Experimental Evidence: A Residential Time of Use Pilot

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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 developed for the winter of 2006/07. The time of use rate project provides BC Hydro with opportunities to: (1) 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; (2) learn about customers' pricing preferences and their responses to pricing signals and (3) 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.

The purpose of this impact evaluation is to provide decision and policy makers an estimate of the impacts 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 is to determine whether customers respond to pricing signals and information on energy use as well as determine the magnitude of the responses.

This study used a variety of methods including random assignment of customers to different time of use rate groups, different communication groups and control groups, interviews with project staff, documents review, focus groups, pre and post customer surveys addressing energy and conservation behaviors, and econometric analysis in order to assess and understand customers' pricing preferences and their responses to pricing signals.

Analysis of customer self-reported behaviours for typical winter seasons before the pilot and for the TOU pilot period and a control group uncovered strong evidence that treatment group households were successful in shifting their evening on-peak use of many electrical end-uses to off-peak times. Customer response to pricing signals in the form of TOU rates was significant with treatment groups exhibiting both a "demand response effect" and "conservation effect". Average treatment group participant's consumption was 29 kWh or 9.6% lower than the control group for the evening peak period, and 112 kWh or 8.6% lower for total consumption.

Introduction

With many jurisdictions encouraging electricity market deregulation, increasing attention has been paid to the use of time varying retail electricity prices. With these time-of-use (TOU) rates, electricity prices are higher during peak periods, when marginal costs of generation and distribution are higher, and therefore lower during off-peak periods, when the marginal costs of generation and distribution are lower. When presented with TOU rates, customers need to determine whether or not to adjust their consumption of electricity, given the costs and benefits of alternative courses of action. A recent report by the Federal Energy Regulatory Commission (2006) points out that customers' abilities to respond to time-based rates depends on three factors: the time-based rates are appropriately communicated to customers; customers have the ability to respond to rates through load control systems or self-generation; and customers have time-based metering so that the utility can determine how much energy (and possibly capacity) was used when.

As a part of BC Hydro's Advanced Metering Initiative (AMI), a time of use rate pilot involving 2,000 residential customers was developed for the winter of 2006/07 (November 1, 2006 – February 28, 2007). 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. 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 pilot is to determine whether customers respond to pricing signals and information on energy use and to determine the magnitude of the responses. More specifically, the TOU rate pilot provides BC Hydro with the opportunities to: (1) 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; (2) learn about customers' pricing preferences and their responses to pricing signals; and (3) 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 residential TOU pilot offers: more rate options; more control over electricity costs; and potential savings on electricity bills.

Rate Design

The design principles used in developing the TOU pilot rates are 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 are as follows: first, the rate is a **voluntary** rate with customers choosing whether or not to participate in the experiment; and second, the TOU rate has a **two-part rate structure**, which includes a basic charge, energy charges based on TOU prices, a balancing amount and a bill guarantee. In order to test a reasonable range of rate alternatives, there are five experimental rates (T1 – T5) and one control rate (C). The rates vary by number of peaks, by peak rate and by off peak rate as shown in Table 1 below.

Table 1: BC Hydro Winter Weekday TOU Pilot Rate Design

Experimental Group	Morning Peak	Evening Peak	Off Peak Rate (¢ / kWh)	Peak Rate (¢ / kWh)
T1	-	4-9 pm	6.33	19.0
T2	-	4-9 pm	6.33	25.0
T3	-	4-9 pm	4.5	28.0
T4	7-11am	4-9 pm	4.5	15.0
T5	7-11am	4-9 pm	4.5	20.0
C	-	-	6.33	6.33

Notes, ¢ means Canadian cents.

A number of utilities have undertaken TOU rate pilots for residential, commercial and industrial customers, while some utilities have put in place mandatory TOU rates, particularly for larger customers. A substantial literature has examined the impacts of these TOU rates, and some of the major studies are listed in the bibliography. Key findings of these studies include the following: (1) customers respond to TOU rates by shifting peak, reducing consumption or some combination of the two; (2) since the peak shifting or consumption change to a price differential is relatively small, relatively large peak to off peak price ratios are required to have significant impacts; (3) permanent TOU rates have larger impacts than experimental (or temporary) rates; (4) demand charges can have effects comparable in size to TOU rates; and (5) enabling strategies such as promotion of load shifting technologies can substantially increase the impact of TOU rates.

