# INDUCED INVESTMENT IN ENERGY-USING DURABLES: AN ECONOMIC EFFICIENCY ANALYSIS*

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## I. INTRODUCTION

There have been numerous government and public utility sponsored programs that have attempted to induce greater household investment in high efficiency energy-using durables through tax incentives, rebates and education in order to conserve energy. A prime motivation for such programs is the perceived lack of long-run cost minimization by households. Numerous studies have come to this conclusion.[1] Explanations of this phenomenon have ranged from a Pigouvian defective telescopic faculty on the part of households to unreasonably high individual discount rates.[2]

Since energy conservation is the prime motivation of these programs, they are normally evaluated by the amount of energy that they save. But utility maximizing households might substitute money for more indoor thermal comfort once they observe their energy bills fall. This would partially offset any energy savings. Thus the level of energy savings might understate the benefits from such programs.

If households are sub-optimally investing in energy-using durables, then they are incurring deadweight losses. The benefit of the above mentioned programs would then be the reduction of these deadweight losses. It then follows that these energy conservation programs should be evaluated by their effects on economic efficiency rather than by the amount of energy they save.

Using a model developed by Scoggins (1987) and data gathered from 505 Florida households, we show that a program that would induce greater investment in air conditioners with high energy efficiency ratings would reduce energy consumption only slightly and would cause rather than reduce deadweight losses. For induced increases in ceiling insulation, energy savings would again be slight but the effect on deadweight losses is uncertain. This casts serious doubts on both the efficacy and economic efficiency of such programs.[3] Section II formally establishes the model and section III applies the data for econometric estimation. The results are analyzed and compared to the findings of Hausman (1979) in sections IV and V. The conclusions of the study are summarized in section VI.

## II. THE MODEL

In Scoggins (1987), a utility maximization household production model was developed. Its distinguishing feature from previous models is that it allows for the measurement of exact consumer's surplus, even when the household's budget constraint is non-linear. For the purposes of this study, this non-linearity might arise from the possible non-constant returns to scale in the production of indoor thermal comfort.

In the model, we specify a household utility function and an indoor thermal cost function:

$$U(Z,G,R) \tag{1}$$

and $$C(Z,P,K), \tag{2}$$

where Z is indoor thermal comfort (a function of indoor temperature), G is a composite of all other consumption goods, R is a vector of household characteristics, P is the price of electricity, and K is a vector of n energy-using durables characteristics. Both functions are differentiable. U is continuous, monotonically increasing and separable in Z and G. C is a short-run cost function since for each household, K is assumed fixed.

From equations (1) and (2), we derive the uncompensated comfort consumption (UCC) function,

$$Z = F(P,R,K,Y), \tag{3}$$

where Y is household income. F is an observable function which delineates the combinations of Z, P, R, K and Y that maximize utility. By inverting F to solve for $K_i$ (the i-th element in vector K), and substituting this result into the marginal cost of comfort ($C_Z$), we reveal an uncompensated marginal benefit (UMB) function of comfort,

$$B_Z(Z,P,R,K^i,Y), \tag{4}$$

where $K^i$ denotes the vector K <u>excluding</u> the i-th element.

Graphically, this process is illustrated in figure (1). By varying the level of $K_i$ which shifts the marginal cost curve, we "trace-out" a marginal benefit function. This function is analogous to Marshallian demand. And the shaded area between the ex-post and ex-ante marginal cost curves and $B_Z$ is analogous to the change in consumer's surplus.

By integrating over $B_Z$ and $C_Z$, we can see that the benefit to the household from the change in $K_i$ is

$$C(Z^0,K_i^0) - C(Z^1,K_i^1) + B(Z^1) - B(Z^0), \qquad (5)$$

where the superscripts 0 and 1 respectively denote ex-ante and ex-post values. B is referred to as the uncompensated total benefit (UTB) function. For expositional simplicity, all other arguments have been suppressed.

Thus from the observable consumption and cost functions, we can measure the benefit to a household of an increase in the ceiling insulation level or the air conditioner efficiency. If we subtract the costs of the investment in these durables from the benefit measure, we have a measure of the possible deadweight loss of under-investing in them.

