A Model of Appliance Efficiency Choice Using Stated and Revealed Preference Data

Terry J. Atherton, Cambridge Systematic, Inc.
Caroline Chen, Southern California Edison Company
Rick Ridge, Pacific Consulting Services, Inc.
Kenneth Train, University of California, Berkeley

A private electric utility company in California has sponsored a study to develop a series of customer decision models designed to quantify the factors influencing equipment purchase and DSM program participation decisions. These models, specified as nested logit to capture the interrelationships among these decisions, are developed using information obtained on customers' stated preferences for and tradeoffs among various equipment price and feature attributes. The advantage of using state preference data (versus revealed preferences) is that it is possible to include program and equipment attributes that are not currently offered. This information was collected using a three-staged telephone/mail/telephone survey in which respondents were presented with a series of choice experiments. Each of these choice experiments described to the respondent:

- A hypothetical situation which may trigger a purchase decision (e.g., the breakdown of a major appliance, the introduction of a new technology, etc.); and

- Two or more equipment alternatives that are relevant to the customer for the decision scenario being described.

Each of these equipment alternatives is described in terms of technology attributes (e.g., price, energy savings, etc.), program attributes such as incentive delivery mechanisms (rebates, low-cost lease arrangements, low interest financing, etc.), and the level of incentive available.

This paper presents estimation results for the models developed for residential customers.

Introduction

In this paper, we present a model that can be used to forecast customers' choice between standard and high efficiency equipment, and the impact of utility incentives (such as rebates and financing) on this decision. This model serves as a tool for the evaluation and design of DSM programs, and as part of the appliance-choice component of utilities' end-use forecasting systems.

The model is constructed with a combination of "stated-preference" and "revealed-preference" data. The choices that customers actually made in the real world are called "revealed-preference" data, because the customer's preferences are revealed through its actual choice. For example, a customer who buys a high efficiency refrigerator reveals that he/she prefers the high efficiency refrigerator to a less efficient version that was also available to him/her. In contrast, "stated-preference" data are obtained by asking customers what they would choose in hypothetical situations that are described to the customer. For example, in an interview, a customer might be presented with descriptions of two refrigerators with different price and operating costs, and be asked to choose between them.

Stated-preference data provide two important benefits. First, the choice situations can be constructed to provide substantial variation in the primary factors that affect customers' decisions. In our case, the purchase price, operating cost, and rebate level associated with different appliances were varied in the hypothetical choice situations that we presented to customers. There is considerably less variation in these factors in the real world. With greater variation, more precise estimates of the impact of each factor can be obtained. Second, financing arrangements have not been offered by the utility historically. Stated-preference data provide information on customers' responses to these arrangements, while revealed-preference data are not available.

Stated-preference data have an obvious and important limitation, namely, that customers do not always do in the real world what they say they would do in a hypothetical situation. Because of this limitation, it is useful to combine stated-preference data with revealed-preference data, using the revealed-preference data to "ground" the model in actual behavior.

We combine revealed-preference and stated preference data in the following way. We estimate the parameters of the model on the stated preference data. That is, we use the stated preference data to determine the relative importance that customers place on purchase price, operating cost, rebates, and financing terms. Then, we calibrate the model on the revealed-preference data. That is, we adjust the constants and other parameters of the model such that the model with these adjustments (called the calibrated model) correctly predicts the actual choices of customers from the revealed preference data. This procedure uses the strengths of each type of data. The stated preference data have the advantage of considerable variation in factors that affect the customers' decisions; these data are therefore used to determine the relative importance of these factors. The revealed preference data have the advantage of representing what customers actually do; these data are used to calibrate the model such that it predicts actual choices correctly.

This procedure for using stated and revealed preference data also reflects the findings of previous research. Other studies have shown that stated-preference data provide accurate information on the *relative* importance of factors that affect customers' choices (e.g., the importance of purchase price relative to operating cost in the choice of appliance) even though they tend to over-predict the extent to which customers actually take actions (e.g., buy a high efficiency refrigerator). These findings imply that estimation on stated-preference data and calibration on revealed preference data is an appropriate procedure.

In the sections below, we describe the general structure of the model, its specification, the estimated parameters obtained from the stated-preference data, and the calibration on revealed preference data. These data were obtained through a telephone survey of 400 residential customers of Southern California Edison (SCE).

