MULTIPLE MODELING OF PROPENSITY TO ADOPT RESIDENTIAL ENERGY CONSERVATION RETROFITS

by

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ABSTRACT

This paper concerns the propensity of American homeowners to adopt three residential energy conserving practices (adding insulation, adding storm doors or windows, adding caulking or weatherstripping). We present an analysis of the National Interim Energy Consumption Survey of 1978-1979 using two distinct statistical models: the multivariate log-linear/logistic model, and the multivariate structural probit model with latent variables. The two models are shown to be complementary in that they provide different answers to different questions.

KEY WORDS


ACKNOWLEDGEMENT

We are grateful to Dr. Bengt Muthén for his helpful comments about our structural probit model, and for supplying us with an early version of his LACCI program. Dr. Houston Stokes supplied an improved version of our multivariate log-linear/logistic program; Rosemary Gallavan, S. Ganeshalingam, and Steven Ullery managed the data and ran the programs.
1. Introduction and Summary

This paper examines the relationships between residential energy conservation practices and the characteristics of households that may practice them. The study is confined to three specific residential energy conservation practices that involve making some structural change (retrofit) to the house:

\( P_1 \) = Adding storm doors or windows, or adding doors or windows with insulating glass (this practice is called ASTORMS in the computer program and model);

\( P_2 \) = Adding some type of insulation in the roof, attic, or outside walls (AINS);

\( P_3 \) = Installing weatherstripping around outside doors or windows, caulking around windows or doors leading outside; or installing plastic coverings over outside windows or doors (ASELFDO).

To explain these practices the study explores 16 potentially exogenous, socio-economic and demographic characteristics of households. The research has developed from work described in Press and Tanur (1982).

The types of relationships developed in this paper are of interest for both basic research and for policy considerations. Knowledge about what kinds of people are most likely to employ practices \( P_1, P_2 \), and \( P_3 \) might shed light on the kinds of people who are likely to adopt other kinds of "innovations." Differentiation between those who adopt
one kind of retrofit and those who adopt another may give us clues to the social and psychological processes that underlie adoption. In turn, these clues to typifications and processes should be of use to policy-makers in targeting campaigns to encourage adoption of conservation practices.

Investigations of energy conservation related methodologically to the present research include work by McFadden (1978), who used a logistic regression model for choice of residential location; Hausman (1979), who used a discrete choice model (logistic regression) for purchase of energy-using durables; and McFadden and Dubin (1982), who investigated a heating model for single family detached dwellings, using data from the same annual survey we used (see Section 2), although their data set covered a later period. A National Academy of Sciences report (1982) suggested several hypothetical models for behavioral and social aspects of the propensity to conserve energy.

Social scientists have suggested that researchers should deal realistically with the energy user as more than a "rational man consumer/investor." Specifically, Darley and Beniger (1981) suggested we deal with our jointly varying data multidimensionally. Moreover, others have suggested that attitudes of energy users towards conservation be studied. Indeed, many such attitudinal studies have been carried out; an excellent review is presented in Farhar, Weiss, Umfeld, and Burns (1979). A recent example that traces a causal model from contextual influences through personal values to behavior is presented by Black, Stern, and Elworth (1985). Darley and Beniger (1981) call for the application of a model proposed by Rogers and Shoemaker (1971) in
understanding why some innovations are adopted and some are not, and why some people adopt and some do not.

In the sequel we study two complementary (not alternative) models to understand the very complex collection of processes associated with residential energy conservation propensity and behavior, as manifested by the adoption of the three retrofit practices, $P_1$, $P_2$, and $P_3$. The models have different objectives and attempt to answer different questions about residential energy conservation processes. The first model is a multivariate log-linear/logistic model; the second, a multivariate structural probit model with latent variables. (The multiple modeling approach was also adopted by Maddala and Trost (1981).)

The first of our two models assumes the joint probability of adopting any subset of the three energy conservation practices we study can be broken down into effects attributable to each of the practices separately, and finds that each effect depends in a logical way upon whether or not the household had already implemented such a practice, as well as on other explanatory variables. In our second model, we use the structural probit analysis to look at "propensity to add retrofits" as latent intervening variables, partially generated by a few contextual explanatory variables which we are able to measure, and which, in turn, precipitate the adoption of specific retrofits. Data from the National Interim Energy Consumption Survey (NIECS) of 1978-1979 were used to estimate the two models.

