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REAL–TIME FEEDBACK AND RESIDENTIAL ELECTRICITY CONSUMPTION: THE NEWFOUNDLAND AND LABRADOR PILOT

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Dean C. Mountain is a faculty member of the McMaster Michael G. DeGroote School of Business and an associate member of the Department of Economics.

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REAL-TIME FEEDBACK AND RESIDENTIAL ELECTRICITY CONSUMPTION: THE NEWFOUNDLAND AND LABRADOR PILOT

Dean C. Mountain*
DeGroote School of Business

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A pilot study was undertaken in Newfoundland and Labrador to determine whether provision of a real-time feedback device is sufficient to provide residential customers with the information needed to reduce their electricity consumption. A panel based econometric methodology, which controlled for such factors as weather, appliance and housing stock, and demographic determinants influencing electricity consumption, was used to quantify the impacts of the real-time monitor in reducing energy (kWh) use. The study also provided some important insights about socio-economic factors that influence conservation responsiveness, a feature that may assist in developing targeted energy efficiency programs. For example, the electric water heating households showed a higher savings than non-electric water heating households. While positive attitudes toward conservation significantly increase the reduction in electricity when using the real-time monitor, seniors, in their employment of the real-time monitor, do not conserve as much. Overall, the aggregate reduction in electricity consumption (kWh) across the study sample was 18.1%. The paper describes the experimental design, the data collection, the evaluation model, the conservation results, and customers' attitudes and perceptions regarding the real-time monitor.

Keywords: Real-time monitor, instantaneous feedback, conservation, residential electricity, seniors, panel based econometric methodology

JEL Classification: C93, D83, J14, Q27, Q47

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1.0 INTRODUCTION

The objective of this pilot study is to determine whether real-time consumption feedback empowers users to effectively reduce energy consumption. As part of this, a quantification of this reduction is undertaken. The pilot is unique in that it provides us with a sample distinct from other real-time pilots. It provides a sample size spread across diverse geographic regions with respect to weather. It also covers a great variety of heating, water heating and appliance configurations. There is also a great diversity of household income and demographic characteristics. The pilot evaluation makes use of a relatively rich pre-experiment historical data set (approximately thirty months) and a parallel control sample that is completely unaware of the pilot.

The principal focus is to test the impact of real-time feedback. Consequently, during the pilot, no intrusions with the customer were initiated. Thus, there was no provision of conservation literature, no conservation goal setting, nor any rate incentives.

Usually, residential electricity consumers see their bill either on a monthly, bimonthly, or quarterly basis. Furthermore, even under regular billing there are delays between the billing date and the time of receiving the bill. By the time the customer receives billing information, the connection between the customer's actions with respect to electricity usage and resulting bill is most often lost. In addition, usually no breakdown of consumption by time of day is provided to the customer. And even though a customer has a meter which can be read periodically, it's probably not very accessible and may be perceived as difficult to understand. In fact, electricity is one of the unusual commodities for which immediate feedback regarding actual consumption does not occur when used.

The goal is to evaluate how consumers' behavior changes if the flow of consumption information were altered and direct feedback monitoring were provided. As part of meeting this goal, the report will quantify the change in kilowatt-hour consumption due to availability of direct feedback information. More specifically, the report evaluates the results of a pilot where customers received direct real-time feedback using the PowerCost Monitor™. The PowerCost Monitor™ involves a display unit that can be placed anywhere in the house. It shows exactly how much electricity is being used at that moment and what it costs. Among other things, it displays current kWh and total monthly kWh of the total consumption of the house. The study tests the hypothesis of whether this display of information provides the necessary feedback encouraging conservation.

The feedback tested here falls into the category of "direct feedback" (see King and Delurey (2005)). While this particular pilot, focuses on an in-home type of display, other types of direct feedback could include displaying consumption on the internet, smart meters operated by smart cards and two-way communication systems showing consumption and cost information, prepayment meters, and device monitors inserted between the plug and wall socket on appliances.

More indirect methods of providing feedback involve the utility processing the data and sending this data to the customer. Such methods could include more frequent bills, sending actual bills (rather than estimates), or comparing year over year estimates normalized for weather.

In the earlier literature, the results of providing feedback information has been somewhat mixed. Many experiments showed success (e.g., McClelland and Cook (1979), Winett, Neale and Grier (1979)). Other studies (e.g., Becker (1978) and Seligman and Darley (1977)) showed failure. Darby (2001) reviews about thirty-eight feedback studies. Twenty-one of the studies are direct feedback studies and ten of the twenty-one studies show an impact of less than 10%. The highest savings – in the range of 20% - occurred using a table-top interactive cost and power display unit, a smart card meter for prepayment of electricity, and an indicator showing cumulative cost of using an electric cooker. Where a special electronic or PC display was not used, direct feedback consisted of frequent readings of a standard household meter, sometimes accompanied by keeping a diary or chart following household use. Some of the feedback studies also provided advice or information regarding potential savings. There, the resulting impact was as much as 10%.

Hydro One (see Mountain (2006)) undertook a similar pilot to the one described in this report. There, the overall average reduction was observed to be 6.5%, with higher response for those with electric water heating and lower response for those with electric heating.

For the current pilot, no intervention occurred. Because the objective is to isolate the effect of the provision of more frequent feedback, no further advice or consultation with the household occurred regarding possible conservation actions.

2.0 THE TECHNOLOGY

In the Newfoundland pilot, the instantaneous feedback was provided by the PowerCost Monitor™ manufactured by Blue Line Innovations Inc. This monitor has many features designed to provide the homeowner with information regarding their electricity consumption. The monitor that was used in this pilot displayed consumption in dollars per hour, total dollars and predicted dollars. Consumption was also displayed in current kWh, total kWh and predicted kWh. In addition to these features, the user was also able to view the current CO^2 emissions, total CO^2 emissions and predicted CO^2 emissions, as well as the temperature. The monitor is completely portable and can be carried from room to room.

In addition to the in-home device itself, the monitor, there is also a transmitter. The transmitter is attached to an existing electro-mechanical utility meter with a ring clamp. The transmitter tracks the electricity consumed by counting the turns of the meter disk. The transmitter continuously sends a wireless signal to the in-home device which displays the consumption in real-time.

3.0 THE PILOT

In order to quantify the impact with a desired level of statistical accuracy, a stratified random sample was designed to cover three geographic regions of Newfoundland Power. The stratification was based on Dalenius Hodges and Neyman allocation techniques. Six kWh strata were chosen. The original sample is comprised of 100 participants who were to be given the real-time monitor and another 18 control customers who were not to be given the real-time monitor. The stratification is shown in Table 3-1. The sample size is sufficiently large such that even if the study is left with 40% usable data (due to attrition, technical difficulties, lack of billing data or lack of customer information), accuracy at the 95% level of significance is guaranteed for generalizing to the population.

With previous annual billing data, a list of possible participants for the pilot, falling into each of the six strata, was used for telephone recruitment. During the telephone recruitment, additional screening was used to eliminate those customers who planned to move within six months, those who were seasonal customers, those who lived in a triplex, four-plex or six-plex, those who were renters, as well as those whose meters were located inside the house. After verifying that the customer was eligible (subject to the above restrictions), the real-time monitor was offered to the customer. Real-time monitors were then given to the pilot participants between April 2005 and August 2005.

