CUSTOMER PARTICIPATION AND LOAD IMPACTS OF THE PG&E VOLUNTARY RESIDENTIAL TIME-OF-USE EXPERIMENT

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ABSTRACT

The paper reports the results of an analysis of Pacific Gas and Electric Company's residential time-of-use experiment. Under this experiment, residential customers were offered various voluntary TOU tariffs with different price structures and peak period definitions. The experiment examined the customer acceptance of these rates and compared the loads of participants with those of control groups who remained on standard domestic rates. The experiment was unusual because of the voluntary nature of the TOU program, the wide variation in tariffs offered under the program, the maintenance of rigorous experimental control groups, and the extensive data collected in conjunction with the program.

The analysis identified the features of the voluntary rates that customers found most attractive, the appliance holdings and other characteristics of volunteer households, and the changes in load patterns attributable to the TOU tariffs. Statistical analyses were performed to quantify the effects of incremental changes in prices and other features on customer participation and load response. The implications of these participation and demand models for rate design and possible revenue attrition were investigated.

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INTRODUCTION

Time-of-use pricing for electricity has long been advocated as a means of promoting the efficient economic allocation of scarce generation resources with varying installed and operating costs and other characteristics. However, TOU tariffs have gained only moderate acceptance in the electric power industry. While many utilities have instituted TOU tariffs, only small percentages of customers are usually billed under these rates. This is particularly true in the residential sector. A recent survey of 123 investor owned utilities sponsored by EPRI showed that while over fifty percent had TOU tariffs in the residential sector, less than one percent of their customers were billed under these rates (*Innovative Rate Design Survey*, EPRI EA-3830, January 1985).

The two major arguments against TOU pricing are, first, that any efficiency gains will not compensate for the additional metering and program administration costs and, second, that the tariffs will have adverse distributional impacts by shifting the revenue requirement from larger customers with flexible loads to smaller ones with inflexible loads. In response to such arguments, many utilities, including PG&E, have designed TOU tariffs with fixed charges to defray the metering costs and have offered them on a voluntary basis. The distributional impacts of these tariffs depend critically on the usage characteristics of volunteers and their willingness to modify usage patterns in response to the time differentiated rates. If volunteers are unwilling to shift usage, then only those who could reduce their bills under the optional rate would join, resulting in a revenue loss that must be recovered from nonparticipants. This shift in the revenue burden from volunteers is mitigated to the degree that the cost savings from reduced peak period usage and the stimulative effect of off-peak discounts offset the revenue loss. It is even feasible, in principle, to design a voluntary rate that is self sustaining in the sense that it imposes no revenue burden on nonparticipants. (See The Theory of Public Utility Pricing, by Stephen J. Brown and David S. Sibley for discussion of the design of voluntary tariffs with such characteristics.) An important empirical question is whether it is practically feasible to design such a tariff that will appeal to significant portion of customers, and what are the optimal characteristics of this tariff in light of the expected participation rates and load responses.

While several time-of-use pricing experiments have been conducted in the past to study customer response, their findings have limited application to this empirical issue. All of the experiments conducted in the seventies that are the bases for numerous analyses of electricity demand by time-of-day were mandatory. One would expect that the average customer response to mandatory rates would be significantly different from the response to voluntary rates. The voluntary rates would tend to attract customers with low on-peak shares who would pay less under the TOU tariff, even without shifting usage patterns. They would also tend to attract customers who, for unobserved reasons, are more willing than the average customer to modify their usage patterns.

Given the importance of estimating customer response to voluntary TOU rates for rate design and the limited use of previous estimates, PG&E undertook an experiment to examine the issues of participation and load response. Under the experiment, various TOU tariffs were offered to residential customers in different geographical operating divisions of PG&E. Surveys were administered to a sample of households who volunteered and a control group that declined the offer. Usage data were collected for the volunteer and control households over a two year period during which they were billed under the flat rates (in the first year) and TOU rates (in the second year). The nature of the issues for which the experiment was designed and the the structure of the treatments and controls are described below.

