MODELING THE IMPACT OF RESIDENTIAL TIME OF USE RATES

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ABSTRACT

As a part of BC Hydro's Advanced Metering Initiative (AMI), a time of use rate pilot project involving some 2,000 residential customers was implemented for winter 2006/07 and winter 2007/08. Customers participating in the project had an advanced meter installed at their house, and they also received information on how they could save energy during the peak period and shift load from the peak period to the off peak period. The goal of the project was to determine whether customers respond to pricing signals and information on energy use and to determine the magnitude of the responses. This study used a variety of evaluation methods including random assignment of customers to different treatment groups and control groups, interviews with project staff, documents review, focus groups, pre and post customer surveys, and econometric analysis in order to assess and understand customers' pricing preferences and their responses to pricing signals.

KEY WORDS

Time of use rates, regression models, randomized controlled experiment, generalized linear models.

1. Introduction

A number of utilizes have undertaken demand response programs for residential customers, while some utilizes have put in place mandatory time-of-use rates and critical peak pricing. The purpose of these demand response purposes is to: (1) increase economic efficiency by better matching rates to the time-varying costs of energy production and distribution; (2) provide economic signals to customers to use energy appropriately; and (3) delay investment in new production and distribution physical plant.

A substantial literature has examined the impacts of time varying rates and other demand response activities. Some references to this literature include [1] – [14]. Some key findings of these studies include the following: (1) customers respond to time varying rates by shifting peak, reducing consumption or some combination of the two; (2) since the peak shifting or consumption response to a price differential is relatively small, relatively large peak to off peak price ratios are required to have significant impacts; (3) permanent time varying rates have larger impacts than experimental (or temporary) rates; and (4) enabling strategies such as promotion of direct load control can increase the impact of time of use rates.

As part of BC Hydro's Advanced Metering Initiative (AMI), a Conservation Rate Initiative (CRI) time of use rate pilot initially involving some 1,950 residential customers was developed for the winter of 2006/07 and continued for the winter of 2007/08. The time of use rate project provided BC Hydro with opportunities to: (1) gain operational experience with advanced metering infrastructure; (2) gain an understanding of customer needs for information about and acceptance of available and affordable ways to save energy and shift their load to off peak periods; (3) learn about customers' pricing preferences and their responses to pricing signals; and (4) assess whether and to what extent pricing can be used as a tool to delay future supply needs and infrastructure investments. For residential customers, the time of use project offers: more rate options; more control over electricity costs; and potential savings on electricity bills.

After attrition and data cleaning, the second year sample consisted of 1,717 BC Hydro customers living in the Lower Mainland, Fort St. John and Campbell River. There were 206,006 usable records of daily consumption with 1,602 records discarded because of missing information.

Customers participating in the pilot had an advanced meter installed at their house, which reported interval data on their demand and consumption on an hourly basis. Customers were randomly assigned to a control group or one of several treatment groups. Treatment group customers received information on how they could save energy during the peak period and shift load from the peak period to the off peak period, and they had access to the CRI website for consumption information for their account.

The design principles used in developing the TOU pilot rates were as follows: encourage economic efficiency; minimize impacts on other rate payers, by using a rate design that is customer revenue neutral and that collects the revenue requirement; use TOU daily peak periods that are short in duration, simple for customers to use, and easy to administer; and, select a rate design that is fair and avoids windfall gains or losses to customers.

The rate attributes and structure were as follows: first, the rate was a voluntary rate with customers choosing whether or not to participate in the experiment; second, customers were randomly assigned to the control group or to treatment group; and, third, the TOU rate has a two-part rate structure, which includes a basic charge and energy charges based on TOU prices. In order to test a reasonable range of rate alternatives, there are six experimental rates (1141 – 1145) and one control rate (1101). The rates vary by number of peaks, by peak rate and by off peak rate as shown in Table 1 below.

