A RAND NOTE

THE EFFECT OF TIME-OF-USE RATES IN THE LOS ANGELES ELECTRICITY STUDY

Bridger M. Mitchell and Jan Paul Acton

October 1980

N-1533-DWP/HF

Prepared For

The Los Angeles Department of Water and Power
The John A. Hartford Foundation

Rand
SANTA MONICA, CA. 90406

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PREFACE

The Los Angeles Electricity Rate Study--a five-year project begun in 1975--is designed to yield information about the effect of alternative pricing structures for residential consumers. The experimental plans include time-of-use, seasonal, and time-invariant rates for approximately 1800 households over a 30-month period. The study is being conducted jointly by the Los Angeles Department of Water and Power and The Rand Corporation, with partial funding from the U.S. Department of Energy. Extensions of this work are being supported by a grant from the John A. Hartford Foundation.

This Note summarizes the basic time-of-use results and provides estimates of the effect of 17 time-of-use rate structures on peak period demand and total electricity consumption. A preliminary version of this research was reported to the Electric Utility Rate Conference sponsored by the Department of Energy in Denver, April 1980.

The report should be of particular interest to electric utilities and regulatory bodies investigating consumer responses to new rates. It should be of more general interest to economists and policy analysts for the analytic framework it provides for evaluating and forecasting the effects of time-of-use pricing.

Related Rand research on electricity pricing and demand can be found in the following publications:

- *Design of the Los Angeles Peak-Load Pricing Experiment for Electricity*, Willard G. Manning, Jr., Bridger M. Mitchell, and Jan Paul Acton, R-1955-DWP, November 1976.
- *Lessons To Be Learned from the Los Angeles Rate Experiment in Electricity*, Jan Paul Acton, Willard G. Manning, Jr., and Bridger M. Mitchell, R-2113-DWP, July 1978.
- *Peak-Load Pricing: European Lessons for U.S. Energy Policy*, Bridger M. Mitchell, Willard G. Manning, Jr., and Jan Paul Acton, Ballinger Publishing Company, 1978.
- *The Los Angeles Senior Citizen Lifeline Electricity Rate*, Timothy J. Sullivan, R-2278-DWP/NSF, January 1979.

- o *Sample Selection in the Los Angeles Electricity Rate Study*, Winston K. Chow and Bridger M. Mitchell, R-2430-DWP, July 1979.
- o *Conducting a Survey Using the Client's Staff: Evaluation of Interviewer Performance in the Electricity Rate Study*, Sandra H. Berry, R-2223-DWP, September 1979.
- o *Evaluating Time-of-Day Electricity Rates for Residential Customers*, Jan Paul Acton and Bridger M. Mitchell, R-2509-DWP, November 1979.
- o *Do Time-of-Use Rates Change Load Curves?*, Jan Paul Acton and Bridger M. Mitchell, R-2588-DWP/EPRI, May 1980.
- o *Seasonal Electricity Demand and Pricing Analysis with a Variable Response Model*, Lee A. Lillard and Jan Paul Acton, R-2425-DWP, May 1980.
- o *Planning, Processing, and Analyzing Data for Residential Load Studies*, Jan Paul Acton and Bridger M. Mitchell, N-1534-DWP, June 1980.
- o *Residential Electricity Demand Under Tune-of-Day Pricing: Exploratory Data Analysis from the Los Angeles Rate Study*, Willard G. Manning, Jr., and Jan Paul Acton, R-2426-DWP, December 1980.
- o *Electricity Consumption by Time of Use in a Hybrid Demand System*, Bridger M. Mitchell and Jan Paul Acton, R-2628-DWP, forthcoming.

SUMMARY

This Note summarizes the basic results of alternative time-of-use (TOU) pricing structures for residential consumers in the Los Angeles Electricity Rate Study conducted by the Los Angeles Department of Water and Power and The Rand Corporation. In all, 1268 households were available for time-of-use analysis; 931 households were observed on one of 17 time-of-use (TOU) rates applied either 5 or 7 days per week (for a total of 34 different rate structures) and 337 other households were observed on seasonal, flat, or declining block rates.

