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HOUSEHOLD WATER CONSERVATION RETROFIT ACTIVITY:
A DISCRETE CHOICE MODEL USING SURVEY DATA

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ABSTRACT

Economic analyses of residential water demand have typically
concentrated on price and income elasticities.  In the short run, a
substantial change in water prices might induce only small changes in
consumption levels.  As time passes, however, households will have the
opportunity to "retrofit" existing water-using equipment to make it less
water-intensive.  This produces medium- to long-run demand elasticities that
are higher than short-run studies suggest.  We examine responses to water
conservation questions appearing on the Los Angeles Department of Water and
Power's 1983 Residential Energy Survey.  We find that households' decisions
to install shower retrofit devices are influenced by the potential to save
money on water <u>heating</u> bills.  We attribute toilet retrofit decisions more to
non-economic factors which might be characterized as "general conservation-
mindedness."  The endogeneity of these retrofit decisions casts some doubt on
the results of studies of individual households that treat voluntary
retrofits as exogenous.

# THE DETERMINANTS OF HOUSEHOLD WATER CONSERVATION RETROFIT ACTIVITY
## A DISCRETE CHOICE MODEL USING SURVEY DATA

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Economic analyses of residential water demand have typically concentrated on price and income elasticities. (For example, see Howe and Linaweaver [1967], Hanke [1970], Young [1973], Morgan and Smolen [1976], Gibbs [1978], Danielson [1979], Foster and Beattie [1979], Billings and Agthe [1980a,b], Chicoine, Deller, and Ramamurthy [1986], and Teeples [1988a,b]). In the short run, a substantial change in water prices may induce only small changes in consumption levels.[1] Some of these changes are merely behavioral and temporary.

As more time passes, however, households will have the opportunity to "retrofit" existing water-using equipment to make it less water-intensive. Some of these medium-run retrofits are simple and inexpensive. As households gradually install water conservation retrofits, the eventual price elasticity of demand for water should be higher than short-run studies suggest. For instance, Carver and Boland [1980] find a short-run time-series elasticity for aggregate annual water use of less than 0.1, but their long-run cross-sectional elasticities are higher, at roughly 0.7. Whether or not demand elasticies for water are greater in the long than the short run is an important issue in water resources planning. This paper focuses directly upon specific conservation decisions that can create higher long-run demand

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[1] Carver and Boland [1980] describe in detail the dynamics of a household's adjustment to higher water prices.

elasticities but which typically appear only as shift factors affecting the short-run residential demand curve for water.

Vast opportunities exist for household water conservation. Although residential water use is small relative to the huge quantities of water consumed in agriculture,[2] large amounts are consumed by households. For instance, residential water use in California as of 1979 was about 140 gallons per capita per day (Gibbons, citing Milne [1979]), of which only about 5 percent was for essential drinking and cooking. Furthermore, of the approximately 70 gallons used in indoor consumption, about 32 gallons are devoted to toilet systems and 21 gallons to bathing and personal use. Palmini and Shelton (1982) report similar results, estimating the distribution of total household water use to include 39 percent for toilets and 31 percent for baths and showers. They study the effects of water conservation devices such as faucet aerators, toilet-tank devices, and shower flow controls and estimate an average annual savings of about 7400 gallons per home that installed one or more of the devices. In the aggregate, these individual household savings can add up to substantial water conservation in the residential sector.

Very little research exists concerning household decisions to retrofit for water conservation. Even the precise definition of conservation has required care (Baumann, et. al., 1984). Empirical data from a conservation program in a suburb of New Jersey are analyzed by Palmini and Shelton (1982). They use single-equation linear regression analysis to explain the daily water consumption of 97 households. Their explanatory variables include the

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[2] Consumptive use of water for municipal purposes (primarily residential and public use) is less than ten percent of total U.S. water consumption (Gibbons [1986]).

number of people in the household, gross household income, and a "water conservation variable." However, they treat the water conservation variable as purely exogenous. This exogeneity assumption is questionable. In fact, individuals who freely choose to install conservation retrofits may be systematically more likely also to engage in behavioral changes that decrease water consumption. If so, the estimated influence of retrofitting on water consumption is upwardly biased. The problem is one of "self-selectivity." Had the water-saving equipment been imposed on households randomly, the decreases in water consumption attributed to the retrofit devices would be smaller than they were found to be when equipment use was optional.

Another study of the effects of conservation programs on water consumption is Moncur [1987]. His analysis uses single equation techniques on pooled time-series cross-section data from Hawaii. To measure the impact of conservation programs, he includes a dummy variable to indicate water-billing periods in which voluntary restrictions were in effect. Unlike Palmini and Shelton's study, selectivity bias is not a problem in this study because the dummy variable for water restrictions is not household-specific, but time-specific.

Berk et al. [1981] analyze the effects of water conservation programs during the 1976-1977 California drought. They use aggregate data for 57 geographical areas (mostly public water districts), so selectivity is not a concern in their single-equation models either. While they worry whether price should be treated as exogenous in their water consumption equations, they make no mention of the potential endogeneity of voluntary program participation at the household level.

In contrast to these studies, the research described in our paper

explores the <u>determinants</u> of the retrofit decision. Our data set does not contain information on water consumption, so a selectivity-corrected water consumption model is not possible. However, demonstrating the potential endogeneity of the retrofit decision provides a warning to other researchers. Selectivity bias should be an important consideration in subsequent assessments of the effectiveness of water conservation programs such as the New Jersey experiment described by Palmini and Shelton.