We shall show that this second model (structural probit) is richer in structure than is the log-linear logistic model (because the latter
model formulation does not normally include latent variables). The probit model suggests that the threshold for adopting P₃ is less than that for P₂, which in turn is less than that for P₁. Moreover, a household's propensity to adopt any one of the three practices depends, of course, on whether that household has already adopted that practice. Interestingly, that propensity depends, in addition, on whether the household has previously adopted the other energy conservation retrofits.

Another result is that while the log-linear/logistic model finds that different sets of explanatory variables are responsible for each of the three contributions to the joint probability of adoption, the structural probit model finds that essentially the same set of explanatory variables explains the threshold stimulus for adoption for all three practices.

The data set is described fully in Section 2; the models are described in Section 3. We present our empirical results in Section 4 where we also compare the results of the two models and discuss their substantive and methodological implications.

2. Data

The data for our analysis come from the National Interim Energy Consumption Survey, carried out during the winter of 1978-1979 by Response Analysis Corporation of Princeton, New Jersey, for the Office of Consumption Data Systems, Energy Information Administration, U.S. Department of Energy. This was a national survey of 4,081 households, with sampling by multi-stage area probability sampling, relatively
large cluster sizes, and primarily personal interviewing. The survey instrument is given as an Appendix in Press and Tanur (1982).

Our analysis is confined to those households in which the head of the household (or spouse) responded to a personal interview; where the household paid for its own heat and had occupied the house since before the beginning of the reference period (January 1977 to the time of the interview); where the house was owner-occupied and single family; and where all the retrofit questions were answered. All analyses were based on the 1641 households that fulfilled all these criteria.

We used the survey data to construct three kinds of variables: endogenous (dependent), binary variables indicating retrofit adoption or not; binary "eligibility" variables indicating whether a household was physically capable of adopting a retrofit or not, in the sense that the household had not already done so at the beginning of the reference period; and exogenous (independent) variables that might influence adoption.

We used three endogenous variables, each coded "one," if the household reported adopting the retrofit(s) in question, and "zero" otherwise: ASTORMS indicated whether the household reported adding storm doors or windows during the reference period (that is, the adoption of practice $P_1$); AINS indicated whether the household reported adding insulation to the attic or roof or to the walls during the reference period (that is, the adoption of practice $P_2$); and ASELFDO indicated whether the household reported adding weatherstripping, caulking around doors or windows, or plastic covering over windows during the reference period (that is, the adoption of practice $P_3$).
A detailed description of the construction of the binary variable for eligibility to add storm windows will be illustrative. If at the end of the reference period the number of windows reported covered with storms was smaller than the total number of windows in the residence, we coded the variable "one." The variable was also coded "one" if at the end of the period the total number of windows covered with storms equaled the number of windows and the family reported having added storm windows during the reference period. The variable was coded "zero" if at the end of the reference period the total number of windows covered with storms was the same as the total number of windows in the residence and the household did not report adding storm windows during the reference period; this meant to us that at the beginning of the reference period all storm windows possible had been installed. Because weatherstripping, caulking, and adding plastic covers are "repeatable" retrofits, we did not construct "eligibility" variables for these activities.

Our third set of variables were descriptions of the household that were used as additional exogenous variables. These and the eligibility variables are shown in Table 1.

3. Modeling

The process by which households decide to adopt, or not adopt, a particular residential energy conservation practice involves a compounding of various factors. Ultimately, it involves developing certain attitudes toward energy conservation, and then following through on those attitudes with specific behavior.
Table 1

