Modeling Energy Savings and Cost Effectiveness Performance: A Regression Analysis of North American Residential Lighting Programs

K. H. Tiedemann, BC Hydro, Vancouver, BC
I. M. Sulyma, Research 4 Results, Vancouver, BC

Abstract

Energy efficient lighting programs have been the most important source of residential energy savings for many utilities in Canada and the United States. The purpose of this paper is to examine the role and impact of various marketing activities on residential electricity savings for lighting using cross-section econometric modeling. This paper has the following conclusions:

First, utility residential lighting programs vary substantially in terms of the marketing mix. For the twenty programs for which comprehensive information could be found, average annual budgets were about \$11.8 million; about 60% of programs featured other energy-efficient lighting products in addition to CFLs; and about 20% of program employed multi-level incentives (both upstream and downstream).

Second, standard engineering algorithms were used to estimate energy savings on a common basis across utilities. For the twenty programs examined, average energy savings were 98.9 GWh per year.

Third, cost effectiveness was estimated using the utility cost of conserved energy. For the twenty programs examined, the cost of conserved energy was \$0.035 per kWh.

Fourth, the determinants of energy savings were estimated using appropriate cross-section regression modeling. The models confirmed that the size of program budgets and the breadth of the offer were statistically significant determinants of program savings, but disconfirmed an impact of the depth of the program marketing on energy savings.

Fifth, the determinants of the cost of conserved energy were also estimated using appropriate cross-section regression modeling. The models confirmed that the size of program budgets and the breadth of the offer were significant determinants of the cost of conserved energy, but disconfirmed an impact of the depth of the program marketing on cost of conserved energy.

Introduction

By the mid-1980s, a number of electric utilities in Canada and the United States were offering demand side management (DSM) programs, which encouraged their customers to increase energy efficiency and reduce energy consumption. These DSM programs were largely motivated by the regulatory requirements of Public Utility Commissions to put supply side and demand side activities on a similar footing, given evidence from engineering and economics studies that it was sometimes more cost effective to meet incremental needs for additional energy services by changing-out current technologies for more efficient ones than by building new electric system capacity.

For residential electricity customers, lighting programs have been the largest source of energy savings in many jurisdictions. Although utility DSM programs set the stage for energy conservation in Canada and the United States, perhaps the most important single event influencing residential lighting energy efficiency was the launch of the Green Lights Program by the U.S. Environmental Protection Agency in 1991. As a voluntary partnership between government and the private sector, Green Lights proved to be the catalyst that led to a surge of interest in energy efficiency including enhanced and expanded DSM activity.

A number of studies have evaluated the impacts of residential lighting programs on energy savings (see references). To date, most of these savings have come from the promotion of purchase and installation of standard twister or spiral compact fluorescent lamps (CFLs). As a significant degree of market transformation has been achieved with standard CFLs replacing incandescent lamps, a number of utilities and other DSM implementing agencies have started to provide support for the purchase and the installation of specialty CFLs including reflectors, A-lamps, globes and dimmable lamps; for Energy Star lighting fixtures; and for LEDs.

An extensive literature review was undertaken to understand the values of these various parameters used in energy savings algorithms, calculate energy savings, and collect additional information to inform the econometric modeling. The data bases examined included the Social Science Research Network, the Consortium for Energy Efficiency, the California Measurement Advisory Council (CALMAC), International Energy Program Evaluation Conference Proceedings (IEPEC) and Scopus. Detailed information was found for twenty residential lighting programs as discussed below. In a number of cases, only some of the parameters were provided directly in the study, but the other parameters could be derived from related information

Residential lighting programs have emphasized four main marketing mechanisms:

(1) Upstream Buy-Down. Upstream buy-downs involve incentives to manufactures to have the retailers mark down the cost of qualifying energy efficient lights and fixtures at the time of purchase.

(2) Downstream Buy-Down. Downstream buy-downs typically involve point-of-sale or mail-in coupons to allow the purchaser to obtain the product at a discounted price.

(3) Direct Installation. Direct installation typically involves the direct installation of CFLs at the time of a residential home energy audit.

(4) Give Away. Give away typically involves provision of free CFLs at promotional events or through the mail. Direct installation and give away programs were common in the early days of residential lighting programs in order to build customer product awareness and experience, but they are now relatively little used.