We base our study on households' responses to the Los Angeles Department of Water and Power (LADWP) Residential Energy Survey of 1983. Among other topics, the survey addresses the installation of two inexpensive water conservation devices: shower head flow restrictors and toilet tank water displacement devices. (We will refer to these simply as shower and toilet devices.)[3]

Ideally, it would be desirable to specify a fully "utility-theoretic" model of water conservation choices by households. However, such models will be difficult to calibrate because these retrofit decisions involve relatively small pecuniary costs and savings. The most discernible factors influencing these decisions are likely to be sociodemographic as much as economic. For example, merely having "a sense of responsibility" regarding resource use could account for a substantial proportion of conservation activity. One task of this project is to determine empirically whether measurable economic variables seem to have any effect on households' decisions.

What generates a household's "demand" for water conservation activity? <u>Ex ante</u>, we anticipated that four general factors might be important. These

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[3] We have previously used other questions on this survey to analyze household energy conservation activity (Cameron and Wright, [1988]).

include (i) the awareness on the part of the respondents of the need for water conservation, (ii) the perceived benefits of installing the retrofit measures, (iii) the availability of the retrofit devices and the opportunity to install them, and (iv) the "conservation-mindedness" of the respondents. Since these underlying factors are fundamentally unobservable, we must devise sets of proxy variables to represent them.

Section II of this paper contains a brief description of the LADWP data set and the criteria for selecting the estimation sample. In Section III, we explain why specific observable variables are entertained as candidates to proxy the four underlying general factors. Section IV reviews the structure of a polytomous logit model and demonstrates how it can be generalized to a nested version. Section V gives empirical estimates for two classes of nested models. We use the final calibrated model in section VI for an array of simulations which convey the practical implications of the findings.

### THE LADWP DATA SET

The data set used for this study consists of responses to the LADWP 1983 Residential Energy Survey. The two questions upon which we focus our attention read as follows:

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Have you implemented any of the following conservation measures? (CIRCLE ALL THAT APPLY) . . .

E. INSTALLED WATER-SAVING SHOWERHEADS
    1 - Yes, within the last year    3 - No, never done
    2 - Yes, prior to a year ago    4 - Not sure

F. INSTALLED TOILET TANK WATER DISPLACEMENT DEVICES
    1 - Yes, within the last year    3 - No, never done
    2 - Yes, prior to a year ago    4 - Not sure

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Before we can undertake any general analysis of the responses to these questions, it is desirable to limit our models to a relatively homogeneous sub-population of households. We concentrate on single-family, owner-occupied dwellings.[4] Other criteria for deleting observations include missing information on income bracket, house vintage, size of household, years in residence, or education level. Furthermore, less than 3% of our final sample responded "not sure" to each of the retrofit questions. Thus, there is not enough information to draw useful inferences about the characteristics of households responding this way, so our analysis will concentrate on the three main responses to the water retrofit question: "yes, last year," "yes, before last year," and "no, never done." In preliminary models reported in a separate appendix, we examined distinct models for each of the retrofit measures which distinguished all three possible responses. In the work emphasized in the body of this paper, we model the two decisions jointly, and aggregate the two possible "yes" responses into a single "yes" answer.

Membership in one of the omitted categories might be somehow systematically related to individual households' responses to the water conservation questions. We therefore emphasize _weighted_ estimates of our fitted discrete choice models. The weights scale the active sample observations to reflect the frequency of different types of households in the

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[4] Since simple discrete choice models imply a more-or-less common set of preferences across all respondents, such limitations are advisable. Otherwise, systematic behavior patterns in separate types of households might be inadvertently obscured by the pooling of disparate preferences.

entire population.[5] The acronyms, descriptions, and descriptive statistics for the unweighted and weighted samples appear in Table 1.

## RATIONALE FOR CONSIDERING CANDIDATE EXPLANATORY VARIABLES

To proxy for households' awareness of water conservation (the first general factor), we have explored several informedness variables. These include a dummy variable for those households who have had energy audits.[6] We also include a variable for education level, since Berk et al. [1981] find that conservation programs are more effective in communities with higher education levels. Further, we consider a dummy variable which takes on a value of one if the respondents lived in their current residence during the 1976-1976 drought.[7]

To proxy for the second factor, the "perceived benefits" from installing water conservation devices, we have experimented with household size and number of bedrooms. These variables may account for scale economies in the use of these devices. We examine the square footage of the house, because larger houses are likely to have more bathrooms.[8] We have also looked at house vintage, since older houses may have less-efficient showers and

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[5] The weights are calculated using population data on "cells" distinguished by general household location ("Metro," "Harbor," or "Valley") and electricity consumption.

[6] We assume that awareness of resource use in general may affect water conservation behavior.

[7] If a household weathered the previous drought somewhere in the affected area of the Southwest, we would expect them to be more cognizant of water rationing and other inconveniences that accompany shortages. Unfortunately, our data do not allow us to determine where the respondents lived if they have not occupied their current residence since that time.

[8] The survey does not contain data on the number of bathrooms in the residences.

toilets.[9]

Household income may also be important. Differences in implicit time costs and the marginal utility of income may affect households' perceptions of the benefits and costs associated with retrofitting. We have also explored the use of a dummy variable that takes on a value of one for houses built after 1978. This variable is intended to account for the fact that California building codes required low-volume toilets after 1977 and low-flow shower heads after 1978.

Initial level of water use may also affect households' perceptions of the benefits from water conservation. In particular, we have attempted to control for typical levels of hot water use. This seems prudent because the shower flow restrictors save on energy as well as water bills. Consequently, the decision to install water-saving measures may reflect anticipated joint water and energy savings. To account for this, we include dummy indicator variables for the presence of a dishwasher, a clothes washer, and a pool or spa. We have also considered variables proxying for the severity of the localized climate, since this may influence water use.[10] Finally, we have experimented with a dummy variable to control for any special effects due to the presence of older adults or small children. These houses are typically occupied for more of the day, which could affect total at-home water use.