As shown in Hausman (1981), when dealing with the measure of deadweight losses, the use of uncompensated demand functions may present a significant degree of approximation error. Analogously, the use of an uncompensated consumption function might also present significant error.

Hausman's solution to this problem was to estimate the parameters of an expenditure function through the use of Roy's identity. The change in the value of the expenditure function is an exact measure of the change in consumer's surplus.

To derive an expenditure function for our household production case, we use the modified Roy's identity from Scoggins (1987),

$$F(P,R,K,Y) = C^{-1}_{K_i}(-v_{K_i}/v_Y, P, K^i), \qquad (6)$$

where v is the indirect utility function. From the observation of the uncompensated consumption function, the parameters of the indirect utility function can be measured. To derive the expenditure function (e), we simply invert v,

$$Y = e(P,R,K,v) = v^{-1}(P,R,K,Y). \qquad (7)$$

Thus by measuring the change in the value of the expenditure function, we use the change in exact consumer's surplus (either the equivalent or compensated variation) to further refine our deadweight loss measure.

## III. ESTIMATION

Due to the complexity of the model, our choices of functional forms for the cost and consumption functions were somewhat limited. Our best results came from a Cobb-Douglas cost function,

$$C(Z,P,K) = AZ^{\alpha}\left(\prod_{i=1}^{n} K_i^{\beta_i}\right)P, \qquad (8)$$

and (what we will call) a Hausman indirect utility function,

$$v = Y^{\tau} - BP^{\sigma}\left[\prod_{i=1}^{n} K_i^{\delta_i}\exp(\theta X)\right], \qquad (9)$$

where X is a vector of socio-economic variables. If there is a change in the value of $K_j$, then from these two equations, we can derive the following (log-linear) consumption function,[4]

$$Z = [B\delta_j/A\tau\beta_j]^{1/\alpha}Y^{(1-\tau)/\alpha}P^{(\sigma-1)/\alpha}\left[\prod_{i=j}^{n} K_i^{(\delta_i-\beta_i)/\alpha}\right]\exp(\theta X). \qquad (10)$$

Since we are estimating a simultaneous system of equations, (8) and (10), where an endogenous variable appears on the right-hand side (Z), we employ the three-stage least squares regression procedure.

We obtained our data from an experiment conducted by the Florida Power and Light Company (FPL). In this experiment, 288 FPL customers were given some combination of conservation retrofits which consisted of ceiling insulation (up to a minimum of R-19), high efficiency air conditioners and heat pumps. Another 217 customers included in the experiment were given no retrofits.

From October 1982 through December 1983 (15 billing months), these 505 households' monthly electricity consumption (by their central units) was observed. Other variables which affect central climate control usage (such as number of household occupants, square footage, etc.) were observed at the start of the experiment. For home cooling, we were able to use 1535 monthly observations. The results from the cooling observations are revealed in table (1).

## IV. ANALYSIS

### Parameter Estimation

As can be seen, the $R^2$ for the system is not large (.3). This normally would indicate that the model does not explain a large degree of the variation in the dependent variables. However there are two relevant notes to be made here: (1) this is a study using cross-sectional data and is therefore not expected to have a very large $R^2$ value and (2) one of the dependent variables (COMF) was measured in categories. Since a point observation was needed, the mean value of each category was used. Thus some of the variation in COMF was not observed which tended to reduce the value of the $R^2$ for the system of equations.

Of the parameter estimates in the cost function, what is of particular interest is that neither the coefficient for EER nor for INSUL was significantly different from zero at the 95% confidence level. This is very surprising since increased efficiency ratios and insulation levels have been hailed as the most promising avenues for further energy conservation. However the purpose of this paper is not to prove the sign of any particular coefficient in the cost function . What is hoped is that the parameter estimates are the best estimates of the correct values of the coefficients attainable in spite of the high "noise" level present in this data sample.

For the estimation shown above, the "name-plate" EER (as given by the air-conditioner manufacturer) was used. During the course of the experiment, FPL tested the central units of the participants for the actual EER's. When regressed on the name-plate EER (using OLS), the actual EER had an intercept term of 1.62 and a slope parameter of .56. The $R^2$ value was .1326.

