ENERGY EFFICIENCY CHOICE IN THE PURCHASE OF RESIDENTIAL APPLIANCES

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ABSTRACT

This paper provides a quantitative analysis of the behavior of the market for the purchase of energy efficiency in residential appliances and heating and cooling equipment. We examine the historical efficiency choices over the period 1972-80 for eight consumer products: gas central space heaters, oil central space heaters, room air conditioners, central air conditioners, electric water heaters, gas water heaters, refrigerators, and freezers. We characterize the behavior of the market for these products by an aggregate market discount rate. Except for air conditioners, the observed discount rates are much higher than real interest rates or the discount rates commonly used in life-cycle cost analysis of consumer choice. They appear to be relatively constant, even though fuel prices escalated rapidly over the time period. We conclude from these results that the market for energy efficiency is not performing well. Several explanations of the under investment in efficiency are proposed: 1) lack of information about the costs and benefits of energy efficiency; 2) prevalence of third party purchasers; 3) unavailability of highly efficient equipment without other features; 4) long manufacturing lead times; and 5) other marketing strategies.

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INTRODUCTION

This study provides a quantitative analysis of the behavior of the market for the purchase of energy efficiency in residential appliances and heating and cooling equipment. Accurate forecasts of residential energy use require quantitative assessments of market decisions about energy efficiency. The results of our investigation of market behavior can lead to a better understanding of the barriers to investment in energy conservation. Understanding market behavior over time is a prerequisite to an evaluation of the need for and the importance of policies to promote energy efficiency.

The importance of the analysis to DOE's assessment of Consumer Products Efficiency Standards relates to its use in forecasting the behavior of the market. Most of the direct impacts of standards (energy savings, net present benefit, and cost of proposed standards) depend critically on the degree to which higher efficiency would be incorporated into new products in the absence of standards. The research will lead to improvements in the methodology and data in the base case residential energy forecasting, thereby improving estimates of the impacts of proposed Consumer Products Efficiency Standards.

In this study, we examine the historical efficiency choices for eight consumer products: gas central space heaters, oil central space heaters, room air conditioners, central air conditioners, electric water heaters, gas water heaters, refrigerators, and freezers. These products were selected because they account for a major part of residential energy consumption, data on efficiency and costs are readily available, and they are under consideration by DOE for efficiency standards.

We characterize the behavior of the market for these eight products by a single quantity which we call an aggregate market discount rate. The aggregate market discount rate quantifies the behavior of the market as a whole with respect to energy efficiency decisions. Choices by individual purchasers are constrained by the decisions made by the manufacturers of appliances, the wholesalers or retailers who distribute them, and the third party appliance installers such as builders or plumbers. The value of the discount rate reflects the actions of all these decision makers. It is determined empirically from data on the efficiency and cost of appliances purchased between 1972 and 1980. By examining the historical behavior of the market discount rate, we can better understand the factors that influence efficiency choice. Furthermore, the market discount rate can be used as a parameter in forecasting future residential energy consumption. More detail about this work may be found in an LBL report being prepared for publication.[1]

METHOD

A discount rate is a measure of the present value of money received or spent in the future. For example, if someone values an income of \$110 received a year from today the same as an income of \$100 received today, that person has a discount rate of 10 percent per year. Thus, given the discount rate r, one can calculate the present value of a stream of income (or expenditures) using the formula

$$PV = \sum_{t=1}^{N} \frac{X_t}{(1+r)^t},$$

where
X_t = Income in year t
and
N = Duration of income stream in years.
For a constant stream of income, this formula becomes

$$PV = PWF \cdot X_t,$$

where we have defined the present worth factor by

$$PWF = \sum_{t=1}^{N} \frac{1}{(1+r)^t} = \frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right) \qquad (1)$$

The analysis assumes that the behavior in the appliance marketplace can be characterized as if the purchasers of appliances minimize the life-cycle cost of owning and operating them. The observed average efficiency choice is characterized by an aggregate market discount rate. This measure is the discount rate at which the minimum of the life-cycle cost curve is at the observed average efficiency choice. Even if purchasers do not actually decide on the basis of life-cycle costs, the market discount rate is useful as a measure of market imperfections. This formulation looks at decision-making for products of different efficiencies but the same fuel type. It does not account for other factors that might influence consumer choice.