The third factor is the "availability of the water conservation devices and the opportunity to install them." We have used a dummy variable with a

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[9] However, older houses may also have fewer bathrooms -- a factor which (controlling for number of household members) might reduce the durations of individual showers.

[10] To proxy for climate severity, we use data for heating and cooling degree days at the weather stations nearest each residence. In addition, we include a dummy variable equal to one if the home is air conditioned.

value of one if the respondents have lived in their current residence for less than two years at the time of the survey. This controls for the effects of the LADWP mass mailing of water retrofit kits in June, 1981. However, it may also control for new homeowners who intend to install the devices but have not yet done so. We have therefore also estimated models that include a variable for the length of time the family has lived at the residence.

The fourth factor was the "conservation-mindedness" of the respondents. We have considered two groups of overall (water and energy) resource conservation variables as proxies. One category reflects the behavioral adjustments the household reports having made to diminish hot water consumption. (These include using cold water for laundry, lowering the water heater thermostat, and installing a water heater blanket.) These variables help detect whether households install shower devices primarily to conserve hot water and therefore to conserve water heating fuel. We ultimately incorporate these variables in the form of an index.[11]

The other category of "conservation-mindedness" proxies consists of non-water conservation measures reported by the household. These include adding attic, wall, and floor insulation. Also included are caulking, low-wattage lighting, window shading, and clock thermostats. We use an index summarizing these activities as well.

Finally, we consider two other types of information. Households

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[11] The advantage to using the indices is that they may serve as valuable summary measures of the relationship between certain categories of retrofit measures and the dependent variables. Such summary measures are likely to be more useful than any individual conservation measure. In using the indices, however, we are implicitly imposing the restriction that the coefficients on all the dummy variables contained in each index are identical. Because this may be questionable, we will perform likelihood-ratio (LR) tests for each index versus the full set of dummy variables to determine the validity of the restrictions implied by the indexing procedure.

undertake _energy_ retrofit measures primarily to save money on energy bills. Most of the households in our sample (about 91%) use the same fuel for both hot water and space heating. It is thus possible that non-water conservation measures save money on the same bills that cover water usage. We want to separate "conservation-mindedness" from the desire simply to save money on bills that reflect hot water use. Thus, we included a dummy variable for households using the _same_ fuel for water and space heating. Finally, we consider a dummy variable taking on a value of one for households with energy-saving pool covers. Households may install pool covers to reduce evaporative water losses.[12]

## ORDINARY AND NESTED POLYTOMOUS LOGIT CHOICE MODELS

Maddala [1983] provides a comprehensive discussion of the maximum likelihood (ML) estimation of ordinary polytomous logit models. For brevity, we will only outline the standard models here. This provides the background for our generalization to a less-common nested polytomous form.

In considering these households' water conservation decisions, we can define a set of four mutually exclusive and exhaustive outcomes. The respondent can report installing (i) both devices (ii) just water-saving shower devices (iii) just toilet tank devices, or (iv) neither device. In the subsample suitable for the joint model, we find the following frequencies for each response: install both devices (295 households, 29.9 percent); install shower devices only (208 households, 21.1 percent); install toilet devices only (145 households, 14.7 percent); and install neither measure (340

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[12] To make valid use of this variable, we must, of course, control for the presence of pools. Thus, we will include in all specifications a dummy variable which takes on a value of one if the household owns a pool or a hot tub.

households, 34.4 percent).[13]

We might begin by treating these four alternatives symmetrically in an ordinary polytomous logit model. When there are m alternatives and $y_i$ is the vector of characteristics describing household i, then the polytomous logit probability that a household with characteristics $y_i$ will select alternative j is:

$$(1) \qquad P_{ij} = \exp(\alpha_j' y_i) \ / \ \sum_{k=1}^{m} \exp(\alpha_k' y_i).$$

Typically, the researcher selects one alternative (say, m) as the "numeraire" alternative and the probabilities are transformed by multiplying by $\exp(-\alpha_m' y_i)/\exp(-\alpha_m' y_i)$. Since only m-1 probabilities can be independent, we adopt the normalization that $\alpha_m = 0$, so that the probabilities can be simplified to:

$$(2) \qquad P_{ij} = \exp(\alpha_j' y_i) \ / \ [1 + \sum_{k=1}^{m-1} \exp(\alpha_k' y_i)],$$

$$P_{im} = 1 \ / \ [1 + \sum_{k=1}^{m-1} \exp(\alpha_k' y_i)].$$

If $S_{ij} = 1$ when household i is observed to choose alternative j and $S_{ij} = 0$ otherwise, the logarithm of the likelihood function is:

$$(3) \qquad \log \mathcal{L} = \sum_{i=1}^{n} \sum_{j=1}^{m} S_{ij} \log P_{ij}.$$

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[13] In programs described by Palmini and Shelton (1982), where kits including basic retrofit devices were distributed to individual households, roughly two-thirds of the conservation kits were utilized, in whole or in part.

The probabilities in this model are non-linear functions of the $y_i$ variables. Thus, the coefficients $\alpha_j$ are not as easy to interpret as ordinary least squares regression coefficients. However, they enter quite simply into a "log-odds" formula:

(4)     $$\log(P_{ij}/P_{i\ell}) = (\alpha_j - \alpha_\ell)'y_i.$$

If $\alpha_{jr} > \alpha_{\ell r}$, an increase in the level of household characteristic r will increase the log-odds of selecting alternative j over alternative $\ell$. As special cases, however, we can consider choice probabilities relative to the numeraire alternative (for which the $\alpha_\ell$ coefficients are all normalized to zero). In these cases, the $\alpha_j$ coefficients will indeed convey the sign (and the statistical significance) of the effect of each variable $y_i$ upon the probability of choosing alternative j relative to the numeraire alternative.