EXPERIMENTAL ISSUES

PG&E's experiment was aimed at addressing issues in two general areas. The first concerned the characteristics of volunteers versus nonvolunteers. The second concerned the changes in on-peak and off-peak electricity usage patterns of volunteers in response to the TOU rates.

In the first area concerning customer characteristics, the following experimental issues were identified:

- What are the on-peak and off-peak usage patterns of volunteers versus nonvolunteers under the standard domestic tariff?
- What are the demographic characteristics and appliance ownership patterns of volunteers versus nonvolunteers?
- What are the awareness, attitudes, and stated preferences toward TOU rate characteristics of volunteers versus nonvolunteers?

In the second area concerning changes in usage patterns under the TOU tariffs, the following experimental issues were identified:

- What are the changes in on-peak and off-peak usage by volunteers in response to the TOU rates?
- How do the relative on-peak and off-peak prices under TOU rates affect usage?
- How does the timing of the peak period affect the changes in on-peak and off-peak usage in response to the TOU rates?

DESCRIPTION OF PG&E'S EXPERIMENT

Background

PG&E first offered voluntary TOU rates to residential customers in 1982. The original rate was authorized on a limited basis, involving 1,000 customers who consumed in excess of 1,000 kWh per month. In 1983 PG&E expanded the program, installing 20,000 more meters on high-use residential customers. Prior to approving further expansion, though, the California Public Utilities Commission (CPUC) in late 1983 ordered PG&E to test the customer acceptance, load impacts, and cost-effectiveness of a variety of alternative rate designs (Decision No. 83-12-068).

In response to the CPUC order, in 1984 PG&E initiated a two-year experiment involving approximately 5,000 residential customers and eight alternative TOU tariffs. The experimental tariffs differed along a number of dimensions:

- the definition of the peak period;
- the peak to off-peak price ratio;
- the variation in the rates by season;
- the number of rate tiers; and
- the existence of a baseline credit.

Each rate was designed to be revenue neutral with respect to PG&E's standard residential tariff, so that a customer with monthly usage (in total and distributed by TOU period) equal to the class average would receive an equivalent bill under any of the eight TOU rates or the standard non-TOU rate.

Experimental Design

The experiment was designed to permit both longitudinal and cross-sectional comparisons of customer usage patterns, and to enable researchers to explicitly model and estimate customers' choices of rate options and their price-responsiveness. Table I summarizes the experimental design. Customers were randomly selected and assigned to one of three groups--treatment volunteers, control volunteers, and non-volunteers--based upon their response to recruitment literature.

During the first year of the experiment (1985), all of the participants were billed under the standard residential schedule. During the second year (1986), one group of volunteers was placed on TOU rates, while the remaining volunteers and a group of nonvolunteers with TOU meters continued under the standard residential tariff. The volunteers who went on TOU rates in the second year were assigned to one of the eight alternative schedules summarized in Table II.

The panel nature of the experimental design allows researchers to compare usage patterns in a variety of ways. For example, a pre- versus post-treatment comparison is provided by comparing the consumption of the treatment volunteers in 1985 and 1986 (i.e., Cell A2 versus Cell A1 in Table 1). Two types of cross-sectional comparisons are also possible. The effects of consumption patterns on a customer's propensity to volunteer can be investigated by comparing volunteers and nonvolunteers under standard rates during the first year of the experiment (i.e., Cells A1 and B1 versus Cell C1). The effects of TOU rates on volunteers' consumption patterns can also be examined, by comparing volunteers under the TOU rates and volunteers under the standard rate during the second year (i.e., Cell A2 versus Cell B2).

Customer Recruitment

The target population for the TOU experiment consisted of residential customers whose average monthly usage exceeded 800 kilowatt-hours during the previous twelve months. A random sample of customers meeting this requirement was drawn and customers were recruited with a direct mail package. Each customer received a description of a single TOU rate and could volunteer for that rate only. The rate which was offered varied depending on the geographical location of the customer. Volunteers were randomly assigned to either the treatment or control group, and PG&E installed time-of-use meters on these volunteers soon after they enrolled in the TOU rate program.