We have reviewed a number of other studies focusing on residential TOU rates for utilities with at least one million customers, including a comparison with the BC Hydro TOU rates. This information was used to build a database of some 29 residential customer TOU rates offered by 24 utilities (Tiedemann 2007). Some key observations from this review include the following (all numbers are in U.S. cents). (1) Median peak rate is 16.07 cents per kWh, which is just below BC Hydro's lowest peak rate of 16.15 cents per kWh. (2) Median off peak rate is 3.66 cents per kWh, which again is just below BC Hydro's lowest off peak rate of 3.82 cents per kWh. (3) Median peak to off peak ratio is 3.6, which is between BC Hydro's two lower peak to off peak ratios of 3.0 and 4.0. (4) Median monthly charge is $6.12, compared to BC Hydro which has a monthly charge of $3.14 for all residential rates. This comparison suggests that BC Hydro's set of TOU rates is reflective of standard utility practice in rate design.

Approach

The study used a variety of methods including random assignment of participating customers to different TOU rate groups, different communication groups and control groups, interviews with project staff, documents review, focus groups (Rink 2006, Rink & Mould, 2007), pre and post customer surveys addressing energy and conservation behaviors (Pedersen 2007), and econometric analyses in order to assess and understand customers' pricing preferences and their responses to pricing signals (Tiedemann 2007).

Participants were randomly assigned to one of the treatment groups or the control group in three different municipalities in three different regions (Lower Mainland, Vancouver Island and the North). This means that there should be no significant market effects, such as free ridership or self selection, affecting the internal validity of the experiment. There are three basic designs, a one peak period design for the Lower Mainland, a two peak period design for Vancouver Island, and a one peak period design for the North. Only the evening peak is addressed in this report. 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 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.

Insight into customer information needs and their awareness and acceptance of the AMI meters, Blue Line Display Monitors (which provide in-home information on energy consumption and the cost of energy consumed) and the TOU rate was also gained through pre and post participant surveys. The majority of the behavioural questions in the survey are based on four-point scales (always, usually, occasionally, never). For any behaviour, statistical testing focuses on the post pilot survey question top-two box score (proportion always + usually). Random assignment to experimental and control groups with fairly large sample sizes (as a proportion of their populations) supports the assumption that pre-pilot scores for all groups were equal (Cook & Campbell, 1979; Campbell & Stanley, 1963). Thus Z-tests for the difference in the post pilot treatment and control group proportions, based on pooled variance estimates are appropriate.

Metered data were 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 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 (Campbell & Stanley, 1963).

The basic method of the impact analysis is 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 nine treatment groups for the Lower Mainland, including three rate classes times three communication levels as noted in Table 2. Communication groups included Group A, who received the **standard** communications package (a Welcome Pack and a Kick Off Pack). The **enhanced** communication Group B (who received additional email communications throughout the first year peak pilot period) and Group C (who received the **enhanced** communications package B, **plus** a **Blue Line Display Monitor** which provides in-home information on energy consumption and the cost of energy consumed).

Table 2: TOU Pilot Populations By Rate Group, Region and Communications Type

		Lower Mainland (N=433,000)				
Peak to Off Peak Price	**Total**	**A**	**B**	**C**	**Vancouver Island (N=8,900)**	**North (N=11,900)**
T1 (19¢ / 6.33¢) pm	438	134	116	108		80
T2 (25¢ / 6.33¢) pm	423	118	115	104		86
T3 (28¢ / 4.5¢) pm	316	105	116	95		
T4 (15¢ / 4.5¢) am, pm	96				96	
T5 (20¢ / 4.5¢) am, pm	98				98	
Total Treatment	1371	357	347	307	194	166
Total Control	699	530			97	72
Total	2070	1541			291	238

Source: Pedersen 2007. A = Standard communications B = Enhanced communications (Treatment group participants in Vancouver Island and the North also received enhanced communications) C = Enhanced communications + Blue Line Monitor

To estimate the average impact of time-varying rates on the share of energy use on peak several simple regression models were estimated using individual customer data. Equation (1) was estimated using ordinary least squares for each of the three regions. Coefficient β provides an estimate of the impact of the peak to off peak price ratio on the ratio of peak and off peak energy use. Equation (2) then uses the estimated parameter values from equation (1) to forecast the potential impact of alternative peak to off peak price ratios on the ratio of peak to off peak consumption, where an asterisk indicates the estimated value of the parameter.