The log-odds derivatives are useful for policy purposes. However, it is also informative to adopt a "representative household" interpretation of the polytomous logit model's fitted probabilities. If our sample is truly random, we can view each household as representative of some large equal number of identical households. The fitted probabilities then imply the proportion of those identical households that select each alternative. The sum (across the sample) of each of the fitted probabilities gives the proportion of the sample choosing each alternative. We can use this interpretation to simulate the effect on each household's retrofit decisions of broad changes in household characteristics.

As an alternative to the ordinary polytomous logit specification, we could embed the choices of whether or not to install each of the two conservation measures in a two-level _nested_ polytomous choice model. The

first partitioning of the choice set concerns whether or not to undertake any of the water-conserving measures. The second partitioning distinguishes between the three possible combinations that involve at least one type of device being installed. Nested logit models are usually formulated with alternative-specific explanatory variables.[14] However, for small numbers of alternatives, it is straightforward to specify a version which employs only household-specific explanatory variables.[15]

Nesting in a multiple choice model allows us to control, to a certain extent, for non-zero error correlations across alternatives. If subsets of alternatives have more in common among themselves than they do with alternatives not belonging to that subset, non-zero error correlations are a distinct possibility. In some sets of alternatives, one choice involves no action and the others require the expenditure of time, effort, or money. One would expect a priori that a nested model would reveal the presence of error correlations among the active alternatives.

The nested polytomous logit model for households' joint choices regarding whether to install neither, one, or both of the water conservation measures has the following structure. Let choice A represent "doing nothing." Let B represent "doing at least one conservation measure." Conditional on the choice of B, households have the option of doing both retrofits (j=1), just a showerhead retrofit (j=2), or just a toilet retrofit (j=3).

The probabilities of each of the four possible outcomes are $P_{iA}$ and $P_{ij}$ = $(P_{iB})(P_{i,j|B})$, j = 1,...,m (where m=3 in this application). The

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[14] See McFadden [1981].

[15] The hybrid model is outlined in Maddala [1983, pp. 44-46].

conditional probabilities in the "lower level," the $P_{i,j|B}$, can be estimated

using ordinary polytomous logit methods:

$$(5) \qquad P_{i,j|B} = \exp(\alpha_j'y_i) \;/\; [1 + \sum_{k=1}^{m-1} \exp(\alpha_k'y_i)],$$

$$P_{i,m|B} = 1 \;/\; [1 + \sum_{k=1}^{m-1} \exp(\alpha_k'y_i)].$$

The logarithm of the denominator of these probabilities can serve as an

exponentially weighted average of the "desirability" of the subset of

alternatives including some retrofit activity. This average is often called

the "inclusive value" (IV). When considering a household's choice at the

next level (between A and B), the inclusive value, $IV_B$, enters as an

alternative-specific explanatory variable attached to the B alternative.

There is no inclusive value for the A alternative, so $IV_A = 0$. The

household's choice between A and B is determined primarily by household-

specific explanatory variables, but $IV_B$ will also influence their decision.

At the next level, normalizing $\gamma_B=0$, the choice probabilities will be given

by:

$$(6) \qquad P_{iA} = \exp(\gamma_A'y_i - \rho IV_B) \;/\; [\; 1 + \exp(\gamma_A'y_i - \rho IV_B) \;],$$

$$P_{iB} = 1 \;/\; [\; \exp(\gamma_A'y_i - \rho IV_B) \;].$$

It is possible to estimate the fitted value of IV from an initial

polytomous logit model involving only the three "do-something" alternatives.

We can then use this estimated quantity as an explanatory variable in the

second stage for the "do-nothing/do-something" decision. However, sequential

estimation is inefficient since it treats the estimated IV as a deterministic

explanatory variable.  It is preferable to estimate both levels of the choice structure simultaneously.  This requires a general non-linear function optimization program.  The component probabilities for $P_{i,j|B}$ remain as above, but in the full-information maximum likelihood (FIML) specification, the "upper level" probabilities are:

$$(7) \qquad P_{iA} = \exp(\gamma_A'y_i - \rho\log(1 + \sum_{k=1}^{m-1} \exp(\alpha_k'y_i))) \; / $$

$$[ \; 1 + \exp(\gamma_A'y_i - \rho\log(1 + \sum_{k=1}^{m-1} \exp(\alpha_k'y_i))) \; ],$$

$$P_{iB} = 1 \; / \; [ \; 1 + \exp(\gamma_A'y_i - \rho\log(1 + \sum_{k=1}^{m-1} \exp(\alpha_k'y_i))) \; ].$$

Let $S_{iA}$ and $S_{iB}$ be indicator variables describing which of the two alternatives A and B are chosen, respectively.  Also, let $S_{i1}$, $S_{i2}$ and $S_{i3}$ tell which of the "do-something" alternatives, if any, the household selects. $(S_{i1} + S_{i2} + S_{i3} = S_B.)$  The probabilities can be combined to yield a log-likelihood function specific to this application:

$$(8) \qquad \log \mathcal{L} = \sum_{i=1}^{n} [ \; S_{iA}\log P_{iA} + S_{iB}\log P_{iB} + \sum_{k=1}^{3} S_{ik}\log P_{ik|B} \; ].$$

Optimizing this log-likelihood function with respect to the unknown parameters yields point estimates of the parameters.  Our software package, GQOPT, uses numerical second derivatives to generate an approximate Hessian matrix.  We use the inverse of this Hessian to compute asymptotic standard

error estimates, which we employ in our asymptotic t-test statistics.[16]

This likelihood function can be very time-consuming to optimize. It is thus important to determine whether the nested model is sufficiently superior to the non-nested model to warrant its use for forecasting and simulation. If the results for the nested model do not clearly dominate those from the non-nested model, expedience would dictate that we consider the non-nested model a reasonable, inexpensive alternative. The nested model may dominate the ordinary polytomous logit model, however. Failing to use it then can result in our ignoring potentially important unobservable characteristics which exert similar influences on the magnitudes of the error terms associated with each of the "do-something" alternatives.