General Structure of the Model

The model considers four generic options that could be available to customers when purchasing a particular type of equipment, such as a refrigerator:

A. Standard equipment (i.e., standard efficiently level);

B. High efficiency equipment without financial incentives from the utility;

C. High efficiency equipment with a rebate from the utility; and

D. High efficiency equipment with financing from the utility.

Depending on the situation, some or all of these options are actually available. For example, if the utility does not offer any incentives for the purchase of high efficiency equipment, then only Options A and B are available. If the utility offers rebates but not financing, then Options A-C are available but not Option D; this situation has historically been the case for SCE's customers. Note that Option B is available in this situation because customers can (and many do) purchase high efficiency equipment but not apply for a rebate. In the future, utility financing may be provided as an extra option, in which case all four options, A-D, would be available. Or, financing may replace rebates as the type of incentive offered by the utility, in which case Options A, B, and D will be available, but not Option C.

The model forecasts customers choices in all of these situations. As such, it can be used to evaluate past DSM programs as well as to forecast customers' choices for future programs. For example, historically SCE has offered rebates for installation of energy efficient equipment. To evaluate the program, a critical question is whether (or, to be precise, how many) participants in the program would have purchased high efficiency equipment if the rebate had not been offered. The model can be used to address this question. In particular, the model is run with only Options A and B available (with Option C excluded). The proportion of customers who are forecast to choose Option B in this run provides information on free ridership, that is, on how many customers who chose Option C would have chosen Option B if Option C were not available. Similarly, the model can be used to design future programs. For example, an important question in designing financing options is whether financing should be offered as an option in addition to rebates or as a replacement for rebates. The efficacy of each approach is determined by running the model twice: once with all four options available to customers (to represent financing as an extra option) and then with Options A, B, and D, but not C (to represent financing as a replacement for the rebate program).

The attributes of the equipment and the utility programs affect the choices of the customer, and the model incorporates these attributes. For example, the extra cost of high efficiency equipment, relative to the standard equipment, affects the customer's predicted choice, as does the annual savings from the high efficiency equipment. The size of the rebate affects customer's choices; and, if financing is being considered, the amount of the purchase price that the utility would be willing to finance, as well as the terms of the loan (such as the interest rate and length of loan) affect the customer's decision. The model can be used to design programs by forecasting customer's choice under different rebate levels and different financing packages.

Specification

The customer faces a discrete choice among several options, namely, some combination of Options A-D. The customer obtains some level of well-being, or "utility," from each option and chooses the option that provides him/her with the greatest utility. Some components of this utility are observed; for example, the purchase price, operating cost, and the availability of a rebate or financing are observed. Other factors, such as the customer's uncertainty about the reliability of the appliance, are unobserved. The utility that the customer obtains from each option can therefore be decomposed as follows into a portion that depends on observed variables and a portion that depends on unobserved factors:

$$U_i = \beta x_i + \epsilon_i \text{ for } i = A,B,C,D \qquad (1)$$

If the unobserved factors ε_i were uncorrelated over the four options, then the customer's choice could be described as a logit model. In reality, however, unobserved factors are expected to be correlated over Options B, C, and D. These three options are the same in that they entail the high efficiency appliance; they differ only in how the appliance is paid for. Any unobserved factors that relate to the high efficiency appliance, such as concern about its reliability, is the same for these three options, meaning that the ε's are correlated over Options B, C, and D.

Nested logit models explicitly recognize correlations in unobserved factors over options. Specifically, let the unobserved factors be distributed generalized extreme value, with correlation between ϵ_B, ϵ_C, and ϵ_D. McFadden (1978) shows that under this distribution, the probability that the customer chooses Option A when all four options are available is:

$$P(A|A,B,C,D) = \frac{e^{\beta X_A}}{e^{\beta X_A} * \left[e^{\frac{\beta X_B}{(1-\lambda)}} + e^{\frac{\beta X_C}{(1-\lambda)}} + e^{\frac{\beta X_D}{(1-\lambda)}} \right]^{1-\lambda}} \qquad (2)$$

The probability of choosing Option B when all four options are available is:

$$P(B|A,B,C,D) = \frac{e^{\frac{\beta X_B}{(1-\lambda)}} * \left[e^{\frac{\beta X_B}{(1-\lambda)}} + e^{\frac{\beta X_C}{(1-\lambda)}} + e^{\frac{\beta X_D}{(1-\lambda)}} \right]^{-\lambda}}{e^{\beta X_A} * \left[e^{\frac{\beta X_B}{(1-\lambda)}} + e^{\frac{\beta X_C}{(1-\lambda)}} + e^{\frac{\beta X_D}{(1-\lambda)}} \right]^{1-\lambda}} \qquad (3)$$

The probabilities for Options C and D are similar to that for B, except with x_C or x_D replacing x_B in the first term in the numerator. The parameter λ captures the similarity in unobserved factors among Options B-D. A value of $\lambda = 0$ implies no similarity, such that the unobserved factors are independent across these three options; in this case, the nested logit model becomes a simple logit. Values of λ above zero indicate, as expected, positive correlation in unobserved factors.

