sells his home and receives the under-capitalized value γV.

Using equation (1) we can solve for the equilibrium value of V:

$$V = \frac{1+r}{r+p-p\gamma}. \tag{2}$$

The implicit discount rate implied by equation (2) is clearly a function of both the probability of moving and the degree of capitalization. Consumers discount at the rate $r + p(1-\gamma)$ when calculating the value of the capital improvement. When $p = 0$, the probability of moving is zero and the relevant event horizon is infinite.[11] In this case, $V = (1+r)/r$—the value we found before. When the market fully capitalizes the capital good, $\gamma = 1$, and again $V = (1+r)/r$. In this case, the uncertain event horizon has no affect on the valuation. Finally, when the market fully discounts the capital good, $\gamma = 0$ and $V = (1+r)/(r+p)$ which shows that the relevant discount rate increases by the probability of moving (an event which, in this case, forces the consumer to sustain a complete loss of his investment).

Equation (2) can be used to recover implicit discount rates using the estimated relationships determined from probabilistic choice models or from hedonic regression models. Each empirical approach provides an estimate of the tradeoff between operating and

---

durable goods have finite lifetimes over which they experience some physical depreciation. In addition, we assume that consumers' planning horizons are infinite. Our model is meant to be illustrative of a world in which the average period of time spent by the household in a given house is short relative to the lifetime of the durable under consideration. Our formulation is similar to Levhari and Mirman (1977) who consider the case of non-stochastic investment decisions made by consumers with stochastic lifetimes.

[11] Throughout the remainder of this paper, we will use the term event horizon to denote the length of time a household owns a given house.

capital costs. However, one important distinction must be made. The logic of the probabilistic choice model develops the tradeoff between operating and capital costs at the time of capital *purchase*. A typical specification of indirect utility for durable purchase assumes, for example, that:

$$U = \beta' X + \beta_1(\text{Capital Cost}) + \beta_2(\text{Operating Cost}) + \epsilon.$$

The estimated tradeoff between capital and operating costs (the effect on capital cost from a one dollar reduction in operating costs) is given by

$$-\frac{d(\text{Capital Cost})}{d(\text{Operation Cost})} = \hat{\beta}_2/\hat{\beta}_1.$$

The logic of the hedonic regression studies develops the tradeoff between *realized* capital values and future operating cost savings. In a typical hedonic regression model, the price of the home P is taken to be a linear-in-parameters function of housing characteristics and the annual energy bill:

$$P = \lambda' Z + \lambda_1(\text{BILL}) + \epsilon$$

.

In this case the estimated tradeoff between capital values and operating cost savings, $dP/d(\text{BILL}) = \hat{\lambda}_1$. Since $\hat{\lambda}_1$ measures the effect of a one dollar decrease in operating costs on the *realized* capital value, it is not directly comparable to the estimate $\hat{\beta}_2/\hat{\beta}_1$ determined within the probabilistic choice setting. The two estimates are related by the degree of capitalization γ described above. Since λ_1 measures the realized value (i.e., resale value) of a one dollar reduction in operating cost and β_2/β_1 measures the actual value (i.e., cost) of a one dollar reduction in operating costs, we have:

$$\frac{\lambda_1}{\gamma} = (\beta_2/\beta_1).$$

Using the stochastic horizon model, we know that either (λ_1/γ) or (β_2/β_1) can provide an estimate of $(1+r)/(r+p-p\gamma)$. Thus, under the maintained assumption that the hedonic pricing and probabilistic choice approaches are comparable in the sense that they each are capable of measuring how consumers discount future operating costs against current capital costs, we can infer the degree of housing market capitalization:

$$\gamma = \frac{\lambda_1}{(\beta_2/\beta_1)} = \frac{(\beta_1/\beta_2)}{(1/\lambda_1)}. \tag{3}$$

We have expressed γ using the second equality in equation (3) because it is simply the ratio of the "standard discount rates" (without correction for uncertain event horizons or similar adjustments for real price escalation) as calculated in the literature from the probabilistic choice models and the hedonic regression models respectively.