## EMPIRICAL RESULTS

These nested polytomous logit models are computationally intensive. Thus, they are an inappropriate medium for extensive specification searching. Instead, we have conducted some preliminary modeling with non-nested polytomous logit models for the two conservation measures considered separately. Other preliminary models used the four alternatives in the joint decision in ordinary polytomous models, which ignored the potential for correlated errors.[17]

Recall our initial discussion of candidate explanatory variables. Many

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[16] Of course, we have employed exogenously determined weights in the estimation process, based upon the corresponding relative frequencies of basic respondent types in the estimating sample and in the original survey. A modest revision of the standard error estimates to compensate for these weights would be appropriate if it were critical to have highly accurate values.

[17] The SAS PROC MLOGIT routine provides algorithms for estimating the parameters for these models but does not allow for weights.

potentially important variables seem to have no statistically significant effect on water conservation retrofits. Among the informedness variables, energy audit participation and previous drought experience have discernible effects. Education does not.

Of the "perceived benefits" variables, household size, house size, number of bedrooms, and house vintage have no apparent effect in either linear or quadratic functional forms. Nor does household income have any effect, surprisingly. The dummy variable for houses built after the 1978 regulations does not make a significant contribution, even though one would expect a smaller probability of retrofitting if retrofits were not necessary. Dishwashers and pools or spas make a persistent difference in our models. In contrast, localized climate has no apparent effect on these decisions, and neither does the presence of older adults or small children.

"Availability of the water conservation devices and the opportunity to install them" was our third category. Strangely, occupancy of the same dwelling during the 1981 mailing of conservation kits seems to make no difference.

"Conservation-mindedness" is fundamentally difficult to capture, but the configuration of households' preferences will depend on this attribute. A history of efforts to conserve hot water does correspond to higher probabilities of installing water-saving retrofits. General (energy) resource-conserving activity is also correlated with water-saving retrofits. Whether or not households use the same fuel for both water and space heating occasionally had some small effect in preliminary models, but its contribution is not robust across specifications.

Point estimates for our initial formulation of a nested polytomous

choice model appear in Table 2. The first column reflects a decision between "doing nothing" and "doing something." The omitted category among the "do something" alternatives is "toilet devices only." We reserve our discussion of the calibrated models until we have further refined the specification.

A statistical test of the hypothesis that $\rho - 1$ is a test for the adequacy of the ordinary polytomous logit model. One approach is simply to examine the asymptotic t-ratio for this parameter. This Wald-type test will clearly fail to reject $\rho=1$ since $\rho=0$ is not rejected. However, we can alternatively use a likelihood ratio test. This test is more reliable than a Wald test, since it uses maximized likelihood values for both the unrestricted and restricted models. We do not report results for the corresponding ordinary polytomous model in this paper. However, the maximized value of the log-likelihood function in the unrestricted (nested) model is higher by 18.58. This rejects the ordinary polytomous logit model and suggests that the nested model is superior in this application.

In this initial nested polytomous logit specification, we specify a model with identical vectors of explanatory variables for each choice. However, many of the fitted coefficients are not statistically significant at the 5% level. While one must exercise extreme caution with specification searches, it is worthwhile to experiment with dropping some of the least significant variables. We can use likelihood ratio tests to insure that this pruning of the basic model does not result in any serious compromise of its fit.

Table 3 displays a minimal model, where all slope coefficients are now

statistically significant.[18] All remaining explanatory variables are discrete.

The estimated value $\rho$ is smaller than in the full model, but it is now significantly different from unity. Nevertheless, it still bears a value outside the 0-1 interval. Values larger than unity are quite common in empirical applications of other types of nested logit-based models. Train, McFadden, and Ben-Akiva [1987] argue that a value exceeding one implies that substitution among nests (i.e. between the "do nothing" and "do something" alternatives) occurs more readily that substitution within nests (i.e. among the three "do something" alternatives).[19] This is plausible here.

Nested conditional logit models are now fairly common. However, nested polytomous logit choice models of the type reported here are rare. We have addressed some questions regarding the determinants of household water conservation decisions in this paper. However, we have also used this data set as a vehicle for illustrating an unusual econometric technique. Systematically testing the selective exclusion of different subsets of explanatory variables from each pairwise choice within a polytomous model is

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[18] It is certainly possible that a different arbitrary choice for the numeraire alternative among the "do something" choices would have resulted in somewhat different asymptotic t-ratios for some of the estimated coefficients and possibly different exclusions in this process. When a set of specific results is critical (rather that a general overview of variate relationships), all specifications should certainly be examined. Here, however, the data are sufficiently weak that the extensive computational time is probably not justified.

[19] Borsch-Supan [1987] explains that $\rho > 1$ can mean that the "density" function for the nested multinomial logit (NMNL) model may become negative. He argues that "because the 'density' function is negative only at certain points and integrates to one, a redefinition of the density should be possible that reconciles the NMNL choice probabilities with utility maximization" in at least part of the domain. The possibility of constructing supports which salvage the density function means that NMNL choice probabilities can be meaningful even if $\rho > 1$.

novel. We simultaneously estimate all of the unknown parameters in our nested polytomous logit choice model using full-information maximum likelihood. It is therefore relatively simple to constrain individual parameters to zero and to test these restrictions statistically.