Note that the probability for any option depends on the attributes of all the options. Thus the probability of choosing the standard appliance depends on its own price, the price and savings of the high efficiency appliance, and the amount of rebate and the financing arrangements that are offered for purchase of the high efficiency appliance. Presumably, this probability decreases when more attractive rebates and financing arrangements are offered.

If only some of the four options are available, then the probability for each is the same as above except that the terms for the unavailable options are left out. For example, if no DSM programs are offered, such that the customer has only Options A and B, the probability of choosing Option A is:

$$P(A|A,B) = \frac{e^{\beta X_A}}{e^{\beta X_A} + e^{\beta X_B}} \qquad (4)$$

and the probability of choosing Option B is $(1-P_A)$.

Estimation on Stated Preference Data

Stated preference data were collected for three appliances: refrigerators, air conditioners, and lamps. For each appliance, customers were offered a series of binary choices, each of which consisted of a choice between a standard appliance and a high efficiency version. The high efficiency measure was either offered without any incentive, or with a rebate, or with a financing package. That is, the customer was presented with a choice between Option A and either Option B, C, or D. In the case of lamps, the high efficiency measure was taken to be compact fluorescent bulbs; because of their low cost, financing packages were not included in the hypothetical choice situations for lamps.

Estimation on these binary choice data provides information on the relative importance of factors affecting customers choices (i. e., on *ß)* but does not provide information on the correlation in unobserved factors over the high efficiency options (i.e., λ). Additional stated preference data were collected to estimate λ, as well as to provide more information on *ß*. In particular: in addition to the binary choices between a standard and a high efficiency appliance, surveyed customers were also presented with two or three high efficiency appliances each of which had a different incentive package. For example, the customer might be presented with a high efficiency appliance that had no rebate or financing, another high efficiency appliance on which a rebate was offered, and a third high efficiency appliance with a financing arrangement. The customer was asked which of these options he/she preferred. (That is, Options B, C, and D were described, and the customer was asked which he/she would choose.) These choices provide information on *ß* and λ.[1]

Separate models (i.e., separate values of *ß* and λ) were estimated for each appliance. For each appliance, a basic model was estimated first. This model contains characteristics of the appliances, but no demographics. This model is appropriate to use in situations in which the analyst does not have data on the distribution of socioeconomic variables, as is often the case for end-use forecasting systems. A second model was then estimated that includes characteristics of the customer, such as income and education level. In this model, the importance that the customer places on the purchase price relative to operating cost and other factors depends on the characteristics of the customer. A series of tests were also performed to determine the most appropriate set of variables to enter and the functional relations between variables.

Basic Model Results

The basic model for each of the three appliances is given in Table 1. Note that the price variable is price net of any rebate; that is, the price variable is the price of a standard appliance in Option A, the price of the high efficiency version in Option B, the price of the high efficiency appliance *minus* the rebate in Option C, and the price of the high efficiency appliance in Option D. The financing arrangement for Option D is captured in two variables. The "amount borrowed" is the amount of the purchase price that the utility finances; the difference between this and the purchase price is the down payment that the customer pays under the financing arrangement. The "monthly payment" is the amount that the customer must pay each month to repay the loan. It depends on the interest rate, the repayment period, and the amount borrowed. Note that the model for lamps does not include financing variables, since, due to their low price, financing arrangements were not offered to customers for lamps.