While in theory it is possible to measure both the degree of capitalization and the implicit average event duration, the immediate absence of parallel studies which attempt to both analyze consumer durable choices and housing prices within the same time frame and within the same geographic market preclude such a calculation. However, the following empirical regularity should be observed. One would reasonably expect that areas with colder climates would more fully capitalize the value of energy conserving capital investments. Other things equal, this implies that discount rates obtained from probabilistic choice models in cold regions should be larger than those obtained from probabilistic choice studies conducted in areas with more moderate temperatures. This was precisely the pattern discovered in Dubin (1985) when identically estimated choice models were compared for space heating durable equipment in the Pacific Northwest with estimates obtained from a study of purchase decision made in the U.S. at large.

Our simple model of stochastic event horizons also provides insight into the likely bias that previous estimates of discount rates could have experienced. Equation (2) implies that for a given estimate of V (using either λ_1/γ or β_2/β_1), the implicit functional relationship between r and p makes $\partial r/\partial p$ negative provided that p is not too large (a very short expected tenure) or γ is not too small (very little capitalization). Since discount rates have been calculated in the literature under the implicit assumption that $p = 0$, we should expect that the more reasonable assumption of non-zero p would lower previously estimated implicit discount rates.[12]

4 Conclusions

This paper has demonstrated that probabilistic choice studies of consumer durable purchases and hedonic housing price regression studies measure similar but non-identical discount factors. The difference between the two methods embodies the tendency of the market for residential dwellings to less than fully capitalize energy improvements. As long as the *market fails* to fully capitalize conservation improvements in the residential

[12]According to equation (2), the maximum upward bias in the discount rate is equal to the probability of moving. Average turnover rates in the housing market of four to eight years imply maximum corrections to the discount rate from 12.5 to 25 percent.

housing stock, and provided that dwellings continue to be bought and sold by economic agents with differing levels of information, it continues to be possible for individual discount rates to exceed the levels which are socially desirable for optimal social decision making. Those factors which cause the degree of capitalization to differ from unity (such as moral hazard, risk, uncertainty, and asymmetric information) make it entirely possible that consumers can and will make individual decisions which are rational from their perspectives but still lead to too-low levels of social conservation.

TABLE 1

IMPLICIT DISCOUNT RATES FOR THERMAL INTEGRITY AND SPACE HEATING SYSTEM CHOICES

Study	General Approach	Implicit Discount Rate (%)	Comments
		Space Heating System and Fuel Type	
Goett (1978)	choice model	36.0	Using preferred model.
Dubin (1985)	choice model	2.0 - 10.0	Depends on model specification.
Dubin (1988)	choice model	6.5 - 10.5	Depends on model specification.
Goett and McFadden (1982)	choice model	6.5 - 16.0	Depends on model specification.
Goett (1983)	choice model	4.4 21.0	Households without central air conditioning. Households with central air conditioning.
Berkovec, Hausman and Rust (1983)	choice model	25.0	
Lin, Hirst and Cohn (1976)	choice model	7.0 - 31.0	Depends on fuel type.
Cambridge Systematics, Inc. et al. (1988)	choice model	67.6	Furnace replacement.
		Thermal Integrity Measures	
Corum and O'Neal (1982)	engineering approach	10.0 14.0 19.0 - 21.0	Gas-heated homes. Oil-heated homes. Electricity-heated homes.
Cambridge Systematics, Inc. et al. (1988)	choice model	39.6	Wall insulation.

Note: Discount rates are calculated assuming no real energy price appreciation and infinite useful life. All studies estimated logit models. Cole and Fuller (1981) assume a 15-year useful life for measures; others assume an infinite useful life. Lin, Hirst and Cohn (1976) used aggregate data for estimation, while all others used individual household data.

Source: Newlon and Weitzel (1991). (Newlon and Weitzel note that table data was "derived from Cambridge Systematics, Inc., et al. (1988) or directly from the cited studies.")

