Using Multiple Lines of Evidence to Evaluate Residential Energy Conservation Programs

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ABSTRACT

Electric and gas utilities have expended considerable resources to understand the impact of residential energy conservation programs. This paper argues that the cost effectiveness and reliability of savings estimates can be improved by using a multiple lines of evidence evaluation approach. In the multiple lines of evidence approach, a variety of data sources are used to collect information on key evaluation questions of interest. The multiple lines of evidence approach is used here to compare prelaunch engineering and postlaunch evaluation savings estimates for three residential energy conservation programs at BCHydro. The realization rates were 76 percent for Residential Lighting, 75 percent for Refrigerator Buy-Back, and 41 percent for Water Heater Blanket.

Introduction

Electric and gas utilities have expended substantial resources to understand the impact of residential energy conservation programs. In some cases, simple engineering algorithms are used to understand the impact of these programs. These algorithms typically use administrative information and conventional values for key parameters and apply these, say, to ASHRAE formulae. Utilities are generally aware of the limitations of these estimates but are often reluctant to undertake more comprehensive evaluations because of concerns over the cost, timeliness or complexity of more comprehensive approaches.

A number of recent studies have examined issues pertaining to cost effectiveness and efficiency in impact evaluations of residential programs. Goldberg et. al. (1997) used billing and survey data to analyze the impact of a residential central air conditioner program. They concluded that survey-free methods were justified if free riders were not an issue and if the nonparticipant group is comparable to the participant group in terms of the propensity to install non-program related measures. Mahone et. al. (1996) leveraged sidewalk and mail survey data to build DOE-2 models of houses which had not been recipients of detailed on-site audits. Rather, a small sample of detailed audits was undertaken for specific models of homes and then applied to up to seven more houses of the same model. Mast et. al. (1997) compared standardized methods with suit-to-fit methods for the evaluation of two refrigerator recycling programs. By leveraging existing data to answer some evaluation questions, they found that resources could be saved for evaluation issues where there was no preexisting information. West et. al. (1996) used a longitudinal analysis of ten years of billing data combined with site audits to examine the persistence of residential housing retrofit savings. By careful integrating selection of data and techniques, they were able to obtain highly significant results with very small samples.

These papers suggest that several considerations are critical in making residential impact evaluations both cost effective and reliable. These considerations include the following:

- first, there are frequently significant differences between savings estimates derived from prelaunch engineering estimates and postlaunch evaluated savings;
- second, discrepancies are sometimes due to overly simple engineering algorithms and others times due to inaccurately estimated parameter values;
- third, market effects such as free riders, spillover and attrition need to be incorporated into equations for savings estimates.

The purpose of this paper is to show how the multiple lines of evidence approach was applied to the evaluation of three residential energy conservation programs at BCHydro. An outline of the paper is as follows. The next section outlines the multiple lines of evidence approach. This is followed by three sections which discuss the Residential Lighting, Refrigerator Buy-Back and Water Heater Blanket programs in turn. The final section provides some conclusions.

Approach

The three case studies examined in this paper use the multiple lines of evidence approach. The multiple lines of evidence approach uses a variety of data sources in situations where no single source can provide appropriate evidence on all parameters of interest. Typically with the multiple lines of evidence approach, two or more data analysis techniques are employed, with each technique drawing upon one or more data sources. For each case study, the basic methodology is to compare, for each program, estimates of energy savings generated by conventional engineering algorithms, on the one hand, with energy savings estimated using the multiple lines of evidence approach, on the other hand.

During the design stages of the evaluations, careful consideration was given to the most cost effective way to get high quality and reliable information on program energy savings, demand savings and cost effectiveness. To save space, only the energy savings estimates are reported here. Generally for residential energy conservation programs at BCHydro, the preferred approach has been the traditional difference of differences using weather normalized billing data. This has been particularly successful for major renovations programs where savings of ten percent or more are quite feasible. The alternative of adapting the initial engineering equations to incorporate a more comprehensive set of factors and to incorporate measured data was used for three reasons. First, it was important to understand the limitations of our prelaunch estimation procedures so new programs could be planned with better estimates. Second, we wanted to understand the quantitative importance of various sources of error in the initial estimates. And third, there was concern that the relatively small savings of technologies examined here could be swamped by noise using billing data based procedures.

Residential Lighting

The Residential Lighting program was launched in 1990. The purpose of the program was to encourage residential customers to install more energy efficient lighting measures instead of standard incandescent lighting products. BCHydro included rebate forms for residential customers in mail out promotions. A limitation of three fixtures per customer was stipulated to ensure that the fixtures were for residential applications only. Rebates were offered for compact fluorescent hardwire fixtures, adapter and lamp sets, self-contained units and compact fluorescent bulbs.