Eligibility and Exogenous Variables

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOORSEL</td>
<td>= 1, if household was eligible to add storm doors or doors with insulating glass; 0, otherwise;</td>
</tr>
<tr>
<td>WINSEL</td>
<td>= 1, if household was eligible to add storm windows or windows with insulating glass; 0, otherwise;</td>
</tr>
<tr>
<td>ATTSSEL</td>
<td>= 1, if household was eligible to add attic or roof insulation; 0, otherwise;</td>
</tr>
<tr>
<td>WALLSSEL</td>
<td>= 1, if household was eligible to add insulation to the outside walls of the house; 0, otherwise;</td>
</tr>
<tr>
<td>KRURURB</td>
<td>= 1, if household is located in a rural area; 0, otherwise;</td>
</tr>
<tr>
<td>MARØ1</td>
<td>= 1, if head of household was currently married; 0, otherwise;</td>
</tr>
<tr>
<td>SMALLKID</td>
<td>= 1, if the household included a child 5 years old or younger; 0, otherwise;</td>
</tr>
<tr>
<td>OLDFOL</td>
<td>= 1, if the household included an individual over 70 years old; 0, otherwise;</td>
</tr>
<tr>
<td>NOTWORK</td>
<td>= 1, if the household included a person who was not employed even part-time; 0, otherwise;</td>
</tr>
<tr>
<td>WHITENW</td>
<td>= 1, if the respondent was white; 0, otherwise;</td>
</tr>
<tr>
<td>MAXED</td>
<td>= years of education of respondent or spouse, whichever is greater;</td>
</tr>
<tr>
<td>ESTINC</td>
<td>= Respondent's estimate of total (gross) combined income for all household members; coded as midpoint of interval;</td>
</tr>
</tbody>
</table>
Table 1 (continued)

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHEATDD</td>
<td>= heating degree days = sum (over days of the heating season) of the difference between 65 degrees and the mean temperature of the day. High numbers of degree days signify cold climates;</td>
</tr>
<tr>
<td>AGEHOUSE</td>
<td>= difference between the time of the survey and the respondent's estimate of when the house was built; calculated from midpoints of intervals; all houses built before 1940 were arbitrarily assigned a building date of 1920;</td>
</tr>
<tr>
<td>NROOMS</td>
<td>= number of rooms in the house;</td>
</tr>
<tr>
<td>NHELDMEM</td>
<td>= number of members in the household.</td>
</tr>
</tbody>
</table>
For example, a household may develop a strong propensity towards energy conservation, but it may not have the monetary and human resources to purchase insulating materials, and to install them; in this case, a particular retrofit practice will not be adopted.

We propose two distinct models for understanding energy conservation propensity and behavior:

A. The multivariate log-linear/logistic model;
B. The multivariate structural probit model with latent variables.

They will each be described below. We will employ the same data set to estimate both models. The issue of which model is the "correct" one does not arise. It is a matter of using one (Model A) to study adoption behavior, and using the other (Model B) to study propensity towards residential energy conservation. Each model will be useful for different purposes.

3.1 Log-linear/Logistic Model

Model A models residential energy conservation adoption behavior directly. It relates three correlated, observable, binary adoption variables to 16 observable explanatory variables through a multivariate log-linear regression model (see Nerlove and Press, 1973). Besides the basic research questions concerning the relations between socio-demographic characteristics and adoption practices, this model addresses policy questions. One of its further objectives is to relate possible
policy targeting variables (such as household income, education level, and ethnicity) to the probabilities of adopting residential energy conservation retrofit practices. Thus, certain types of neighborhoods and households could be targeted by policy-makers for campaigns for particular kinds of retrofit adoptions. Whether this type of targeting should take the form of targeting "high probability" neighborhoods or households (because the campaign would more likely be successful there), or targeting "low probability" neighborhoods or households (because few adoptions would be likely to occur there in the absence of such a campaign) is a policy question not addressed in this research.

Within the model, we study the effects of each of the separate adoption practices on the joint probability of adopting all three practices. We also study conditional dependencies of two adoption practices with the third variable held fixed. Moreover, we permit the effects to be explainable in terms of specific explanatory variables. The model is presented below.

Define the adoption variable (endogenous):

\[
y_{ij} = \begin{cases} 
1, & \text{if household } j \text{ adopted residential energy conservation practice } P_i \text{ during the reference period;} \\
0, & \text{otherwise,}
\end{cases}
\]

for \( i=1,2,3, \) and \( j=1,\ldots,1641 \).