This indicates that the name-plate EER is not a very good estimate of the actual EER and that for high values of name-plate EER (around 10) the actual EER is much less (around 7). The FPL engineers attributed the discrepancy more to improper installment rather than manufacturer error. However regardless of the cause of the discrepancy, these results do not augur well for the energy savings of large scale conservation programs that concentrate on efficiency ratios.

When used in the system regressions, actual EER had a smaller and slightly more significant parameter estimate (in the cost function) than name-plate EER. But when included in the comfort consumption function, actual EER had a positive and not very significant parameter estimate. In contrast, in the comfort consumption regression, the name-plate EER parameter was negative and highly significant. This indicates households were basing their cooling decisions primarily from manufacturer supplied data and not from actual cost savings. Since this study attempts to measure household's preferences, the more significant variable (name-plate EER) was used in the final simulations.

## Choice of Decision Variable

As detailed in section II, to derive a marginal benefit function (both income compensated and uncompensated), we use an exogenous variable that appears in both the (marginal) cost function and the consumption function. Theoretically any variable that appears in both functions can be used. But since in empirical analysis, estimation bias is always a possibility, economic theory must be used to select the variable that produces the most plausible results. This will be known as the "decision" variable.

A first approximation criterion for the selection of the decision variable is obvious. An increase in a variable that leads to a reduction in total and marginal cost should lead to an increase in the level of comfort consumed. Thus the sign of a variable's parameter estimate in the cost equation should be opposite to the sign of the variable's parameter estimate in the consumption equation. Of the five possible candidates (SQFT, CAP, INSUL, name-plate EER, actual EER, and HAGE), only name-plate EER and HAGE pass this criterion.

Since SQFT and CAP are both highly correlated with income, their positive correlation with both cost and level of comfort is not surprising. However, INSUL and actual EER are not highly correlated with income. A possible explanation of their positive correlation (with COMF) is the nature of the experiment itself. Since its primary motivation was energy conservation, participants may have been subliminally encouraged to conserve energy (by raising their thermostat settings) more than they would have otherwise. Also since most of the variation of INSUL and actual EER was induced by the experiment, participants may not have had sufficient time (one cooling season) to regain their equilibrium.

As illustrated by figure (2), the only way a reduction in marginal cost can lead to a reduction in the level of comfort consumed is by having an upward sloping UMB which is steeper than the marginal cost curve. For normal goods, of which comfort is one, the UMB should be downward sloping. And even if the UMB was upward sloping, having a greater slope than the marginal cost curve would lead to an unstable equilibrium. Therefore, the only economic explanation is that when the experiment participants' marginal cost curves shifted rightward, there was a concomitant leftward shifting of the UMB.

The leftward shifting may have been caused by the fact that the participants knew they were in a conservation study and their energy consumption was being monitored. If this were the case, then using actual EER or INSUL would give us erroneous estimates of consumer's surplus.

The next criterion for choosing the decision variable is the slope of the implied UMB. As stated above, economic theory tells us that the slope of the Marshallian demand function (or in this case the UMB) is negative for a good that's consumption is positively correlated with income (i.e., a normal good).

For the model used here, the sign of the exponent for the level of comfort in the UMB function determines the sign of the slope. The value of the comfort exponent in the UMB function ($\Omega$) is

$$\Omega = [\alpha\delta_j/(\delta_j - \beta_j)] - 1. \tag{11}$$

Using the estimates above, if name-plate EER were the decision variable, $\Omega$ would equal .96, thus giving the UMB a positive slope. This results from the increase in the level of comfort consumed being greater than can possibly be justified by the observed reduction in marginal cost. As illustrated by figure (3), the level of comfort consumed increased as marginal cost decreased, but the observed UMB, $UMB_o$, was upward sloping and not as steep as the marginal cost curve. The only plausible economic explanation is that the actual UMB shifted rightward. The participants that received high efficiency air conditioners might have anticipated a much greater cost reduction than they actually experienced. It is interesting that when actual EER was used in the regression equations instead of name-plate EER, the UCC coefficient had the opposite sign, but was much less significant. This indicates that the households were basing their consumption decisions more on the expected cost reduction than the actual cost reduction.

The conflicting estimates of the shift in the UMB gives further support to the suspicion stated above that after one cooling season, the households had not regained an equilibrium. The usefulness of the model is underscored here since it has eliminated from consideration a parameter estimate that at first glance appears plausible but in fact is not.