## SIMULATIONS

What are the practical implications of the minimal nested polytomous choice model? The analytical expressions for the derivatives of the choice probabilities (with respect to the household characteristics) are awkward. They are non-linear functions of both the estimated parameters and the data. Therefore, it is easiest to demonstrate the responsiveness of household choices to changes in the explanatory variables by conducting counterfactual simulations.

Table 4 details the simulations we have explored using the calibrated minimal model. First, we compare the fitted choices to those actually made. Subsequent rows give the revised choices predicted by the model under various counterfactual conditions. For the discrete explanatory variables, we examine the predicted choices if either all or none of the households displayed this characteristic. The index variables merely count the number of conservation measures of different types that the household has undertaken. Thus, we examine the predictions of the models if every household had conducted just one additional conservation measure (any one). Clearly, this simulation is only sensible if we restrict it to households with at least one conservation measure remaining in each category.

Table 5 presents an alternative summary of the simulation results from the minimal nested model. Here, we re-aggregate the separate and joint decisions to install each of the two measures. The "shower" column in Table

5, for example, is the sum of the two shower-related columns in Table 4.

Of all the simulation results, the easiest to interpret is probably the second column for "no action" in Table 5. For each simulation, this column tells the change in the number of households predicted to take <u>no</u> water conservation actions. If all of the 988 households in the sample had experienced the 1976-77 drought (DDROUGHT = 1), about 21 more households would have installed at least one of the two devices. If every household had undergone an energy audit (DAUD = 1), about 41 more households would have acted to conserve water via retrofits. Somewhat paradoxically, the model suggests that if every household had a dishwasher, <u>fewer</u> water conservation retrofits would have taken place. Perhaps those without dishwashers have a very low income and thus worry more about saving money on water bills. In contrast, having a pool or spa (correlated with higher income) may make the household very conscious of water consumption. This might account for the model's predictions of more retrofits if more households have pools or spas. The importance of both the water-related and the general resource-saving indexes (DWTRCON and DGENCON) confirms that the installation of shower and toilet devices is correlated with other conservation activity.

One might expect that a negative change in the "no action" column ought to be matched by a positive change in each of the two retrofit columns in Table 5 (and vice versa). This is the case for the DDROUGHT, the DAUD, and the two conservation index simulations. Simulated changes in DDROUGHT and DAUD induced changes of slightly larger absolute magnitude for toilet devices than for shower devices. For the simulated index changes, however, the effects on shower device installation were largest. The presence or absence of dishwashers and pools or spas, however, have mixed effects on the two

conservation measures. If all households had a pool/spa, the model predicts
that total shower device installation would increase, but fewer toilet
devices would be installed. This just means that the mix of retrofit
activity would shift.

## IMPLICATIONS AND CONCLUSIONS

Water resource planning for the residential sector should not rely
exclusively on short-run studies targeted at establishing the demand for
water as a function of price, income, and requirements variables. Over the
medium to long term, water conservation measures by households have the
potential to produce substantial savings in consumption, since such a small
fraction of daily consumption is essential. An understanding of the
propensities of households to make discrete changes in their water
requirements seems crucial to any assessment of long-run water demand
elasticities.

The water conservation decisions examined in this paper are probably not
motivated solely by pecuniary factors because of the small costs and savings
presently involved. The most important determinants of water conservation
decisions are probably household attitudes not captured by the survey.
Still, we have used the survey data to determine which measured factors
influence households' decisions to install the retrofit measures. We have
found evidence that households' awareness of general resource conservation
needs (as proxied by DDROUGHT and DAUD) are positively correlated with the
decision to install both retrofit devices.[20]

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[20] There also appears to be substantial complementarity in the two
water conservation measures -- those undertaking one retrofit activity seem
to be more inclined to do the other. This tendency comes through quite
clearly in preliminary separate models for each measure which include a dummy

No water price variation was present in our survey sample. With low water prices and no price variation, price effects are necessarily absorbed by the constant terms in our models. However, the price of hot water depends upon the prices of both inputs to its production (water and energy). Thus, we capture water price effects only indirectly through our "hot water" consumption proxy variables. Hot water conservation seems to be popular. Significant coefficients on variables related to hot water conservation suggest that shower retrofit activity is motivated largely by the desire of households to save money on energy bills.[21] If the price of hot water increased because the price of water increased, demand for shower conservation retrofits would undoubtedly be affected the same way.

Pecuniary considerations appear to have a lesser effect on toilet device installation than on shower retrofits. Most likely, this is due to the absence of an energy-saving motive in the toilet retrofit decision. Instead, there is a marginally significant relationship between general conservation measures and toilet retrofits. This suggests that installation of toilet devices is probably motivated by general conservation concerns rather than by a desire to save money. (The relationship between general water conservation activity and toilet retrofitting is positive. However, it is not nearly as consistent or as strong as with shower

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variable indicating whether the other measure has been done. These results are described in an appendix to this paper. The tendency is also noted by Palmini and Shelton [1982]. Collinearity among separate dummy variables forces them to use a weighted index of conservation measures as their crucial explanatory variable.

[21] In addition, results from the separate model of shower retrofit activity indicate that house vintage and household size, which influence total possible savings by affecting the savings per device installed (due to differences in the efficiency of shower equipment and the number of showers taken, respectively) are significantly related to shower retrofit activity.

retrofitting.) Under current water pricing policies, unmeasurable

psychological factors -- such as the desire to conserve resources for the

common good -- appear to be more influential than economic considerations in

determining a household's toilet retrofit decisions.

It is crucial to emphasize that we do not find that pecuniary

considerations are unimportant in explaining water conservation retrofit

activity. On the contrary, pecuniary motives are very influential when

savings are substantial (specifically, when energy savings are possible).