Define the joint adoption probability

\[
p_{i_1 i_2 i_3}(x_j) = P(y_{1j} = i_1, y_{2j} = i_2, y_{3j} = i_3 | x_j),
\]
where $i_1, i_2, i_3$ take on the values 1 or 0, depending upon whether or not an energy conservation practice is adopted, or not; and $x_j$ denotes the vector of 16 explanatory variables for household $j$.

For Model A, we assume (after supressing the $j$, designating household),

$$
\log p_{i_1 i_2 i_3}(x) = \mu + \alpha_{i_1} + \beta_{i_2} + \gamma_{i_3} + \delta_{i_1 i_2} + \epsilon_{i_2 i_3} + \xi_{i_1 i_3} + \eta_{i_1 i_2 i_3},
$$

where $\mu$ denotes the overall effect; $\alpha_{i_1}$ denotes the effect on the joint probability, $p$, of the first conservation practice being at level $i_1$; $\beta_{i_2}$ denotes the effect on $p$ of the second conservation practice being at level $i_2$; $\gamma_{i_3}$ denotes the effect on $p$ of the third conservation practice being at level $i_3$; $\delta_{i_1 i_2}, \epsilon_{i_2 i_3}, \xi_{i_1 i_3}$ denote second order interaction effects of practices 1 and 2, practices 2 and 3, and practices 1 and 3, respectively; and $\eta_{i_1 i_2 i_3}$ denotes the third order interaction effect among the three practices.

The three adoption practices are independent if and only if all three second order interaction effects, and the third order interaction effect, are zero. We permit all of the main effects to depend linearly on the explanatory variables, $x$, whereas we assume the interaction effects are constant. Thus, for example, assume $\alpha_{i_1} = x_i^* \zeta_{i_1}$, where $\zeta_{i_1}$ denotes an unknown vector of coefficients. Finally, we adopt the
usual analysis of variance constraints on the effects to make identification of all parameters possible. Thus, $\alpha_1 = \beta_1 = \gamma_1 = 0$, and $\delta_{i2} = \delta_{i1} = 0$, etc., where a dot in place of a subscript means that we have averaged over that subscript.

Our data consist of a sample $(y_{1j}, y_{2j}, y_{3j}, x_j)$, for $j = 1, \ldots, N$, where $N$ denotes the number of households in the survey ($N = 1641$). We use maximum likelihood estimation (MLE) to estimate the parameters of the model. The procedure has been implemented in a computer program developed by Nerlove and Press, called Log-Lin. An improved version of Log-Lin, supplied by Houston Stokes, was used on the University of California, Riverside, IBM-4341. Fractions of households that have adopted a particular energy conserving practice are interpreted as estimates of the probability of adopting this procedure by the underlying population.

3.2 Latent Variable/Structural Probit Model

Model B is a multivariate structural probit model with latent variables. We use the same three binary adoption variables (endogenous) and the same 16 exogenous variables defined by the vector $x$. In between these two sets of variables, however, we assume some structural relations involving unobservable latent variables.

Assume $y_i = 1$, if $y_i^* > \tau_i$, $i = 1, 2, 3$, and $y_i = 0$, otherwise. The $y_i$'s are the (observable) binary adoption variables defined above. The $y_i^*$'s are (unobservable) latent variables, and the $\tau_i$'s are unobservable threshold values. Assume
\[ y_i^* = \lambda_i \eta, \quad i = 1, 2, 3, \quad (2) \]

and

\[ \eta = \gamma^\top x + \xi, \quad x = (x_i), \quad (3) \]

where

\[ g(\xi) = N(0, \psi), \quad (4) \]

\( \gamma \) is a vector of unknown coefficients, and \( \xi \) is normally distributed with mean zero and variance \( \psi \). For identification purposes we take \( \lambda_1 = 1 \), a priori. The model is seen to be driven by a single scalar latent variable \( \eta \), which in turn gives rise to three separate latent variables, by simple proportionality. In fact, we could rewrite the model in the form:

\[ y_i = \begin{cases} 1, & \text{if } \eta > (\tau_i / \lambda_i), \quad i = 1, 2, 3 \\ 0, & \text{otherwise} \end{cases} \quad (5) \]

The two models are depicted in Figure 1, in path analysis format, for convenient comparison. Note that in Figure 1, the double bars in the boxes for \( y_1, y_2, y_3 \) denote binary variables. Moreover, all circled variables are unobservable (latent), while variables in boxes are assumed to be observable.

