Voluntary Time-of-Use Rates Induced Load Shifting and Peak Load Reduction

S. Mostafa Baladi, Christensen Associates
Joseph A. Herriges, Iowa State University
Thomas J. Sweeney, Midwest Power Systems

This paper presents key findings of the voluntary residential Time-of-Use (TOU) rate experiment implemented during the summers of 1991 and 1992 at Midwest Power Systems (MWP). This study addressed two principal issues: First, how do volunteers differ from non-volunteers in terms of their load patterns and socio-demographic characteristics? Second, how do volunteers alter their load patterns in response to the TOU rates? From among the volunteers, 575 were randomly chosen to receive load research meters. These volunteers were then randomly divided into a volunteer treatment group and a volunteer control group. In addition, load research meters were installed for 200 non-volunteer households.

Several key findings emerge from the analysis: First, volunteers, on average, have essentially the same appliance holdings and usage patterns under standard rates as non-volunteers. Thus, self-selection does not lead to revenue erosion for the utility. Second, econometric analysis indicates that volunteers reduced their on-peak usage by 24 percent, with little or no change in their off-peak consumption. These changes were even more pronounced on days when the system peaked, with on-peak usage dropping by over 28 percent. Third, the ownership of major electrical appliances significantly increased the percentage reduction in on-peak kWh induced by TOU pricing. And finally, the reductions in on-peak kWh were not concentrated in any one hour.

Introduction

Three years ago, Midwest Power Systems (MWP) began the process of expanding its voluntary Time-of-Use (VTOU) rate offering to residential customers. The objective of this expansion was to enroll a minimum of 2,500 households in the program by the summer of 1991. At the same time, the expansion incorporated a Residential Energy Study to provide the utility with information essential to understanding the impact of its VTOU program on both program participants and utility costs, and to aid in future modifications to the tariff. In particular, the goals of the study were to answer the following questions:

- How do volunteers compare with non-volunteers in terms of their initial load patterns? The voluntary nature of Midwest Power's Time-of-Use (TOU) rate program creates an incentive for households with little on-peak usage to volunteer. These households can benefit from program participation, in the form of reduced electricity bills, without changing their usage patterns. The risk is that their participation can lead to revenue erosion problems for the utility if it is not offset by other program participants or by usage pattern changes in response to the TOU rate.

- How do volunteers alter their usage patterns in response to TOU rates? The success of a TOU rate program depends upon the ability and willingness of customers to alter their usage in response to the TOU price signals. To the extent that households shift usage from on-peak hours to the lower cost off-peak hours, the program will generate operating and capacity cost savings. These savings are needed to offset the additional metering and administrative costs associated with TOU rates. Observed changes in customer usage patterns can also be used to assess the impact of the TOU rate on the well-being of program participants.

The purpose of this paper is to provide answers to the above questions based upon an analysis of usage and survey data from the two summers of the study. In this paper, we have attempted to draw together the results from both summers of the project, avoiding statistical details of the research and relying, instead, on graphical presentation of the results. A full presentation of the methodology and the results are reported in Baladi and Herriges (1992), Baladi et al. (1993), Baladi and Herriges (1993 a,b,c). This paper is organized as follows: study design and implementation, followed by response to the voluntary TOU program. In that section the participation decision and response to TOU rates are discussed. Finally, the summary and conclusions are presented.

Study Design and Implementation

Basic Experimental Design

The Residential Energy Study was developed as part of Midwest Power's efforts to expand its voluntary TOU rate program. With a goal of recruiting a minimum of 2500 residential households, this experiment provided a rare opportunity to learn more about residential response to voluntary TOU rates. As indicated in the Introduction, the study was designed to answer two key questions: (1) How do volunteers compare with the general residential population? and (2) How do volunteers alter their usage patterns in response to TOU rates? Answers to both of these questions are essential to evaluating the existing VTOU program and to developing and targeting future residential TOU rate offerings.

In order to address the above questions, an experiment was designed to gather detailed usage and socio-demographic information on a subsample of TOU program volunteers, as well as a sample of non-volunteers. The design has two dimensions, one reflecting the division of the target population into various treatment and control groups and the other dimension indicating changes in each group's rate schedule over time. Table 1 illustrates the basic design of the experiment.

Implementation of the design began with the selection of a random sample of 60,000 residential households in Midwest Power's service territory. Beginning in December 1990, these households were offered participation in the VTOU program. This resulted in the first division of the customers, namely into the volunteer and non-volunteer groups.