We are left with HAGE as the last potential decision variable. With HAGE as the decision variable, $\Omega$ would equal -2.59. Thus HAGE meets all the criteria for a decision variable. The fact that HAGE (the age of the house) renders plausible results lends more support to the disequilibrium theory. Any cost saving housing characteristics that are correlated with HAGE (such as tree shade, etc.) have been well established for a long time. Since the variation of HAGE was not induced by the experiment, unlike the other potential decision variables, HAGE might have been insulated from the psychology of the experiment and therefore be more truly exogenous than the other variables. Thus the use of HAGE as a decision variable does not tell us how the households actually reacted to the conservation program, but how rational households <u>will</u> react to cost reductions.

However with a standard error of 4.6, we must be cautious with our estimate of the sign of $\Omega$. As stated above, since comfort was measured categorically, this large variation was expected. It will be shown that in spite of the large variation of our estimates, our conclusions are valid.

<u>Simulation</u>

<u>Uncompensated Measures</u>. We can use the parameter estimates from above to simulate the effects of a program that induces greater investment in high efficiency energy-using durables. Using the mean values of the observed data, we derive the following equations:

$$\text{Cost:}\quad C = (7.4 \times 10^{25})(\text{HAGE})^{-.09}(\text{COMF})^{12.95}, \qquad (12)$$

$$\text{Marginal Cost:} \quad C_Z = (9.6 \times 10^{26})(\text{HAGE})^{-.09}(\text{COMF})^{11.95}, \tag{13}$$

$$\text{UCC:} \quad \text{COMF} = .0.013(\text{HAGE})^{.006}, \tag{14}$$

$$\text{UMB:} \quad B_Z = .24(\text{COMF})^{-2.59}, \tag{15}$$

and

$$\text{UTB:} \quad B = -.15(\text{COMF})^{-1.59}. \tag{16}$$

One of the goals of the FPL experiment was to determine the effect on energy consumption of raising the EER rating for each residence to 10. Therefore we will simulate the affect on consumer's surplus of an increase in the EER rating from its pre-experiment mean of 7 to 10.

From the marginal cost and UMB functions, we can determine that the increase in EER would induce a decrease in the thermostat setting from $78.15^{\circ}$ to $77.82^{\circ}$. Therefore, the change in consumer's surplus would be \$.091 per cooling day and the actual reduction in the average daily cost of comfort would be \$.01. Had the thermostat setting not been endogenous to the EER rating, as some cost effectiveness studies assume, the reduction in average daily cost would have been \$.089. Therefore the model predicts that as much as 88.8% of the potential reduction in cost will be taken up in the form of greater comfort levels.

To measure the reduction (or increase) in the deadweight loss from such an inducement, we must subtract from the increase in consumer's surplus the cost of the investment. For a typical 3 ton system, the cost per EER point is \$100 per ton. Thus the incremental cost of increasing the EER rating from 7 to 10 would be \$900. The expected useful life of the system is 10 years.

Even if there were 360 cooling days in a year (which there isn't), the yearly increase in consumer's surplus would only be \$32.76. Even if the increase in consumer's surplus in future years is not discounted, the incremental cost (\$900) greatly outweighs the benefit (\$327.60). Thus such an inducement would neither conserve a significant amount of energy nor be economically efficient.

Another major goal of the FPL experiment was to estimate the effect on energy consumption from a increase in ceiling insulation to an R-value of as high as R-29. The estimated equations tell us that an increase in a residence's ceiling insulation from the pre-experiment mean of R-10 to R-29 would induce a thermostat setting reduction from 78.1° to 77.79°. The resulting increase in consumer's surplus would be \$.087 per cooling day and the reduction in average daily cost would be \$.009. If the thermostat setting had not been endogenous to the insulation level, the daily cost reduction would have been \$.084. Thus the model predicts (again) that 88.8% of the potential cost reduction would be taken up in the form of increased comfort levels.