Figure 1 illustrates the effect of different discount rates on the position of the minimum of the life-cycle cost curve. At higher discount rates, the slope of the operating cost component is lower, and the the minimum is at higher annual energy consumption and lower appliance efficiency. For central air conditioners, a discount rate of 20 percent puts the minimum of the LCC curve at 34 million Btu, corresponding to the annual energy consumption during 1980. This point is marked on all three curves. Rather than using the discount rate to locate the minimum of the life-cycle cost curve, we reverse the process and determine the market discount rate from the position of the minimum, which is assumed to occur at the average energy use.

The life-cycle cost for an appliance is the sum of the purchase cost and the discounted operating cost:

$$LCC = PC + PWF \cdot FP \cdot TI \cdot E, \tag{2}$$

where PWF is the present worth factor defined above, FP is the average fuel price (assumed constant over time, i.e., the consumer expects no price escalation), TI is the relative thermal integrity, and E is the average annual energy consumption by the appliance. The thermal integrity factor is included for temperature-sensitive appliances to account for the effects of changes in the thermal characteristics of the building shell, such as insulation, on energy consumption. Finding the minimum of Equation 2 with respect to energy and solving for the present worth factor gives

$$PWF = \frac{-1}{FP \cdot TI} \left.\frac{dPC}{dE}\right|_{E_{\min}}. \tag{3}$$

Hence, given the analytic form of the cost vs. energy use curve, we can evaluate the derivative dPC/dE at the annual energy use corresponding to average efficiency purchased during any year and determine the aggregate market discount rate.

For the purchase cost vs. energy use relationship we fit the data to an exponential curve of the form

$$E = E_\infty + (E_0 - E_\infty)\exp[-A(C-1)]. \tag{4}$$

<u>where</u>

- E = annual unit energy consumption (UEC)
- E_0 = highest UEC
- E_∞ = minimum UEC attainable at infinite purchase cost
- C = PC / PC_0
- PC = purchase cost corresponding to E
- PC_0 = purchase cost corresponding to E_0

and A is a parameter determined from the shape of the curve. Using this expression, the present worth factor becomes

$$PWF = \frac{PC_0}{A \cdot FP \cdot TI} \frac{1}{(E - E_\infty)}. \tag{5}$$

The data required to perform an analysis of aggregate market behavior include: 1) purchase price and unit energy consumption of alternative design options for each product; 2) average efficiency purchased; 3) energy prices; 4) thermal characteristics of houses; and 5) average appliance lifetimes.

The major sources of data on the costs and energy use of appliances are the engineering and economic analyses performed for the U.S. Department of Energy analysis of Consumer Product Efficiency Standards.[2,3] These reports provided estimates of the purchase prices of individual appliances with different efficiencies, as well as estimates of their average usage. Supplemental data were obtained from Arthur D. Little, Inc. to extend the data back in time to 1972, and forward to 1980 from the original data sets for 1978. The data were aggregated from the various appliance classes into a single set of data points representing the product type. Finally, a least squares fit was performed to the functional form specified above to obtain the parameters of the curve. A typical cost vs. energy use curve is shown in Figure 2.

The U.S. DOE CS-179 Survey of Manufacturers[3] provides historical data from appliance manufacturers on the average efficiencies of units shipped in 1972 and 1978. The efficiency factor (e.g., efficiency, energy efficiency ratio, etc.) for each model is multiplied by the number of units of the model shipped in that year, then summed over all models and divided by the total shipments to give the shipment weighted energy factor (SWEF). Table I shows the SWEFs used to calculate the market discount rates. Efficiency data from trade associations and individual manufacturers were used as a check on our results.

Average energy prices for the three years were obtained from the Energy Information Administration.[4] Winter and summer marginal electricity rates are used for heating and cooling equipment, respectively. Marginal rates are calculated as the average rate for the 500 to 1000 KWh per month block. Thermal integrity factors were defined as the relative annual energy consumption for space conditioning end uses, reflecting changes from the stock house in existence in 1977 in terms of thermal characteristics (including insulation, window glazings, infiltration, etc.). The thermal integrity values for historical years were estimated from survey data.[5] The appliance lifetimes are the same values used in the Consumer Product Efficiency Standards analysis.[2]

RESULTS

Aggregate market discount rates were calculated for years 1972, 1978 and 1980. The first step is to estimate the parameters of the annual energy use vs. purchase cost curve for each appliance. Evaluating Equation 5 at E corresponding to the SWEF gives the present worth factor, which is then converted to a discount rate. The results presented in Table II are based on a single cost-efficiency curve for each appliance covering the period 1972-80. The tabulated discount rates are expressed in percent per year. Changes in discount rates over time for a single appliance are due to changes in SWEF, fuel prices, and, in the case of temperature sensitive appliances, thermal integrity. The observed discount rates fall in the range from less than 20 to more than 200 percent per year. Those for central space heating and water heating appear to be increasing over the time period, whereas the others are either decreasing or remaining constant.