(1) kWh peak/kWh off peak = $\alpha + \beta$ peak price/off peak price + error

(2) kWh peak/kWh off peak = $\alpha^* + \beta^*$ peak price/off peak price

Results

The meter installation process and related data communication transfer and analysis activities were examined through interviews with program staff and stakeholders and through focus groups with participants. Initially, a number of the TOU meters were not communicating or providing valid data to the vendor's server[1] in November, reducing the precision of the planned analysis.

Customer Awareness and Acceptance

The objective of the pre and post pilot participant surveys was to gather information regarding participants' conservation attitudes and behaviours, and most importantly, their on-peak use of electricity for various end-uses throughout the four month winter pilot. An additional objective was to solicit feedback on various facets of the pilot for future planning purposes.

Participants in each of the pilot treatment and control groups were asked to complete a pre-pilot survey in October 2006 and post-pilot survey in March 2007. A self-administered mixed-mode methodology was used, where participants either received surveys via e-mail for Internet completion or in the form of printed, mailed copies. Due to random assignment to the experimental groups, there are no differences in the age, gender or any other demographics of treatment and control participants. Table 2 (above) details the initial population of participants by rate group, region and communications type.

A total of 2,070 pre-pilot surveys were sent to participants and 1,720 pre-pilot surveys were completed for a response rate of 88%, and with the finite correction factor, a maximum margin of error of $\pm$ 1.0% at the 95% confidence level. A total of 1,870 post-pilot surveys were sent to participants yielding 1,305 completions for a 70% response rate, and with the finite correction factor, a maximum margin of error of 1.5% at the 95% confidence level. As the returned samples for both the pre and post pilot surveys were representative of the initial pilot population by rate group, region and communications type, it was not necessary to mathematically weight the survey responses.

[1] For the pilot two different vendors provided meters, related software and communication protocols. The communication protocols are complex systems in which signals carrying the metered information are passed along a series of cell-phone like devices to the vendor's server where the metered data is stored and eventually transferred to the utility.

Comparison of pilot participants and BC Hydro residential customers. To gain insight as to how the demographic profile of the TOU pilot participants aligns or differs from BC Hydro's greater population of residential customers, TOU pilot participants were compared with similar households living in single detached homes in BC Hydro's service territory (Pedersen 2006). Compared to the overall population of residential customers living in single detached houses, the pilot is somewhat over-represented by women aged 35 to 45 years of age, living in homes with at least two other people. The most striking difference, however, is their level of education as 44% have earned university degrees compared to 25% among the related population. It follows that the total annual household income among pilot participants is much higher than average as 45% reportedly earn $80,000 (CAD) or more compared to 34% among the related customer base.

Given that pilot participants were proactive in voluntary opting-in to the pilot, TOU participants, regardless of whether they were subsequently assigned to the a treatment or control groups, may bring a stronger pro-conservation ethos with them to the pilot as compared to that shared by the majority of BC Hydro's residential customers living in single detached homes. This may have been tempered by the fact that households were 'guarantied' no increase in overall billing as part of the pilot agreement. Pilot participants emerge as being more knowledgeable than many others about how to conserve electricity in their homes, more active in looking for opportunities to save energy in everything they do, more willing to be flexible in their energy habits for a greater good, more likely to make the connection between their own household's energy use and its impact on the environment, and more likely than others to make the connection between their own household's energy use and its impact on the environment.

Like BC Hydro's overall population of customers in single detached houses, nearly all TOU participants own their homes. However, their houses are older than most others and, on average, about 100 square feet larger in floor area. Rolled-up together, households recruited into the TOU pilot are significantly more likely than single detached houses across BC Hydro's entire service territory to have natural gas as their main space heating fuel, 81% versus 64%.

For the 12 months previous to the launch of the pilot, participating households used an average of about 1,700 fewer kWh of electricity than among all other single detached houses across the BC Hydro's service territory. However, their lower consumption can not be attributed to their under-reliance on electricity for space heating as their average annual usage is lower for each of the main fuel types. Instead, it appears as though their strong conservation behaviours overcome the fact that their homes are older, larger in area, and larger in occupancy, which are all drivers of higher consumption.

These differences between pilot participants and the comparable BC Hydro residential customer base limit the external validity of this project, or the ability to forecast the impact of a mandatory residential TOU rate based on the results of this voluntary TOU experiment.