The results reported in this Note are based on a covariance analysis of the effects of the 17 separate TOU rate plans. The estimated effects provide strong evidence that TOU rates alter the time-of-day distributions of residential loads. Less clearly, they suggest that TOU rates also affect total consumption. Covariance analysis of the Los Angeles data also confirms that observed experimental behavior is broadly consistent with the economic theory of demand. Peak period use is reduced by peak prices, and the reduction is greater the higher the price level.

As an alternative to the analysis of covariance, one can estimate a system of demand equations and thereby determine a full set of own- and cross-price elasticities by time of day. Estimates based on this approach are reported elsewhere.*

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*R-2628-DWP, "Electricity Consumption by Time of Use in a Hybrid Demand System," Bridger M. Mitchell and Jan Paul Acton, forthcoming.

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The opinions expressed are the authors' and are not necessarily shared by any of Rand's corporate sponsors.

I. INTRODUCTION

The Los Angeles Electricity Rate Study, jointly undertaken by the Los Angeles Department of Water and Power and The Rand Corporation over the 1975-1980 period, included extensive variation in rate forms and rate levels so that statistically identified own- and cross-price effects could be determined over a wide variety of costing and demand conditions. The study had two major components--a seasonal experiment, in which the price was constant throughout the day but varied between winter and summer, and a time-of-use experiment, in which rates varied over 3-hour rating periods.[1] This Note summarizes the basic time-of-use (TOU) results.[2]

DESIGN OF THE TOU EXPERIMENT

In all, 1268 households were available for time-of-use analysis. Nine hundred and thirty one households were observed on one of 17 TOU rates that apply either 5 or 7 days per week (for a total of 34 different rate structures). An additional 337 households faced either seasonal, flat, or declining-block rates but had their use recorded continuously; they served as "control" households for time-of-use customers, and their consumption could be included in much of the analysis. Magnetic tape cassette meters recorded the electricity use every 15 minutes for these 1268 households.

Table 1 shows the distribution of experimental households by rate plans. Five congruent rate periods (09-12, 12-15, 15-18, 18-21, 21-09) permit data from the 17 TOU rate plans to be analyzed simultaneously in a single demand system.

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[1] Optimal experimental design followed procedures developed by Conlisk and Watts (1969), and individuals were assigned to particular procedures developed by Morris (1979). See Acton, Mitchell, and Manning (1977) for an overview of the study and its policy objectives; Manning, Mitchell, and Acton (1979) for a description of the statistical design; and Chow and Mitchell (1979) for a description of the sampling procedures.

[2] See Lillard and Acton (1980) for an analysis of seasonal demand.

Table 1

EXPERIMENTAL HOUSEHOLDS ON CASSETTE METERS BY RATE PLAN

No.	Peak Period i	Peak Period Hours	Prices per kWh (cents) Peak	Off-Peak	Average[a]	Number of Households on Peak Rates Mon.-Fri.	Mon.-Sun.
00	--	00-24	Conventional Declining Block Rate		--	--	175
0S	--	00-24	Seasonal[b]		--	--	68
0A	--	00-24	2	2	2.00	--	56
0B	--	00-24	5	5	5.00	--	38
1	1	09-12	5	2	2.36	37	34
2	1	09-12	9	2	2.84	24	27
3	1	09-12	13	2	3.32	9	9
4	2	12-15	9	2	2.86	18	16
5	2	12-15	13	2	3.36	10	10
6	3	15-18	5	2	2.43	9	9
7	3	15-18	9	2	3.01	34	35
8	3	15-18	13	2	3.59	29	39
9	4	18-21	5	2	2.56	9	10
10	4	18-21	9	2	3.30	27	26
11	4	18-21	13	2	4.04	26	25
12	5	21-09	5	2	3.28	72	71
13	3-4	15-21	7	2	3.34	16	15
14	2-4	12-21	5	2	3.36	49	56
15	2-4	12-21	9	2	5.18	27	27
16	1-4	09-21	5	1	3.30	27	30
17	1-4	09-21	9	1	5.59	35	34
TOTALS						458	810

[a]Average price per kWh computed for the reference load curve at a flat rate.

[b]Households with seasonal plans and cassette meters are used in the share analysis but not in the total consumption analysis.