Table 3-1: Real-Time Pilot Stratification: Newfoundland

Urban Central

kWh range	number of meters	control meters
0 – 6000	2	0
6000 – 10500	2	1
10500 – 16500	3	0
16500 – 24000	3	0
24000 – 35000	3	1
>35000	4	1
Total	17	3

Rural Central

kWh range	number of meters	control meters
0 – 6000	3	1
6000 – 9000	1	0
9000 – 13500	3	1
13500 – 21000	4	1
21000 – 30000	3	0
>30000	3	0
Total	17	3

Urban East

kWh range	number of meters	control meters
0 – 6000	2	1
6000 – 12000	3	1
12000 – 18000	3	0
18000 – 24000	2	0
24000 – 35000	4	0
>35000	3	1
Total	17	3

Rural East

kWh range	number of meters	control meters
0 – 6000	2	0
6000 – 12000	3	0
12000 – 18000	3	1
18000 – 24000	2	1
24000 – 35000	4	1
>35000	3	0
Total	17	3

Urban West

kWh range	number of meters	control meters
0 – 6000	2	0
6000 – 10500	3	1
10500 – 16500	3	1
16500 – 24000	3	0
24000 – 30000	1	0
>30000	4	1
Total	16	3

Rural West

kWh range	number of meters	control meters
0 – 6000	2	1
6000 – 10500	2	0
10500 – 15000	3	0
15000 – 22500	4	1
22500 – 30000	2	1
>30000	3	0
Total	16	3

4.0 EVALUATION

In order to assess the impact of the real-time monitor on kWh usage, the kWh usage was monitored from the date of initial usage until December 2006. To enhance accuracy of the kWh monitoring once the real-time monitor was given to the customer, monthly reads of the meter occurred. Billing data was also collected for up to 24 months for all pilot participants prior to initial usage of the real-time monitor. However, during this pre-pilot period, sometimes the billing data was not collected as frequently; sometimes bimonthly.

The participants were followed, including the pre-experiment period, for around three and a half years. Therefore, it was important that weather was controlled for and that demographic and appliance changes in the residence were accounted for. With respect to weather, daily heating degree day and cooling degree day information, collected from the relevant local weather station, was matched with billing cycles of the pilot participants. Three questionnaires were administered, one at the beginning of the pilot, one at the midpoint and one at the end. All questionnaires sought information on dwelling characteristics (such as square footage, age of dwelling, etc.), appliance holdings, and demographic characteristics. The first questionnaire also looked back to obtain historical information covering previous years regarding appliance/demographic characteristics and changes during that time. Because the participants' billing consumption was continually monitored, it was critical that any change in dwelling/appliance/demographic characteristics were recorded over the pre-pilot and pilot period.

An econometric model is used to measure possible conservation effects due to the use of the real-time monitor. This model is specified such that it controls for other factors influencing electricity consumption in order that the real-time feedback effect can be isolated. There are three aspects which contribute to this control. The first aspect is that each participant was monitored on a before- and after- basis. The second aspect is that there is a parallel control sample who did not receive such a monitor. One reason for this parallel control sample is that it allows control for possible conservation that may have occurred anyways during the sample time period. The third aspect is that the model controls for the electricity consumption responding to traditional factors such as weather, appliance configuration and household demographics.

Following the pilot and control participants through time provides us with panel data. The panel data provides the necessary input for analysis by an appropriately specified econometric model.

5.0 THE MODEL

Before describing some of the data considerations and the estimation procedure, a precise description of the model follows. It provides a description of a model of daily kWh consumption for household i at time t. Because the billing cycle varies through time for each participant and across participants, all billing data is normalized by number of days in the billing period.

Depending on the appliance and heating/water heating configuration of a household, the total consumption in the absence of the real-time monitor is deemed to be a function of variables influencing electric heating usage, electricity water heating usage, and other appliance usage. In addition, there may be time trend related factors perhaps related to prices and overall conservation attitudes that may influence electricity usage. All of these factors described in the following specification are in the functions $f^1(\cdot,\cdot), f^2(\cdot,\cdot), f^3(\cdot,\cdot), and\ f^4(\cdot,\cdot)$. Once the real-time monitor is used by the customer, further variables may come into play. They are captured in the function $g(\cdot,\cdot)$.

More precisely, the logarithm of daily kWh consumption for household i at time t is $\ln y_{it}$, where $\ln y_{it}$ is decomposed as follows:

$$\ln y_{it} = f^1(\underset{\sim}{x}^1_{it},\underset{\sim}{\alpha}) + f^2(\underset{\sim}{x}^2_{it},\underset{\sim}{\beta}) + f^3(\underset{\sim}{x}^3_{it},\underset{\sim}{\gamma}) + f^4(\underset{\sim}{x}^4_{it},\underset{\sim}{\delta}) + g(\underset{\sim}{z}_{it},\underset{\sim}{\theta}) + \mu_{it}$$

for those households with some part of their heating load serviced by electricity, $f^1(\underset{\sim}{x}^1_{it},\underset{\sim}{\alpha}) = \underset{\sim}{x}^{1\prime}_{it}\underset{\sim}{\alpha}$, with parameter vector $\underset{\sim}{\alpha}$, is a linear function of a vector of independent variables ($\underset{\sim}{x}^1_{it}$) influencing the electric heating load, in the absence of the real-time monitor;

for those households with electricity water heating load, $f^2(\underset{\sim}{x}^2_{it},\underset{\sim}{\beta}) = \underset{\sim}{x}^{2\prime}_{it}\underset{\sim}{\beta}$, with parameter vector $\underset{\sim}{\beta}$, is a linear function of a vector of independent variables ($\underset{\sim}{x}^2_{it}$) influencing the electric water heating load, in the absence of the real-time monitor;

for all households, $f^3(\underset{\sim}{x}^3_{it},\underset{\sim}{\delta}) = \underset{\sim}{x}^{3\prime}_{it}\underset{\sim}{\delta}$, with parameter vector $\underset{\sim}{\delta}$, is a linear function of a vector of independent variables ($\underset{\sim}{x}^3_{it}$) influencing the remaining electricity loads, in the absence of the real-time monitor;

for all households, $f^4(\underset{\sim}{x}^4_{it},\underset{\sim}{\lambda}) = \underset{\sim}{x}^{4\prime}_{it}\underset{\sim}{\lambda}$, with parameter vector $\underset{\sim}{\lambda}$, is a linear function of a vector of trend-related independent variables ($\underset{\sim}{x}^4_{it}$) influencing the total electricity load, in the absence of the real-time monitor;

for all households using the real-time monitor, $g(\underset{\sim}{z}_{it},\underset{\sim}{\theta}) = \underset{\sim}{z}^{\prime}_{it}\underset{\sim}{\theta}$, with parameter vector $\underset{\sim}{\theta}$, is a linear function of a vector of independent variables ($\underset{\sim}{z}_{it}$) influencing the electricity load, in the presence of the real-time monitor; and,

μ_{it} is a stochastic error with possible autocorrelation and heteroskedasticity.

Briefly, the various components reflect the critical factors that influence the corresponding usage.

5.1 Electric Heating Formulation

For those houses with some part of the dwelling heated with electricity, we would expect the size of the house (measured in square feet), the age of the dwelling, the weather (measured in heating degree days), the number of residents, and income to probably matter.

$$f^1(\underset{\sim}{x}^1_{it}, \underset{\sim}{\alpha}) = \underset{\sim}{x}^{1\,\prime}_{it}\,\underset{\sim}{\alpha} =$$

$$\left(\alpha_0 + \alpha_1 NR_{it} + \alpha_2 IN_{it} + \alpha_3 A1_i + \alpha_4 A2_i + \alpha_5 A3_i + \alpha_6 A4_i + \alpha_7 A5_i + \alpha_8 A6_i\right) \bullet DF_{it} SQ_{it} HDD_{it}$$

where

DF_{it} is the proportion of the dwelling heated by electricity at time t;

HDD_{it} is the normalized (per day) heating degree days (with reference temperature 18 degrees Celsius) measured during time t;

SQ_{it} is the square footage of the dwelling;

NR_{it} is the number of residents in the household;

IN_{it} is household income;

$$A1_i = \begin{cases} 1 & \textit{dwelling built between } 1940 \textit{ and } 1969 \\ 0 & \textit{otherwise} \end{cases}$$

$$A2_i = \begin{cases} 1 & \textit{dwelling built between } 1970 \textit{ and } 1986 \\ 0 & \textit{otherwise} \end{cases}$$

$$A3_i = \begin{cases} 1 & \textit{dwelling built between } 1987 \textit{ and } 1990 \\ 0 & \textit{otherwise} \end{cases}$$

$$A4_i = \begin{cases} 1 & \textit{dwelling built between } 1991 \textit{ and } 1993 \\ 0 & \textit{otherwise} \end{cases}$$

$$A5_i = \begin{cases} 1 & \textit{dwelling built between } 1994 \textit{ and } 1998 \\ 0 & \textit{otherwise} \end{cases}$$

$$A6_i = \begin{cases} 1 & \textit{dwelling built } \sin ce\ 1999 \\ 0 & \textit{otherwise} \end{cases}$$