Participant satisfaction. Among treatment group participants expressing an opinion, 81% assess their overall experience with the TOU pilot as either "excellent" or "good". Perhaps due in part to a greater ease in shifting their on-peak use of electricity and a greater extent in doing so, at least on a self-reported basis, participants with electric space heating fuel are significantly more likely to rate their overall experience with the pilot favourably than participants with natural gas space heating fuel.

Very closely reflecting their overall experience with the pilot, 83% of treatment group participants indicate that they either "definitely would" or "probably would" continue for a second year of the program next fall if it is offered under the very same set of conditions relating to the on-peak times, on-peak and off-peak rates, balancing charge, bill guarantee and meter. Although a total of 78% of treatment group participants rate the explanation of the balancing charge favourably, qualitative research during the pilot revealed not only a poor understanding of the amount, but little awareness of it. All evidence points to the belief that participants in this study have a misunderstanding of the balancing charge, despite their claim of having a good one. Participants clearly indicate, however, that the absence of a bill guarantee would have a detrimental impact on their likelihood of signing-on for a second year of the program.

Among Lower Mainland participants with Blue Line Display Monitors, about five in ten of them report having used the monitors at least several times each week in the first month of the pilot. This proportion, however, decreased to about four in ten in the final two months. There is significant division in opinion with respect to the overall performance of the monitor, 43% rate it favourably and 31% rate in unfavourably.

Self reported changes in behaviours. Statistical analysis uncovers strong evidence that treatment group households were successful in shifting their evening on-peak use of many electrical end-uses to off-peak times, in turn, revealing favourable "demand response effects". This analysis is based on their self-reported behaviours for typical winter seasons before the pilot and for the TOU pilot period itself, and a control group to help isolate and validate the effects.

For the evening peak, treatment group households showed the most substantial drops in their top-two box usage scores (always + usually) for major household cleaning appliances such as dishwashers (31% ⇨ 11%), clothes washers (25% ⇨ 11%) and clothes dryers (24% ⇨ 9%). They also showed very favourable shifts in their evening on-peak use of hot water for baths and showers (46% ⇨ 35%) and, despite being in the space heating season, electric heaters including portables and baseboards (30% ⇨ 23%).

To a lesser degree, participants on a TOU rate also shifted their on-peak use of stove top elements, ovens, microwave ovens and lighting in various rooms of the home. There does not appear to be a successful demand response effect for end-uses relating to the television and entertainment usage, nor for end-uses relating to computers and home office.

The ease of shifting usage and the extent in doing so is correlated to the same group of drivers – age, space heating fuel, home occupancy size, household composition and consumption. That is, older participants, houses with electrical space heating, households with fewer occupants (especially those without children and/or young adults) and those with relatively lower electricity consumption all emerge as being the most successful, on this self-reported basis, in shifting their on-peak usage.

Just as there has been a "demand response effect" for many end-uses, there has also been a "conservation effect" in that treatment group participants reported having reduced their use of electricity for some behaviours relating to space heating, water use/laundry and lighting.

In terms of the specific treatment group, households on each of the various pricing plans report broad success in shifting their on-peak use of electricity. Having said this, households on the Vancouver Island T5 rate plan (4:1 on-peak to off peak price) can be ranked number one. For select end-uses, especially dishwashers, electric heaters and lighting, the households which received enhanced communications (Group B) throughout the pilot out-performed households which received standard communications (Group A). Homes with Blue Line Display Monitors report less success than all others in the amount of electricity they believe they were able to shift.

Customer Response to Pricing Signals

Table 3 summarizes the estimated total and peak energy consumption reductions for December 2006 – February 2007 (n=1,950). Data for November are not included due to issues with missing data, calibration of the meter readings or the peak hour setting. Any usable information for November was, however, included in the regression analysis reported below.

The consumption reductions are calculated by first calculating the difference between treatment group consumption and control group consumption by region and then averaging over the treatment groups in a given region. The average results for all three regions are weighted based on each region's share of total participants.

Treatment groups exhibit both a significant "demand response effect" and "conservation effect", particularly early in the pilot period. For all three regions, average treatment group consumption was 29 kWh or 9.6% lower than the control group for peak, and 112 kWh or 8.6% lower for total consumption.