The estimated parameters have the expected signs. These signs are the same for all three appliances, and so the implications of these signs are the same for all three appliances. In particular: (i) Price enters with a negative sign. If the extra price that a customer must pay for a high efficiency appliance relative to the standard one rises, and yet the savings from the appliance and all incentives remain the same, fewer customers will choose the high efficiency appliance. (ii) Savings enter with a positive sign. If the savings from a high efficiency appliance are higher, and the extra price and the incentives are the same, more customers will choose the high efficiency appliance over the standard one. (iii) The rebate is subtracted from price for Option C; and the price variable net of rebate enters with a negative sign. Increasing the rebate on a high efficiency appliance (all else constant) decreases the net price of the high efficiency appliance and therefore increases the number of customers who choose it. (iv) A more attractive financing package increases the number of customers who choose a high efficiency appliance. The amount borrowed enters with a positive sign, meaning that, for a given price, customers prefer to put less down (i.e., borrow more). The monthly payment enters with a negative sign, meaning that customers prefer a lower interest rate and a longer repayment period, both of which reduce the monthly payment. Note that, since amount borrowed enters separately, the coefficient of monthly payment indicates the impact of interest rates and repayment period holding amount borrowed constant.

The values of the estimated parameters provide quantitative information about the size of these effects. We consider the quantitative estimates sequentially below:

1. Willingness to Pay for Marginal Investments in Efficiency

   The coefficients of the savings and price variables indicate customers' willingness to pay, on the margin, for additional savings from a high efficiency appliance. In particular, the ratio of these coefficients gives the increase in price that a customer would be willing to incur when buying a high efficiency

Table 1. Basic Model Estimated on Stated Preference Data

Variables	Estimated Parameters (t-statistics in parentheses)					
	Refrigerator		Air Conditioner		Lamps	
Price Net of Rebate	-0.003407	(12.5)	-0.001520	(7.0)	-0.07585	(11.5)
Savings	0.007653	(16.5)	0.002613	(8.7)	0.02585	(3.1)
Amount Borrowed	0.001140	(5.6)	0.0005569	(4.0)	-	
Monthly Payment	-0.003853	(1.5)	-0.001351	(0.8)	-	
Constant for Option B	1.460	(20.7)	0.8248	(4.8)	1.413	(5.3)
Constant for Option C	1.676	(25.9)	1.045	(6.3)	1.680	(6.5)
Constant for Option D	1.021	(11.4)	0.06369	(0.3)	-	
λ	-0.121	(3.42)	0.0451	(1.24)	-	
Number of Observations	6,081		2,858		3,216	
Likelihood Ratio Index	0.275		0.205		0.201	

appliance in order to obtain one dollar of extra savings per year. For refrigerators, this ratio is $2.25.

It is important to note that this figure represents customers' willingness to pay on the margin. It does not imply, for example, that customers are willing to pay $225 for a high efficiency refrigerator over a standard version if the high efficiency refrigerator saves $100 per year. The proportion of customers who would purchase the high efficiency refrigerator in this case depends on other variables in the model, including the constants for each option, which represent the average effect of uncertainty and other unobserved factors. (The model calculates this proportion based using the formulas given in Section II and the estimated coefficients in Table 1.) The marginal willingness to pay of $2.25 means the following: Suppose a high efficiency costs $300 more than the standard version and saves $100 per year. Some number of customers would buy the high efficiency refrigerator. Now, suppose the high efficiency refrigerator saved $101 per year instead of $100 and cost $302.25 instead of $300 more than the standard version. The marginal willingness to pay of $2.25 means that the same number of customers would buy this refrigerator: adding a dollar to savings and $2.25 to price does not change customer's choice between the high efficiency and standard refrigerators. Going a step further: if the price was more than $2.25 higher, then fewer customers would buy the high efficiency refrigerator; and if the price was less than $2.25 higher, then more customers would buy it.

The marginal willingness-to-pay can also be expressed as the required return that a customer needs on the margin to be willing to make an investment. An investment that costs $2.25 and provides $1 per year return provides a 44 percent return on investment. This implies that if a high efficiency refrigerator is made even more efficient, the proportion of customers who choose it will remain the same if this extra efficiency provides a 44 percent return, and will rise/fall if it provides a larger/smaller return. Note again that this required return is for investments at the margin.

The implicit discount rate for marginal investments depends on customers' expectations about the life of the appliance and the growth rate in real energy prices. For appliances with very long lives, and assuming no growth in energy prices, the implicit discount rate is the same as the required rate of return. For shorter lives, or for positive growth in energy prices, the implicit discount rate is lower than the required rate of return. If customers consider refrigerators to have a 10-year life, and expect no real growth in energy prices, then a required rate of return of 44 percent implies a discount rate of 30 percent on the margin.