5.2 Electric Water Heating Formulation

For electric water heating, the number of residents, the age composition, income and hot water related appliances matter.

$$f^2(\underset{\sim}{x}^2_{it}, \underset{\sim}{\beta}) = \underset{\sim}{x}^{2\,\prime}_{it}\,\underset{\sim}{\beta} =$$

$$\left(\beta_0 + \beta_1 NR_{it} + \beta_2 APDW_{it} + \beta_3 APCW_{it} + \beta_4 IN_{it} + \beta_5\, NAG1_{it} + \beta_6\, NAG2_{it}\right) \bullet DW_{it}$$

where

$$DW_{it} = \begin{cases} 1 & if\ \ dwelling\ has\ electricity\ water\ heating \\ 0 & otherwise \end{cases};$$

NR_{it} is the number of residents in the household;

$APDW_{it}$ is the wattage of all dishwashers in the dwelling;

$APCW_{it}$ is the wattage of the clothes washing machines in the dwelling;

IN_{it} is household income;

$NAG1_{it}$ is the number of household members less than or equal to 14; and,

$NAG2_{it}$ is the number of household members greater than or equal to 15 and less than or equal to 19.

5.3 Other Electricity Load Formulation

For the other electricity component, the number of residents, the income, and the stock of appliances should matter.

$$f^{3}(\underset{\sim}{x}^{3}{}_{it}, \underset{\sim}{\delta}) = \underset{\sim}{x}^{3}{}_{it}{}' \underset{\sim}{\delta} = \delta_0 + \left(\delta_1 + \delta_2 NR_{it} + \delta_3 IN_{it}\right) \bullet APT_{it} + \delta_4 APONM_{it}$$

where

NR_{it} is the number of residents in the household;

IN_{it} is household income;

APT_{it} is the total wattage of the following appliances: clothes dryer, dishwasher, freezer, microwave, mini-bar, personal computer, range, refrigerator, television, washing machine;

$APONUM_{it}$ is the total number of saunas, hot tubs and whirlpools.

5.4 Trend-Related Formulation

The trend-related formulation is very simple. There is a dummy variable for summer months, a dummy variable for winter months, and a time trend index. If there are conservation impacts happening, regardless of the usage of the real-time monitor, the coefficient corresponding to the time trend index would be expected to be negative and statistically significant from zero.

$$f^{4}(\underset{\sim}{x}_{it}^{4}, \underset{\sim}{\lambda}) = \underset{\sim}{x}_{it}^{4}{}' \underset{\sim}{\lambda} = \lambda_1 LRP_{it} + \lambda_2 DSM_{it} + \lambda_3 DWN_{it} + \lambda_4 \sqrt{T_{it}}$$

where

LRP_{it} is the logarithm of the real price of residential electricity;

DSM_{it} is the proportion of billing days for time t in the months of June, July and August;

DWN_{it} is the proportion of billing days for time t in the months of December, January and February; and,

T_{it} is a time index.

5.5 Real-Time Monitor Impact Formulation

Variables influencing the feedback include the configuration of space heating, water heating and air conditioning, income, education, and the age distribution of household members. Furthermore, it is desirable to test whether there is any attenuation of impact during the pilot. In other words, does the feedback response diminish or increase during the time of using the real-time monitor? Because of the extreme variation in cold weather across the sample in the winter months, in addition to modeling the feedback as a linear term involving heating degree days interacted with proportion of dwelling heating by electricity, a nonlinear term involving the square root of heating degree days is also added.

$$g(\underset{\sim}{z}_{it},\underset{\sim}{\theta}) = \underset{\sim}{z}_{it}'\underset{\sim}{\theta} =$$

$$\begin{pmatrix} \theta_0 + \theta_1 DF_{it}(1-DSM_{it}) + \theta_2 DF_{it}HDD_{it} + \theta_3 DF_{it}\sqrt{HDD_{it}} + \theta_4 DW_{it} + \\ \theta_5 \ln(SQ_{it}) + \theta_6 NR_{it} + \theta_7 IN_{it} + \theta_8 ED1_{it} + \theta_9 ED2_{it} + \theta_{10} EDPR_{it} + \theta_{11} NAG4_{it} + \theta_{12} CSV_{it} + \\ \theta_{13}\sqrt{TD_{it}} + \theta_{14} DSP_{it} + \theta_{15} DSM_{it} + \theta_{16} DFL_{it} \end{pmatrix} \bullet D_{it}$$

where

DSP_{it} is the proportion of billing days for time t in the months of March, April and May;

DSM_{it} is the proportion of billing days for time t in the months of June, July and August;

DFL_{it} is the proportion of billing days for time t in the months of September, October and November;

DF_{it} is the proportion of the dwelling heated by electricity at time t;

HDD_{it} is the normalized (per day) heating degree days (with reference temperature 18 degrees Celsius) measured during time t;

$$DW_{it} = \begin{cases} 1 & \text{if dwelling has electricity water heating} \\ 0 & \text{otherwise} \end{cases};$$

DA_{it} is the proportion of the dwelling air conditioned at time t;

IN_{it} is household income;

$ED1_{it}$ = *number of household members whose highest level of education is high school*;

$ED2_{it}$ = *number of household members whose highest level of education is college or university*

$EDPR_{it}$ is the proportion of household members aged 15 years and over whose highest level of education is no less than high school;

CSV_{it} is a conservation index;

$NAG4_{it}$ is the number of household members 65 and over; and,

TD_{it} is the time in days since the real-time-monitor was installed.

6.0 DATA CONSIDERATIONS

After assembling the data, a number of issues had to be accommodated. Although infrequently, there were, at times, technical difficulties with the monitor. For those observations, until the technical difficulties were corrected, the affected data were dropped from the analysis. The billing period corresponding to installation is dropped because the observation is mixed in nature. The first part of the billing period corresponds to no usage of the real-time monitor and the second part of the billing period corresponds to usage of the real-time monitor.

Only actual meter reads were used. This is particularly relevant to the pre-pilot period where estimated bills were sometimes sent to customers. Moreover, there were some sample participants who did not respond in filling out any of the three questionnaires. If a participant responded to only the first or first and second questionnaires, they were followed as long as questionnaire data was available. If a participant moved during the pilot, the participant was followed up until their departure. After the above data inspection, there were 2263 usable observations. This consisted of 58 pilot participants and 10 control households.

Because billing cycles are customer- and time-specific, all heating and cooling degree day information was matched precisely to the billing cycle.

For many of the already cited reasons, it becomes clear very quickly that the resulting data set is comprised of observations separated by multiple time lags. Even for one customer, sometimes (either due to variation in billing cycles, long periods between actual reads, or dropped observations for reasons described above) the lags between midpoints of actual reads vary. For example, in looking at the distance between observations for one participant, there may be one month, two months or even three months.

The underlying error is assumed to be AR(1). That is $u_{it} = \rho u_{i,t-1} + e_{it}$. The selection of the model's parameters is based on maximizing the likelihood function. Where possible, except for starting observations, we formulate the model in differences between consecutive observations. The advantages of this technique, with respect to handling possible selection bias, are outlined in Ham, Mountain and Chan (1997). To account for the variation in lags across the sample, a concentrated likelihood function in the spirit of Beach and MacKinnon (1978) is formulated.

Denote $\underset{\sim}{X}_{it}' = \left(\underset{\sim}{x}^1{}_{it}', \underset{\sim}{x}^2{}_{it}', \underset{\sim}{x}^3{}_{it}', \underset{\sim}{x}^4{}_{it}', \underset{\sim}{x}^5{}_{it}', \underset{\sim}{z}_{it}' \right)$ and $\underset{\sim}{\tau}' = \left(\underset{\sim}{\alpha}', \underset{\sim}{\beta}', \underset{\sim}{\gamma}', \underset{\sim}{\delta}', \underset{\sim}{\lambda}', \underset{\sim}{\theta}' \right)$.

Denote k_{it} as the distance in months between the observation at time t and $t-1$.