To understand these year-to-year differences, we performed an analysis of the sensitivity of the results to changes in SWEF and the cost curve parameters. The observed discount rate is extremely sensitive to the assumed SWEF; a change in SWEF of less than five percent could explain the year-to-year differences. Of the parameters of the cost-energy use curve, the greatest sensitivity is to the value of E_{∞}. Since the other three parameters enter Equation 4 in a similar way, they all have the same percentage effect.

It is our judgement that the SWEFs are known to within five percent. They would thus lead to relatively little uncertainty in the discount rate. The parameters of the cost-efficiency curve are less well known, perhaps to within ten percent. Because of the fitting procedure, E_{∞} may be too low, leading to a high discount rate, possibly by as much as 20 percent. Future work on the cost and efficiency of the most efficient products should lead to better estimates of these parameters. We do not believe that the uncertainty will affect the observed change in discount rate over time.

In calculating the discount rates, we assume that purchasers do not anticipate any escalation in real fuel prices. This assumption may not be warranted, but it is a conservative one. Putting an assumed inflation rate for energy into the calculation would result in higher values for the observed discount rates.

As a check on our results, market discount rates were calculated for refrigerators, freezers, gas furnaces, and room and central air conditioners using historical data on efficiencies from several additional sources. The discount rates show the same trends as the CS-179 data.

The high discount rates observed in this study make it difficult to interpret them as of the operation of a rational market. If a consumer's discount rate is higher than the current interest rate and if prices reflect costs, a rational consumer would borrow money to purchase a more efficient appliance. For example, an investment of $21 to include increased door insulation, a higher compressor efficiency, a double door gasket, and an anti-sweat heater switch in a refrigerator would save $22 per year at 1980 fuel prices, an annual return of 105 percent on the investment. The data, however, indicate that these investments are not prevalent. We believe that the high discount rates show that imperfections in the market prevent consumers from making economically optimal decisions because:

- consumers may not have adequate information about appliance efficiencies or access to capital markets;

- the person purchasing the appliance may not be the one who uses it;

- the price of the appliance may be determined by factors other than efficiency;
- or high-efficiency appliances may not be produced in large enough quantities to satisfy the demand.

Thus all the participants in the marketplace could contribute to making the discount rate high.

CONCLUSIONS

Several generalizations may be made from the basic results: (1) the values of the aggregate market discount rate for the appliances studied are higher than real interest rates or the discount rates commonly used in life-cycle cost analyses of consumer choice; (2) the aggregate market discount rates appear to be relatively constant over time, with rates for some products (space and water heating) increasing somewhat over the past decade and rates for others (freezers and refrigerators) decreasing over the same time period; and (3) the sensitivity analyses show considerable changes in results as inputs are varied. This large variation combined with other limitations of the analysis suggests that considerable care must be used in discussing the numerical results; however, the first two observations are likely to be meaningful in a qualitative sense.

Overall, the high values of the aggregate market discount rates in Table II indicate that the average appliance or heating and cooling system purchased does not include energy efficiency measures that yield very high returns on investment. Several different explanations of the phenomena of underinvestment in energy efficiency in the residential sector have been proposed:

- lack or high cost of information about costs and benefits of energy efficiency improvements or a lack of understanding by purchasers of how to use this information if it is available;
- the prevalence of indirect or forced purchase decisions (e.g., landlord purchase of equipment for rental property; need for immediate replacement of malfunctioning equipment);
- unavailability of high efficiency equipment in retail stores or the unavailability of highly efficient equipment without other features (so-called "gold-plating") that may not be desired by the average purchasers;
- manufacturer°s decisions to improve product efficiency are often secondary to other design changes and take several years to implement; and/or

- marketing strategies by manufacturer or retailer that intentionally lead to sales of less efficient equipment.

Several studies have been initiated to compare these explanations with empirical data.