To measure the welfare effect, we again need to compare the cost of the increased insulation with its benefit. For ceiling insulation, the industry rule of thumb for material and installation cost in Florida was \$.015 per R-value per square foot. Therefore, the cost of installing R-19 of insulation in a

2,000 square foot residence would be approximately \$570. There is no set useful life span for ceiling insulation. If we generously estimate the number of cooling days per year to be 270 and assume that the ceiling insulation doesn't depreciate at all over time, then the cost reduction per year would be \$23.49. If the discount rate were 4.12% or less, then the cost of the insulation would exceed the benefit, in other words the deadweight loss would be reduced. If the reduction in heating costs are taken into consideration, it is entirely possible that households are indeed under-investing in ceiling insulation. But due to the high relative variance of the estimate, we cannot draw any conclusions regarding the economic efficiency of induced ceiling insulation investment.

Income-Compensated Measures. Since we are estimating deadweight losses, it is possible that using an uncompensated measure of consumer's surplus might lead to significant approximation error. Thus we should use the exact consumer surplus measures, compensating variation (CV) or equivalent variation (EV), whenever it is practical to do so. Using the estimates of the model, we determine the expenditure function to be,

$$e = (v + 6.81(HAGE)^{-.009})^{1.09}. \qquad (17)$$

Using the mean values of the data, we can determine that an increase in EER from 7 to 10 is equivalent to increasing HAGE from 8.38 to 17.32. The resulting CV would be \$.091 and EV would be \$.092. Therefore for this increase in EER, the change in consumer's surplus (before rounding) would be .51% less than EV and .69% more than CV.

Likewise, an increase in INSUL from 10 to 29 would result in a CV of \$.086 and a EV of \$.087. Therefore for this increase in INSUL, the change in consumer's surplus (before rounding) is .72% less than EV and .8% more than CV.

In neither case is the approximation error, even for the deadweight loss, significant. Therefore in future studies of this sort, if household income observations are not available, which precludes the estimation of an expenditure function, the use of consumer's surplus should be adequate.

## V. COMPARISON OF RESULTS

In Hausman (1979), the demand for window air conditioners is analyzed. Hausman estimated consumers' apparent discount rates using data on air conditioner prices, EER ratings and sales data. By treating the incremental cost of a higher EER rating as an investment in exchange for future operating cost reductions, Hausman estimated that the discount rate was approximately 25%. Noting that this estimate seemed very high, he attributed it to a "defective telescoping" effect on the part of consumers. In other words, at the observed rate of sales for air conditioners, it would take a discount rate of 25% to make the present value of predicted future cost reductions equal to the observed incremental cost of investment in air conditioners.

In his study, Hausman made the reasonable assumption that the EER rating (a measure of the required electricity for a given amount of heat displacement) was an accurate predictor of the electricity requirements of an air conditioner and that it was not sensitive to varying conditions. Therefore Hausman predicted that an increase in the EER rating from 7.5 to 8 would decrease energy consumption by 6.4% (if the thermostat setting didn't change).

The results of our study however, indicate that energy consumption would decrease by only .58% from such an EER rating change (if the thermostat setting did not change). Thus, Hausman's predicted future operating cost reductions may have been grossly overestimated, which would result in an overestimated discount rate.

This situation might be similar to the problem frequently encountered by owners of new cars that fail to achieve their predicted gas mileage according to the EPA gas mileage rating. The EPA rating is not a good predictor of actual gas mileage and consumers are informed of this. The EPA rating is determined under controlled conditions by an impartial government agency and is intended to be used for comparison purposes only. In contrast, the EER rating is calculated by the manufacturer. If the findings of this study are accurate, then EER ratings should be viewed with at least as much skepticism as EPA ratings.

## VI. CONCLUSIONS

Since the days of the fuel shortage in the 1970's, industry experts have concluded that consumers were not fully taking advantage of several cost saving investments in energy-using durables. These conclusions were drawn on a number of assumptions, namely that consumers would not choose to substitute money for increased comfort levels and that laboratory tested efficiency ratings for these durables would be consistent under varying conditions.

Using a utility maximization model, we found that for the group of households tested (on average), the substitution of money for increased comfort was very significant (approximately 90%), although the variance of the response was relatively high. This would indicate that the reduction of electricity consumption will be very difficult to achieve through customer subsidization or rebate programs.

As for the perceived lack of cost minimization on the part of households, we found that in the case of high efficiency air conditioners, the observed households were making the correct decisions. The future increases in consumer's surplus from a high EER rating would not offset the increase in the initial cost of the air conditioning system.