Denote A as the set of observations corresponding to the initial time period for which we have data on a household. Let the number of observations in set A be $\overline{A}$.

Denote B as the set of observations where the distance (measured in months) since the last observation corresponds to the lagged distance. Let the number of observations in set B be $\overline{B}$.

Denote C as the set of observations where the distance (measured in months) since the last observation does not correspond to the lagged distance. Let the number of observations in set C be $\overline{C}$.

The sets $A, B,$ and C are mutually exclusive and exhaustive. Thus, the total number of observations in these three sets ($\overline{A} + \overline{B} + \overline{C}$) equals N, the total number of observations.

The concentrated likelihood function to be maximized (in terms of $\underset{\sim}{\tau}$ and ρ) is:

$$\left[\frac{\overline{A}+\overline{C}}{2}\right]\ln(1-\rho^2)-0.5\sum_i\sum_{\substack{t\\ i,t\in C}}\ln(2(1-\rho^{k_{it}}))-0.5\sum_i\sum_{\substack{t\\ i,t\in B}}\ln\left(\frac{1-\rho^{2k_{it}}}{1-\rho^2}\right)$$

$$-\frac{N}{2}\left[\begin{array}{l}\sum_i\sum_{\substack{t\\ i,t\in A}}\left(\ln y_{it}-\underset{\sim}{X}_{it}'\underset{\sim}{\tau}\right)^2+\sum_i\sum_{\substack{t\\ i,t\in B}}\left(\left(\Delta\ln y_{it}-\rho^{k_{it}}\Delta\ln y_{i,t-k_{it}}\right)-\left(\Delta\underset{\sim}{X}_{it}'\underset{\sim}{\tau}-\underset{\sim}{\rho}^{k_{it}}\Delta\underset{\sim}{X}_{it}'\underset{\sim}{\tau}\right)\right)^2\\+\sum_i\sum_{\substack{t\\ i,t\in C}}\left(\Delta\ln y_{it}-\Delta\underset{\sim}{X}_{it}'\underset{\sim}{\tau}\right)^2\end{array}\right]$$

7.0 RESULTS

7.1 Reasonableness of Model

The above concentrated likelihood function is maximized using a grid search involving ρ. The estimated parameters corresponding to the maximum likelihood corresponding to the final model are in Table 7-1. The optimal ρ is -0.184. We also tested for heteroskedasticity of the error (e_{it}), where the heteroskedasticity was modeled as a function of the squares of the variables denoting ownership of electric heating/electric water heating/air conditioning equipment (and interacted with heating and cooling degree information and square footage). Using White's test, it appears that heteroskedasticity is not present ($\chi^2(2)=4.99<5.99=\chi^2(2)^{crit}_{.05}$).

A quick look at the parameters of the model shows most parameters with relatively low standard errors. The model seems to be well specified; $R^2=0.9283$. This is a very good fit for such panel data.

For the electric heating model pertaining to no presence of a real-time monitor, as expected, the higher the number of residents in the household, the lower is the consumption. This is an effect commonly observed in the conditional demand literature. Not unexpectedly, the age of the dwelling seems to matter in explaining electric heating consumption. Furthermore, the bigger the house, the more electricity is used (e.g., α_0 and the other α parameters are statistically significant from zero). Notice that the income coefficient is negative both in the electric heating submodel. Perhaps, in economic terms, one could characterize the electricity required for heating and cooling is such a necessity that it is an inferior good. However, this may also be related to the idea that the higher the level of income, the more investment is made by households in insulation and weather proofing of the dwelling (and for new home purchases, this means a more energy efficient dwelling in terms of heat or cooling loss) ultimately leading to less electricity used in heating and cooling. This phenomenon was also evident in the results of the Hydro One pilot.

With respect to electric water heating load, the number of residents positively affects electricity usage in Newfoundland. But, a negative adjustment must be made for the number of children less than or equal to nineteen. Similar to the electric heating loads, water heating loads are affected negatively by income.

Table 7-1: Estimated Parameters of Final Model: Newfoundland

	Scaling Factor	Parameter	Standard Error
		Electric Heating Parameters (All variables interacted with $DF_{it}SQ_{it}HDD_{it}$)	
α_0	10^{-4}	0.2647	0.0237
$\alpha_1 : NR$	10^{-6}	-0.3044	0.0539
$\alpha_2 : IN$	10^{-10}	-0.9105	0.2131
$\alpha_3 : A1$	10^{-5}	0.5830	0.3573
$\alpha_4 : A2$	10^{-6}	0.5038	1.4920
$\alpha_5 : A3$	10^{-5}	0.6094	0.2265
$\alpha_6 : A4$	10^{-4}	0.1279	0.0422
$\alpha_7 : A5$	10^{-4}	0.1127	0.0427
$\alpha_8 : A6$	10^{-5}	-0.4522	0.2918
		Electric Water Heating Parameters (All variables interacted with DW_{it})	
β_0	10^{0}	1.4442	0.2898
$\beta_1 : NR$	10^{0}	0.1821	0.0406
$\beta_2 : APDW$	10^{-3}	0.4853	0.4105
$\beta_3 : APCW$	10^{-2}	-0.3034	0.2238
$\beta_4 : IN$	10^{-4}	-0.1404	0.0271
$\beta_5 : NAG1$	10^{0}	-0.4909	0.0637
$\beta_6 : NAG2$	10^{0}	-0.1073	0.0524
		Other Electricity Load Parameters	
δ_0	10^{0}	3.9901	0.2421
$\delta_1 : APT$	10^{-3}	-0.1117	0.0502
$\delta_3 : IN \cdot APT$	10^{-8}	0.2684	0.0526
$\delta_4 : APONM$	10^{0}	0.3505	0.0501

Table 7-1 (continued)

	Scaling Factor	Parameter	Standard Error
		Trend-Related Parameters	
$\lambda_1 : LRP$	10^0	-0.5611	0.1415
$\lambda_2 : DSM$	10^0	-0.1896	0.0178
$\lambda_3 : DWN$	10^0	0.2524	0.0160
$\lambda_4 : \sqrt{T}$	10^0	-0.1398	0.0275
		Real-time Monitor Impact Parameters (All variables interacted with D_{it})	
$\theta_1 : (1 - DSM)$	10^0	0.2770	0.0760
$\theta_2 : DF \cdot HDD$	10^{-1}	0.1607	0.1008
$\theta_3 : DF \cdot \sqrt{HDD}$	10^0	-0.1143	0.0606
$\theta_4 : DW$	10^0	-0.2895	0.1188
$\theta_5 : \ln SQ$	10^0	-0.1119	0.0652
$\theta_6 : NR$	10^0	0.2617	0.1516
$\theta_7 : IN$	10^{-5}	0.2171	0.1865
$\theta_8 : ED1$	10^0	-0.2326	0.2063
$\theta_9 : ED2$	10^0	-0.2754	0.2164
$\theta_{10} : EDPR$	10^0	0.7496	0.5364
$\theta_{11} : NAG4$	10^0	0.1118	0.0723
$\theta_{12} : CSV$	10^{-1}	-0.4956	0.2443
$\theta_{15} : DSM$	10^{-1}	0.9573	0.0431

R^2: 0.9283
Log of the Likelihood Function: -5607.37
Number of Observations: 2263

For the other electricity load (base load) parameters, all coefficients of explanatory variables are positive and all but one is statistically significant from zero. Generally, the greater the number of appliances, the higher is the electricity consumption. In particular, the number of saunas, hot tubs and whirlpools significantly increase household load. As well, as income and the number of residents increase, base load consumption increases.

With respect to trend-related variables, there is a significant seasonal impact aside from weather ($\lambda_2 < 0, \lambda_3 > 0$). The underlying trend conservation effect ($\lambda_4 < 0$) and the price responsiveness are significant ($\lambda_1 < 0$).