In Model B we assume conditional independence of the observables conditional on the latent variables. Specifically, assume
Log-linear/Logistic Model of Energy Conservation

Structural Probit Model of Energy Conservation

FIGURE 1
\[ P(y_1 = i_1, y_2 = i_2, y_3 = i_3 | y_1^*, y_2^*, y_3^*) = P(y_1 = i_1 | y_1^*) P(y_2 = i_2 | y_2^*) P(y_3 = i_3 | y_3^*) \]

This model is estimated by a method proposed by Muthén, 1984, involving a three-stage, limited information, generalized least squares estimation procedure, using a computer program called LACCI: Latent Variable Analysis with Dichotomous, Ordered Categorical, and Continuous Indicators.

4. Empirical Results and Discussion

Empirical marginal and joint probabilities of adoption of the retrofit practices appear in Table 2. A glance at those probabilities shows clearly that adoption of one retrofit is not independent of adoption of the others. Further, the respondents are far more likely to adopt the self-help measures than either of the other classes of retrofits. This suggests, in the spirit of Guttman scaling, that the self-help measures are "easier" to adopt (as indeed we would expect from considerations of expense and trialability). In fact, the empirical probability that a respondent would adopt either or both of the "harder" retrofits and not adopt the self-help measures is only .148--the proportion of non-Guttman scale type responses. We shall see this kind of scaling result reflected in the threshold results of the probit model with latent variables detailed below, but before discussing the empirical results of that model, let us turn to the results of the log-linear logistic model.
Table 2

Empirical Marginal and Joint Adoption Probabilities

<table>
<thead>
<tr>
<th>Event</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(ASELFDO)</td>
<td>0.506</td>
</tr>
<tr>
<td>P(ASTORMS)</td>
<td>0.171</td>
</tr>
<tr>
<td>P(AINS)</td>
<td>0.159</td>
</tr>
<tr>
<td>P(ASELFDO ∩ ASTORMS)</td>
<td>0.125</td>
</tr>
<tr>
<td>P(ASELFDO ∩ AINS)</td>
<td>0.116</td>
</tr>
<tr>
<td>P(ASTORMS ∩ AINS)</td>
<td>0.057</td>
</tr>
<tr>
<td>P(ASELFDO ∩ ASTORMS ∩ AINS)</td>
<td>0.052</td>
</tr>
</tbody>
</table>

4.1 Results of Log-Linear Modeling

Letting $p_{111}(x) = P(y_1 = 1, y_2 = 1, y_3 = 1 | x)$ we find the estimated equations (see Equation (1)),

$$
\log \hat{p}_{111}(x) = x' \hat{\alpha}_1 + x' \hat{\beta}_1 + x' \hat{\gamma}_1 \\
+ \hat{\delta}_{11} + \hat{\epsilon}_{11} + \hat{\xi}_{11} + \hat{\eta}_{111},
$$

(6)

where:

$$
\begin{bmatrix}
x' \hat{\alpha}_1 \\
adding\ storm\ (doors\ or\ windows)
\end{bmatrix}
= -4.87223 + 1.1304 (DOORSEL) + 2.0767 (WINSEL) \\
(-8.3777) (8.9154) (11.794) \\
+ .24577 (KRURURB) + .39638 (SMALLKID) \\
(2.5564) (2.0880) \\
+ .00031684 (NHEATDD), \\
(8.6193)
$$