Participation in the study was voluntary. Households were first interviewed to determine basic household demographics and appliance ownership. If they were eligible for the study (i.e., paid their own electricity bill, no family member worked for Rand or the Los Angeles Department of Water and Power, etc.), they received an offer to join the study and pay for electricity under an experimental rate. Our desire to estimate demand curves that might apply in future circumstances led to plans under which some households could have been worse off if their electricity remained unchanged. Those households were offered quarterly compensation in the form of "participation payments" based on their preexperimental level of use; the payments were unaffected by experimental use. Although self-selection bias is an appropriate concern in such voluntary experiments, over 92 percent of the eligible households offered an experimental rate plan accepted it; in this case at least, selection bias appeared to be empirically unimportant.

Household Information

Extensive household-specific information was collected in three surveys made at the beginning, the midpoint, and the end of the survey. Data on household composition, appliance ownership, income, and attitudes were collected during each 30-minute interview. In the present analysis, we use the responses provided in the first two surveys, which apply most directly to the 24-month period of data used for the empirical analysis. Household values for income, family size, and housing rental value are updated from the end-project survey.

Weather Data

Hourly weather data are collected in each of three climate zones in the city of Los Angeles: (1) a mild coastal zone with moderate summer and winter temperatures, (2) an inland valley zone with more extreme temperatures in both summer and winter, and (3) a civic center area with intermediate temperatures. We reflect weather through heating and cooling degree hours, taken as deviations from $65^{o}F$.[1]

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[1] Cooling-degree hours (CDH) = max ($T^{o}F - 65^{o}$, 0); heating-degree (HDH) = max ($65^{o} - T^{o}F$, 0). Both are averaged over the month in the relevant rate period.

II. OVERVIEW OF THE ANALYTIC APPROACH

Our basic model of electricity consumption by time of use may be schematically represented by three types of systematic components plus unmeasured factors (random error):

$$(1) \quad \text{electricity consumption}_{hjt} = \text{weather component}_{hjt} + \text{household component}_{hj} + \text{price component}_{hj} + \text{error}_{hjt}.$$

Consumption in kilowatt hours at hour h, by household j, in month t depends on the weather; on household characteristics including electrical appliances, behavioral patterns, and economic resources; and on the time-of-use prices charged for electricity.

The primary objective of a TOU electricity pricing experiment is to accurately measure the price component of electricity consumption so that the changes in load resulting from proposed TOU rates can be estimated and the economic benefits of such pricing evaluated. To do so, however, the weather and the household-specific components of consumption must be accurately accounted for.

THE HYBRID MODEL OF DEMAND

In this Note we adopt a three-stage approach.

1. We estimate the variation in hourly consumption that results from month-by-month variation in weather and subtract that amount from total consumption in each time period in each month.
2. We determine how the remaining consumption, net of weather effects, is distributed over the hours of the day. Because hourly consumption data were not measured prior to the introduction of TOU rates in the Los Angeles experiment, the "permanent" or normal use in each time period must be distinguished from the response to TOU rates. To accomplish this we estimate a reference load curve (for a household of

given characteristics) that indicates the proportions of daily electricity consumption used in each period of the day when a uniform price for electricity is charged at all hours. The experimental TOU rates are then used to explain deviations from this load curve.

3. We explain the level of total consumption of electricity by the household's characteristics and the overall costliness of electricity, making use of the period-specific information derived in stage 2.

ANALYSIS OF COVARIANCE ESTIMATES

We estimate the price-component effects by first standardizing all households to a common reference load curve and then measuring separately, for each of the 17 weekday TOU rates in the Los Angeles experiment, their effect on consumption in each rate period and on total consumption. This *analysis of covariance* method imposes a minimum number of assumptions when the original data are processed and reveals the basic patterns of response produced by the experiment. It amounts to assuming that the responses of 17 groups of households on different TOU rates have nothing in common.[1]

These estimates yield own- and cross-price elasticities of demand for five rate periods and permit prediction of load shifts due to proposed TOU rate plans, including rates not directly tested in the experiment.

UNIT OF ANALYSIS

The household is the unit for present analysis. Consumption data for each household are available for each 15-minute interval over the 30 months[2] of its participation in the experiment--approximately 100 million observations. The data available to explain electricity use are of two basic types.

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[1] The empirical results reveal regularities among the different groups that are consistent with the economic theory of consumer demand. In Mitchell and Acton (1980) we combine data from all 17 TOU rate plans into a two-level demand system and estimate its complete set of parameters.

[2] Covering the period July 1976-June 1979.