7.2 The Impact of the Real Time Monitor

Does the real-time monitor affect consumption? Originally, a much larger real time submodel was estimated. The statistically significant remaining models are shown in Table 7-1. Notice that a number of the remaining coefficients are statistically significant at either the 5% or 10% level of significance. The statistical significance of the remaining θ_i illustrates that the real-time monitor has a significant impact on customer behavior. There are a number of important determinants (see Table 7-1). The heating configuration, the presence of electric heating, the size of the dwelling, the number of residents, their income, their levels of education, the number of senior citizens, attitudes toward conservation and seasonality all play a role in affecting the impact of the real-time monitor on customer behavior. A few items to highlight include the positive relationship between reduction in consumption and education and attitudes to conservation ($\theta_8, \theta_9, \theta_{12} < 0$) and the negative relationship between reduction in consumption and number of residents, income, and number of senior citizens ($\theta_6, \theta_7, \theta_{11} > 0$).

As noted, an important determinant of the responsiveness is the electric heating/electric water heating. This is illustrated in Table 7-2 which shows percentage kWh savings and percentage impacts due to real-time monitoring. The impacts are calculated at sample averages. Sample averages for square footage, number of residents and income are reported. For example, when DF=1 and DW=1 (an all-electric house), the impact is -19.79%. Contrast this with DF=0 and DW=0 (no electric water heating and no electric heating) where the impact is -8.78%.

Looking at Table 7-2, it is clear that the largest impact occurs for customers with electric water heating and without electric heating (-22.45%). The participants without electric water heating and without electric heating show reductions of 8.78%. Both of these impacts are statistically significant at the 95% level of significance. The higher results for those households with electric water heating are in agreement with the results of the Hydro One pilot of Ontario.

Over the entire sample, the overall average reduction in Newfoundland is 18.06%. These results are significantly higher than the response in Ontario and above the 10% reduction observed in four programs surveyed by Darby (2001) where information about conservation was provided to households. But again, it is to be noted that in the Newfoundland pilot no such conservation information was given to participants.

Table 7-2: Percentage Impact of Real-Time Monitor: By Heating-Water Heating Configurations---Newfoundland

	Sample Estimates			
Electric Heating: (Percentage of house heated with electricity: DF)	100	0	0	0<DF<100
Electric Water Heating:	Yes	Yes	No	Yes
Sample Proportion	0.367	0.277	0.115	0.241
Square Footage	1829	1548	1458	1743
Number of Residents	2.81	2.54	1.52	2.93
Income	53732	52595	53581	84184
kWh Before Real-time Monitor	27996	10965	5584	17681
Change in kWh Due to Real-time Monitor	-5540.0	-2461.7	-490.1	-2616.3
Percentage Response (%)	-19.79	-22.45	-8.78	-14.80

Table 7-3 provides another perspective. Here, there is a comparison of the savings for a house of identical size and identical demographics and appliance configuration in each of the geographic regions of the pilot. For example, in the Eastern (Avalon) region of Newfoundland, while the electric heating/electric water heating households show conservation impacts of 10.0%, the non-electric heating/electric water heating impact averages at 21.4%. The remaining part of Table 7-3 examines the impacts in each of the other two regions.

Table 7-3: Percentage Impact of Real-Time Monitor: By Heating-Water Heating Configurations---Newfoundland

By Region in Newfoundland

Electric Heating: (Percentage of house heated with electricity: DF)	100	0	0	0<DF<100
Electric Water Heating:	Yes	Yes	No	Yes
		Avalon		
Square Footage	2013	2013	2013	2013
Number of Residents	2.61	2.61	2.61	2.61
Income	47382	47382	47382	47382
Annual Heating Degree Days	4408.1	4408.1	4408.1	4408.1
kWh Before Real-time Monitor	26510	11295	5283	16503
Change in kWh Due to Real-time Monitor	-2651.7	-2412.0	-855.8	-1785.3
Percentage Response (%)	-10.00	-21.36	-16.20	-11.50

Table 7-3 (continued)

By Region in Newfoundland

Electric Heating: (Percentage of house heated with electricity: DF)	100	0	0	0<DF<100
Electric Water Heating:	Yes	Yes	No	Yes

Central

Square Footage	1786	1786	1786	1786
Number of Residents	2.86	2.86	2.86	2.86
Income	45848	45848	45848	45848
Annual Heating Degree Days	4762.2	4762.2	4762.2	4762.2
kWh Before Real-time Monitor	27783	10508	NA	17533
Change in kWh Due to Real-time Monitor	-6880.0	-2160.1	NA	-2247.8
Percentage Response (%)	-24.80	-20.56	NA	-12.82

Table 7-3 (continued)

By Region in Newfoundland

Electric Heating: (Percentage of house heated with electricity: DF)	100	0	0	0<DF<100
Electric Water Heating:	Yes	Yes	No	Yes

West Coast

Square Footage	1763	1763	1763	1763
Number of Residents	2.87	2.87	2.87	2.87
Income	63970	63970	63970	63970
Annual Heating Degree Days	4503.9	4503.9	4503.9	4503.9
kWh Before Real-time Monitor	29110	13032	7181	16960
Change in kWh Due to Real-time Monitor	-5963.5	-3138.3	-168.3	-2902.8
Percentage Response (%)	-20.49	-24.08	-2.36	-17.12

8.0 CUSTOMERS' ATTITUDES AND PERCEPTIONS REGARDING THE REAL-TIME MONITOR

Having quantified the conservation impact of the real-time monitor, the study will now review the participants' attitudes toward the real-time monitor and their perceptions of their behavior.

Table 8-1 to Table 8-3 indicate a very high level of satisfaction with the real-time monitor. According to questionnaire statistics, 75.0% of the participants felt the monitor made a difference in their homes. The majority of the participants (76.3%) reported that they planned to continue using the monitor after the pilot was complete. When asked how useful they found the monitor in helping them conserve energy, 76.3% of the participants ranked the monitor 3 or greater on a scale of 0 to 5. If we decompose the sample into houses heated entirely by electricity versus all other houses, unlike the Ontario sample, participants in electrically heated houses do not see the monitor as less useful than those in non-electricity heated houses.

Table 8-1: Customer Perception of Whether the Monitor Made a Difference in Their Homes

Did the Monitor make a difference in your home?				
	Number of Individuals			
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	3	4	0	7
Yes	14	10	3	27
No	2	5	2	9

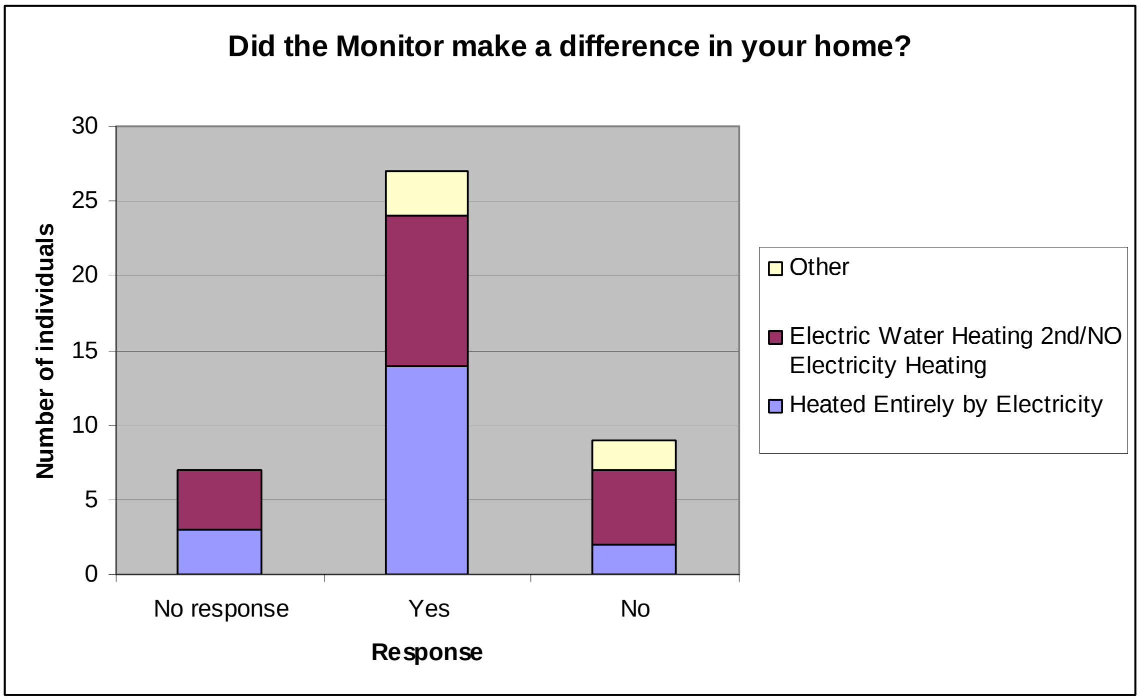


Table 8-2: Customer Expectations of Continuance of Use Following Study

Do you plan to continue using PowerCost Monitor after study is over?				
	Number of Individuals			
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	3	2	0	5
Yes	14	12	3	29
No	2	5	2	9