As noted above, there is considerable published research on residential energy efficient lighting programs, but there appear to be no published quantitative studies of the impact of marketing variables on energy savings. This study helps fill this gap by:

(1) building a database of comparable marketing information for a set of residential energy efficient lighting programs;

(2) estimating program savings and the cost of conserved energy using suitable engineering algorithms; and

(3) using appropriate regression modeling to explore the determinants of program energy savings and the cost of conserved energy.

An outline of this paper is as follows. The second section summarizes the twenty utility energy efficient lighting programs used in the analysis. The third section describes how the outcome variables were developed. The fourth section summarizes the data and the regression modeling approach. The fifth section provides the results of the regression modeling. And the sixth section provides conclusions.

Program Summaries

We undertook an extensive literature review to understand the scope and impacts of residential lighting programs, collect information for the calculation of the energy savings and cost of conserved energy outcome variables, and collect additional information to inform the econometric modeling. For several utilities, there were evaluations available for multiple years, and in these cases the study covering the 2010 program year was used.

Table 1 provides a summary of the twenty utility residential lighting programs used in this study. This information includes the name of the utility, the service territory, the residential lighting products incented by the program (CFLs, CFL fixtures, LEDs, LED fixtures), and the marketing levels used (downstream, upstream).

Table 1. Utility Residential Lighting Program Summaries

	State/ province	Residential Lighting Products Included				Marketing Levels	
		CFLs	CFL fixtures	LEDs	LED fixtures	Downstream	Upstream
Allegheny	MD,PA	X	-	-	-	X	-
Ameren IL	IL	X	-	-	-	-	X
Avista	WA,ID,OR	X	-	-	-	X	-
BC Hydro	BC	X	X	-	-	X	-
ComEd	IL	X	X	-	-	X	-
Connecticut	CT	X	X	X	X	X	X
E. Vermont	VT	X	X	X	X	X	X
ET Oregon	OR	X	-	-	-	-	X
Fortis BC	BC	X	-	X	X	X	-
Hydro Que.	PQ	X	X	-	X	X	X
Long Island	NY	X	X	-	-	X	X
NV Energy	NY	X	X	-	-	X	-
PacifiCorp	UT,ID,WY	X	X	-	-	X	-
PG&E	CA	X	X	X	X	-	X
Platte River	CO	X	-	-	-	X	-
Potomac	DC,MD	X	-	-	-	X	-
Progress	NC,SC	X	-	-	-	X	-
SMUD	CA	X	X	-	X	X	X
Salt River	AZ	X	-	-	-	X	-
SCE	CA	X	X	X	X	-	X

Sources. Utility websites and Summit Blue, Itron, ODC and Michaels Engineering, Commonwealth Edison Company, Energy Efficiency/Demand Response Plan (6/1/2008-5/31/2009) Evaluation Report: Energy Star Lighting, December 10, 2009; The Cadmus Group, Inc., Efficiency Maine Trust Residential Lighting Program Evaluation: Final Report, November 1, 2012; Itron, Verification of Reported Energy and Peak Savings from the EmPOWER Maryland Energy Efficiency Programs, April 21, 2011; Tetratech and NMR Group, Focus on Energy 2010 CFL Savings, February 7, 2011; NMR Group, RLW Analytics and GDS Associates, Residential Lighting Markdown Impact Evaluation, January 20, 2009; KEMA, New Jersey's Clean Energy Program Residential CFL Impact Evaluation and Protocol Review, September 28, 2008; KEMA, Final Evaluation Report: Upstream Lighting Program, February 8, 2010; The Cadmus Group, Colorado Home Lighting Program Process and Impact Evaluation Report, January 22, 2010; Cadmus, New Hampshire Home Performance with Energy Star Program, June 13, 2011; California Public Utilities Commission, 2006-2008 Energy Efficiency Report, June 2010..