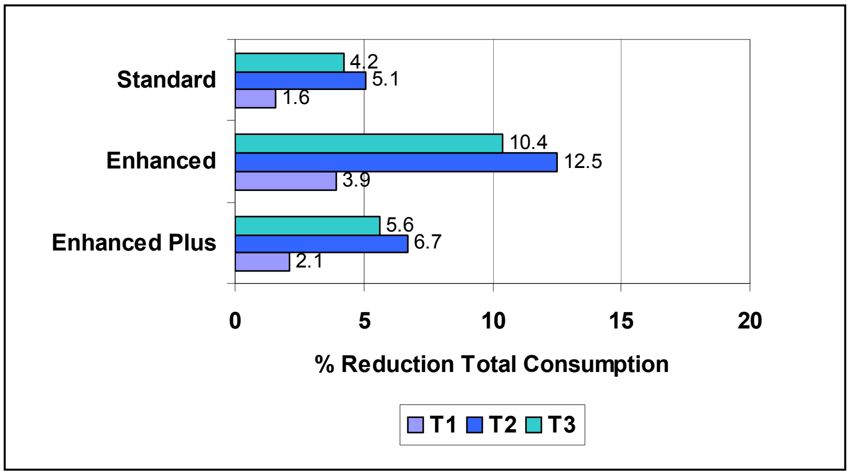
Table 3: Reductions in Peak and Total Consumption

	Peak Consumption			Total Consumption		
Month	**Ave Treatment (kWh)**	**Ave Control (kWh)**	**% Reduction**	**Ave Treatment (kWh)**	**Ave Control (kWh)**	**% Reduction**
Dec	255	284	10.2	1141	1321	13.6
Jan	318	356	10.7	1292	1401	7.8
Feb	246	265	7.2	1158	1205	3.9
Average	273	302	9.6	1197	1309	8.6

Customer Response to Communications

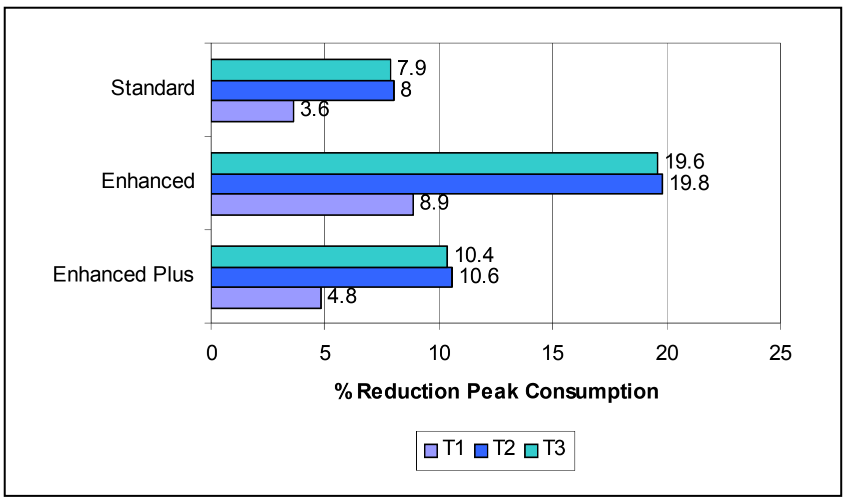
In the Lower Mainland enhanced communications (Group B) had a significant impact on total consumption for some rate options (see Figure 1). The consumption reductions are calculated by first calculating the difference between the communication group consumption and control group consumption. Recall that communication groups included those who received the **standard** communications package (a Welcome Pack and a Kick Off Pack). The **enhanced** communication group who received additional email communications throughout the first year peak pilot period and a third group who received the **enhanced** communications package, **plus** a **Blue Line Display Monitor** (which provides in-home information on energy consumption and the cost of energy consumed).

Figure 1: Impact of Communication Type on Total Consumption



In the Lower Mainland enhanced communications (Group B) had a significant impact on peak consumption (see Figure 2).

Figure 2: Impact of Communication Type on Peak Consumption



Impact of Peak to Off Peak Price on Peak to Off Peak Consumption

Table 4 below presents the results of four regression models explaining the impact of peak to off peak price on peak to off peak consumption for two of three regions, for the months of November and December 2007. Results for the North are not provided due to relatively small sample sizes and relatively high levels of missing and problematic data. The coefficients for each model are shown in the relevant column with the t-statistics for the coefficients shown below the coefficients in parentheses. The F-statistic measures the statistical significance of the linear regression with the significance level shown in parentheses.