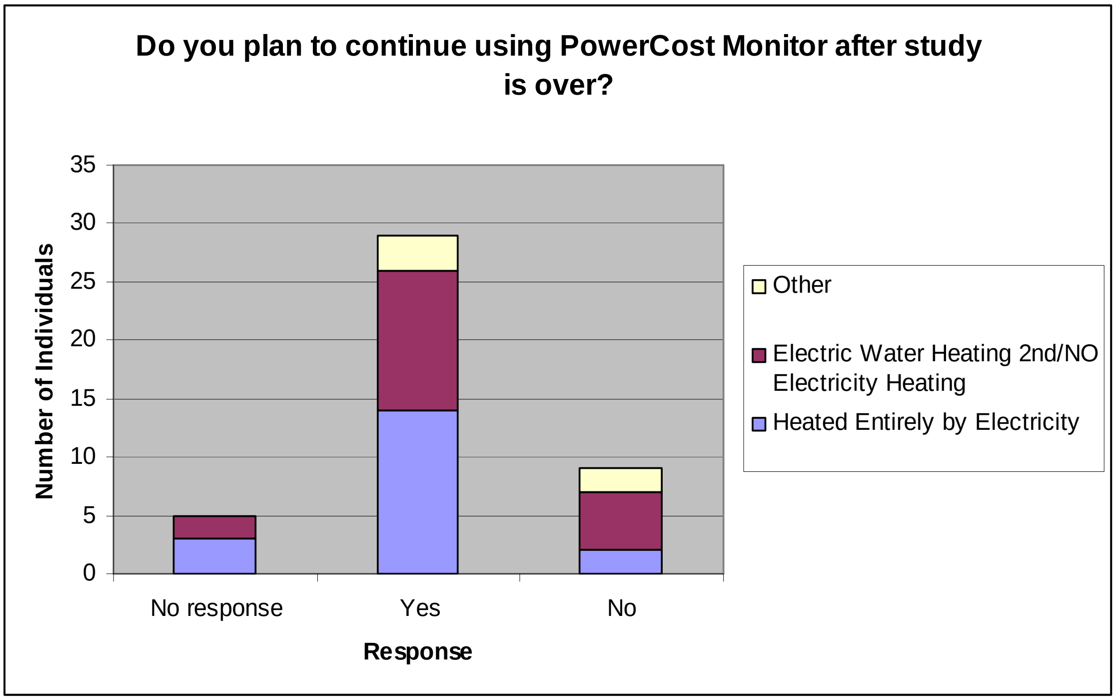


Table 8-3: Customer Perception of the Usefulness of the Monitor

Usefulness of Monitor				
	Number of Individuals			
Usefulness	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	2	3	0	5
1	2	3	2	7
2	1	1	0	2
3	4	5	1	10
4	6	6	1	13
5	4	1	1	6

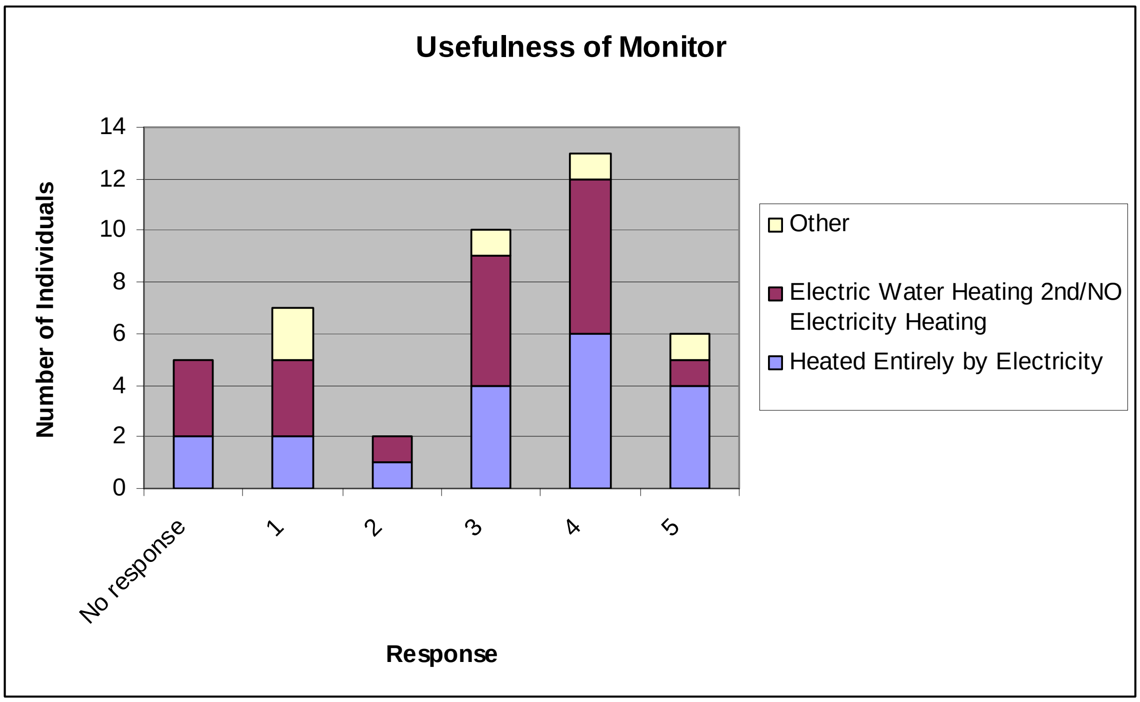


Table 8-4 provides an indication of how often participants consulted their real-time monitor. Our findings indicated that 54.1% of the participants consulted the monitor either daily or multiple times per day. Relative to Ontario (38.9%) the Newfoundland participants consulted their monitor much more often. This supports the much large actual kilowatt-hour reductions measured in Newfoundland.

Table 8-4: Frequency with which Customers Reported Checking the Monitor

How often do you check the PowerCost Monitor?				
	Number of Individuals			
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	4	2	0	6
Rarely	1	5	2	8
1-2 Times Weekly	4	2	0	6
3-5 Times Weekly	0	2	1	3
Daily	5	7	1	13
Multiple Times Per Day	5	1	1	7