This implicit discount rate, while perhaps seeming higher than expected for a "rational" customer, is actually somewhat lower than previous findings on residential customer's choice of refrigerator efficiency levels. Cole and Fuller (1980) found implicit discount rates ranging from 61 to 108 percent in household's choices of refrigerator efficiency level. Meier and Whittier (1983) estimated that 60 percent of residential refrigerator buyers in the Pacific region had discount rates exceeding 34 percent. Finally, McRae (1980) asked consumers in a survey "How much would you have to save per month to spend an extra $100 for the (high efficiency) refrigerator?" The average discount rate implied by their responses was 53 percent.

We turn now to the willingness to pay, required rates of return, and implicit discount rates for air conditioners and lamps. The air conditioner model implies that customers are willing to pay $1.72 for an extra dollar of savings from a high efficiency air conditioner. This implies a required rate of return for investments in marginal efficiency improvements in air conditioners of 58 percent. With a 10-year life and no growth of energy prices, this translates into a 36 percent discount rate for investment on the margin. This figure is somewhat higher than Hausman's estimate of 26.4 percent for a useful life of 9.94 years, and of 29 percent for an infinite life.

The model for lamps implies that customers are much less willing to invest in savings from fluorescent lamps. Customers are only willing to pay 34 cents for one dollar of extra savings per year, which means that the required rate of return is 294 percent. This figure is not irrational however if customers expect the lamps to last only a few months. For example, if customers expect the bulbs to last six months, this 294 percent required return on the margin is equivalent to a discount rate of 32 percent.

One final note on the model's implications for willingness to pay for savings: The models include option-specific constants. For refrigerators, for example, the constant for the high efficiency refrigerator without any incentives (Option B) is 1.46. These constants give rise to the difference between the willingness to pay on the margin versus for the total investment. It is generally appropriate to include such constants (see Train 1986). However, in the situation at hand they can provide erroneous predictions in extreme situations. In particular, suppose a customer is offered a choice between two refrigerators that have the same price and operating costs, but one of them is called "high efficiency" while the other is not. Since the price is the same and the there are no savings, the only difference between the observed utility that customers obtain from these two refrigerators is captured by the constant, which is positive for the one labeled "high efficiency." The model would therefore predict that more than half of the customers would choose the "high efficiency" refrigerator, even though in actuality the two refrigerators are essentially the same. This prediction may or may not be erroneous, depending on how customers would actually behave in this situation. (Customer might simply like the idea of having a refrigerator that is called high efficiency.) However, when viewed from the perspective of required rates of return and implicit discount rates for total investment (rather than on the margin), this prediction implies that a share of customers have required rates of return and discount rates of zero. Because of this issue, it is perhaps advisable to use the model only when the high efficiency measures offer meaningful savings, or to be even more stringent, when they offer returns that are in the range of data that were used in estimation.

2. Effect of Rebates

As described above, the price variable was calculated net of rebate in Option C. Therefore, the model implies larger rebates induce more customers to buy the high efficiency appliances, through lowering the price that the customer must pay for the appliance.[2]

The effect of rebates is greater, however, than the effect on price only. The option-specific constant is larger for Option C than Option B. This means that, aside from the size of the rebate, the mere existence of the rebate makes customers more willing to choose the high efficiency measure. This phenomenon has been found in other studies (e.g., Train 1988). It might reflect customer's uncertainty about high efficiency appliances: customers might feel more comfortable that the appliance will actually delivery the promised savings if the energy company "backs" the appliance with the offer of the rebate.

The impact of offering rebates, incorporating the size of the rebate and the positive effect of the rebate independent of its size, is determined by simulation with the model. In particular, the share of customers predicted to buy the high efficiency appliance when the rebate is not offered is P(B/A,B). The predicted share when the rebate is offered is P(B/A,B,C) + P(C/A,B,C). The difference between these two shares is the impact of the rebate program (absent spillover effects).

3. Effects of Financing Arrangements

The financing arrangement that the utility offers is captured in the variables "amount borrowed," and "monthly payment. " As stated above, these variables enter with the expected signs, indicating that: (i) holding price constant, the more that the customer is able to borrow (i.e., the less the customer must put down), the more likely the customer is to buy the high efficiency appliance, and (ii) the lower the interest rate and the longer the repayment period, the more likely the customer is to buy the high efficiency appliance.