Model 1 presents the November results for Vancouver Island. This model is statistically significant at the 10% level. The coefficient on the peak to off peak price ratio is negative as expected, and it is statistically significant at the 5% level. Model 2 presents the December results for Vancouver Island. This model is not statistically significant at conventional significant levels. The coefficient on the peak to off peak price ratio is negative as expected, but it is not statistically significant, although it is larger than its standard error. These results for Vancouver Island show some evidence of peak shifting. A convenient interpretation of this information is as follows: if the peak to off peak ratio is two, then the ratio of peak to off peak energy for Vancouver Island falls by about 1%.

Model 3 presents the November results for the Lower Mainland. This model is statistically significant at the 1% level. The coefficient on the peak to off peak price ratio is negative as expected, and it is statistically significant at the 1% level. Model 4 presents the December results for the Lower Mainland. This model is also statistically significant at the 1% level. The coefficient on the peak to off peak price ratio is again negative and significant at the 1% level. These result show strong evidence of peak shifting. If the peak to off peak price ratio doubles, then the ratio of peak to off peak energy falls by between 1% and 2%.

Table 4: Peak to Off Peak Consumption Regression Results

	Vancouver Island		Lower Mainland	
	(1) November	**(2) December**	**(3) November**	**(4) December**
Constant	0.439*** (0.01000)	0.371*** (0.00906)	0.258*** (0.00300)	0.216*** (0.00307)
Peak to Off Peak Price	-0.00564* (0.00353)	-0.00326 (0.00314)	-0.00456*** (0.00081)	-0.00279 (0.00082)
F	2.55 (0.10)	1.08 (0.30)	31.90 (0.00)	11.47 (0.00)

Note. One, two or three asterisks mean that coefficient is significant at the 10%, 5% or 1% level respectively. Standard errors for coefficients and probability for F-test are shown in parentheses.

A major advantage of the regression based approach is that impacts of TOU rates can be forecast for rates that were not part of the design. As noted above, the estimate and parameters from equation (1) and various assumed peak to off peak price ratios were substituted into equation (2) to provide estimates of pricing impacts. Table 5 provides these forecasts of peak to off peak consumption for the assumed peak to off peak ratios varying from 1:1 to 1:6, which is approximately the range of estimates covered by the pilot. Two aspects of this analysis are worth noting. First, the estimates for Vancouver Island appear to be reasonable and are fairly consistent across November and December. Second, the estimates for the Lower Mainland are roughly in the same range as those for Vancouver Island and show a material ability for the TOU rate to reduce peak to off peak energy consumption.

Table 5: Pricing Impacts: Peak to Off Peak Consumption

	Vancouver Island		Lower Mainland	
Peak to Off Peak Price	**November**	**December**	**November**	**December**
1:1	0.433	0.368	0.253	0.213
2:1	0.428	0.361	0.249	0.210
3:1	0.422	0.358	0.244	0.208
4:1	0.417	0.355	0.240	0.205
5:1	0.411	0.352	0.235	0.202
6:1	0.425	0.348	0.231	0.199

The study has two major limitations. First, a substantial number of the initially installed TOU meters were not communicating or providing valid data to the vendor's server in November and a smaller number were not providing valid information in December. This means that the precision of the statistical analysis is lower than planned. Second, the statistical analysis does not explicitly consider the impacts of the balancing charge or the bill guarantee. Since these are common across all treatment groups, these impacts cannot be determined with the data available. Note, the impact of a mandatory residential TOU rate cannot readily be inferred from this voluntary experiment, since participants in a mandatory rate might respond differently than the voluntary participants in this experiment.

Conclusions

Analysis of customer self-reported behaviours for typical winter seasons before the pilot and for the TOU pilot period and a control group uncovered strong evidence that treatment group households were successful in shifting their evening on-peak use of many electrical end-uses to off-peak times. For the evening peak, treatment group households showed the most substantial drops in their top-two box usage scores (always + usually) for major household cleaning appliances such as dishwashers (31% ⇨ 11%), clothes washers (25% ⇨ 11%) and clothes dryers (24% ⇨ 9%). They also showed very favourable shifts in their evening on-peak use of hot water for baths and showers (46% ⇨ 35%) and, despite being in the space heating season, electric heaters including portables and baseboards (30% ⇨ 23%). In addition, TOU rate participants reported having reduced their overall use of electricity for some behaviours relating to space heating, water use/laundry and lighting.