The control group of nonvolunteers was randomly selected (subject to minimum installation quotas for each of PG&E's operating regions) from the set of customers who had been offered a time-of-use rate but declined to participate. Time-of-use meters were installed on these nonvolunteers to measure their on-peak and off-peak consumption although they are billed under the standard residential rate throughout the experiment.

EXPERIMENTAL FINDINGS ON CHARACTERISTICS OF VOLUNTEERS VERSUS NONVOLUNTEERS

The first area of investigation concerned the characteristics of volunteers versus nonvolunteers. These included pre-TOU load characteristics, demographic attributes and appliance ownership patterns, and attitudes toward TOU rates. The load characteristics were identified by collecting usage data from TOU meters for a one year period under the standard domestic tariff prior to switching to the TOU rates. The other data on household characteristics were collected from three surveys that PG&E conducted at intervals throughout the experiment. The first two were administered in the Spring and Fall of 1985 before the TOU rates took effect, and the third was taken in the Winter of 1986, shortly after TOU rates began for some volunteers. Each survey was administered to a group of volunteers and a sample of the control nonvolunteers. Each survey included a battery of questions about the household's socioeconomic and dwelling attributes and appliance holdings. In addition, volunteers were asked about the attractiveness of various aspects of the TOU rate schedules and their general attitudes about energy use.

Load Characteristics of Volunteers Versus Nonvolunteers

To investigate differences in load patterns of volunteers and non-volunteers, PG&E compared the on-peak and off-peak usage of the two groups in 1985, before the TOU rates took effect. Average monthly values were tabulated and compared to identify significant differences. These are shown in Figures 1 and 2. The results showed that, although their on-peak usage tends to be quite similar to that of non-volunteers, volunteers use about ten percent more electricity during the off-peak period. These higher off-peak usage shares make TOU rates attractive because households can take advantage of the off-peak price discounts.

Demographic Characteristics and Appliance Ownership Patterns of Volunteers Versus Nonvolunteers

To examine the effects of household characteristics on propensity to volunteer, two sets of analysis were performed. First, tabulations of the mean survey responses for volunteers and nonvolunteers were used to identify significant differences between the two groups. Second, a multivariate analysis of the participation rates identified the characteristics that most strongly explained program participation, after controlling for other relevant factors.

The results showed that household demographics, appliance holdings, and energy use patterns are all important factors in predicting household participation in the voluntary program. Households with fewer members, fewer small children, an older and more educated head, and a larger dwelling are most likely to volunteer. Household income, if viewed in isolation, has a positive effect on the probability of participating, although this appears to be due to its correlation with dwelling size and education. As expected, households that own more discretionary appliances (e.g., dishwashers, clothes, washers and dryers, and, in some PG&E climate zones, central air conditioners) are also more likely to volunteer, presumably due to a greater ability to shift load and benefit from the lower off-peak rate.

Attitudes of Volunteers Versus Nonvolunteers Toward TOU Rates

Analysis of the participant surveys showed that the most important feature of TOU rates, from the standpoint of customer acceptance, is the timing of the peak period. Households stated a strong aversion to taking service on a TOU rate with a peak period that extended past 6:00 p.m. Households showed a general willingness to postpone afternoon activities that used electricity, but "drew the line" at the dinner hour.

A second feature that elicited strong opinion from experimental customers is the TOU meter charge. This charge is added to customers' monthly bills to pay for the additional cost of a TOU meter compared to a standard one. Although it is not large ($3.00 per month), it is perceived as inequitable, since customers on traditional rates do not pay a similar charge. One remedy for this problem of perceived inequity is to increase customer education efforts to explain to TOU customers that all customers pay for the cost of their meters in their rates, and that the TOU meter charge covers only the additional cost of a TOU meter compared to a standard one. A better long-term solution, though, is to change one or the other rate (i.e., either add a meter charge to the traditional rate or "bury" the additional cost of the TOU meter in the various energy charges) so that the two are comparable.