(7)
\[
\begin{align*}
\begin{bmatrix}
\frac{x'}{\beta_1}^{*}
\end{bmatrix}
&= -6.4884 + 4.1143 (\text{ATTSEL}) + 1.0285 (\text{WALLSEL}) \\
&\quad (-9.8266) \quad (20.794) \quad (7.7671) \\
&- 0.35060 (\text{KRURURB}) + 0.71692 (\text{MAR01}) \\
&\quad (-3.5469) \quad (4.4156) \\
&- 1.4446 (\text{OLDFOLK}) + 1.2907 (\text{WHITENW}) \\
&\quad (-6.7258) \quad (5.8583) \\
&+ 0.00034095 (\text{NHEATDD}) - 0.033838 (\text{AGEHOUSE}) \\
&\quad (6.2810) \quad (-9.2453)
\end{align*}
\] (8)

\[
\begin{align*}
\begin{bmatrix}
\frac{x'}{\beta_1}^{*}
\end{bmatrix}
&= -0.36019 (\text{ATTSEL}) + 0.32235 (\text{MAR01}) \\
&\quad (-2.8867) \quad (2.6327) \\
&+ 0.35152 (\text{SMALLKID}) - 0.34118 (\text{OLDFOLK}) \\
&\quad (2.3732) \quad (-2.6177) \\
&+ 0.54617 (\text{WHITENW}) + 0.046021 (\text{MAXED}) \\
&\quad (3.0506) \quad (2.5993) \\
&- 0.000013545 (\text{ESTINGOME}) + 0.000096339 (\text{NHEATDD}) \\
&\quad (-3.2506) \quad (3.4602) \\
&+ 0.0082274 (\text{AGEHOUSE}) - 0.062105 (\text{NROOMS}) \\
&\quad (3.0912) \quad (-2.0496) \\
&+ 0.10010 (\text{NHSLDMEM}) \\
&\quad (2.9896)
\end{align*}
\] (9)

\[
\begin{align*}
\hat{\xi}_{11}^{(1,2)} &= 1.1157, & \hat{\xi}_{11}^{(2,3)} &= 1.6639 \\
&\quad (4.7068) & \quad (4.3059) \\
\hat{\xi}_{11}^{(1,3)} &= 1.6137, & \hat{\eta}_{111}^{(1,2,3)} &= 0.76875 \\
&\quad (4.4291) & \quad (2.0389)
\end{align*}
\] (10)
Explanatory variables not present in Equations (7), (8), and (9) did not have coefficients that were statistically significant at the 5% level or smaller. (Note that the third order interaction term is only marginally significant.) The figures in parentheses below the coefficients are asymptotic Student t-ratios.

The log-likelihood function was -2019.016 for this model, so that there is no doubt that we have established a statistically significant relationship.

It is clear from Equation (10) that the three factors are not independent. Since the three way interaction term has a t-ratio of about 2, however, the factors are close to being conditionally independent, pairwise.

Equation (7) shows us that the effect on the joint probability for all three adoptions of adding storm doors or windows increases with eligibility to adopt this practice (because the storm doors or windows have not yet been added). This effect on the joint probability also increases when the household is rural, when there are small children at home, and as the number of heating-degree-days increases.

The effect on the joint probability for all three adoptions of adding insulation (see Equation (8)) increases with eligibility to add insulation and increases for urban households; it increases if the household has married occupants, as the number of heating-degree-days increases, and if the occupants are white. The effect decreases if there are old people in the household, and decreases as the age of the house increases.
The effect on the joint probability for all three adoptions of the do-it-yourself factor decreases with eligibility to add attic insulation; the effect increases if married people live in the household; it increases if there are small children at home; it decreases if there are old people at home; it increases in white households; and increases with the education level of the household heads. The effect decreases with the household income (so the lower the income, the more of a contribution there will be to the joint adoption probability), the effect increases with the number of heating degree days, with the age of the house, and with the number of household members, but decreases with the number of rooms in the house.

4.2 Results of Structural Probit Modeling

The structural probit model we developed is defined by Equations (3), (4), and (5). Empirical results obtained from fitting this model to the NIECS data using the computer program LACCI are given below. (Values given in parenthesis below coefficients are again asymptotic t-ratios.)