Customer response to pricing signals in the form of TOU rates was significant with treatment groups exhibiting both a "demand response effect" and "conservation effect", particularly early in the pilot period. For all three regions, average treatment group participant's consumption was 29 kWh or 9.6% lower than the control group for the evening peak period, and 112 kWh or 8.6% lower for total consumption.

In the Lower Mainland enhanced communications had a significant impact on total consumption for some rate options and a significant impact on peak consumption for all rate options. The Blue Line Display Monitors (Group C, Enhanced Plus) did not appear effective and were not perceived by participants as helpful in shifting or reducing their consumption.

Four regression models help explain the impact of peak to off peak price on peak to off peak consumption for two of three regions, for the months of November and December 2006. If the peak to off peak ratio is two, then the ratio of peak to off peak energy for Vancouver Island falls by about 1%. The results for the Lower Mainland show strong evidence of peak shifting. If the peak to off peak price ratio doubles, then the ratio of peak to off peak energy falls by between 1% and 2%. Using the regression equations to forecast rates that were not part of the pilot design provides peak to off peak ratios varying from 1:1 to 1:6, which is within the range covered by the pilot and shows a material ability for TOU rates to reduce peak to off peak energy consumption.

Bibliography

Aigner, D. and L. Lillard. 1984. "Measuring Peak Load Pricing Responses from Experimental Data." J. of Business and Economic Statistics, 2.

Architectural Energy Corporation. 2003. Advanced Utility Metering. Report Prepared for the National Renewable Energy Laboratory, U.S. Department of Energy. NREL/SR-710-33539.

Braithwait, S. 2003. "Residential TOU Price Responsiveness in the Presence of Interactive Communication Equipment." In Faruqui and Eakin.

Campbell, Donald and Julian Stanley. 1963. *Experimental and Quasi-Experimental Designs for Research.* Houghton Mifflin: Boston, MA.

Caves, D. W., and E. E. Leamer. 1984. "Estimation of Time-of-Use Pricing Responses in the Absence of Experimental Data." J. of Econometrics, 26.

Caves, D. W., L. Christensen and J. A. Herriges. 1984. "Consistency of Residential Customer Response in Time of Use Experiments." J. of Econometrics, 26.

Charles River Associates. 2005. Impact Evaluation of the California Statewide Pricing Pilot, Final Report. CEC Website, Working Group 3.

Cook, Thomas D. and Donald T. Campbell. *Quasi-Experimentation: Design and Analysis Issues for Field Settings.* Rand McNally: Chicago IL.

Faruqui, A. and K. Eakin, eds. 2000. Pricing in Competitive Electric Markets, Kluwer Academic Publishers: Dordecht, Netherlands.

Faruqui, A. and S. George. 2005. "Using Demand Models to Estimate the Impact of Dynamic Pricing in California." Proceedings of the 2005 International Energy Program Evaluation Conference.

New York. Federal Energy Regulatory Commission (2006). Federal Energy Regulatory Commission, Assessment of Demand Response and Advanced Metering: Staff Report, Docket AD06-2-000, August 2006.

Peak Load Management Alliance (PLMA). 2002. Demand Response: Principles for Regulatory Guidance. March 2002.

Peak Load Management Alliance (PLMA). 2002. Demand Response: Design Principles for Creating Customer and Market Value. November 2002.

Pedersen, M. 2006. *2006 Residential End-Use Study*, Power Smart Evaluation, Power Smart Evaluation, BC Hydro, August.

Pedersen, M. 2007. "Conservation Research Initiative: Quantitative Analysis of Self-Reported On-Peak Behaviours. BC Hydro, Power Smart, July.

Rink, D., 2006, Conservation Research Initiative, Phase One, Synovate, Project Number 06-0769.

Rink, D., and N. Mould, 2007. Conservation Research Initiative, Phase Two, Interim Key Findings, Synovate, Project Number 06-0769.

Tiedemann, K.H. 2007. "Conservation Rate Initiative, Milestone Report. BC Hydro, Power Smart, August.

Tiedemann, K. H. 1999. "Using Meta-analysis to Understand the Impact of Time-of-use Rates." Statistics Canada International Symposium Series, 1999.

U.S. Department of Energy. 2004. Approaches for the Application of Advanced Meters and Metering Systems at Federal Facilities through Alternative Financed Contracts.

U.S. Department of Energy. 2006. Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them. A Report to the United States Congress Pursuant to Section 1252 of the Energy Policy Act of 2005. February 2006.