- *Time-dependent-variables* are chiefly measures of weather conditions, but also the occurrence of vacations and changes in household appliances and demographic factors.
- *Household-dependent variables* are effectively constant over the life of the experiment. They are the price of electricity by time of day and the household's appliances, demographic, and economic characteristics.

Such voluminous data require some degree of aggregation prior to analysis. For this Note we have used 24 months of data from January 1977 to December 1978, a period during which nearly all households faced only their experimental rates. We aggregated the raw 15-minute observations in each period, K_{hjt}, into the average daily consumption in each month. Using the 10 rate periods in Table 2 our initial data unit is the kilowatt-hour measure

$$\tilde{X}_{ijt} = \frac{1}{n_{hjt}} \sum_{h \Sigma H(i)} K_{hjt}$$

where

h	is the index of 15-minute intervals,
$H(i)$	is the set of intervals in rate period i,
j	indexes the household,
t	indexes the month, and
n_{ijt}	is the number of effective days of observations per month.

Table 2

TIME OF USE RATE PERIODS

Hours	Weekday	Weekend
09-12	1	6
12-15	2	7
15-18	3	8
18-21	4	9
21-09	5	10

Note that the daytime periods 1-4 and 6-9 are each 3 hours long while the overnight periods, 5 and 10, are each 12 hours long; there is no additional price variation in these overnight periods. Unless stated otherwise, all analysis in this Note refers to average daily consumption in each period.

III. EMPIRICAL RESULTS

In the hybrid model of demand, we first remove the weather component of electricity use in order to obtain a reference load curve. The weather-adjusted data are then used to examine the household component and price component of consumption by time of day and in total.

WEATHER-SENSITIVE CONSUMPTION

The primary cause of month-to-month variation in electricity consumption that is measurable with available explanatory variables is weather. Temperature differences cause electricity use to vary by time of day, a variation that is essentially independent of the price of electricity.[1] Consumption $\tilde{X}_{ijt}$ in period i is made up of two components--a weather component, $W_i(\cdot)$, plus a component for household j that is invariant to weather conditions, α_{ij}. To estimate the weather component of monthly consumption in each rate period, we follow work reported earlier and assume that the effective stock of weather-sensitive appliances varies with their capacity, the area to be cooled or heated, and outside temperature.[2] For example, the air conditioning variable (AC) takes into account differences in the mean consumption rates of central, wall, and evaporative units; and house size. Electric space heaters (HEAT) are used by only 6 percent of the experimental households and are represented by a single consumption index. Heating and cooling appliances are affected quadratically by temperature (TEMP), measured in monthly mean cooling degree-hours per rate period for air conditioning and in heating-degree hours for space heating. Hourly temperature readings are available for three distinct climatic zones in Los Angeles, but not at each residence; the degree-hour variable for each household is therefore taken to be that measured for its zone in the city. The other time-dependent variables that influence

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[1] In addition to temperature, humidity and the amount of natural illumination alter electricity use. These secondary factors are not incorporated into the estimates presented here except to the extent that they vary systematically by weather zone.

[2] See Acton, Mitchell, and Sohlberg (1980).

monthly consumption are whether a member of the household is normally at home during the period (HOME) or is on vacation in that month (VAC).[1] Ten weather equations, one for each rate period, take the following general form:

$$(2) \qquad \tilde{X}_{ijt} = \alpha_{ij} + W_i(AC_{jt}, HEAT_{jt}, TEMP_{ijt}, VAC_{jt}, HOME_{jt}) + e_{ijt}$$

$i = 1, \ldots, 10$ (rate period),
$j = 1, \ldots, n$ (household),
$t = 1, \ldots, T$ (month).

The error, e_{ijt}, is assumed to be independently distributed with constant variance.

Estimated over T = 24 months with n = 1273 households, the weather equations explain 14 to 44 percent of the variation in mean monthly weekday and weekend consumption by rate period. The weather component is readily interpreted as the mean hourly consumption of electricity used for cooling or heating at a given outside temperature. Table 3, which calculates hourly consumption, shows that when the temperature in the morning is 80°F, households with central air conditioning use an average of .54 kWh per hour for space cooling. This value falls at midday and then rises substantially in the afternoon and evening periods. The variation in mean rate of consumption undoubtedly reflects the varying probability that the home is occupied in the later hours of the day and also, perhaps, the increased energy required to cool unoccupied rooms that have heated up by later afternoon.