Finally, customers reacted very favorably to the opportunity that TOU rates offer to increase their control over their electric bill. This reaction is not directed to a specific feature of TOU rates, but to the general TOU rate structure which offers a lower rate for at least a portion of the billing period. Many customers felt that they had approached the limit of their ability to conserve electricity, so that their bills under conventional rates were uncontrollable. TOU rates give them the ability to "control their destiny," at least to some extent, and limit bill increases without suffering reduced levels of electric consumption and declines in their quality of living. This finding suggests that marketing efforts that emphasize the aspect of giving a customer greater control over its electric bill will have success.

EXPERIMENTAL FINDINGS ON LOAD RESPONSE OF VOLUNTEERS UNDER TOU RATES

The second area of issues concern the load response of volunteers under the TOU rates and the sensitivities of these response to the prices and other rate characteristics. These issues were addressed through two sets of analysis. In the first, the changes in peak and off-peak use by volunteers under the transition to TOU rates were compared with those for a control group of volunteers who remained under the standard rate. In the second, a conditional demand analysis of peak and off-peak consumption was performed to quantify the sensitivity of the usage to prices and other TOU rate characteristics, as well as to weather, household attributes, and appliance holdings.

Comparison of Consumption Patterns Under TOU Versus Flat Rates

The basic qualitative issues under the load impact analysis concern whether volunteers responded to the time-of-use rates by reducing their peak period electricity use and increasing their off-peak use. Given the experimental design where the enlistment was randomized and some volunteers remained on flat rates during the second year, these issues can be answered, at least in aggregate, by examining the changes in consumption of the first year volunteers from 1985 to 1986 and comparing them to those of second year volunteers who remained on the flat rate. Since volunteers were assigned to the two groups at random, any systematic differences in the changes in consumption patterns between the groups can be attributed to the imposition of TOU rates.

The pattern of changes in electricity use under the transition to TOU rates are compared with the year-to-year changes for a control group of volunteers who remained on standard rates over the two years. This is presented in Figure 3 which shows the differences in the year to year **changes** by billing month between the treatment volunteers and control volunteers. Average monthly off-peak usage of the treatment volunteers rose and peak usage fell consistently **relative** to that of the control group. In those months where the treatment group's off-peak usage fell between the two years, that of the control group fell even more. The control group's average off-peak use actually declined between 1985 and 1986. Overall, volunteers increased their off-peak electricity consumption by an average of forty-one kWh per month relative to the control group after changing to time-of-use rates.

Under the experimental design, the changes in use by the control group are due to weather variations and other factors that are also common to the treatment group and would affect them similarly. Any differences in the changes are attributable to the only factor that varies systematically between the two groups, the rate structure. Overall, the peak consumption of the treatment volunteers declined eight percent and off-peak consumption rose five percent relative to that of the control volunteers. Both of these relative changes are much greater than could be attributed to any sampling error with at least ninety-nine percent confidence.

Conditional Demand Analysis of TOU Consumption

While the simple comparisons of year-to-year peak and off-peak consumption by treatment and control volunteers confirm that the TOU rates induce significant changes in usage patterns, their value is limited for quantifying the impacts of TOU electricity price changes on consumption after controlling for weather, demographics, and other factors that influence use. This quantification of price responses is critical to TOU rate design because the cost effectiveness of the voluntary rates depends on the magnitude of the shift in loads relative to the price changes.

In order to quantify the sensitivities of peak and off-peak consumption to electricity prices, conditional demand analysis of the monthly consumption was performed. Conditional demand analysis is an application of regression techniques to merged energy billing and survey data where detailed representa-

tions of appliance holdings and their characteristics are included in the empirical specification. The analysis identifies the contributions of the individual appliances to overall demand, as well as the impact of prices after controlling for appliance holdings and other variables.