Initial rebate levels were set to maximize early participation to encourage appropriate stocking by suppliers. Initial rebates were $25.00 for the purchase of a hard wire fixture, $7.50 for an adapter and lamp set, $5.00 for a self contained unit and $1.00 for a compact fluorescent bulb. Rebate levels were adjusted over time to reflect sales and changes in supplier pricing as penetration increased. Efficient lighting products were sold through the regular supply channels such as building supply houses, lighting stores and hardware stores. BCHydro arranged for marketing and promotional activity and maintained relationships with trade allies, but an external clearing house was used to process applications and make payments to customers.

For the Residential Lighting program, pre-launch estimates of technology savings were based upon the following algorithm.

(1) $ES = (WR - WI) * HRS$

where

ES = average kW.h savings per fixture per year

WI = average wattage installed (ie. post)

WR = average wattage replaced (ie. pre)

HRS = average annual hours of operation.

Because savings levels and costs varied substantially by technology, it is convenient to focus on one technology - adapters - in detail. Based on discussions with trade allies, it was initially assumed that a typical 60 watt incandescent bulb would be replaced by a 13 watt compact bulb plus 2 watt ballast. Operating hours were assumed to be 5 hours per day or 1825 hours per year. Estimated savings for each adapter were thus 82 kW.h per year.

For the Residential Lighting program, evaluation estimates were based upon the following algorithm.

(2) $ES = (WR - WI) * HRS * (1 - ATT) * (1 - FR + SO)$

where

ATT = attrition rate

FR = free rider rate

SO = spill over savings rate

and other terms are as above.

Most of these data were estimated using survey information. These included a survey of some 300 participants (who had sent in rebate coupons) and some 400 nonparticipants. The participant survey included questions on lighting fixtures replaced and purchased, installation location, hours of use by season, attitudes towards the product and the program and household demographics. The average wattage replaced was estimated at 73 watts with a replacement wattage of 18 watts plus 2 watts ballast. Averaging summer and winter use gave an estimated use of 3.26 hours per day or some 1150 hours per year. Free riders were estimated at 25 percent, spill over at 34 percent and attrition at 10 percent. This yielded an evaluated net savings rate of 60 kW.h per year.

The realization rate was about 73%. Two main factors drive this result. First, evaluated average measure savings were 53 watts as opposed to the estimate of 45 watts so that the savings in terms of installed wattage were actually better than predicted. Second, hours of use based on the evaluation were 1190 annually as opposed to 1825 annually for the preprogram estimates. The net effect of market forces - free riders, tagons, attrition - were quite small.

Refrigerator Buy-Back

The Refrigerator Buy-Back program was also launched in 1990. The program's objectives were to reduce the growth rate of saturation of second refrigerators, pick-up and dispose of unwanted refrigerators in an environmentally friendly manner and give a large number of customers a chance to participate in a Power Smart program.

The Refrigerator Buy-Back program initially offered a $30 rebate for each refrigerator picked-up and offered free pick-up and disposal. Rebates were adjusted over time in reaction to the level of customer response. The program was administered by BCHydro staff. A clearing house performed customer screening, assisted with scheduling and processed rebates. Private contractors handled pick-up, temporary storage as needed and transport to the dismantling facility. The dismantling facility removed the refrigerant and capacitors and prepared the hulk for recycling.

For the Refrigerator Buy-Back program, pre-launch estimates of technology savings were based upon the following algorithm.

(3) $ES = (AUTO*APRO + MAN*MPRO)*(1 - FR)$

where

ES = average kW.h savings per refrigerator per year

AUTO = average annual consumption of automatic defrost units

APRO = proportion of automatic defrost pickups

MAN = average annual consumption of manual defrost units

MPRO = proportion of manual defrost pickups

FR = free rider rate.

Average consumption of manual and automatic defrost refrigerators was based on a comprehensive conditional demand study. This regression estimated the consumption of automatic defrost refrigerators at 1894 kW.h per year and that of manual defrost refrigerators at 1223 kW.h per year. An end use survey estimated the stock of automatic defrost second refrigerators at 33 percent and that of manual defrost refrigerators at 67 percent. Free ridership was arbitrarily set at 40 percent. This yielded preprogram estimated savings per unit of 863 kW.h per year.

For the Refrigerator Buy-Back program, evaluation estimates were based upon the following algorithm.

(4) ES = (AUTO*APRO + MAN*MPRO)*(1 - FR + SO)*OR

where

SO = spill over savings rate

OR = operating refrigerator returns rate, ie. share of refrigerators picked up which actually operated when plugged in, and other terms are as above.