For space heating, the weather component of mean consumption shows little variation at 50°F over the weekday time periods. This regularity, and the lower mean rate of consumption in the overnight period, is consistent with a constant daytime thermostat setting that is set back to a cooler level overnight. Weekend consumption rates for heating are somewhat higher in the daytime.

[1] Our fixed-coefficient model assumes that the same weather component, W_i, applies to all households facing the same temperature and having similar heating and cooling equipment. Considering the coefficients as random variables allows an alternative specification that would permit the weather-sensitive consumption to vary by household. For an application of this approach in the context of seasonal electricity pricing see Lillard and Acton (1980).

Table 3

WEATHER-SENSITIVE CONSUMPTION: MEAN CONSUMPTION PER HOUR, HOUSEHOLDS WITH CENTRAL AIR CONDITIONING AND ELECTRIC SPACE HEATING (kWh)

Period		Cooling (Ave. kWh at 80°F)		Heating (Ave. kWh at 50°F)	
i	hour	Weekday	Weekend	Weekday	Weekend
1	09-12	.54	.54	1.33	1.76
2	12-15	.20	.10	1.63	2.24
3	15-18	.70	.65	1.59	1.91
4	18-21	1.93	1.89	1.25	1.13
5	21-09	(a)	(a)	.86	.79

[a]Temperature (80°F) is outside range of data observed after 9 p.m.

Because electric space heating is not widely used in Los Angeles these estimates are somewhat less reliable than those for air conditioning.

Time-of-Use and Total Consumption in an Analysis of Covariance Framework

The weather component, incorporating the effects of temperature and vacation days, accounts for essentially all of the month-to-month variation in any given household's consumption that can be systematically attributed to the time-dependent variables measured in the experiment. The consumption remaining to be explained is the household-specific component α_{ij}--household j's mean 24-month consumption in period i net of weather-related electricity consumption--given by the expression

$$(3) \qquad \alpha_{ij} = \frac{1}{T} \sum_t [(\tilde{X}_{ijt} - \hat{W}_i(AC_{jt}, HEAT_{jt}, TEMP_{ijt}, VAC_{jt}, HOME_{jt})]$$

Because virtually all of the time-dependent explanatory variables have been incorporated into the estimated weather component, the remaining analysis is conducted using variables that are essentially constant for each household j.

kWh Share Equations

To analyze the distribution of consumption by time of use, consider the relative weekday load curves for household j.[1] In terms of the five rate periods in the experiment, this load curve is given by its weekday consumption component α_{ij} in each period divided by total daily weekday consumption, or

$$s_{ij} = \frac{\alpha_{ij}}{\alpha_j}, \quad i = 1 \ldots 5$$

where

$$\alpha_j = \sum_1^5 \alpha_{ij}$$

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[1]For expository convenience we refer to weekday loads and shares. A similar analysis is carried out for weekend consumption.

These consumptions shares, s_{ij}, vary systematically with household characteristics; they are also changed by TOU rates.

We estimate five share equations of the form

$$(4) \qquad s_{ij} = f(DEMO_j, APPL_j, PLAN_j) + e_{ij}$$

$$= a_i + \sum_k b_{ik} DEMO_{kj} + \sum_k c_{ik} APPL_{kj} + \sum_m d_{im} PLAN_{mj} + e_{ij},$$

$$i = 1, \ldots, 5$$

using vectors of demographic ($DEMO_k$) and appliance ($APPL_k$) variables and a vector of dummy variables ($PLAN_m$) indicating the particular rate plan assigned to the household. (For example, $PLAN_{1j} = 1$ if household j is on TOU rate plan 1.) These equations are estimated by ordinary least squares with the same set of explanatory variables in each equation, ensuring that the sum of the estimated shares is 100 percent for each household. They explain 18 to 38 percent of the variation in mean weekday relative loads.

The estimated appliance and demographic coefficients control for variation in relative load curves due to household-specific characteristics. They indicate, for example, that under a flat rate a household with a swimming pool consumes a substantially greater proportion of its weekday electricity during periods 1, 2, and 3, and less in periods 4 and 5. Similarly, households with electric dryers and washing machines have higher relative loads in the early part of the day and lower loads in the evening and overnight periods. Multi-person households have higher afternoon loads when children are likely to be at home.