The results for ceiling insulation were less certain. Due to the high variance of the estimates, we could not rule out the possibility that households would be better off with increased levels of ceiling insulation. Ceiling insulation would presumably reduce space heating costs in cold weather months. Since we only had data on cooling, we were unable to draw any conclusions regarding insulation.

Finally, the model was designed to eliminate the approximation errors of using uncompensated measures of deadweight losses. The results showed that in this case, the approximation error was insignificant.

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## FOOTNOTES

1. See Friedan and Baker (1983), Messenger (1984), Stern (1984), and Stobaugh and Yergin (1979).

2. See Hausman (1979).

3. In this study we ignore all considerations of the possible externalities of being dependent on foreign suppliers of oil or considerations of the cost structure of electric utilities.

4. The use of other functional forms was attempted, but with less satisfactory results.

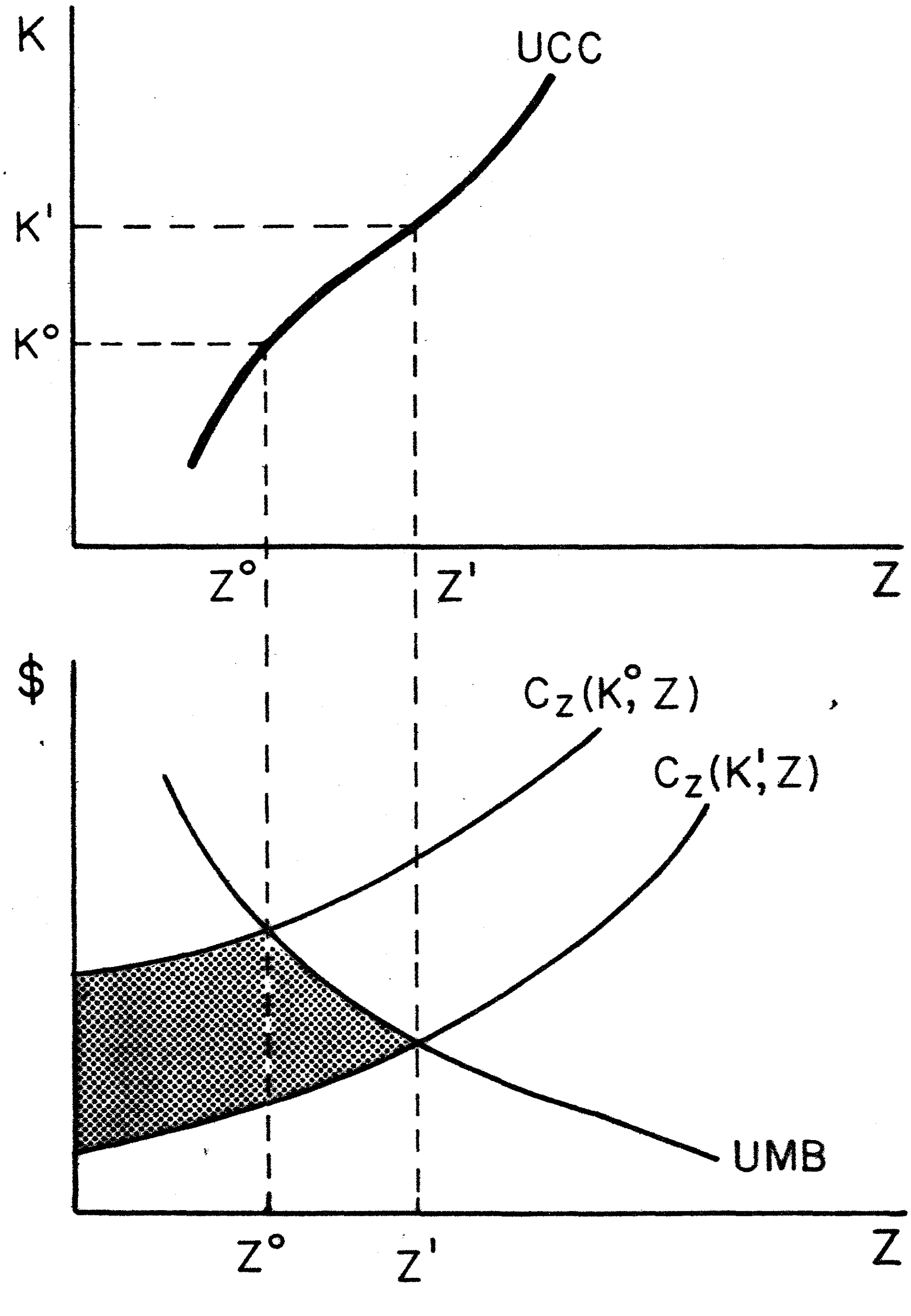


Figure (1)