The conditional demand models were estimated on observations of monthly peak and off-peak consumption for the two year period spanning the transition to TOU rates. In general, the coefficients of the explanatory variables representing electricity prices, household demographics, appliance holdings, and weather were reasonable in magnitude and statistically significant. The key variables of interest for this analysis are the marginal prices of electricity for peak and off-peak in the respective period demand models. The coefficients of these variables quantify the magnitude of the load response to price changes. The coefficients of the simple marginal price variables were negative and highly significant in explaining consumption in both the peak and off-peak demand models. For those TOU rates where the peak period occurred from noon to 6:00 P.M., the estimated models implied that a one cent increase in the peak period price would reduce average monthly consumption by about 3.5 kWh, while a one cent decrease in the off-peak price would stimulate consumption by over twenty-two kWh. At the mean levels of consumption and prices in the sample, the peak and off-peak price elasticities of demand by volunteers are -.23 and -.25, respectively. These are short term elasticities that do not include changes in appliance holdings or operating characteristics to take advantage of the price differential. Separate variables representing price sensitivity for the tariffs with later peak periods showed that volunteer households were less willing to change peak period consumption in response to price changes under these rates.

The estimated conditional models indicate that volunteers are more sensitive to prices in their on-peak consumption, but less sensitive in their off-peak use. For nonvolunteers, the peak and off-peak price elasticities of demand at the means for this sample subgroup are -.15 and -.36, respectively (versus -.23 and -.25 for the volunteers). One would expect significantly larger responses by households in the long run as they change their appliance holdings and characteristics.

LOAD AND REVENUE IMPACTS OF ALTERNATIVE RATES

The estimated conditional demand models were used to simulate TOU program participation rates and the load and revenue impacts of alternative voluntary TOU tariffs with different peak period timing, tier structure, and on-peak to off-peak price ratios. The program participation rates were estimated by computing the economic attractiveness of the optional tariffs, defined in terms of change in consumer surplus, from the demand equations. The load impacts were estimated from the price coefficients in the demand models and the price differentials between the TOU and baseline rates for households to whom the voluntary rates were attractive. The revenue impacts were determined by computing the change in monthly bills for volunteer households. These calculations were performed on a representative sample of households that reflects the distribution of residential customers in PG&E's service territory. The results were summed over the sample to yield average

responses for the population.

The results of the simulations for the experimental rates offered by PG&E are summarized in Table III. The table shows a wide range of program participation rates, and load and revenue impacts. The sources of these variations are most easily understood by considering how the experimental rates were designed. The general tier structure, price ratio, and other features were specified, and then the absolute prices were set to make the rates revenue neutral for a household with defined monthly total and peak period usage. If the tariff had a baseline or second tier, then the subsidies implicit in these were made up by raising the tailblock rates for both the on-peak and the off-peak periods. This would increase the on-peak price premium and reduce the off-peak discount. The net effect of the baseline and second tier allowances is to make the optional tariff more attractive to smaller customers and less attractive to larger customers. Since there are more small customers than large ones, the percentage of households to whom the rates is economically attractive increases. Thus, for example, the D-8G rate with its three tiers is attractive to the largest percent of customers.

The revenue impacts generally (although not entirely) vary in the opposite direction to the participation rates. All of the TOU rates have positive gross revenue impacts due to the $3.00 monthly fixed charge and the off-peak discounts that stimulate total sales. The D-8G rate has the smallest impact because of its three tier structure. The D-8D rate has the greatest revenue impact due to its single tier structure and high price ratio. In fact, it is the only rate where the revenue gain more than offsets the estimated TOU metering and program administration costs of $3.00 per month. The D-8D rate would also cover the change in generation costs for off-peak marginal costs up to $.022 and on-peak marginal costs above $.055 per kWh. This suggests that voluntary TOU tariffs can be designed that are attractive to customers without reducing profits.

CONCLUSION

The analysis of participation and load response under PG&E's residential time-of-use rate experiment has important applications for the design of voluntary rates. One of the key objectives of rate design is to develop such rates with prices and other features that make them attractive to prospective participants, while minimizing the adverse revenue impacts on nonparticipants. Recent theoretical work on optimal rate design suggests that it is possible to formulate such rates that are attractive to some customers without hurting remaining ones. The optimal prices under these rates are computed according to a "Ramsey type" formula where the deviations of prices from marginal costs are inversely proportional to the demand elasticities. In practice, where the optional rates have fixed and variable administration costs and the elasticities vary over customers, it is an empirical question whether it is possible to formulate voluntary rates without shifting some revenue burden to nonparticipants. Simulations of participation and load response using the estimated demand models from the PG&E experiment indicate that such rates are practically feasible.