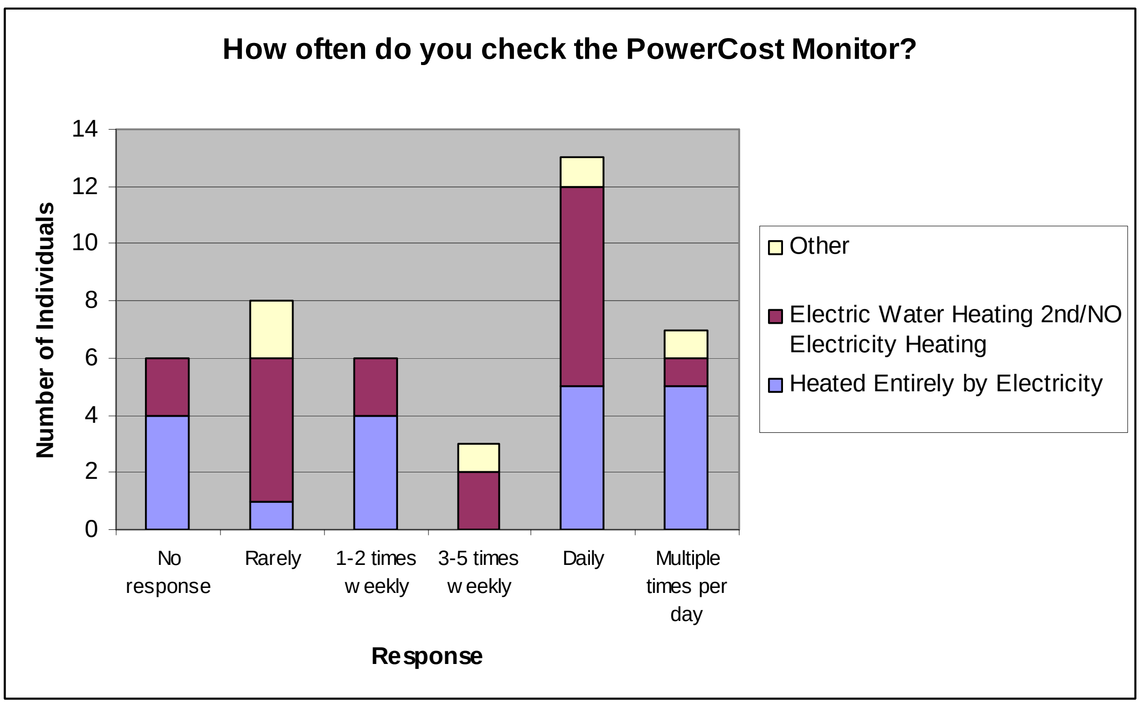
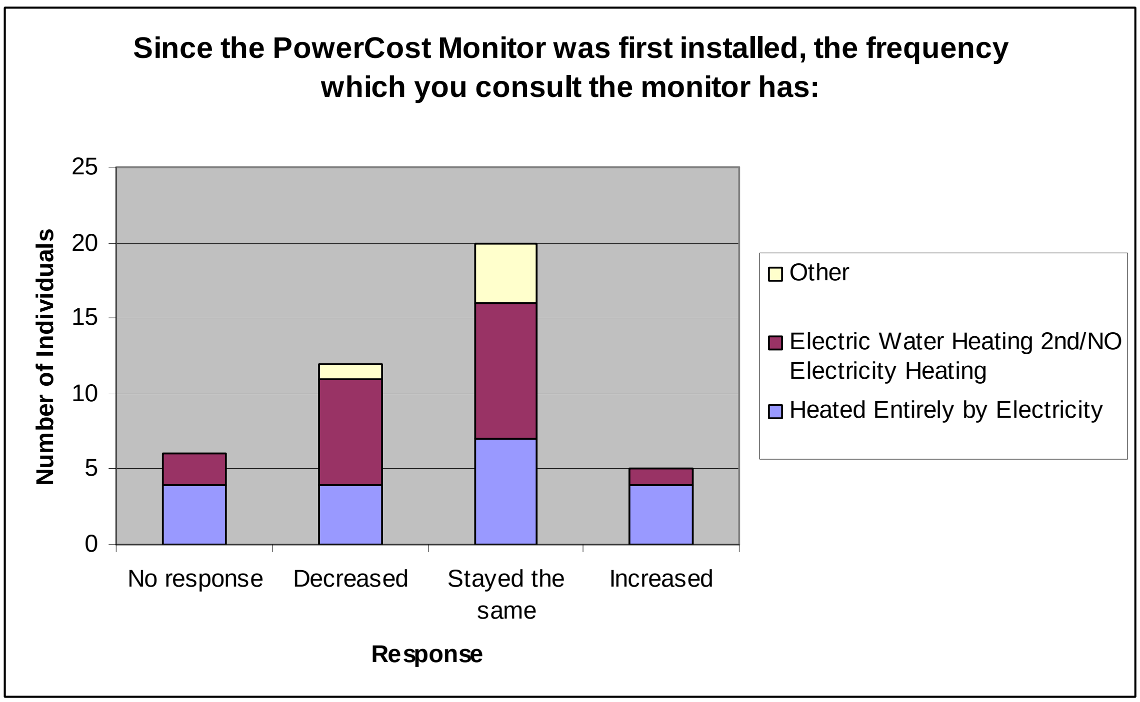


Table 8-5 examines whether the frequency of consulting the monitor has decreased or increased during the pilot. The modal response is that the frequency of consultation has stayed the same.

Table 8-5: Customer Perception of How Their Frequency of Checking the Monitor Has Changed Since Installation

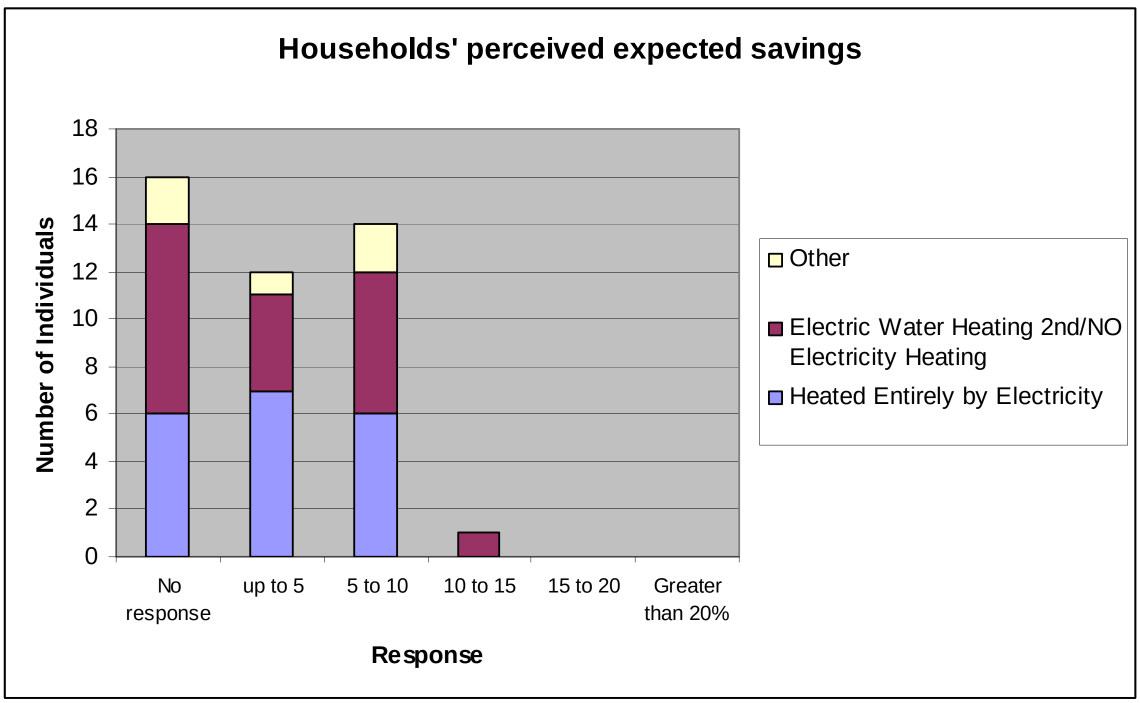
Since the PowerCost Monitor was first installed, the frequency which you consult the monitor has:					
	Number of Individuals				
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total	
No Response	4	2	0	6	
Decreased	4	7	1	12	
Stayed the Same	7	9	4	20	
Increased	4	1	0	5	



The questionnaires also analyzed participants' perception of their savings. Interestingly, when the questionnaire statistics were compared with the actual measured savings there is an understatement of participants' expected savings by Newfoundland participants as illustrated in Table 8-6. While the empirical results suggested an overall reduction of 18.06%, 51.9% of the sample saw their potential savings to be between 5% and 10%.