The volunteer group was then randomly divided into two subgroups. Three hundred volunteers were assigned to the "voluntary treatment" group and were billed on TOU rates beginning May 16, 1991. However, 275 volunteers were assigned to a "volunteer control" group, remaining on standard rates during the first year of the project (i.e., Phase I). This group provides essential information on how TOU volunteers behave under standard rates. Comparing the usage pattern of households in the volunteer treatment and the volunteer control groups during Phase I indicates the usage pattern changes made by volunteers in response to TOU rates. This phase of the project provides for a *cross-sectional* measure of the response to MWP's TOU rate (i.e., a measure based on the comparison of the two groups within the same time period, where the key difference between the two groups is their electric rate structure). It would have been ideal to keep the control customers permanently on standard rates. However, the response estimation bias should be minimal. Customers in the volunteer control group were billed under the TOU rate in the summer of 1992 (i.e., Phase II). This phase of the project provides for *time series* measure of the response to MWP's TOU rate. During this phase (the summer of 1992), both volunteer treatment and control

Table 1. Voluntary Time-of-Use Rates: Experimental Design

	Target Random Sample [60,000]				
	Non-volunteers [57,600]		Volunteers [2400]		
	Non-participants [57,400]	Control [200]	Treatment [2,125]		Control [275]
	Standard Meter	Load Research Meter	3-register	Load Research Meter	Load Research Meter
Phase 1 (Volunteer Control Group on Standard Rate)	57,400	200	1,825	300	275
Phase 2 (Volunteer Control Group on VTOU Rate)	57,400	200	1,825	300	275

customers faced the TOU tariff. Changes in the usage patterns of volunteer controls from Phase I to Phase II may be attributed, at least in part, to TOU pricing.

The non-volunteer group was likewise divided into two groups. The majority of these customers were classified as non-participants, remaining on standard rates and being metered with traditional single register equipment. A random sample of 200 non-volunteers, however, was assigned to a "non-volunteer control" group and given load research meters, providing data on the usage patterns of the non-volunteers under standard rates. Comparing the usage patterns of the non-volunteer control and the volunteer control groups indicates the differences between the initial load patterns of these two groups. This comparison would determine if the initial usage patterns affect the volunteering decision. A similar division of the volunteer test group randomly selected 300 volunteers to be monitored using load research meters. The remaining volunteer test customers were outfitted with 3-register meters.

Rate Design

Midwest Power's Time-of-Use rate was designed to maximize the sum of the program's net benefits to participating and non-participating customers. A detailed description of the design process is provided in Caves et al. (1990). During 1991 summer season, the on-peak to off-peak price ratio is approximately 4.6:1 with on-peak and off-peak prices of respectively 19.58 and 4.23 cents/kWh. As required by policy, the VTOU rate maintained the 1991 and 1992 winter flat rates of respectively 7.30 and 7.59 cents/kWh for non-spaceheating customers (Caves et al. 1990). Finally, when MWP's residential rates increased in 1992, the same percentage increase was applied to the on-peak and off-peak energy charges, maintaining the 4.6:1 on-peak to off-peak price ratio developed in the initial rate design.

Data

The primary source of usage data collected for the Residential Energy Study was the 30-minute kWh readings collected through load research meters on each of the experimental households. The other key data sources used in the analysis of customers' response to VTOU rates were the baseline and exit surveys. The baseline survey was conducted at the beginning of the first summer of the VTOU program, whereas the exit survey took place after the completion of the second summer season. The objective of these surveys was to characterize the TOU program's volunteers and to uncover any distinguishing features of the volunteer treatment, volunteer control, and non-volunteer customers. The appliance holdings, sociodemographic, and customers' attitudinal data used throughout the analysis were drawn from these surveys. The survey results were subsequently combined with load research data on both volunteers and non-volunteers to model the impact of TOU pricing on residential load patterns and to shed light on the factors determining the decision to volunteer for the VTOU program. The response rates for the baseline and exit surveys were 95.5 percent and 93.4 percent, respectively.

Response to the Voluntary TOU Program

The Participation Decision

One concern about voluntary TOU rates is that volunteers may consist primarily of those customers who, under standard rates, already use only a small percentage of their total electricity consumption during the on-peak period. These households benefit from participation in the program without changing their usage patterns, resulting in revenue erosion for the utility with no offsetting operating or capacity cost savings. Three approaches were used to investigate the potential for this problem. They are: (1) a comparison of descriptive statistics from the baseline and exit surveys, (2) a comparison of descriptive statistics from the load research data base and (3) an econometric model of the participation decision itself. Approaches 1 and 2 are reviewed below. Results of the econometric modeling confirms the results of the descriptive statistics analysis and are not reviewed below.