It is interesting to note that for both the refrigerator and air conditioner (recall that financing arrangements were not considered for lamps), the models imply that customers consider $1 of financing to be equivalent to about a third of a dollar lower price for the high efficiency appliance. (The ratio of the coefficient for amount borrowed to that for price is 0.33 for refrigerators and 0.37 for air conditioners.) Stated equivalently, a $3 increase in the amount that a customer can borrow is equivalent to about a $1 decrease in the price of the appliance (holding all else, including monthly payments, constant). Since a rebate decreases the price of the appliance, this implies that $3 in extra financing is seen by customers to be equivalent to a $1 increase in the rebate. Another way to state this is: $1 of extra rebate is three times as valuable to the customer than $1 of extra financing. This considerably higher value for rebates is expected since the customer does not have to be repaid.

The foregoing comments do not necessarily imply that it is more effective for the utility to put money into rebates than into financing. Since the financed dollars are paid back, the present value of $3 of extra financing *might* be less than the present value of $1 of rebate, in which case it would be more cost effective for the utility to increase financing by $3 than to increase rebates by $1. Also, though the welfare, or utility, that the customer obtains is the same for $1 of rebate and $3 of financing, the effect of each on the share of customers who choose the high efficiency measure is not necessarily the same. The rebate and finance options (Options C and D) have different constants, and the financing option has an intervening factor—monthly payment—that enter the calculation of the relative effects. Most importantly, if the amount financed rises, then the monthly payment will generally rise, unless the interest rate and repayment period are changed in ways that keep the monthly payment constant. The equivalence between $1 of rebate and $3 of financing holds only when all other factors, including monthly payment are held constant. If the monthly payment rises with extra financing, then the financing becomes less attractive, and it takes more than $3 of extra financing to be equivalent to $1 of extra rebate.

The model can be used to calculate the proportion of customers who would buy the high efficiency appliance under any combinations of financing arrangements and rebates. The model can therefore be used to assist in determining the most cost effective way to design incentives.

Models With Sociodemographic Characteristics of Customers

Table 2 presents models that include characteristics of the customers. After extensive exploration with different specifications, we concluded that three patterns were evidenced significantly and consistently for the three appliances: (1) Younger customers tended to choose high efficiency appliances more readily than older customers. (2) Customers with more education are more willing to pay for energy savings. (3) Customers with greater income are generally less willing to pay for energy savings. This last conclusion can be restated in a way that better indicates its plausibility, namely: higher income customers require a higher return to be willing to invest in energy efficiency, perhaps because they have more alternative investment opportunities. The models incorporate these three relations.

The age effect is captured in a dummy variable that indicates whether the customer is under 36 years of age. This variable enters the high efficiency options (i.e., B, C, and D). Its positive coefficient indicates that, all else equal, these younger customers are more likely to purchase the high efficiency appliances.

The education and income of the customer denoted by a series of dummy variables that identify whether or not the customer attended some college and the income level of the customer (below $25,000, between $25,000 and $50,000, and over $50,000). The price variable was interacted with these dummies; that is, a different price coefficient was estimated for customers in each education/income category. The specification allows a different willingness to pay for each education/income group. The estimated willingness to pay of each group is given in Table 3. The results conform to the conclusion given above, namely, that higher education customers are willing to pay more, and higher income customers are willing to pay less. Required rates of return for marginal investments are calculated for each group as the inverse of the willingness to pay. And implicit discount rates depend on the expected life of the appliance and the growth rate in real energy prices.

Table 2. Models with Sociodemographics Estimated on Stated-Preference Data

Variables	Refrigerator		Air Conditioner		Lamps	
	Estimated Parameters (t-statistics in parentheses)					
Price for:						
No college, income <$25,000	-0.001825	(4.7)	-0.0005351	(1.6)	-0.05473	(6.1)
No college, income $25,000-$50,000	-0.003549	(9.5)	-0.001621	(4.5)	-0.08225	(9.0)
No college, income >$50,000	-0.005317	(9.9)	-0.001621	(4.5)	-0.2171	(14.4)
Some college, income <$25,000	-0.002056	(3.9)	-0.0005216	(1.4)	-0.03277	(2.9)
Some college, income $25,000-$50,000	-0.003027	(10.2)	-0.0005216	(1.4)	-0.06118	(7.7)
Some college, income over $50,000	-0.004461	(12.7)	-0.001840	(6.5)	-0.09062	(11.5)
Savings	0.007937	(16.80	0.002350	(7.6	0.01822	(2.0)
Amount Borrowed	0.001264	(5.8)	0.0006198	(3.9)	-	
Monthly Payment	-0.003001	(1.1)	-0.001852	(1.0)	-	
Age Below 36, for high efficiency options	0.2197	(2.7)	0.6162	(3.5)	0.8085	(7.6)
Constant for Option B	1.421	(18.1)	0.7562	(4.5)	1.457	(5.0)
Constant for Option C	1.607	(21.9)	1.029	(6.3)	1.783	(6.3)
Constant for Option D	0.8999	(9.2)	-0.06666	(0.3)	-	
λ	-0.101	(3.1)	0.0378	(1.2)	-	
Number of Observations	5,684		2,665		3,008	
Likelihood Ratio Index	0.293		0.225		0.265	