TOU Price Effects on Relative Loads

In the share equations (4), the effect of prices is represented by separate dummy variables $PLAN_m$ for each type of plan. For households on the "2¢-flat" plan who paid 2¢/kWh at all hours, all of the rate plan dummy variables take zero values. Thus, the average consumption of those households in the 2-cent flat plan constitutes the *reference load curve* against which the effects of other plans are compared.[1] At the mean values of the demographic and appliance variables observed in the experiment, the weekday reference load curve is

Period i :	1	2	3	4	5
Share (%) s_i :	11.2	11.5	14.4	19.5	43.4

The covariance analysis specification is effectively "model-free" in prices and allows each TOU rate plan to have an independent effect on the relative load in each of the five rate periods. In Table 4 we summarize these effects in terms of the change in consumption relative to the 2¢ flat reference load, using estimated coefficients d_{im} in the peak periods. The first two rows of the tables are for the 2¢ and 5¢ flat-rate plans in which there is no incentive to shift loads. In subsequent rows the TOU plans are grouped by peak period, in ascending order of peak price.

The upper portion of Table 4 reports the 12 TOU plans with a single 3-hour peak period. The reported values are the mean (percentage-point) changes in the peak period shares. For example, plans 1, 2, and 3 have peak prices of 5¢, 9¢, and 13¢ per kWh respectively from 9 a.m. to noon. These rates reduce the consumption share at this period by 1.5, 2.5, and 3.4 percentage points. The estimated pattern is highly consistent: relative to the reference load at a 2-cent flat rate, TOU rates reduce the share in every peak period, and in most cases higher TOU prices result in greater reductions. Most of the estimated effects are statistically significant.

The lower section of the table shows the results for plans with 6-, 9- and 12-hour peak periods (plans 13-17). In each case, despite the longer peak period, households show reduced relative loads during each 3-hour period that the peak rates are in effect.

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[1] Two cents per kWh is merely a convenient reference value from which to measure load changes. The average price per kWh for experimental households on TOD rates was 3.5¢/kWh. During the experimental period the lowest price for Los Angeles households on standard rates rose from about 2.4¢/kWh to over 5¢/kWh.

Table 4

TIME-OF-USE PRICE EFFECTS RELATIVE TO CONSUMPTION AT 2¢ FLAT PLAN

Plan No.	No. of House-holds	Peak Period i	Peak Period Hours	Prices per kWh Peak	Prices per kWh Off-Peak	Change in Peak Period Weekday Share	t-ratio	Change in Total Monthly Consumption kWh(%)	t-ratio
0A	56	--	00-24	2¢	2¢	--	--	--	--
0B	38	--	00-24	5¢	5¢	--	--	-6.2	(-.72)
Single-Period Peak Plans									
1	71	1	09-12	5¢	2¢	-1.50	(-2.77)	-5.3	(-.67)
2	51	1	09-12	9¢	2¢	-2.49	(-4.24)	-5.8	(-.07)
3	18	1	09-12	13¢	2¢	-3.37	(-4.10)	-14.2	(-1.08)
4	34	2	12-15	9¢	2¢	-2.66	(-3.83)	-7.4	(-.75)
5	20	2	12-15	13¢	2¢	-1.40	(-1.69)	-9.4	(-.84)
6	18	3	15-18	5¢	2¢	-1.86	(-1.90)	-0.0	(-.02)
7	69	3	15-18	9¢	2¢	-1.95	(-3.00)	-8.4	(-1.06)
8	68	3	15-18	13¢	2¢	-2.10	(-3.22)	-7.1	(-.93)
9	19	4	18-21	5¢	2¢	-.66	(-.68)	0.7	(-.06)
10	53	4	18-21	9¢	2¢	-2.36	(-3.37)	-10.7	(-1.29)
11	51	4	18-21	13¢	2¢	-1.22	(-1.72)	-8.7	(-.96)
12	143	5	21-09	5¢	2¢	-.62	(-.56)	-0.7	(-.11)