Survey Responses. Both the baseline and exit surveys reveal that the differences between the volunteers and non-volunteers lie more in their attitudes and perceptions about how they use electricity than in their appliance stocks or demographic characteristics. Volunteer and non-volunteer customers have similar mixes of appliance holdings.

The differences between volunteers and non-volunteers become more pronounced when we turn our attention to the hours during which the two groups use, or at least perceive they use, electricity. For example, while approximately 70% of the customers in each group have central air conditioning, a larger percentage of volunteers report that they use their air conditioning only on the hottest days. Non-volunteers, on the other hand, are more likely to use air conditioning every day. Furthermore, the majority of non-volunteers (56%) report that they run their air conditioners 24 hours a day, compared to 42% in the volunteer group.

Perhaps the most interesting result concerning customers' perceptions appears in the "knowledge" section of the exit survey. Over half of residential households were unable or unwilling to guess the percentage of their total usage consumed during the weekday on-peak hours. This was true of volunteers and non-volunteers alike. However, among those households who did estimate their on-peak share, the non-volunteers *perceived* that they consumed a significantly larger percentage of their total monthly usage during the weekday on-peak hours, compared to their volunteer counterparts. Non-volunteers estimated that they consumed almost half (47. 1 percent) of their monthly usage on-peak, while the average volunteer placed this percentage at less than 30 percent. Even controlling for differences in rate schedules facing the two groups, their simulated on-peak shares are closer to 22 percent for non-volunteers and 18 percent for volunteers.

Usage Patterns—Descriptive Statistics. This subsection reports on the extent to which the perceived and actual usage of non-volunteers and volunteer control customers differ during the first summer season, when both groups were still on standard rates. The actual percentages of average daily usage of these two groups during on-peak hours are compared for each of the four summer analysis months and for the season as a whole (Baladi et al. 1993). The analysis is done for: (1) the month as a whole, (2) non-holiday weekdays, and (3) the day of system peak. Self-selection, as suggested by the survey responses, should manifest itself in a smaller on-peak percentage for volunteer controls. This is not typically the case. These differences are small and not statistically different. For the summer season as a whole, volunteer control customers consumed 23.9 percent of their total usage during the on-peak period, compared to 24.2 percent for the non-volunteers.

Differences between volunteers and non-volunteers could also manifest themselves in the usage levels of the two groups. Low-usage households have to shift a large percentage of their on-peak usage to the off-peak period in order to offset the additional metering charge associated with MWP's VTOU program. As a result, one might expect volunteers to have higher usage levels than non-volunteers. The differences between the two groups are generally small and are statistically insignificant in all cases. These findings remain unchanged when the descriptive statistics are calculated separately for the on-peak and off-peak time periods.

Thus, despite the indication of self-selection in the baseline survey data, the actual consumption patterns of the volunteer control and non-volunteer customers suggest that the problem is not a serious one for the Midwest Power VTOU program. Results show that for weekdays and weekends, the volunteer control customers tend to have a lower level of usage in all hours. However, the load shapes are virtually identical.

Response to Voluntary Time-of-Use Rates

The success of a TOU rate program depends upon the ability and willingness of customers to alter their usage in response to the TOU price signals. Earlier studies of both voluntary and mandatory programs have found that households do in fact alter their usage patterns in response to TOU rates (Caves et al. 1984; Caves et al. 1989; Christensen Associates 1987). This subsection focuses on our key findings on the response to MWP's voluntary tariff.

Descriptive Statistics. The load patterns of the volunteer treatment and volunteer control customers are compared for phase I of the project when the treatment customers were billed on TOU rates and volunteer control customers remained on standard rates. This comparison measures the impact that MWP's VTOU rate structure had on volunteers' usage patterns.