Alternative specification were run for each appliance, including: (i) defining different categories for age, education, and income, (ii) interacting the education/income dummies with savings instead of price, (iii) entering these dummies into the high efficiency options without interaction with price or savings, (iv) interacting the age dummy with price and, separately, with savings, (v) entering the logarithm of price rather than linear price, and (vi) entering price in piece-wise linear combinations. There was no evidence of a non-linear price response: the log(price) entered less significantly than price, and the piece-wise linear components of price entered with quixotic signs. The education/income dummies entered most significantly interacted with price than interacted with savings or as constants in the high efficiency options. (The estimated required rates of return were similar whether the dummies were interacted with price or savings.) Fewer education/income categories were used for the air conditioner model than the other two models because there were fewer surveyed customers on which to estimate this model. Finally, the age dummy entered more significantly as a constant in the high efficiency options than interacted with price or savings.

These models with sociodemographic variables are useful when the analyst has data on the distribution of customer characteristics. Otherwise, the models without these variables (i.e., the model in Table 1) can be used.

Calibration on Revealed Preference Data

Once estimated, the models were calibrated to revealed preference data. In the survey, each customer was asked whether he/she had purchased a refrigerator or air conditioner recently and, if so, whether it was a standard or high efficiency version. If a high efficiency appliance was purchased, the customer was asked whether he/she had received a rebate. The responses provided information on the actual choices of customers (i.e., revealed preference data). Actual choices are expected to differ from stated choices for two primary reasons. First,

Table 3. Willingness to Pay for One Dollar of Extra Savings on the Margin

Variables	Refrigerator	Air Conditioner	Lamps
All Customers (basic model)	$2.25	$1.72	$0.35
Customer Group (model with sociodemographic)			
No college, income <$25,000	4.35	4.39	0.33
No college, income $25,000-$50,000	2.24	1.45	0.22
No college, income >$50,000	1.49	1.45	0.08
Some college, income <$25,000	3.86	4.51	0.56
Some college, income $25,000-$50,000	2.62	4.51	0.22
Some college, income over $50,000	1.78	1.28	0.20

customers might have a tendency to say that they would purchase a high efficiency appliance more readily than they actually do. This phenomenon would evidence itself in the option-specific constants for the high efficiency appliances being higher with the stated preference data than is accurate for actual choices. Second, any time or effort that the customer must expend to receive a rebate, or any lack of awareness about the rebate program, is not reflected in the stated preference situations. In the hypothetical choices, the customer is informed about the rebate and does not have to do anything to receive it.

Both of these phenomena would evidence themselves in the estimated values for the option-specific constants and the similarity parameter λ when the model is estimated on stated preferences data. The revealed preference data were used, therefore, to re-estimate these parameters. In particular, the following procedure was used for the models for refrigerators and air conditioners. (Revealed preference data were not available for lamps.) The coefficients of price, savings, and the other terms were constrained to equal the values that had been estimated with the stated preference data. Using the revealed preference data, the option-specific constants and λ were estimated under these constraints. This re-estimation of constants and λ is called "calibration" because the re-estimated values are those that "force" the model's predicted shares for each option to equal the actual shares. That is, the calibrated model necessarily correctly predicts the actual choice of surveyed customers on average.

Financing arrangements are not currently available from the utility. Consequently, revealed preference data cannot be obtained for Option D. The calibration process estimates the constants for Option B and C, but not Option D. In applications of the model, it is perhaps reasonable to apply the adjustment in the constant for Option C that occurs in calibration to the constant for Option D. That is, if calibration changes the constant for Option C by x units, then the constant for Option D is also changed by x units.