TABLE 2

IMPLICIT DISCOUNT RATES FOR REFRIGERATORS AND OTHER APPLICATIONS

Study	General Approach	Implicit Discount Rate (%)	Comments
Refrigerators			
Gately (1980)	engineering approach	45.0 - 300.0	Compared extra cost of the more efficient of two refrigerators with its reduced operating costs to calculate rate of return on investment. Discount rates shown are implied by purchase of the less-efficient model.
MacRae (1980)	survey approach	53.0	Discount rate estimated from customer survey responses regarding hypothetical purchases.
Meier and Whittier (1983)	engineering approach	from >34.0 to >58.0	Examined sales for a pair of models in four parts of the country. Calculated implied minimum discount rate for purchasers of the less-efficient model.
Other Applications			
Goett (1983)	choice model	36.0	Cooking and water-heating fuel type.
Dubin (1985)	choice model	24.0	Water-heating fuel type.
Dubin (1986)	choice model	44.0	Water-heating fuel type.
Goett and McFadden (1982)	choice model	67.0	Water-heating fuel type.
Berkovec, Hausman and Rust (1983)	choice model	33.0	Water-heating fuel type.
Lin, Hirst and Cohn (1976)	choice model	18.0 - 31.0 23.5	Cooking fuel type, rate depends on fuel chosen. Choice of whether to purchase a freezer.
Cambridge Systematics, Inc. et al. (1988)	choice model	308.0	Clock thermostat.

Note: All studies used logit models. Lin, Hirst and Cohn (1976) used aggregate data for estimation while all others used individual household data.

Source: Newlon and Weitzel (1991). (Newlon and Weitzel note that table data was "derived from Cambridge Systematics, Inc., et al. (1988) or directly from the cited studies.")

Table 3

STUDY	REGION	MODEL & FUNCTIONAL FORM	SAMPLE	EFFICIENCY PROXY
Johnson and Kasserman (1983)	Knoxville, Tennessee	Hedonic; linear OLS estimation	Knoxville Board of Realtors' MLS report of houses sold in 1978 (n = 1317)	Annual household utility bill
Longstreth, Coveney and Bowers (1984)	Columbus, Ohio	Hedonic; polynomial two-stage weighted least squares	Residences included in the Columbus Gas of Ohio 1973 natural gas consumption records, and which changed ownership between 1971 and 1980 (n = 615)	Annual household consumption of natural gas (alternative model estimated using presence of various efficiency attributes as efficiency proxy)
Laquatra (1986)	Minneapolis - St. Paul, Minnesota	Hedonic; OLS estimation	Minnesota Housing Finance Agency Energy Efficient Housing Demonstration Program homes in the Minneapolis - St. Paul Metropolitan Statistical Area (n = 81)	Thermal integrity factor
Dinan and Miranowski (1989)	Greater Des Moines, Iowa	Hedonic; partial Box-Cox estimation	Greater Des Moines Board of Realtors' MLS report of single-family detached dwellings sold in the period January through June, 1982 (n = 234)	Predicted fuel bills per square foot of heated floor area, normalized for temperature differences

Table 4

STUDY	IMPLICIT VALUE OF A ONE-DOLLAR REDUCTION IN ANNUAL FUEL BILL	IMPLICIT MARKET DISCOUNT RATE FOR ZERO EXPECTED REAL FUEL PRICE GROWTH[1] (percent)		
		n = 15	25	50
Johnson and Kasserman	20.73	-	1.5	4.2
Longstreth, Coveney and Bowers	13.88[2]	1.0	5.2	7.0
Laquatra	46.64[3]	-	-	0.3
Dinan and Miranowski	11.63	3.4	7.0	8.4

[1]Negative values not reported.

[2]Based on the reported value of 5.107 for a one hundred cubic foot reduction in annual natural gas consumption, and a mean residential natural gas price in 1980 of $0.368 per hundred cubic feet (Statistical Abstract of the United States: 1988, table 760).

[3]Based on the reported value of 53.82 for a reduction in one TIF (i.e., a savings of one BTU per square foot per heating degree day); a mean living space of 1300 square feet; and a mean residential natural gas price in 1982 of $5.17 per thousand cubic feet and normal seasonal heating degree days of 8007 (Statistical Abstract of the United States: 1988, tables 760 and 354, respectively).

References

Bates, R. W. "Energy Conservation Policy in Developing Countries: The Case for Market Solutions." World Bank Working Paper, April 1991.

Berkovec, J., J. Hausman, and J. Rust. "Heating System and Appliance Choice." Report No. MIT-EL83-004WP, MIT Energy Laboratory, 1983.

Cambridge Systematics, Inc., and Charles River Associates, Inc. *Investments in Conservation Measures* Vol. 1 of *Implicit Discount Rates in Residential Customer Choices*, EPRI EM-5587, February 1988.

Chernoff, Harry. "Individual Purchase Criteria for Energy-Related Durables: The Misuse of Life Cycle Cost." *The Energy Journal* 4 (1983):81-86.