Average daily on-peak kWh is computed separately for three time frames: (1) non-holiday weekdays, (2) weekends and holidays, and (3) the day of system peak. As the results indicate, substantial and statistically significant reductions in on-peak consumption were found throughout the summer season. For the average summer weekday, on-peak usage was reduced by 2.7 kWh, or nearly 22 percent. While these overall reductions in on-peak usage are important, the impact that the TOU rate has on overall utility costs depends to a large extent on whether or not these reductions persist on those days and hours when incremental costs are highest, such as the day of system peak. One concern is that, while households may respond to TOU rate on the typical summer day, their responses might be muted on the hottest summer days. However, as with previous mandatory TOU studies, the problem does not arise for MWP's VTOU program (Caves et al. 1984; Christensen Associates 1987). The reduction in on-peak kWh was more than twice as large on the day of system peak (6.2 kWh or 28.4 percent of peak day on-peak usage) than on the average summer weekday.

Despite the fact that the price of off-peak electricity has decreased under the VTOU rate, the results indicate that usage on both weekdays and weekends during this time period has declined for volunteer treatment customer, though these off-peak reductions are typically small and statistically insignificant. While these findings run counter to expectations, they are not inconsistent with those of previous studies. Mandatory TOU studies have often found that response to TOU rates takes the form of reductions in on-peak consumption, with little change, or even at reductions, in off-peak usage ((Caves et al. 1984). Lost sales during the off-peak period have potentially significant implications of revenue erosion for the utility.

The combined impact of on-peak usage reductions and stable or reduced off-peak consumption leads to a reduction in overall electricity usage throughout the summer season. Summer usage under TOU rates declines by 3.2 kWh per day, or 9.4 percent. On the day of system peak the reduction is over 8 kWh, approximately 6.2 kWh during the on-peak period and 1.9 kWh during the off-peak period.

The primary incentive created by time-of-use rates is for households to reduce their on-peak usage as a percentage of their total electricity consumption. Figure 1 summarizes the change in the on-peak percentage for three time frames: (1) non-holiday weekdays, (2) weekends and holidays, and (3) the day of system peak. As expected, the share of total usage consumed during on-peak hours is significantly lower for the volunteer treatment households, compared to the volunteer controls, during weekdays when the on-peak TOU rate is in effect. On average, the weekday on-peak share is reduced from 35 percent to 31 percent, with the greatest response occurring during the peak summer months of July and August. The smallest response occurs during the first analysis month. In contrast, the response during each month's peak day is consistently high. Finally, during weekends and holidays, when usage during the on-peak and off-peak hours are priced at the same off-peak rate, the on-peak share is often statistically insignificant. This suggests that households may have learned to shift usage away from the on-peak hours primarily when the on-peak rate is in effect.

Modeling the Response to Voluntary Time-of-Use Rates

Our economic model of residential response to TOU rates is based upon a division of customer response into three aspects or stages:

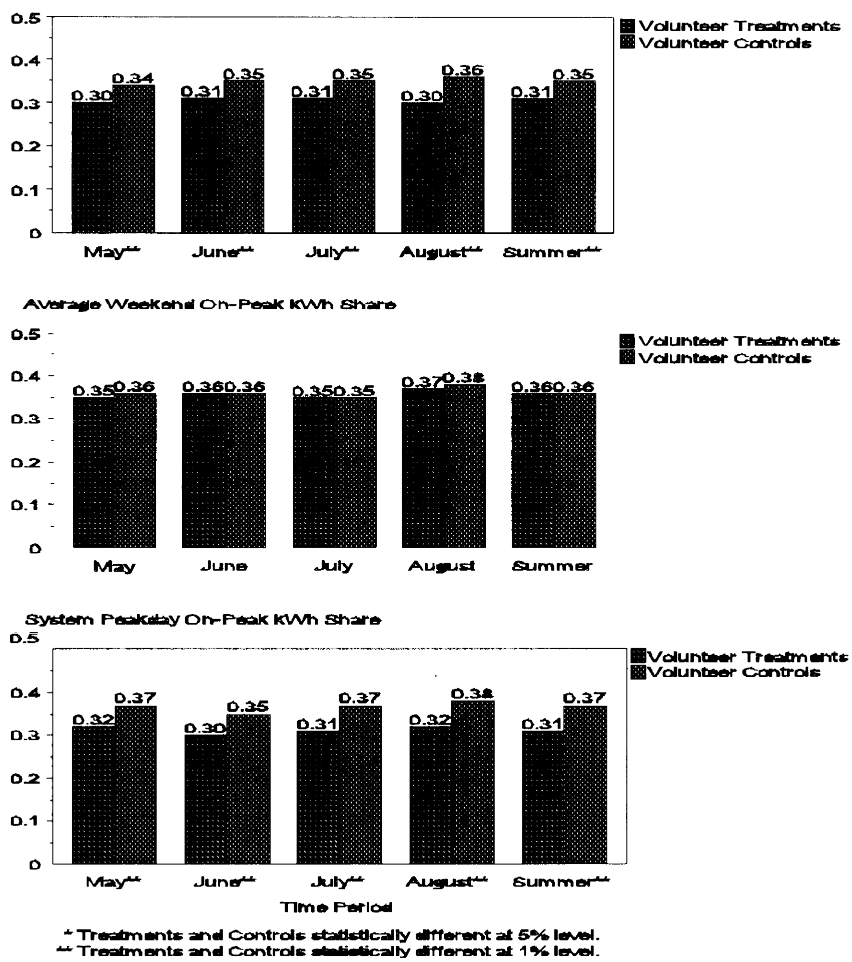

Figure 1. On-Peak Share-Volunteer Treatment versus Volunteer Controls, Average Weekday On-Peak kWh Share

- Stage I models the changes in a customer's on-peak usage share consumed during non-holiday weekdays; i.e., changes in the weekday load shape.
- Stage II models shifts in the loads between weekdays and weekends.
- Stage III models changes in the overall level of electricity expenditures.

This multi-stage approach provides a clear indication of how customers alter their usage patterns in response to TOU rates, not just whether such a response exists. Some customers may respond to TOU rates by shifting on-peak usage to the off-peak periods on weekdays (a Stage I response), leaving weekend usage virtually unchanged. On the other hand, a household may leave its weekday load pattern alone, preferring to respond to the TOU price signal by increasing weekend usage relative to weekday usage (a Stage II response).

The three stages of the model are represented, respectively, by the estimating equations:

$$ln(K_p/K_o) = \alpha_1 - \beta_1 ln(P_p/P_o) \quad (1)$$

$$ln(E_w/E_h) = \alpha_2 + (1 - \beta_2) ln(P_w/P_h) \quad (2)$$

$$ln(E_w/E_h) = \alpha_2 + (1 - \beta_2) ln(P_t/P_g) + \theta ln(Y/P_g) + \rho_3 D_{TOU} \quad (3)$$

where

- P_i denotes the price of electricity during time period i (i=p for on-peak weekday s,= o for off-peak weekdays, and =h for weekend days).
- P_g is a price index measuring the overall price level of non-electricity goods.
- P_w is a price index of weekday energy costs (combining on-peak and off-peak prices during weekdays).
- P_t is a price index for total electricity usage.
- Y denotes household income.
- K_i denotes the level of electricity usage during time period i.
- E_i denotes total energy expenditures during time period i.
- D_{TOU} is a dummy variable which equals 1 if the household is on TOU rates and = O otherwise.

The parameter $ß_1$ measures the percentage reduction in the on-peak to off-peak usage ratio that accompanies each percentage increase in the on-peak to off-peak price ratio. Referred to as the elasticity of substitution between on-peak and off-peak usage, $ß_1$ measures the sensitivity of the customer's weekday load shape to TOU pricing. The parameters $ß_2$ measures the customer's willingness to shift usage from weekdays to weekend days in response to TOU pricing. The term $ß_3$ measures customer response to TOU rates at Stage III. In general, one would expect $ß_3$ to be positive, indicating that a 1 percent increase in the price of electricity would induce a less than 1 percent increase in electricity expenditures, due a reduction in overall electricity usage.

It should be noted that the data on both groups of customers, namely treatment and control customers are used in the above model estimations. The two groups are facing different price ratio, i.e. 1 for the control group and 4.6 for the treatment group. Previous study in this area has shown that the elasticity estimates do not depend on the TOU price ratios used in the estimation (Caves et al. 1984).

Response in the First Year. The basic Stage I model captures how the typical volunteer changes their weekday load shape in response to TOU rates. These changes are characterized by the *elasticity of substitution* between weekday on-peak and off-peak consumption. This elasticity measures the percentage reduction in the weekday ratio of on-peak to off-peak consumption that results from a one percentage increase in the ratio of on-peak to off-peak prices. The larger the substitution elasticity is, the larger are the changes to the residential load shape under TOU pricing.