Water, however, is currently very inexpensive relative to energy. Thus,

specific water-saving motives are of trivial importance among the pecuniary

aspects of water retrofitting activity.[22]

If policy makers wish to encourage household water conservation through

retrofit measures, this research provides several insights and confirms

earlier casual observations. First, one effective non-water-price strategy

may be to publicize widely the pecuniary benefits of energy savings from

shower retrofitting. Second, general conservation-mindedness (which can

result from overall awareness of the need for water conservation) can spur

conservation activity. Because water conservation activity will not bring

noticeable savings in private water bills to most households, appeals that

emphasize the public benefits of water conservation, rather than its private

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[22] Palmini and Shelton [1982] point out explicitly that the water
conservation retrofit program they describe was not undertaken in response to
any kind of immediate water crisis. "Appeals for cooperation with the
program were based on social benefits (of environmental concerns and
forestalling future supply problems) and on the practical and immediate
economic benefits to households of dollar savings on water and energy bills."

benefits, are preferable.[23] Persistently informing the public of the

consequences of serious water shortages will also increase water conservation

activity. A third and very obvious alternative, of course, is to increase

water prices substantially. Although market incentives to promote water

conservation are not traditional (Moncur [1987]), the potential actually to

save money on water bills, as opposed to water-heating bills, would provide

households with stronger pecuniary incentives.[24] Indeed, other studies have

suggested that residential water demand is somewhat responsive to

appropriately measured prices. Increasing water prices, therefore, may be

the only way to bring about truly substantial semi-permanent reductions in

residential water use. Furthermore, medium- to long-run water price

elasticities can be expected to be larger than short-run studies detect.

This will be partly due to the discrete water conservation retrofits that

such price changes will eventually induce. As Moncur [1987] also concludes:

"A conservation program, even if only voluntary, can bolster the price

elasticity, thus reducing slightly the price increase or surcharge required

to bring about any given decrease in consumption."

Finally, the results of this study have strong implications for the

statistical assessment of the benefits of water conservation programs.

Whenever households are relied upon to undertake retrofits voluntarily, the

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[23] Palmini and Shelton [1982] begin by hypothesizing that "even in the absence of a drought, appeals based on the social and, especially, the private economic benefits of water conservation could induce significant public cooperation." Our results seem to confirm this. The Palmini and Shelton study itself does not actually test this hypothesis, since it takes the retrofit decision as an exogenous variable explaining water consumption.

[24] "Life-line" allocations of water at nominal prices could be made available to prevent hardship. Further units of water could bear higher (or even increasing) marginal prices.

potential for selectivity bias must be considered. Households' decisions to install retrofits clearly depend upon household and dwelling attributes which will simultaneously affect observed water consumption. These retrofits are not exogenous. The average water savings to be expected from mandatory imposition of retrofits will almost certainly be less than the savings implied by single-equation water consumption models applied to data involving voluntary retrofits. Therefore, household water consumption decisions and water conservation retrofit decisions should be modeled jointly. Only then can we control for unmeasured attributes which result in the voluntary retrofit decision being correlated with atypically lower water consumption.

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TABLE 1. Brief Description of Variables

| Acronym | Description | Unweighted means (std. dev.) | Weighted means (std. dev.) |
|---|---|---|---|

Continuous variable:

| | | | |
|---|---|---|---|
| NEWSQFT | - square footage of house | 1754.35 (706.39) | 1715.07 (714.09) |

General dummy variables (= 1 under stated condition; = 0 otherwise):

| | | | |
|---|---|---|---|
| DAUD | - has had an energy audit | .20 | .20 |
| DDROUGHT | - same house last drought | .81 | .79 |
| DDWASH | - house has dishwasher | .62 | .55 |
| DPOOLS | - family owns either a pool or spa | .28 | .21 |
| DWSFUEL | - same fuel used for water heat and space heat | .91 | .91 |

Conservation-related dummy variables* (= 1 if household has taken specified action; = 0 otherwise)

| | | | |
|---|---|---|---|
| DBLANK | - added a water heater blanket | .28 | .26 |
| DCAULK | - installed caulking | .42 | .38 |
| DCEIL | - installed ceiling insulation | .56 | .52 |
| DCKTHM | - installed a thermostat clock | .15 | .13 |
| DCOLD | - cold water used for laundry | .49 | .48 |
| DEXTSH | - added window shading | .19 | .17 |
| DFLOOR | - installed floor insulation | .02 | .02 |
| DLOWAT | - installed low-wattage lighting | .32 | .32 |
| DLWTRHT | - reduced water heater temp | .64 | .63 |
| DWALL | - installed wall insulation | .15 | .13 |
| DGENCON | - index of "general" conservation measures (DWALL+DCEIL+DFLOOR +DLOWAT+DCAULK+DEXTSH+DCKTHM) | 1.81 (1.37) | 1.68 (1.37) |
| DWTRCON | - index of "hot-water-related" conservation measures (DCOLD+DLWTRHT+DBLANK) | 1.41 (0.93) | 1.36 (0.95) |

* The prefix "D" indicates only that a retrofit measure has been undertaken, either within the past year or previously.