Table 1. Time of Use Experimental Rate Design

Group	Morning peak	Evening peak	Off Peak (¢ / kWh)	Peak Rate (¢ / kWh)
1141	-	4-9 pm	6.33	19
1141A	-	4-8 pm	6.33	19
1142	-	4-9 pm	6.33	25
1143	-	4-9 pm	4.5	28
1144	8-11 am	4-8 pm	4.5	15
1145	8-11 am	4-8 pm	4.5	20
1101	-	-	6.33	6.33

The purpose of this study is to examine the impact of BC Hydro's residential time of use rate on peak shifting and energy consumption. The structure of the study is as follows. Section 2 provides a model of electricity consumption with time varying prices. Section 3 summarizes the data and method. Section 4 provides the results. Section 5 provides the conclusions.

2. Consumption with Time-varying Prices

Consider a residential customer with preferences between off peak and peak energy consumption who has the sub-utility function for energy $U(C^O, C^P)$. We write the partial derivative of the utility function U with respect to C^O as U_0 and the partial derivative of U with respect to C^P as U_P. The critical concept is the elasticity of substitution υ which measures the percentage change in the proportion of peak and off peak energy consumed due to a change in the marginal rate of substitution:

$\upsilon = d\ln(C^O/C^P)/d\ln(U_P/U_O)$ or

$\upsilon = [d(C^O/C^P)/d(U_P/U_O)]\cdot[(U_P/U_O)/(C^O/C^P)]$

The elasticity of substitution measures the ease with which off peak energy can be substituted for peak energy, and vice versa. The elasticity of substitution is essentially a measure of the curvature of an indifference curve. In other words, the more curved or convex is the indifference curve, the smaller is the elasticity of substitution. If there is no substitution between peak and off peak energy (that is, the indifference curves are L-shaped), the elasticity of substitution is zero. If there is perfect substitution between peak and off peak energy, (that is the indifference curves are straight lines), then the elasticity of substitution is infinity. Consider now a residential customer with preferences between off-peak and peak energy consumption who has the sub-utility function for energy $U(C^O, C^P)$ which takes the standard constant elasticity of substitution (CES) form as follows:

$U(C^O, C^P) = [\omega(C^O)^{-\eta} + (1-\omega)(C^P)^{-\eta}]^{-1/\eta}$

Here the parameter η determines the elasticity of substitution which is given by the expression $\upsilon = 1/(1 + \eta)$ and ω is a weight. Assuming standard two-stage budgeting, the customer maximizes her utility subject to her budget constraint for energy:

$C^O p^O + C^P p^P \leq I^e$

And this yields the following first-order condition:

$P \equiv p^P/p^O = [(1-\omega)/\omega]\,[C^P/C^O]^{1+\eta}$

This first-order condition can be rewritten as follows:

$C^P/C^O = [(\omega/(1-\omega))\,P]^{\upsilon}$

Finally, taking logs of both sides yields the estimating equation for the price elasticity of demand given by α_1

$$\ln(C^P/C^O) = \alpha_0 + \alpha_1 \ln(P)$$

where, $\alpha_0 = - \upsilon \ln((1 - \omega)/\omega)$ and $\alpha_1 = - \upsilon$.

3. Data and Approach

The study used a variety of methods including random assignment of participating customers to different TOU rate groups and control groups, interviews with project staff, documents review, focus groups, pre and post customer surveys addressing energy and conservation behaviors), and econometric analyses in order to assess and understand customers' pricing preferences and their responses to pricing signals. We focus here on the quantitative results.

Participants were randomly assigned to one of the treatment groups or the control group in three different municipalities in three different regions. This means that there should be no significant market effects, such as free riders or self selection, affecting the internal validity of the experiment. There are three basic designs, a one peak period design for the Lower Mainland which includes Vancouver and its suburbs, a two peak period design for Campbell River on Vancouver Island, and a one peak period design for Fort St. John in the North. By using treatment and control groups in regions that are reasonably homogenous with respect to heating requirements, as measured by heating degree days, there is no need to weather normalize the data.

Only single family dwellings were considered for participation in the experiment because of the confounding impact of common walls in multifamily dwellings. All participating customers had an advanced meter installed, whether they were participants or control group members. The operational experience with the AMI meters and advanced technology systems gained through the first year of the pilot was reviewed through interviews with program staff and stakeholders and focus groups with participating customers.