Multiple-Period Peak Plans

Plan No.	No. of House-holds	Peak Period i	Peak Period Hours	Prices per kWh Peak	Prices per kWh Off-Peak	Periods 1	Periods 2	Periods 3	Periods 4	Change in Total Monthly Consumption kWh(%)	t-ratio
13	31	3-4	15-21	7¢	2¢			-1.53	-3.06	-11.7	(-1.13)
14	105	2-4	12-21	5¢	2¢		-1.71	-1.31	-.86	-1.0	(-.15)
15	54	2-4	12-21	9¢	2¢		-1.46	-2.19	-1.91	-9.5	(-1.09)
16	57	1-4	09-21	5¢	1¢	-1.69	-1.29	-.83	-.93	-8.2	(-.93)
17	69	1-4	09-21	9¢	1¢	-1.88	-2.24	-2.80	-1.11	-17.0	(-1.93)

TOU Price Effects on Total Consumption

These results establish that TOU rates systematically alter the time of day distribution of weekday load. To determine whether TOU rates also affect total monthly consumption we combine the weekday and weekend household-specific components of consumption over all rate periods. The estimating equation for total consumption is similar in form to the share equations:

$$(5) \qquad X_j = \sum_{i=1}^{10} \alpha_{ij} = f(DEMO_j,\ APPL_j,\ PLAN_j) + e_j$$

$$= a + \sum_k b_k\ DEMO_{kj} + \sum_k c_k\ APPL_{kj} + \sum_m d_m\ PLAN_{mj} + e_j$$

Because total consumption varies across households from one hundred to several thousand kWh per month, we use an extensive set of appliance and demographic variables to capture systematic differences across households. Overall, the equation explains 72 percent of the variance in average weather-adjusted consumption between households.

The covariance analysis estimates of the effects of TOU plans on total monthly consumption relative to the reference load curve are shown in the last two columns of Table 4. Since all plans are, on average, more expensive than 2¢/kWh, the coefficients are negative in all but one instance, although generally not statistically different from zero. Under the 5¢ flat rate total consumption is reduced 6.2 percent over the 2¢ flat rate. Within groups of plans that have the same peak period there is evidence that higher priced plans resulted in larger reductions in total consumption, although the pattern is more variable than that observed for relative loads.

By specifying equation (5) in linear form we obtain from the estimated coefficients direct estimates of the mean consumption rates of each type of appliance. These values are reliably estimated for most of the major appliances and are consistent with the results obtained from small-sample studies of individual household appliances in nearly all cases. For example, an electric water heater is estimated to consume about 172 kWh/month (exclusive of its use with a clothes washer or dishwasher) and a color television set about 42 kWh/month.

The results for the "demographic" variables in Equation (5) confirm the importance of housing characteristics and family size, as well as income, in explaining household-specific variation in electricity use. These variables are proxies for several factors--unmeasured appliances, rates of appliance utilization, and individual tastes--that also affect overall consumption. The implied income elasticity, about .10 at the sample mean, can be interpreted as the combined effect of greater utilization of a given stock of major appliances plus the ownership of minor, unmeasured appliances. An increase in income also affects the purchase of appliances and choices of housing characteristics; this long-run effect is not captured in the estimated income elasticity.

IV. SUMMARY

The covariance analysis of TOU price effects provides strong evidence that TOU rates alter the time-of-use distributions of residential loads. Less clearly, it suggests that TOU rates also affect total consumption.

In an actual application of TOU rates, households will generally move from a declining-block or a flat rate to a TOU rate that, on average, raises the same total revenue (apart from changes in level of use). Thus, it is not clear, a priori, whether total use can be expected to increase, fall, or remain constant--only a complete demand system analysis can address that question. But the expected effect on peak and off-peak use is unambiguous.

Covariance analysis of the Los Angeles data confirms that observed experimental behavior is broadly consistent with the economic theory of demand. Peak period use is reduced by peak prices, and the reduction is greater the higher the price level. This basic pattern of demand response occurs whether the peak hours are in the morning, afternoon, or evening--or span all of these hours.

To fully exploit the rich experimental design of the Los Angeles data, the price effects can be specified in terms of a system of demand equations. Such an approach enables us to reliably estimate the magnitude of the effects of each rate period's price on both total consumption and its distribution over the day. As reported elsewhere[1] we use a demand system to estimate a full set of own- and cross-price elasticities by time of day. These estimates can then be used to predict the changes in load that would result from introducing a particular TOU rate plan not directly tested in the Los Angeles experiment.

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[1] Mitchell and Acton (1980).

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