TABLE 1

Pacific Gas and Electric Company
Voluntary Residential Time-of-Use Experiment
Experimental Design

1985	1986
(A1) VOLUNTEER PRE-TREATMENT (standard rate)	(A2) VOLUNTEER TREATMENT (TOU rate)
(B1) VOLUNTEER CONTROL (standard rate)	(B2) VOLUNTEER CONTROL (standard rate)
(C1) NON-VOLUNTEER (standard rate)	(C2) NON-VOLUNTEER (standard rate)

Types of Analysis

Longitudinal
TOU Effects (A2 vs. A1)

Cross-Sectional
TOU Effects (A2 vs. B2)
Willingness to Volunteer
(A1 and B1 vs. C1)

TABLE 2

Pacific Gas and Electric Company
Voluntary Residential Time-of-Use Experiment
Summary of Rate Designs

Rate Schedule	On-Peak Hours	Price Ratio	Tiers in Each Period	Baseline Credit?	Seasonal Rates?
D-7	Noon - 6:00 p.m.	2.5:1	Two	No	No
D-8A	Noon - 6:00 p.m. (Summer) 3:00 p.m. - 9:00 p.m. (Winter)	2.5:1	Two	No	No
D-8B	2:00 p.m. - 8:00 p.m.	2.5:1	Two	No	No
D-8C	Noon - 6:00 p.m.	2.5:1	One	Yes	No
D-8D	Noon - 6:00 p.m.	2.5:1	One	No	No
D-8E	Noon - 6:00 p.m.	2.0:1	Two	No	No
D-8F	Noon - 6:00 p.m. (Summer) 3:00 p.m. - 9:00 p.m. (Winter)	2.32:1 1.5:1	Two	No	Yes
D-8G	Noon - 6:00 p.m.	2.4:1	Three	No	No