TABLE 2.  Nested Polytomous Logit Model; Identical Explanatory Variables[a]

| Variable | Do Nothing (Versus Do Something) | Both Shower and Toilet Devices (Versus Toilet Only) | Shower Devices Only (Versus Toilet Only) |
|---|---|---|---|
| constant | 4.163 (1.114)[b] | -0.5306 (-1.279) | 0.8137 (1.572) |
| NEWSQFT | $-4.273 \times 10^{-5}$ (-0.1217) | $-1.879 \times 10^{-5}$ (-0.08751) | $-1.342 \times 10^{-4}$ (-0.5488) |
| DDROUGHT | -0.03263 (-0.04148) | 0.8027 (2.672) | -0.3028 (-0.9185) |
| DAUD | 0.6219 (0.3709) | 0.6048 (1.223) | -0.1250 (0.2537) |
| DDWASH | 1.263 (1.181) | 0.5700 (2.048) | 0.6551 (2.217) |
| DPOOLS | -0.1603 (-0.2134) | -0.1950 (-0.5180) | 0.3236 (0.9402) |
| DGENCON | -0.2279 (-0.9858) | -0.02274 (-0.1864) | -0.02276 (-0.2145) |
| DWTRCON | -0.02508 (-0.02590) | 0.5478 (4.635) | 0.3268 (2.471) |
| DWSFUEL | -1.812 (-0.8427) | -0.5863 (-1.377) | -0.8525 (-1.949) |
| $\rho$ | | 2.245 (0.8152) | |

[a] Maximized log-likelihood function value is -1203.90.  For the corresponding ordinary polytomous logit specification (i.e. with $\rho = 1$ imposed) the maximized log-likelihood value is -1222.48.  The LR test statistic is thus 37.16 while the LR critical value is only 3.84, so $\rho = 1$ is soundly rejected.

[b] Asymptotic t-test statistics in parentheses.

TABLE 3. Minimal Nested Polytomous Logit Model[a]

| Variable | Do Nothing (Versus Do Something) | Both Shower and Toilet Devices (Versus Toilet Only) | Shower Devices Only (Versus Toilet Only) |
|---|---|---|---|
| constant | 1.884 (4.731) | -1.281 (-4.029) | -0.5586 (-2.956) |
| NEWSQFT | - | - | - |
| DDROUGHT | - | 0.8367 (3.874) | - |
| DAUD | - | 0.3351 (2.186) | - |
| DDWASH | 0.9941 (2.761) | 0.5094 (2.274) | 0.5686 (2.397) |
| DPOOLS | - | - | 0.3803 (2.150) |
| DGENCON | -0.1893 (-3.240) | - | - |
| DWTRCON | - | 0.6520 (6.568) | 0.4233 (4.039) |
| DWSFUEL | - | - | - |
| $\rho$ | | 1.838 (5.585) | |

[a] The maximized log-likelihood function value is -1212.21. The LR test statistic for jointly zero coefficients on the omitted variables is therefore 16.62. The chi-squared 5% critical value for 15 restrictions is 25.00, so these restrictions cannot be rejected.

TABLE 4.  Simulated Changes in Choices (Weighted Sample, n - 988)

|  | No Action | Shower& Toilet Devices | Shower Devices Only | Toilet Devices Only |
|---|---|---|---|---|
| Actual choices | 352.80 | 289.15 | 207.91 | 138.14 |
| Minimal Nested Polytomous Logit:  Fitted choices* | 352.80 | 288.87 | 208.52 | 137.81 |
| DDROUGHT = 0 for all | 442.12 | 162.94 | 233.74 | 149.21 |
| DDROUGHT = 1 for all | 331.74 | 317.79 | 203.14 | 135.33 |
| DAUD - 1 for all | 312.02 | 348.06 | 196.38 | 131.54 |
| DAUD - 0 for all | 362.14 | 273.81 | 212.49 | 139.57 |
| DDWASH - 1 for all | 377.62 | 290.27 | 214.16 | 105.95 |
| DDWASH - 0 for all | 325.16 | 286.23 | 200.14 | 176.47 |
| DPOOLS - 1 for all | 314.50 | 274.37 | 266.27 | 132.86 |
| DPOOLS - 0 for all | 363.12 | 293.06 | 192.92 | 138.90 |
| increase DGENCON by 1 if <7 | 316.57 | 303.35 | 220.69 | 147.39 |
| increase DWTRCON by 1 if <3 | 273.24 | 355.77 | 233.04 | 125.95 |

* This portion of the table gives the simulated choices under the Nested Polytomous logit model with the minimal number of explanatory variables for each pairwise choice (all statistically significant at 5% level).

TABLE 5. Aggregated Changes in Choices (Weighted Sample, n - 988)

| | No Action | | Shower Devices | | Toilet Devices | |
|---|---|---|---|---|---|---|
| Actual choices | 352.80 | | 497.06 | | 427.29 | |
| Minimal Nested Polytomous Logit: Fitted choices* | 352.80 | | 497.39 | | 426.68 | |
| DDROUGHT = 0 for all | 442.12 | 89.32** | 396.68 | -100.71 | 312.15 | -114.53 |
| DDROUGHT = 1 for all | 331.74 | -21.06 | 520.93 | 23.54 | 453.12 | 26.44 |
| DAUD = 1 for all | 312.02 | -40.78 | 544.44 | 47.05 | 479.60 | 52.92 |
| DAUD = 0 for all | 362.14 | 9.34 | 486.30 | -11.09 | 413.38 | -13.30 |
| DDWASH = 1 for all | 377.62 | 24.82 | 504.95 | 7.04 | 396.22 | -30.46 |
| DDWASH = 0 for all | 325.16 | -27.64 | 486.37 | -11.02 | 462.70 | 36.02 |
| DPOOLS = 1 for all | 314.50 | -38.30 | 540.64 | 43.25 | 407.23 | -19.45 |
| DPOOLS = 0 for all | 363.12 | 10.32 | 485.98 | -11.41 | 431.96 | 5.28 |
| incr DGENCON by 1 if <7 | 316.57 | -36.23 | 524.04 | 26.65 | 450.74 | 24.06 |
| incr DWTRCON by 1 if <3 | 273.24 | -79.56 | 588.81 | 91.42 | 481.72 | 55.04 |

* This table gives the simulated choices under the Nested Polytomous logit model with the minimal number of explanatory variables for each pairwise choice (all statistically significant at 5% level).

** This column gives the change in the number of households choosing each option. Note that the shower and toilet columns now each include households which choose "both," so totals sum to more than 988.