A significant finding from Table II is that the aggregate discount rates have changed only modestly over time. We are aware of no other work that has investigated the behavior of the market for energy efficiency in residential appliances over time. Previous studies[6-8] estimate discount rates for a single appliance type during one year. Our work indicates that the behavior of the market during the period 1972 to 1980 has been relatively unchanged (in terms of return on investment for energy efficiency in consumer products). The market for appliances does not appear to be influenced by rapidly rising energy prices and consumer awareness of energy issues. This is similar to the results for investment in thermal integrity in houses obtained by Levine and Scott.[9]

Several investigations into the behavior of the appliance marketplace are underway to follow up on this work. We are continuing to examine the possible effects of several programs aimed at making efficient appliances more attractive to purchasers. Studies of utility incentive programs and the FTC labeling program will be completed. Alternative methods for characterizing market behavior, such as internal rates of return and payback period, will be considered.

REFERENCES

1. Ruderman H., Levine M. D. and McMahon J. E., "The Behavior of the Market for Energy Efficiency in the Purchase of Appliances and Home Heating and Cooling Equipment," LBL-15304, (in preparation).

2. U.S. Department of Energy, Conservation and Renewable Energy, "Consumer Products Efficiency Standards Engineering Analysis Document," DOE/CE-0030, (Mar. 1982).

3. U.S. Department of Energy, Conservation and Renewable Energy, "Consumer Products Efficiency Standards Economic Analysis Document," DOE/CE-0029, (Mar. 1982).

4. U. S. Department of Energy, Energy Information Administration, "State Energy Fuel Prices by Major Economic Sector from 1980 through 1977," (Jul. 1979).

5. U. S. Department of Energy, Energy Information Administration, "National Interim Energy Consumption Survey (NEICS)," (1980).

6. Hausman, Jerry A., "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," Bell Journal of Economics, Vol. 10, No. 1 page 33 (Spring 1979).

7. Gately, Dermot, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables: Comment" Bell Journal of Economics, Vol. 11, No. 3, page 373 (Spring 1980).

8. Meier, Alan and Jack Whittier, "Purchasing Patterns of Energy-Efficient Refrigerators and Implied Consumer Discount Rates," Proceedings of the ACEEE Santa Cruz Conference, (1982).

9. Levine Mark D. and R. E. Scott, "Estimates for an Economic Model Incorporating Price and Usage Elasticity Adjustments for Consumer Decision-Making over Energy Efficiency Options in the Purchase of New Single-Family Housing," Lawrence Berkeley Laboratory report in preparation.

Table I. Shipment weighted energy factors (SWEF).

Appliance	1972	1978	1980
Gas Central Space Heater	62.7	63.6	65.9
Oil Central Space Heater	73.6	75.0	76.0
Room Air Conditioner	6.22	6.75	7.03
Central Air Conditioner	6.66	6.99	7.76
Electric Water Heater	79.8	80.7	81.3
Gas Water Heater	47.4	48.2	51.2
Refrigerator	4.22	5.09	5.72
Freezer	8.08	10.07	10.83

Source: Department of Energy Survey of Manufacturers

Table I. Aggregate market discount rates for appliances.

Appliance	1972	1978	1980
Gas Central Space Heater	33.5	41.9	45.1
Oil Central Space Heater	42.8	58.9	85.1
Room Air Conditioner	17.9	19.5	17.3
Central Air Conditioner	17.1	21.8	16.1
Electric Water Heater	209.1	244.4	243.2
Gas Water Heater	66.5	93.4	102.0
Refrigerator	74.0	69.0	59.2
Freezer	167.4	148.8	138.2