Figure 1
PEAK USAGE

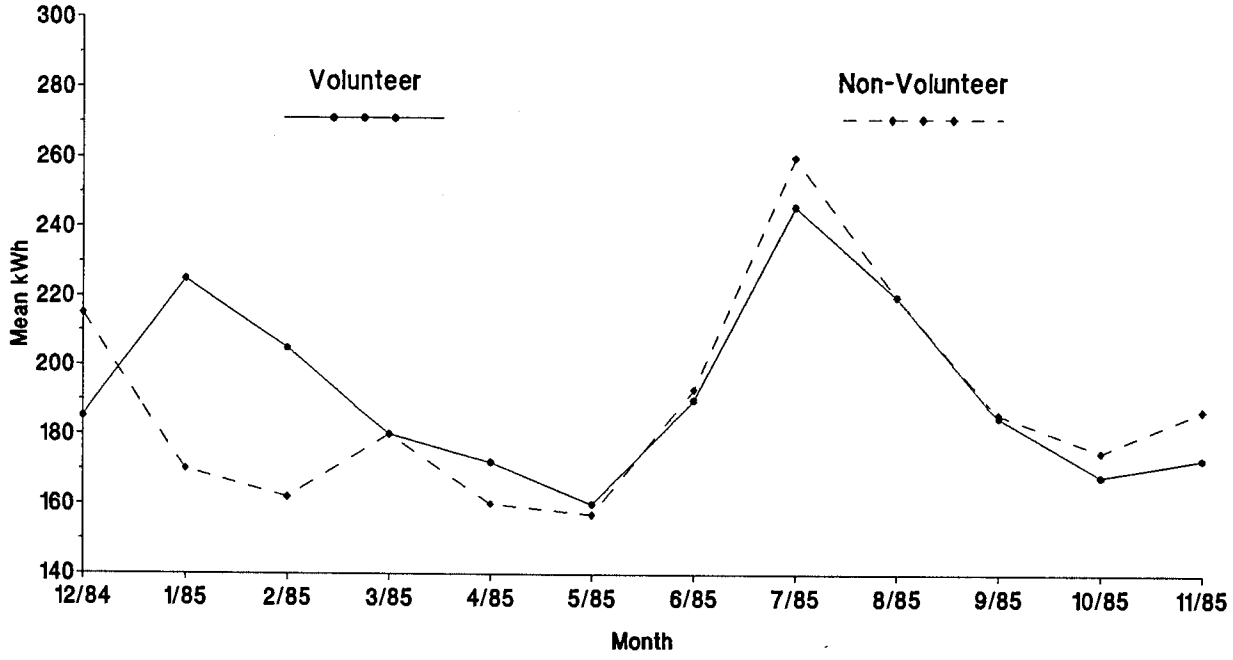

Figure 2
OFF-PEAK USAGE

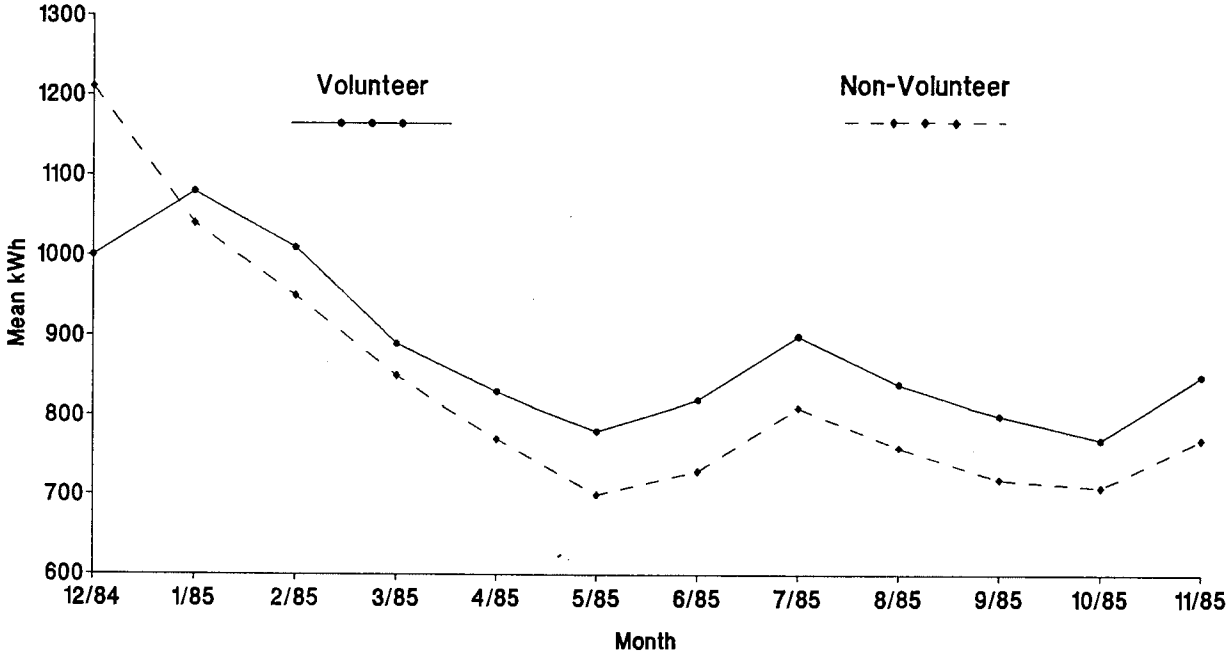

FIGURE 3

DIFFERENCE IN TREATMENT AND CONTROL VOLUNTEERS
SHIFT IN LOADS FROM 1985 TO 1986

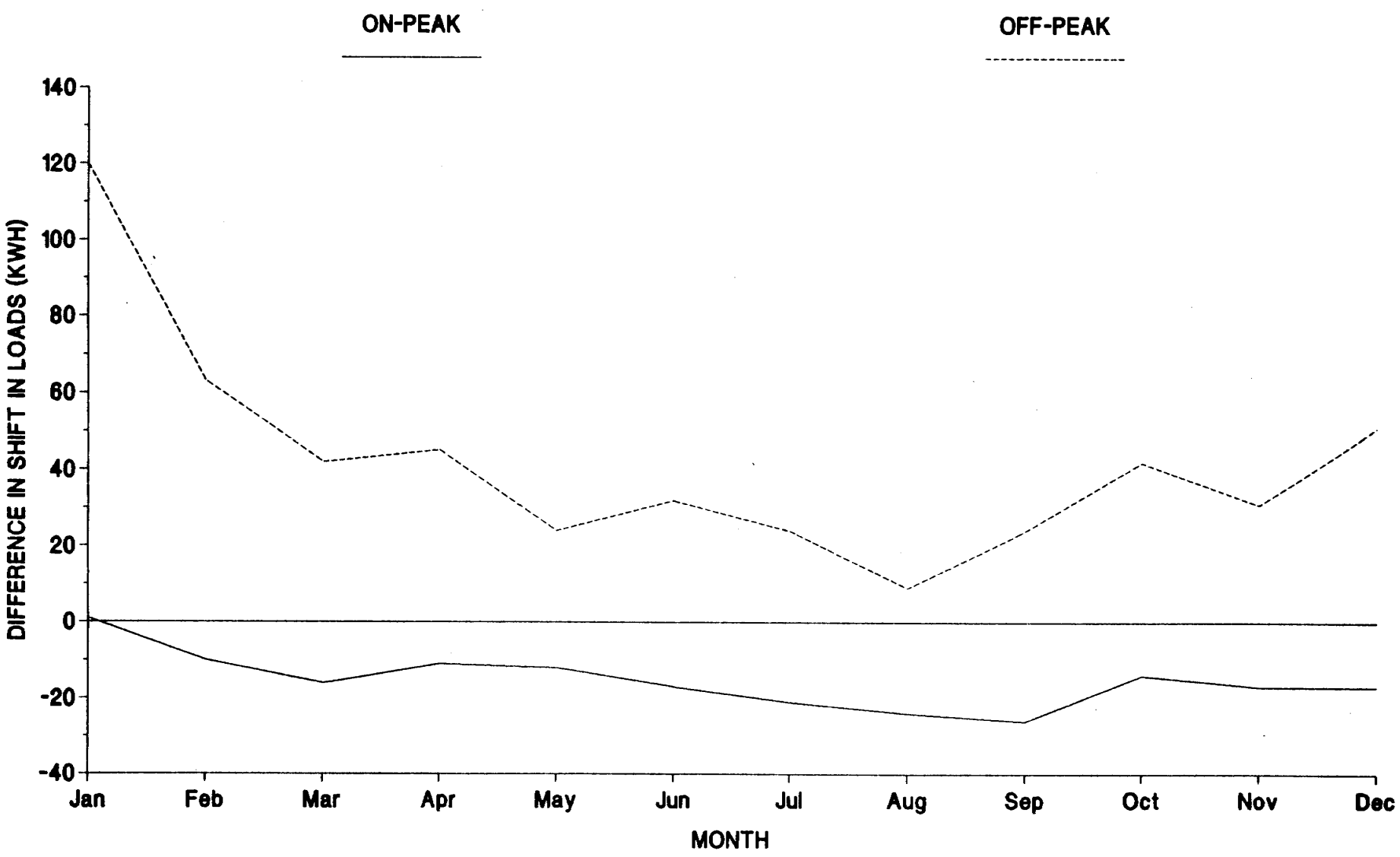

Table 3

SIMULATED PARTICIPATION, AND LOAD AND REVENUE IMPACTS, OF EXPERIMENTAL TOU RATES

	Volunteer Rate	Change in Summer Peak Usage (kWh/month)	Change in Summer Off-Peak Usage (kWh/month)	Change in Winter Peak Usage (kWh/month)	Change in Winter Off-Peak Usage (kWh/month)	Change in Revenues ($ per month)
D-7	37%	-29	+68	-26	+66	+0.90
D-8A	29%	-29	+68	-21	+69	+1.52
D-8B	26%	-24	+71	-16	+63	+2.08
D-8C	42%	-30	+67	-28	+69	+0.41
D-8D	34%	-19	+105	-19	+106	+4.27
D-8E	17%	-20	+65	-18	+61	+2.65
D-8F	44%	-28	+66	-2	+68	+1.56
D-8G	56%	-28	+64	-26	+61	+0.40