Table 4 gives the calibration results. The calibration process for the air conditioner model changed the option-specific constants and λ in the expected way. The constants for both the high efficiency option are lower after calibration to actual choices than from the stated preference data. This implies, as expected, that customers say they would purchase high efficiency air conditioners more readily than they actually do. The constant for Option C goes down further than the constant for Option B. This result reflects the fact that, in the hypothetical choice situations, the customer is necessarily aware of the rebate and does not need to expend any time or effort to obtain the rebate. The share of customers who actually obtain rebates is smaller than would be implied in the stated preferences. The additional drop in the constant for Option C (relative to the drop for Option B) reflects this fact. Finally, λ is estimated to be larger and more significant. Most of the hypothetical choice situations involved a binary choice between a standard and a high efficiency appliance. As stated in Section III, these binary choices do not provide information on λ. Since the stated preference data contain few choice situations that provide information on λ, the estimated values of λ on these data are unreliable. The revealed preference data involve choice between the three Options A, B, and C, which does provide information on λ. The values of λ obtained on these data imply, as expected, that there is a substantial correlation in unobserved factors relating to the high efficiency options.

Table 4. Results of Calibration to Actual Choices

	Estimated Parameters (t-statistics in parentheses)			
	Refrigerator		Air Conditioner	
Basic Models				
Constant for Option B	1.680	(5.2)	-5.710	(0.8)
Constant for Option C	0.04929	(0.1)	-6.398	(0.9)
λ	-0.047	(0.29)	0.639	(1.71)
Number of Observations	191		62	
Models with Sociodemographics				
Constant for Option B	1.149	(2.1)	-6.499	(0.7)
Constant for Option C	-0.8243	(0.61)	-7.778	(0.8)
λ	0.328	(1.71)	0.710	(1.85)
Number of Observations	175		55	

The calibration results for the refrigerator models conform to expectations in two respects but not in another. The constant for Option C is considerably lower than with the stated preference model; as described above for the air conditioner model, this is expected, and reflects the fact that customers, due to a lack of awareness and other factors, do not actually obtain rebates as often as implied by the stated preference data. The value of λ becomes larger, as in the air conditioner models. While it is still negative in the basic refrigerator model, which is implausible, it obtains a reasonable positive value in the model with sociodemographics. The anomaly of the calibration results for refrigerators is that the constant for Option B rises, contrary to the result for air conditioners and to expectations. The adjustment is not large, however. The result might indicate that, for refrigerators, customers' actual behavior fairly closely matches what they say they would do in hypothetical situations.

Endnotes

1. Using the nested logit formula given above, it can be verified that P (A/A coupled with B, C, or D) depends on *ß* only whereas P(./B,C,D) depends on *ß* and λ.

2. Alternative models were estimated in which the rebate amount entered separately, in addition to net price. This specification allows an extra dollar of rebate to be viewed by customers as different from a dollar decrease in price. This extra variable was not significant in any of the three models, meaning that the hypothesis cannot be rejected that an extra dollar of rebate is viewed by customers as being equivalent to a dollar reduction in price. This extra variable also took inconsistent signs (positive in two models and negative in the third), which is not plausible: customers cannot reasonably be expected to value a dollar of rebate more than a dollar reduction in price for two appliances, but less than a dollar reduction for another appliance. The basic models incorporate these results by having price and rebate be valued the same.

References

Cole, H., and R. Fuller. 1980. "Residential Energy Decision Making: An Overview with Emphasis on Individual Discount Rates and Responsiveness to Household Income and Prices." Hittman Associates report, Columbia, MD.

Hausman, J. 1979. *Bell Journal of Economics,* Volume 10, No. 1, p. 33.

McFadden, D. 1978. "Modeling the Choice of Residential Location," in Karquist, et al. (eds.). *Spatial Interaction* Theory *and Planning Models,* North-Holland Publishing Company.

McRae, D. 1980. "Rational Models for Consumer Energy Conservation," in Burby and Marsden (eds.). *Energy and Housing,* Oelgeschleger, Gunn and Hain Publishers.

Meier, A., and J. Whittier. 1983. *Energy,* Volume 8, p. 957.

Train, K. 1986. *Qualitative Choice Analysis,* MIT Press.

Train, K. 1988. "Incentives for Energy Conservation in the Commercial and Industrial Sectors." The *Energy Journal,* Volume 9, No. 3, pp. 113-128.