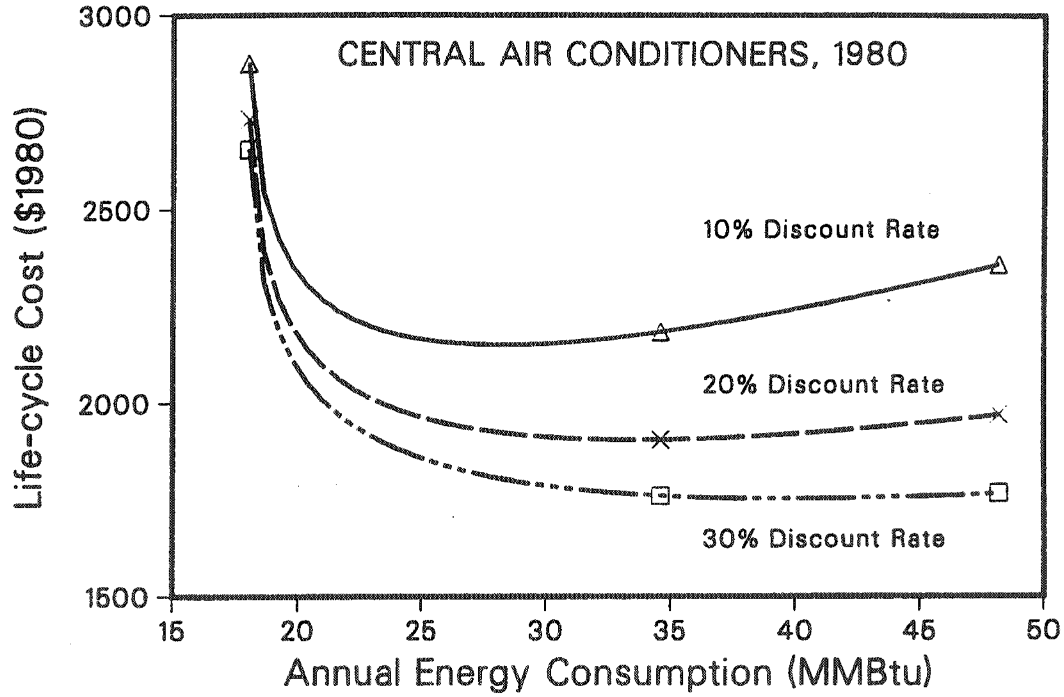

Figure 1. Life-cycle cost curves as a function of discount rate.

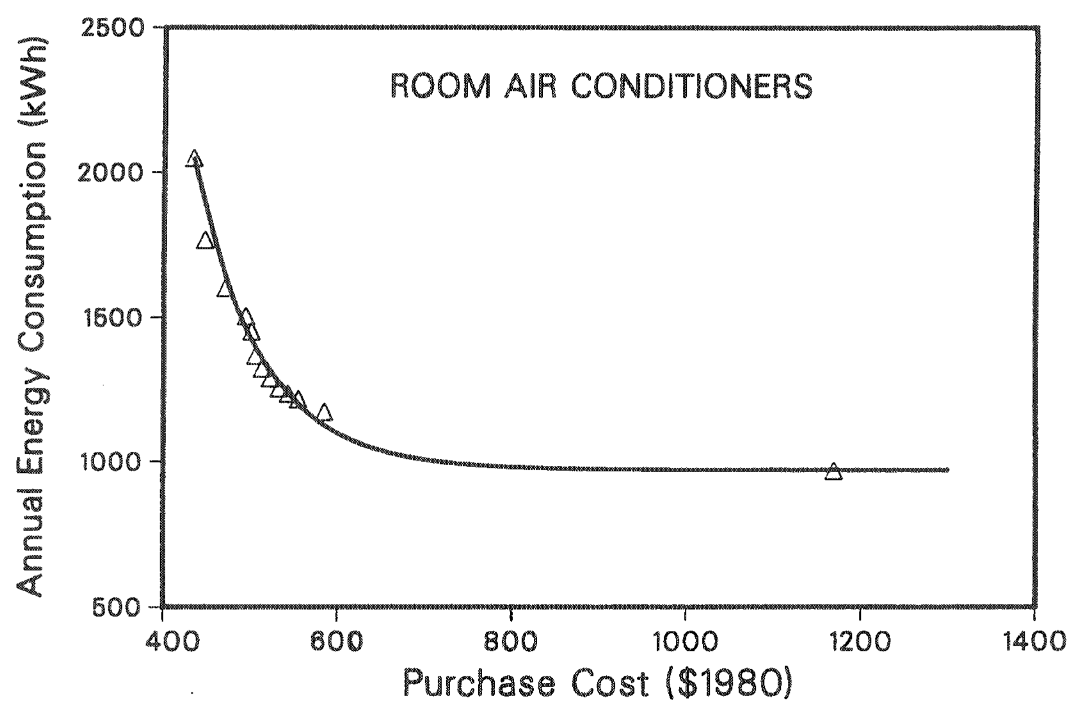

Figure 2. Cost and energy use of design options for room air conditioners.