Table 8-6: Customers' Estimation of Anticipated Savings

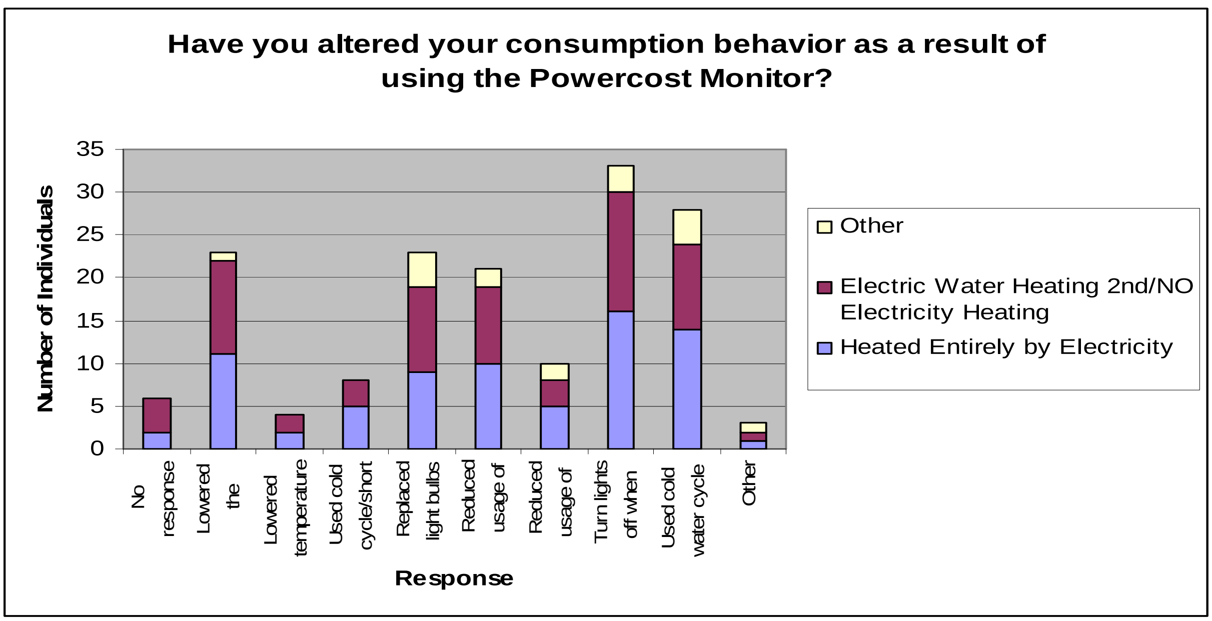
Households' perceived expected savings				
	Number of Individuals			
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	6	8	2	16
Up to 5	7	4	1	12
5 to 10	6	6	2	14
10 to 15	0	1	0	1
15 to 20	0	0	0	0
Greater than 20%	0	0	0	0



How did the participants conserve as a result of using the real-time monitor? Their responses are recorded in Table 8-7. For Newfoundland, the two most popular actions are to turn lights off when not in use and using the cold water cycle on the washer.

Table 8-7: Altered Consumption Behavior Reported by the Customer As a Result of Monitor Use

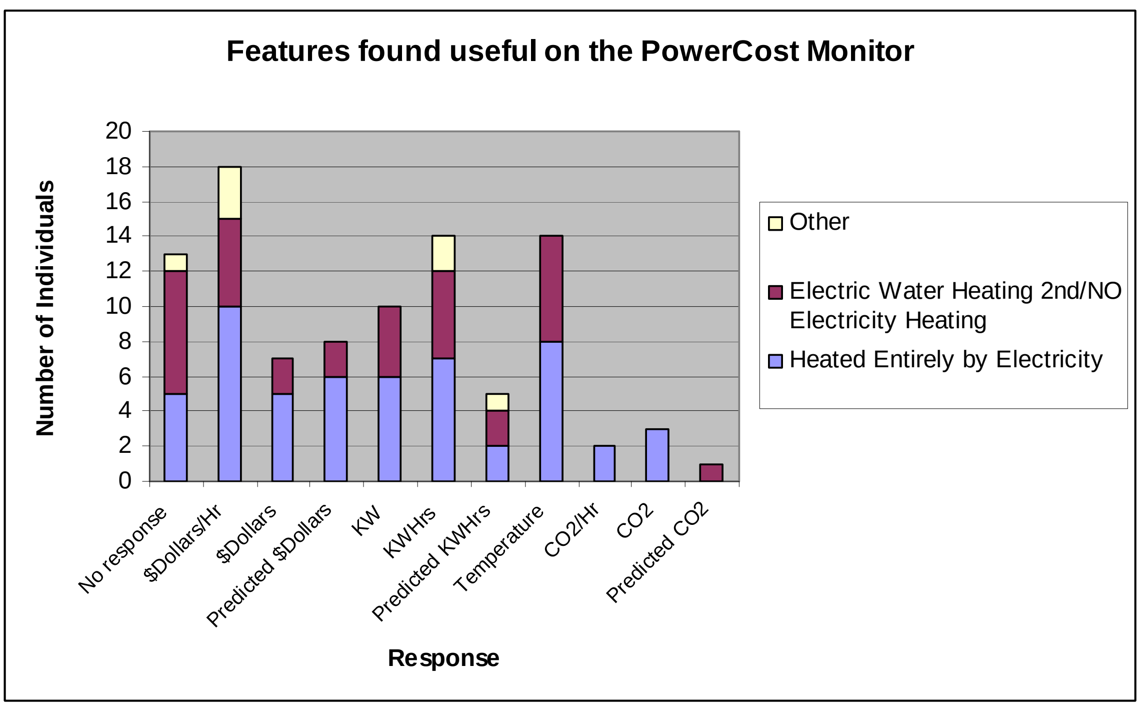
How have you altered your consumption behavior as a result of using the PowerCost Monitor?				
	Number of Individuals			
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	2	4	0	6
Lowered the Temperature on Thermostat	11	11	1	23
Lowered Temperature on Dryer	2	2	0	4
Used Cold Cycle/Short Cycle on Dishwasher	5	3	0	8
Replaced Light Bulbs with Energy Efficient Lighting	9	10	4	23
Reduced Usage of Dryer	10	9	2	21
Reduced Usage of Dishwasher	5	3	2	10
Turn Lights Off When Not in Use	16	14	3	33
Used Cold Water Cycle on Washer	14	10	4	28
Other	1	1	1	3



Finally, Table 8-8 lists the features of the monitor that participants most used. The cost per kilowatt-hour was the most popular feature.

Table 8-8: Customer Indication of Which Monitor Features They Found Useful

Newfoundland Features found useful on the PowerCost Monitor				
	Number of Individuals			
Response	Heated Entirely by Electricity	Electric Water Heating and Supplementary or No Electric Heating	Other	Total
No Response	5	7	1	13
$Dollars/Hr	10	5	3	18
$Dollars	5	2	0	7
Predicted $Dollars	6	2	0	8
KW	6	4	0	10
KWHrs	7	5	2	14
Predicted KWHrs	2	2	1	5
Temperature	8	6	0	14
CO2/Hr	2	0	0	2
CO2	3	0	0	3
Predicted CO2	0	1	0	1



9.0 CONCLUSIONS

1. The pilot study in Newfoundland and Labrador shows that real-time feedback of energy consumption is effective in promoting conservation.

2. The results are statistically significant and support the hypothesis that real-time monitors encourage conservation.
    - This is based on following a significant number of pilot participants over a long period of time. In comparison to previous pilots and demonstration projects regarding direct feedback, the pilot participants were followed for 3.5 years.
    - The experimental design consisted of a stratified random sample, spread across a wide geography, diversity of weather regions, a wide variation in the heating, cooling, water heating and appliance configurations, and a large variety of household income and demographic characteristics.

3. Overall, the average reduction in energy consumption across the whole sample was 18.1% in Newfoundland.
    - Within the Newfoundland sample, attitudes toward conservation and income, and number of residents, age distribution, and heating configuration all play a role in affecting the response to using the real-time monitor. For example, those with a predisposition to energy conservation are likely to respond more than others while senior citizens will not respond as much.

4. The results indicate a persistent response over the study time period and this finding is important for larger deployment of such a device. No reduction in conservation response was detected through the duration of the pilot. Furthermore, the qualitative feedback from participants was positive. They were generally very pleased with the performance and usefulness of the real-time monitor in helping them reduce energy consumption and manage their costs.

5. A higher overall average reduction in energy consumption than that observed in this study can be expected if the real-time monitor is used in conjunction with other conservation and/or price measures.
    - The overall reductions observed in the study correspond only to the impact of real-time feedback. In this pilot, no other price and/or conservation incentives accompanied the real-time monitor. Thus, these results are interpreted as the bare minimum impact.
    - If the real-time monitoring is used in conjunction with other price and/or conservation measures, the conservation impact will be larger.

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