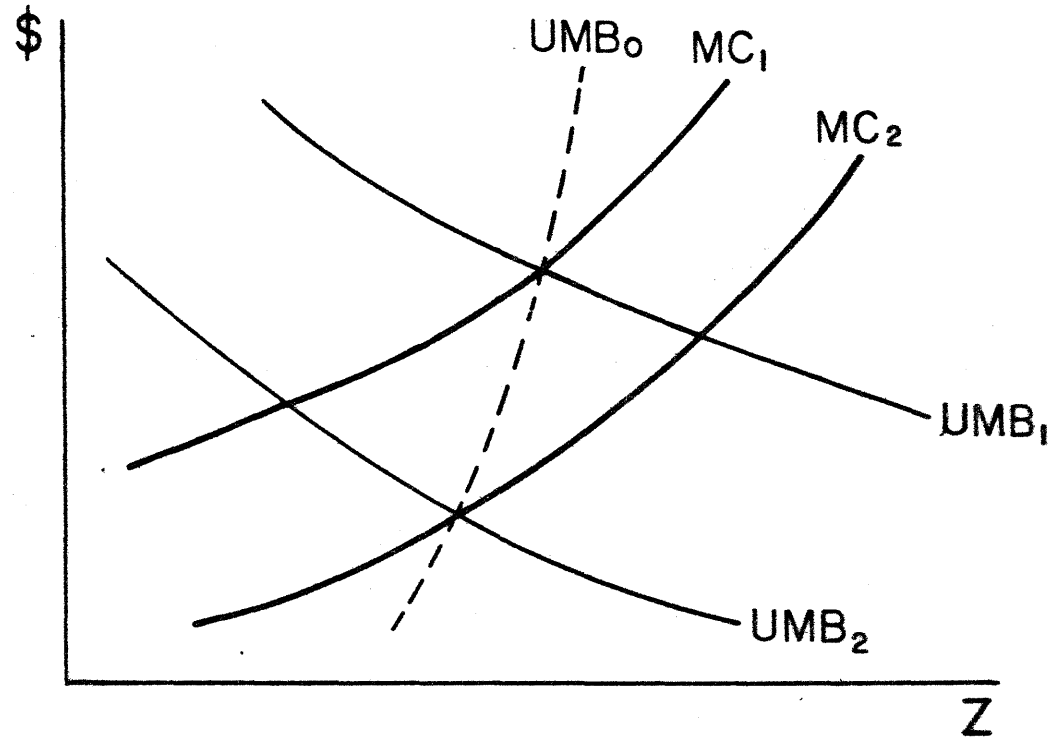


Figure (2)