Table 2 presents the estimates of this Stage I elasticity of substitution for each summer month and for the season as a whole. Consistent with the descriptive statistics, the estimates indicate that households do alter their pattern of electricity usage in response to the TOU price signal. The

Table 2. Elasticities of Substitution Between On-Peak and Off-Peak Usage Stage I - Basic Model's Monthly and Seasonal Estimates (Standard Errors in Parentheses)

Month	Elasticity	
May	.127**	(.022)
June	.143**	(.027)
July	.152**	(.025)
August	.173**	(.025)
Summer Season	.139**	(.022)

** Statistically different from zero at a 1% level elasticity of substitution is consistently positive and statistically different from zero at a 1 percent significance level. In addition, the response estimates fall within a relatively narrow band, ranging from .127 in May to .173 in August, with a gradual increase in response rate over the course of the summer.

The implications of the Stage I elasticities in terms of residential usage patterns are illustrated in Table 3. Table 3 shows how the share of weekday usage consumed on-peak changes as a function of the on-peak to off-peak price ratio (Baladi and Herriges 1993b). For example, under standard rates, the on-peak to off-peak price ratio is 1:1. Table 3 indicates that the corresponding on-peak share is 35.3 percent during the month of August (i.e., on-peak usage is slightly more than one third of total weekday consumption under standard rates). The positive substitution elasticities in Table 2 imply that as the on-peak to off-peak price ratio increases, the corresponding on-peak usage share declines. When the price ratio reaches 4.6:1, as in the MWP TOU tariff, on-peak consumption during August falls to only 29.4 percent of overall weekday usage,

Table 3. Weekday On-Peak Usage Shares Predicted from the Stage I Model

	Predicted On-Peak Share (%)				
Price Ratio	**May**	**June**	**July**	**Aug.**	**Summer Season**
1:1	33.2	34.8	35.0	35.3	34.6
2:1	31.3	32.6	32.6	32.6	32.5
4:1	29.5	30.5	30.3	30.0	30.4
4.6:1	29.1	30.0	29.8	29.4	29.9

The second stage of our three-stage model measures changes in customers' allocations of total usage between weekdays and weekends in response to TOU pricing. For example, under MWP's TOU tariff, weekend and holiday usage is priced entirely at the off-peak rate, while customers face a combination of on-peak and off-peak prices during weekdays. In response to the higher overall price of weekday usage under TOU rates, we would expect households to shift some of their loads to the weekends, reducing the share of the total usage allocated to weekdays. As with Stage I, this Stage II response to TOU pricing is measured in terms of an elasticity of substitution, this time between weekday and weekend usage. As expected, these elasticities are consistently positive and statistically significant for each summer month and for the summer as a whole, indicating that households do shift usage to weekends to take advantage of their lower overall prices.

Table 4 illustrates the implications of the Stage II elasticity estimates in terms of weekday/weekend usage shares. It shows the predicted share of total monthly usage consumed during weekdays under alternative on-peak to off-peak price ratios. For example, for the summer season as a whole, weekday usage constituted 68.5 percent of total usage when customers faced the standard tariff. MWP's TOU tariff, with an on-peak to off-peak price differential, induces customers to reduce this share to 66.1 percent. Similar changes occur for the individual summer months.

Table 4. Weekday Usage Shares Predicted from the Stage II Model

	Predicted On-Peak Share (%))				
Price Ratio	**May**	**June**	**July**	**Aug.**	**Summer Season**
1:1	67.5	65.1	73.4	62.3	68.5
2:1	66.8	64.1	72.5	62.3	67.5
4:1	66.2	63.1	71.3	60.4	66.3
4.6:1	66.0	62.8	71.5	60.1	66.1

Stage III of our model captures the final component of customer response to TOU pricing, namely, the change in a household's total kWh usage, with the corresponding change in their total electricity expenditures. Basically, the Stage III response parameter, similar to the Stage I and II elasticities, measures how households have altered their electricity expenditures, relative to their expenditures on all other goods, as a result of MWP's TOU tariff. Results indicate that electricity expenditures are consistently reduced, relative to other expenditures, with reductions that range from just over 17 percent during the months of May and June to over 25 percent in the month of August. These changes in expenditures are translated in Table 5 into overall reductions in kWh that range from 11.5 percent in June to 18.2 percent in July. The reductions are statistically significant at the 1 percent level for all but the month of June, when the reductions are statistically significant at only a 5 percent level.