\[
\hat{\beta} = \begin{bmatrix} 1.880 & 5.169 & .890 \end{bmatrix}', \\
\sim (11.899) (12.455) (6.953)
\]

\[
\hat{\gamma} = \begin{bmatrix} 1.000 & 3.696 & .895 \end{bmatrix}', \\
\sim (known) (8.556) (8.524)
\]

\[
\text{var}(\eta) = \hat{\theta} = .123, \\
\sim (5.125)
\]

\[
\hat{\eta} = \hat{\gamma}' \hat{x} = (.105)(\text{WINSEL}) + (.525)(\text{ATTSEL}) \\
(3.00) (8.75) \\
+ (.109)(\text{WALLSEL}) + (.155)(\text{MAR01}) \\
(3.21) (3.69)
\]
- (.226)(OLDFOLK) + (.259)(WHITENW) 
\(-4.81\) \(\text{(4.71)}\)

+ (.014)(MAXED) + (.071)(NHEATDD) - (.004)(AGEHOUSE) 
\((2.33)\) \(\text{(6.45)}\) \(\text{(-4.00)}\)

Only coefficients statistically significant at the 5\% level or lower are presented. Thus, only 9 of the 16 possible explanatory variables remain in the model.

Now let \(\delta_i = \frac{\tau_i}{\lambda_i}\), \(i = 1, 2, 3\). Then,

\[
\delta = (\delta_i) = \begin{bmatrix} \hat{\tau}_i \hat{\lambda}_i \end{bmatrix} = \begin{bmatrix} 1.880 & 1.399 & .994 \end{bmatrix} \\
(11.899) (5.073) (3.816)
\]

It is straightforward to check (using the delta method) that in large samples, the standard deviations of ratios \((\tau_i/\lambda_i)\) are bounded from above by

\[
\left| \frac{\text{standard deviation} (\hat{\tau})}{\hat{\lambda}} + \frac{\hat{\tau}}{\hat{\lambda}^2} \cdot (\text{standard deviation} (\hat{\lambda})) \right|.
\]

Those upper bounds give rise to the t-ratios shown above for \(\hat{\delta}\). This means the model may be expressed (using Equation (5)) as

\[
y_1 = 1, \text{ if } \hat{\eta} > 1.880, \quad \hat{\eta} = \hat{\tau}_i / \hat{\lambda}_i \\
y_2 = 1, \text{ if } \hat{\eta} > 1.399, \quad \hat{\eta} = \hat{\tau}_i / \hat{\lambda}_i \\
y_3 = 1, \text{ if } \hat{\eta} > .994, \quad \hat{\eta} = \hat{\tau}_i / \hat{\lambda}_i.
\]
Thus, as \( \hat{n} \), the propensity to adopt residential energy conservation retrofits, increases to .994, and then goes beyond this value to at least 1.880, a family is likely to adopt \( P_3 \), and then \( P_2 \), and then \( P_1 \).

One implication of the results in Model B is that it is easiest for families to adopt the self help measures, and hardest for them to add storm doors, storm windows, or insulating glass. (We note that these results are slightly different from those that follow from the raw empirical probabilities in Table 2, where the adoption probabilities of \( P_1 \) and \( P_2 \), while very close, are reversed.)

The chi-square value for the test of goodness of fit of Model B to the data was 257.661 for 32 degrees of freedom, a statistically significant result.

It is seen that \( \hat{n} \) increases as the three eligibility variables increase (not surprisingly); it increases if the heads of household are married; if the family is white; if the heads of the household are more educated; and if the home is in a cold climate (high number of heating degree days). Conversely, \( \hat{n} \) tends to decrease if there are old folks included in the household; or if the house is old.

The results of Model B suggest that the most easily reached targets for energy conservation are households in neighborhoods with white, better educated, married heads of households in cold climates, where the houses are of recent vintage. We reiterate that whether these easiest targets are the appropriate ones is a policy question not here addressed.
4.3 Discussion

By their very structure the two models shed light on different aspects of the adoption process. The structure of Model A suggested that we examine the effects attributable to each of the adoptions separately to see if they could be treated as independent, or possibly conditionally independent. We conclude that they are surely not independent, but are almost pairwise conditionally independent. The structure of Model B, on the other hand, encouraged us to view the processes leading to the adoption of the three practices as totally intertwined. Moreover, the attitudinal constructs intervening between our measured socio-demographic variables and our measured adoptions of conservation practices appear to be faithful representations of the social and psychological processes involved in decisions to adopt.
REFERENCES