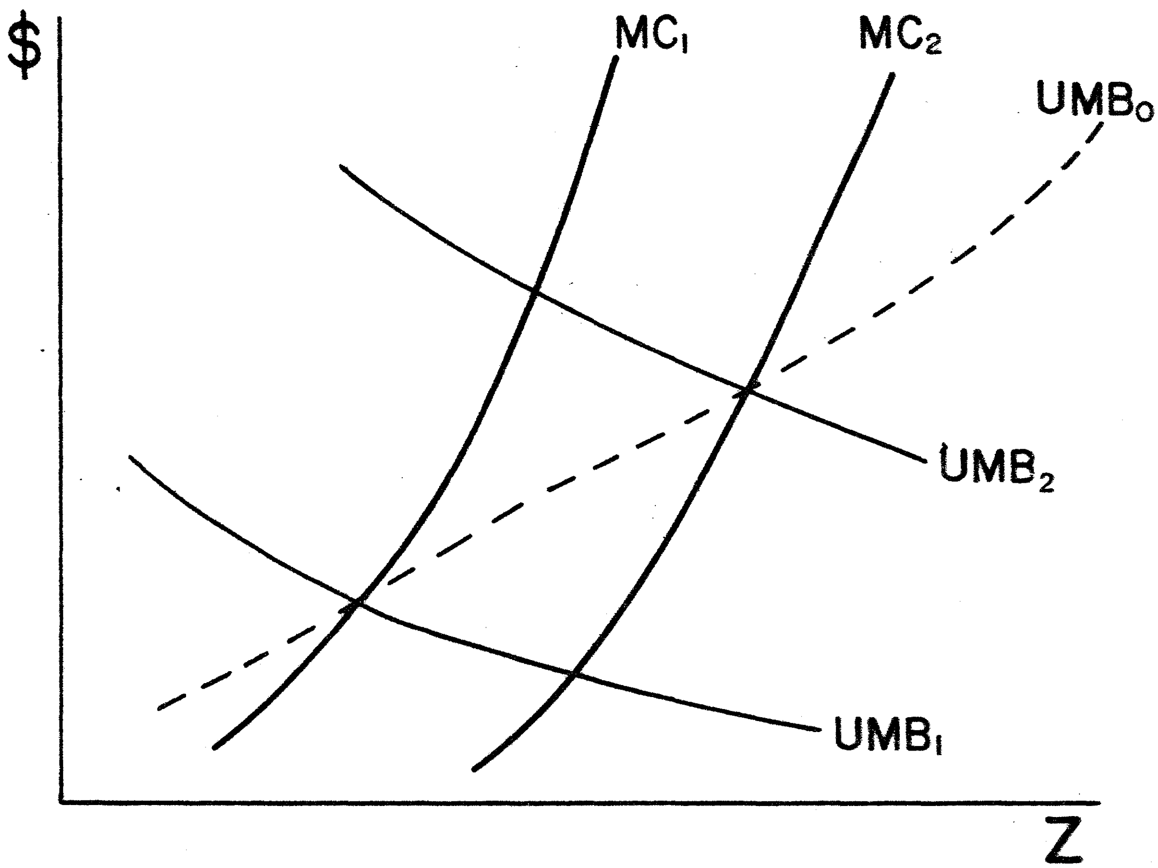


Figure (3)

TABLE (1) Cooling Study Estimation.

| Right-Hand Variables | Left-Hand Variables: COST | COMF |
|---|---|---|
| Intercept | -14.63 (-.69) | -4.58 (-57.52)* |
| COMF | 12.95 (3.52)* | ---- |
| EER | -.17 (-1.09) | .02 (3.65)* |
| INSUL | -.06 (-1.26) | -.003 (-2.4)* |
| TEMP | 14.59 (27.2)* | -.001 (-.07) |
| PRICE | 1.00 (assumed) | .003 (.23) |
| SQFT | .44 (3.65)* | .01 (4.38)* |
| CAP | .45 (3.76)* | .004 (1.22) |
| HAGE | -.09 (-2.45)* | .006 (7.34)* |
| INCOME | ---- | .006 (4.87)* |
| NFAN | ---- | -.003 (-7.55)* |
| NO-6 | ---- | .003 (2.24)* |
| N7-21 | ---- | -.0008 (-1.42) |
| N22-64 | ---- | -.001 (-.96) |
| N65 | ---- | .004 (3.26)* |

Weighted $R^2$ for the system = .3000.

* Significant at the 95% confidence level.

Variable Definitions:

COMF ≡ the comfort index (inverse of the mean thermostat setting),

EER ≡ energy efficiency ratio (heat removal per watt of energy input),

INSUL ≡ R-value of ceiling insulation,

TEMP ≡ average daily mean outdoor temperature for the month,

PRICE ≡ price of electricity,

SQFT ≡ square footage of the residence,

CAP ≡ capacity of the central cooling unit (BTU's/hour),

HAGE ≡ age of the residence,

INCOME ≡ household disposable income,

NFAN ≡ number of paddle fans,

N0-6 ≡ number of people in household 6 years old or younger,

N7-21 ≡ number of people in household between 7 and 21 years,

N22-64 ≡ number of people in household between 22 and 64 years,

N65 ≡ number of people in household 65 years and older.