Metered data was used to calculate average peak period consumption, average off peak consumption, average total consumption and the ratio of consumption during the peak period to consumption during the off peak period. These statistics were calculated separately for each customer in the control group and for each of the treatment groups in each of the three regions, and they were used to calculate differences between treatment group and control group consumption. Summary statistics were calculated across regions by weighting regional results by the ratio of the regional sample to the total sample. Although there was no pre-program metering, this is viewed as a strong research design because of random assignment to the control or treatment groups. The post-only design with a control group is largely immune to the internal threats to validity that are typically an issue when a non-equivalent comparison group must be used instead of a true control group. The basic method of the impact analysis was a post-only comparison of peak, off peak and total consumption with a control group and two treatment groups for the North, a control group and two treatment groups for Vancouver Island, and a control group and three treatment groups for the Lower Mainland.

The elasticity of substitution and price elasticity of demand were modelled using the framework outlined in the previous section using the generalized linear model (GLM). GLM is particularly useful when there are repeated observations on each customer. Nelder and Wedderburn [15] introduced the concept of the generalized linear model (GLM). A GLM is a linear model for the transformed mean of a variable which has distribution in the natural exponential family. The generalized linear model is characterized by three components: a random component which specifies the response function of the dependent variable; a systematic component which specifies a linear function of independent variables which is used as a predictor; and a link component which specifies the functional relationship between the systematic component and the expected value of the random component. We follow the method in Agresti et al [16], but see also Dobson [17], McCullagh and Nelder [18], McFadden [19, 20], and Wedderburn [21, 22, 23].

4. Results

For each account participating in the time of use experiment, hourly consumption information was cleaned and then aggregated to give daily consumption for the off peak period, the peak period and the daily total, for each of the 120 days of the CRI experiment. About 1% of the readings were corrupted in the sense that there were missing hourly values with the metering then catching up and reporting the total for several hours for that meter. Statistically based algorithms were built to allocate this load across the appropriate hours as accurately as possible. For each rate class for each region, the consumption data for peak, off peak and total was aggregated and then averaged to produce daily average consumption for the appropriate customer bin. Finally, the treatment groups in a given region were averaged, and the average daily consumption for each bin was compared with the appropriate daily consumption for the appropriate control bin. Results of the analysis are summarized in Table 2. Note that all of the differences were statistically significant at the 1% level.

Table 2. Consumption by Group (kWh per day)

	Control	**Treat**	**Difference**	**% Difference**
Campbell River				
Av. daily off peak	40.33	38.18	-2.15***	-5.3%
Av. daily peak	21.00	18.16	-2.84***	-13.5%
Av, daily total	61.33	56.34	-4.99***	-8.1%
Fort St. John				
Av. daily off peak	30.92	24.79	-6.13***	-19.8%
Av. daily peak	10.59	8.43	-2.16***	-20.4%
Av. daily total	41.51	33.22	-8.29***	-20.0%
Lower Mainland				
Av. daily off peak	23.55	23.26	-0.29***	-1.2%
Av. daily peak	9.31	8.25	-1.06***	-11.4%
Av. daily total	32.86	31.51	-1.35***	-4.1%
Weighted Total				
Av. daily off peak	27.88	26.99	-0.89***	-3.2%
Av. daily peak	11.43	10.16	-1.27***	-11.1%
Av. daily total	39.31	371.5	-2.16***	-5.5%

Note. One, two or three asterisks indicate that the difference is significant at the 10%, 5% or 1% level respectively.

The impacts of the time of use rate for the second year for the second year of the Conservation Rate Initiative can be summarized as follows.

Impact on Off Peak Consumption. Weighted average off peak consumption for time of use rate treatment participants was 26.99 kWh per day compared to control group off-peak consumption of 27.88 kWh per day. The average off peak consumption of a treatment group participant was 0.89 kWh per day or 3.2% lower than that of the average comparison group participant.

Impact on Peak Consumption. Weighted average peak consumption for time of use rate treatment participants was 10.16 kWh per day compared to control group peak consumption of 11.43 kWh per day. The average peak consumption of a treatment group participant was 1.27 kWh per day or 11.1% lower than that of the average comparison group participant.

Impact on Average Daily Consumption. Weighted average total consumption for time of use rate treatment participants was 37.15 kWh per day compared to control group total consumption of 39.31 kWh per day. The average total consumption of a treatment group participant was 2.16 kWh per day or 5.5% lower than that of the average comparison group participant.