Energy consumption estimates for the evaluation were based on in-home metering of 63 second automatic defrost refrigerators (consumption 1297 kW.h per year) and 69 second manual defrost refrigerators (consumption 520 kW.h per year). A detailed telephone survey of 400 participants collected information on type of refrigerator and customer usage. An analysis of refrigerator disposal using the participant survey as well as a survey of 400 nonparticipants generated a free rider rate of 21 percent but did not identify a significant spill over effect. About 48 percent of the refrigerators picked up were automatic defrost and about 52 percent manual defrost. About 92 percent of refrigerators collected were working. Net evaluated savings were thus 650kW.h per year.

The realization rate was about 75 percent. The main reason for the reduction in savings was the large reduction in estimated consumption from the metering compared to the conditional demand estimates. Inaccurate estimate of the manual/automatic split and the free rider rate were also important.

Water Heater Blanket

The Water Heater Blanket program began in 1988. The purpose of the program was to reduce energy consumption of older, less efficient water heaters until they failed and were replaced by new, more efficient models. In addition to a water heater blanket, each participant received an information package on additional ways to reduce energy consumption for water heating. Eventually the program was expanded to include low flow showerheads and aerators but the initial study focused on savings from water heater blankets alone.

Target markets for the program each year were based on efficiency and equity considerations. Private contractors were hired to do the installations and undertake local marketing and recruitment. BCHydro provided media advertising, marketing support and training for contractors and their staff. BCHydro field staff were responsible for ordering materials for their region, handling inventory and reporting and assisting with local implementation.

For the Water Heater Blanket program, pre-launch estimates of technology savings were based upon the following algorithm.

(5) ES = GBS + TTS

where

ES = average kW.h savings per water heater blanket per year

GBS = gross water heater blanket savings

TTS = temperature turn-back savings.

Gross blanket savings were based on test stand measurements of twenty-two water tanks using Canadian Standards Association C191test stand protocol. Using a test stand tank temperature of 154.4 degrees F and ambient temperature of 70 degrees F, savings for the tested tanks averaged 335 kW.h per year. Temperature turn-back savings were based on the estimate that 15 percent of customers would reduce their water tank temperature settings by 20 degrees F (from 160 degrees F to 140 degrees F) saving about 1100 kW.h per year per affected tank or an average of 165 kW.h per year for all tanks. The estimated savings were the sum of these or 500 kW.h per year.

For the Water Heater Blanket program, evaluation estimates were based upon the following algorithm.

(6) ES = (GBS - ACH - ATL)*(1 - FR + SO) + TTS

where

ACH = adjustment for controlled electric heat areas

ATL = adjustment for tank location

FR = free rider rate

TO = spill over on savings rate.

For the evaluation, contractors tested 817 water tank temperatures in customers' homes and found an average temperature of 133 degrees F or well below the test stand temperature. In addition, room temperatures of 399 participants were 69.3 degrees F. Regression analysis was used to establish the relationship between the room-tank temperature differential, resulting in a reduction of savings of 118kW.h per year. Closet effects (in 37 percent of the cases) reduced savings by an average 2 kW.h per year and cross effects (relevant for 9 percent of homes) reduced savings by 5 kW.h per year. Free riders and spill over were based on surveys of participants and nonparticipants and yielded a free rider rate of 4.5 percent and a spill over rate of 4 percent, and turn-back effects were found to be negligible. The net effect was to reduce evaluated savings to 207 kW.h per year.

The realization rate was just 41 percent. About 95 percent of the reduction was due to just two factors. First, surveyed water tanks were set 20 degrees F below assumed and tested temperatures. And second, there was no evidence of participant thermostat setback as assumed before launch.

Summary and Conclusions

This paper has considered the multiple lines of evidence approach to impact evaluation for three residential energy conservation programs at BCHydro. Three programs were examined: Residential Lighting; Refrigerator Buy-Back; and Water Heater Blanket. For each program, a detailed comparison of results for the pre-launch engineering analysis and the post-launch evaluation was undertaken. There are three critical findings.

First, it is important to use measured data on savings or the drivers of savings. Engineering estimates based on typical or assumed values may not be valid for the building, weather or installation conditions facing a specific utility.

Second, laboratory testing or bench testing is sometimes a reasonable way to get first-order estimates of technology savings. However, it is critical to measure key parameters in situ or under conditions of actual use, and apply these measurements to recalibrate laboratory measurements as appropriate.

Third, estimates of gross technology savings should be supplemented with information on market effects to provide credible net savings estimates. Free riders, tag ons and attrition can make the net effect of a program substantially different from the gross effect.

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