Corum, Kenton R. and Dennis L. O'Neal. "Investment in Energy-Efficient Houses: An Estimate of Discount Rates Implicit in New Home Construction Practices." *Energy* 7 (1982):389-400.

Dinan, T.M. and J.A. Miranowski. "Estimating the Implicit Price of Energy Efficiency Improvements in the Residential Housing Market: A Hedonic Approach." *Journal of Urban Economics* 25 (1989):52-67.

Dubin, Jeffrey A. *Consumer Durable Choice and the Demand for Electricity.* New York-Amsterdam: North-Holland Publishing Co., 1985.

Dubin, Jeffrey A. "Will Mandatory Conservation Promote Energy Efficiency in the Section of Household Appliance Stocks?" *The Energy Journal* 7 (1986):99-118.

Dubin, Jeffrey A., and Steven E. Henson. "An Engineering/Econometric Analysis of Seasonal Energy Demand and Conservation in the Pacific Northwest." *Journal of Business & Economic Statistics* 6 (1988):121-34.

Dubin, Jeffrey A. and Steven E. Henson. "The Distributional Effects of the Federal Energy Tax Act." *Resources and Energy* 10 (1988):191-212.

Gately, Dermot. "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables: Comment." *The Bell Journal of Economics* 11 (1980):373-374.

Goett, A. "Appliance Fuel Choice: An Application of Discrete Multivariate Analysis." Ph.D. Thesis. University of California, Davis, 1978.

Goett, A. "Household Appliance Choice: Revision of REEPS Behavioral Models." Final Report for Research Project 1918-1. Palo Alto, California: Electric Power Research Institute, 1983.

Grether, David. M. and Peter Mieszkowski. "Determinants of Real Estate Values." *Journal of Urban Economics* 1 (1974):127-146.

Hartman, Raymond S. and Michael J. Doane. "Household Discount Rates Revisited." *The Energy Journal* 7 (1986):139-148.

Johnson, R. C. and D. L. Kaserman. "Housing Market Capitalization of Energy-Saving Durable Good Investments." *Economic Inquiry* 21 (1983):374-86.

Kahneman, D. and A. Tversky. "Prospect Theory: An Analysis of Decision Under Risk." *Econometrica* 47 (1979):363-291.

Laquatra, J. "Housing Market Capitalization of Thermal Integrity." *Energy Economics* 8 (1986):134-38.

Levhari, D. and L. Mirman. "Savings and Consumption with an Uncertain Horizon." *Journal of Political Economy* 85 (1977):265-281.

Lin, W., E. Hirst and S. Cohn. "Fuel Choice in the Household Sector." Oak Ridge National Laboratory Report ORNL/CON-2, 1976.

Longstreth, Molly, Anne R. Coveney, Jean S. Bowers. "Conservation Characteristics Among Determinants of Residential Property Value." *Journal of Consumer Research* 11 (1984):564-71.

Lowenstein, George and Drazen Prelec. "Anomalies in Intertemporal Choice: Evidence and an Interpretation." *Quarterly Journal of Economics* 107 (1992):573-597.

MacRae, D. Jr. "Rational Models for Consumer Energy Conservation." In R. Burby and M. Marsden (eds.), *Energy and Housing.* Cambridge, Massachusetts, Oelgeschlager: Gunn and Hain, 1980.

Meier, A. and J. Whittier. "Consumer Discount Rates Implied by Purchase of Energy Efficient Refrigerators." *Energy* 8 (1983):957-962.

Newlon, Scott T. and D. Weitzel. "Do Market Imperfections Justify Utility Conservation Programs? A Review of the Evidence." *The Electricity Journal* 10 (1991):40-53.

Quigley, John and D. Rubinfeld. "Unobservables in Consumer Choice: Residential Energy and the Demand for Comfort." *The Review of Economics and Statistics* 71 (1989):416-425.

Sutherland, Ronald J. "Market Barriers to Energy-Efficiency Investments." *The Energy Journal* 12 (1991):15-34.

Train, Kenneth. "Discount Rates in Consumers' Energy-Related Decisions: A Review of the Literature." *Energy* 10 (1985):1243-54.

U. S. Bureau of the Census. *Statistical Abstract of the United States: 1988* (108th edition). Washington, D.C.: 1987.