Table 3 summarizes the results of the regression models to estimate the elasticity of substitution and the price elasticity of demand. The dependent variable for Equation (1) is the log of average daily consumption in kWh, and the dependent variable for Equation (2) is the log of the ratio of daily peak to of peak consumption. The independent variables are the price in cents per kWh, the log of the ratio of peak to off peak price, the log of heating degree days, the log of annual household income in thousands of dollars, the log of the number of occupants, a dummy variable for a dwelling in the Lower Mainland, a dummy variable for a dwelling in the Fort St. John region, two terms for interaction between region and heating degree days, and a dummy variable for the presence of electric baseboard heat. The standard errors are shown in parentheses, and one, two or three asterisks indicate that the coefficient is significant at the 10%, 5% or 1% level respectively. The statistical results are good with every coefficient significant at the 5% level or better and with all of the coefficients having the expected signs.

Table 3. Regression Models

	Log consumption (1)	**Log peak to off peak consumption (2)**
Constant	-1.73*** (0.050)	0.958*** (0.013)
Log average price	-0.187** (0.092)	-
Log (peak/off peak price)	-	-0.060*** (0.012)
Log heating degree-days	0.429*** (0.021)	-0.044*** (0.015)
Log household income	0.087*** (0.024)	0.032*** (0.011)
Log occupants	0.397*** (0.037)	0.490*** (0.015)
Lower Mainland region	0.261*** (0.065)	-0.423*** (0.047)
Fort St. John region	0.311*** (0.029)	-0.141*** (0.068)
LM*log HDD	-0.293*** (0.022)	0.038** (0.017)
FSJ*HDD	-0.254*** (0.027)	-0.066*** (0.021)
Electric baseboard heat	0.721*** (0.065)	-0.114*** (0.027)
Scale parameter	0.344	0.164
Sample size	206,006	206,006

Notes. Standard errors are in parentheses below the regression coefficients. One, two or three asterisks indicate that the coefficient is significant at the 10%, 5% or 1% level respectively.

Our main interest is in the magnitude and precision of the elasticity of substitution and the price elasticity and these are shown in Table 4. The mean value of the price elasticity is given by the coefficient of the log of the price variable in Equation (1). The mean value of the price elasticity is -0.060 with lower 95% confidence level which is -0.082 and upper 95% confidence level of -0.037. The mean value of the elasticity of substitution is given by the coefficient of log of the ratio of peak to off peak price in Equation (2). The mean value of the elasticity of substitution is -0.187 with lower 95% level of -0.367 and upper 95% confidence level of -0.008.

Table 4. Elasticity Estimates

	Lower 5%	Mean	Upper 5%
Substitution	-0.082	-0.060	-0.037
Price	-0.367	-0.187	-0.008

5. Conclusion

BC Hydro's Advanced Metering Initiative (AMI) was a time of use rate pilot project involving some 2,000 residential customers for winter 2006/07 and winter 2007/08. The purpose of this impact evaluation was to provide an estimate of the impacts of the second year of the residential time of use rate project. Customers participating in the project had an advanced meter installed at their house, and they also received information on how they could save energy during the peak period and shift load from the peak period to the off peak period. The goal of the project was to determine whether customers respond to pricing signals and information on energy use. Key results included the following.

(1) Weighted average off-peak consumption for time of use rate treatment participants was 26.99 kWh per day compared to control group off-peak consumption of 27.88 kWh per day or 3.2% lower than that of the average comparison group participant.

(2) Weighted average peak consumption for time of use rate treatment participants was 10.16 kWh per day, compared to control group peak consumption of 11.43 kWh per day or 11.1% lower than that of the average comparison group participant.

(3) Weighted average total consumption for time of use treatment participants was 37.15 kWh per day compared to control group total consumption of 39.31 kWh per day or 5.5% lower than that of the average comparison group participant.

(4) The mean value of the price elasticity is -0.060 with lower 95% confidence level which is -0.082 and upper 95% confidence level of -0.037.

(5) The mean value of the elasticity of substitution is -0.187 with lower 95% level of -0.367 and upper 95% confidence level of -0.008.

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