The Residential Energy Study was designed to provide two measures of the response to MWP's TOU tariff: (1) a cross-sectional measure using data from only the first summer of the program and (2) a time-series measure comparing changing usage patterns of volunteer controls

Table 5. Percentage Change in Total Usage Predicted from the Stage III Model

Price Ratio	Percentage Change in Total Usage (%) May	June	July	Aug.	Summer Season
1:1	--	--	--	--	--
2:1	-15.1	-14.7	-21.0	-21.1	-22.0
4:1	-12.9	-12.3	-19.0	-18.6	-20.0
4.6:1	-12.2	-11.5	-18.2	-17.8	-19.3

from the first summer to the second. The above time series comparisons were made more difficult, and less precise, by the drastic weather pattern shift between the two years of the project, with the second summer being substantially cooler. Nonetheless, using data from the volunteer treatment households to control for year-to-year weather effects, we were able to measure response elasticities for both seasons (Baladi and Herriges 1993c). In all three stages, the second year elasticities were found to be similar to those obtained for the first year and almost in all cases the elasticities did not differ statistically between years using a 5 percent critical level. These results are consistent with the finding in earlier mandatory studies programs, that TOU response elasticities are stable over time, for at least the first three years after the implementation of a tariff.

The Impact of Customer Characteristics. The above basic analysis was extended in order to determine whether and how the response to MWP's voluntary TOU program varies among customers according to their socio-demographic characteristics. The basic three-stage model was extended to allow customer characteristics to affect both the household's basic pattern of electricity usage under standard rates and their ability to respond to TOU pricing (Baladi and Herriges 1993c). Here, we focus on how twelve customer characteristics alter the customer's responsiveness to TOU pricing. These characteristics, listed in Table 6, have been found to be significant determinants of the response to TOU pricing in many of the earlier mandatory studies of progress.

Beginning with Stage I, the extended analysis results indicate that greater number of electric appliance holdings, such as wall air conditioners, dishwashers, and dehumidifiers, consistently and significantly enhance a household's ability to respond to the VTOU tariff. That is, households with these appliances reduce their on-peak usage, relative to their off-peak usage, by a greater percentage than do households without such appliances. Other demographic characteristics, however, such as household size, appear to have little independent impact on response.

The implications of the appliance ownership effects identified in the above analysis can be seen visually in Figure 2. This figure illustrates how three representative households would alter their weekday on-peak usage share as the on-peak to off-peak price ratio increases. The first *(typical)* household has the average mix of electric appliances listed in Table 6. The second *(electric)* household is assumed to have all of the major electric appliances, including: central air conditioning, electric water heating, an electric stove, a dishwasher, an electric dryer, and a dehumidifier. The third *(non-electric)* household has only wall air conditioning. The three customers are assumed to be identical in terms of all other socio-demographic characteristics. All three households, for the sake of illustration, are also assumed to start with a hypothetical on-peak usage share of 35 percent under MWP's standard tariff. In fact, a customer's on-peak usage share under standard flat rates will vary according to the customer's socio-demographic characteristics. This variation was allowed for in the extended model. The non-electric household's on-peak usage share under standard rates is estimated to be 30.6 percent, while the electric household's share is 35.4 percent and the typical household has a weekday on-peak share of 34.6 percent. Figure 2 uses a common initial on-peak usage share in order to isolate how the household characteristics change a customer's response to TOU rate.

Table 6. Socio-Demographic Variables

Variable	Mean Value
Central Air Conditioning Ownership	.71
Number of Wall Air Conditioning Units	.38
Electric Water Heating	.15
Electric Stove Ownership	.67
Dishwasher Ownership	.60
Electric Clothes Dryer Ownership	.59
Dehumidifier Ownership	.36
Home Ownership	.81
Mobile Home Ownership	.03
Number of Rooms in Home	6.16
Single Parent Family	.04
Total People in Household	2.71

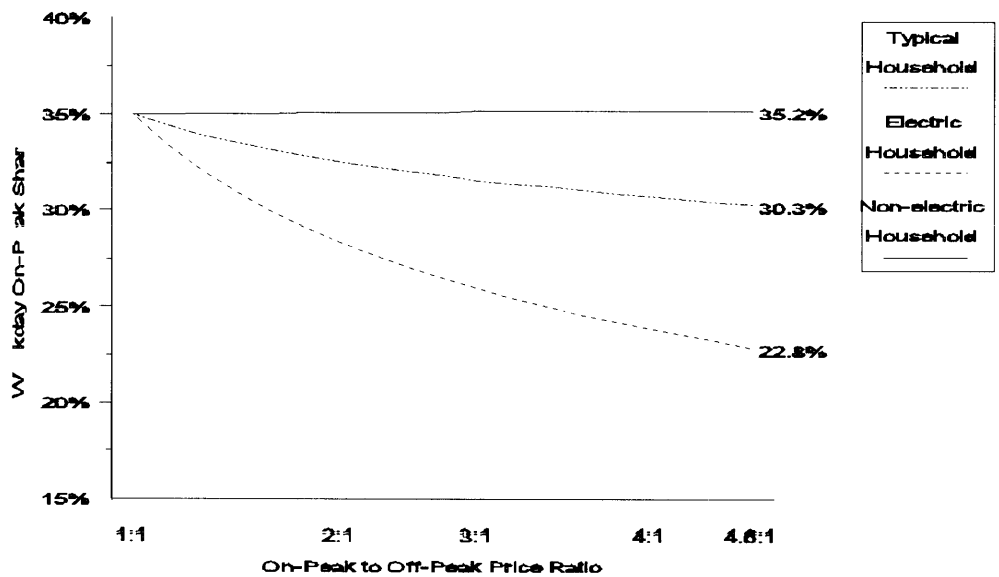

Figure 2. The Response to TOU Rates at Stage 1 — The Impact of Appliance Holdings

The typical household, with an elasticity of substitution of .14 for the summer season as a whole, reduces their on-peak usage share from the assumed 35 percent under standard rates to only 30.3 percent under MWP VTOU tariff. The all electric household, on the other hand, is substantially more responsive to TOU pricing, with an estimated elasticity of substitution of .39. Such customers are estimated to reduce their on-peak share to only 22.8 under MWP 4.6:1 TOU price ratio. In contrast, the non-electric household has an elasticity of substitution that is statistically insignificant and close to zero (-.006). Thus, the TOU tariff has little impact on their pattern of week-day usage. Again, this is to be expected, given the limited electricity the non-electric household has available for shifting. All-electric households, on the other hand, have the ability to reduce or shift their on-peak dishwashing, dehumidifying, and air conditioning activities in order to save under TOU pricing.

The appliance effects found in the extended Stage II and Stage III models are similar to those found at Stage I. For more details, see Baladi and Herriges (1993c).

Summary and Conclusions

The Participation Decision

The initial decision of residential customers to volunteer for MWP's TOU tariff was found to be largely unrelated to any observable pattern in the household's electricity usage or appliance ownership. Volunteers and non-volunteers were virtually indistinguishable in terms of both their total kWh consumption and its distribution between the on-peak and off-peak pricing periods. This finding alleviates the concern that TOU volunteers consist of households who already use only a small percentage of their usage on-peak and, thus, have little capability to shift usage in response to the TOU pricing signal.

While volunteers and non-volunteers proved to be similar in their actual usage patterns, we did find the two groups to differ significantly in terms of the *perceptions* about how they use electricity. Non-volunteers, for example, perceive that almost half of their monthly usage is consumed on-peak, more than twice its actual level of 22 percent, whereas volunteers place this percentage at less than 30 percent. Our conclusions regarding the decision to volunteer are based upon the initial participation decision. Under MWP's VTOU program, volunteers can return to the standard tariff at any time. The Residential Energy Study was not designed to address the long-run impact of this attrition. The limited usage data available suggest drop households may have a higher than average on-peak usage share, but the sample sizes are so small that statistically significant differences did not typically arise.

Response to TOU Pricing

Volunteers on MWP's TOU tariff were found to significantly reduce their on-peak usage (by roughly 24 percent during the first summer season), with little or no change in their off-peak consumption. These changes were even more pronounced on days when the system peaked, with on-peak usage dropping by over 28 percent. Similar results were obtained for the second season of the study, once changes in weather conditions were controlled for. In addition, we found that the ability/willingness of individual households to respond to the TOU tariff is significantly influenced by their appliance holdings and socio-demographic characteristics. In particular, the ownership of major electrical appliances, such as dishwashers, central air conditioners, and dehumidifiers, significantly increases the percentage reduction in on-peak kWh induced by TOU pricing.

While these overall reductions in on-peak usage are important, the efficacy of a VTOU program also depends upon the distribution of these reductions within the on-peak period and, in particular, near the hour when system peaks. A more detailed analysis of the pattern of response to MWP's TOU tariff revealed that the reductions in on-peak kWh were not concentrated in any one on-peak hour, but were distributed proportionately throughout the on-peak period. Off-peak usage changes also tended to be proportional, with the exception that households tended to avoid shifting usage to those hours immediately adjacent to the on-peak period (i.e., shoulder hours). This latter result alleviates the concern that TOU rates might create a secondary needle peak just outside of the on-peak hours.

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