Development of Outcome Variables

The first outcome variable is net energy savings as given by algorithm (1). Key parameters in this algorithm are the difference in watts between the base and the efficient technology (ΔW**)**, annual hours of use (Hours), the installation rate net of replacements which is often called the in-service rate (Install), the free rider rate (FR), the spillover rate (SO), and the number of rebated measures (No). For net energy savings, the basic algorithm is:

$$\Delta kWh = \Delta W/1000 \cdot Hours \cdot Install \cdot (1 - FR + SO) \cdot No. \qquad (1)$$

The second outcome variable is the utility cost of conserved energy as given by algorithm (2). We assume that utilities base investment decisions using life cycle costing, where life cycle costing takes into consideration the fact that economic costs and economic benefits may occur at different points in time so that discounting costs and benefits back to a base year is appropriate. In algorithm (2), CCE is the utility cost of conserved energy in dollars per kWh, Cost is the utility cost in millions of dollars, GWh is annual energy savings in GWh, i is the discount rate which is assumed to be 5% based on the typical utility cost of capital, and n is the length of life of an energy efficient lamp which is assumed to be six years, given typical stated lifetime of 6,000 hours and typical annual use of about 1,000 hours. CEE varies considerably across the nineteen programs, from a low of \$0.005 per kWh to a high of \$0.13 per kWh, and it has an unweighted average of \$0.035 per kWh.

$$CCE = \{Cost/GWh\} \cdot \{[i/[1 - (1 + i)^{-n}]^{-1}\} \qquad (2)$$

Data and Regression Modeling Approach

We estimate the following model of the impact of the energy efficient lighting programs on energy savings, where ΔGWh is the estimated first-year savings for the i^{th} utility in gigawatt hours, α is the constant term, Bud is the annual program budget in millions of U.S. dollars, Bre is a dummy variable for the breadth of the program which takes the value zero if the program promotes only CFLs and takes on the value one if the program promotes additional energy efficient lighting, Mar is a dummy variable which takes on the value zero if the program uses only upstream or downstream marketing and takes on the value one if the program uses both upstream and downstream marketing, and ε is an error term.

$$\Delta GWh_i = \alpha_1 + \beta_{11} Bud_i + \beta_{21} Bre_i + \beta_{31} Mar_i + \varepsilon_i \qquad (3)$$

We estimate the following model of the impact of the energy efficient lighting programs on the cost of conserved energy, where ΔCCE is the estimated constant of conserved energy from the utility perspective, α is the constant term, Bud is the annual program budget in millions of U.S. dollars, Bre is a dummy variable for the breadth of the program which takes the value zero if the program promotes only CFLs and takes on the value one if the program promotes additional energy efficient lighting, Mar is a dummy variable which takes on the value zero if the program uses only upstream or downstream marketing and takes on the value one if the program uses both upstream and downstream marketing, and ε is an error term.

$$\Delta CCE_i = \alpha_2 + \beta_{12} Bud_i + \beta_{22} Bre_i + \beta_{32} Mar_i + \varepsilon_i \qquad (4)$$

Table 2 summarizes the data used in the regression analysis. The variables in the data set are: (1) program projected savings in GWh per year, (2) program budget in millions of dollars, (3) the cost of conserved energy, (4) whether the program offer includes only CFLs or it also includes other advanced lighting products, and (5) whether the marketing mix includes only upstream or downstream incentives or it includes both.

Table 2. Data Summary

Variable	Metric	Mean
Savings	(GWh/year)	98.9
Budgets	($million/year)	11.8
Cost conserved energy	($/kWh)	0.035
Breadth of offer	(0 = CFLs only, 1 = CFLs plus other)	0.60
Depth of marketing	(0 = upstream or downstream, 1 = both)	0.20

Results

Determinants of Energy Savings

Table 3 shows the results of the regression modeling of the determinants of energy savings. The dependent variable is energy savings in GWh per year. The standard errors for the regression coefficients are shown in parentheses below the regression coefficients, and the levels of significance for the F-tests are shown below the F statistics in parentheses. One asterisk indicates that the regression coefficient is significant at the 10% level, two asterisks indicate that the regression coefficient is significant at the 5% level, and three asterisks indicate that the regression coefficient is significant at the 1% level.

Initial regressions were estimated using ordinary least squares. Since the initial regressions suggested the presence of heteroscedasticity in the residuals, which can potentially cause the estimated standard errors of the regression coefficients to be biased and inconsistent, the regression models were re-run using White's heteroscedasticity adjusted least squares, which adjusts for heteroscedasticity. Key findings are as follows.

Model 1 includes the program budget and the breadth of the program as independent variables. The model has good explanatory power with an adjusted R-squared of 0.73, and the regression coefficients on the program budget and the breadth of product variables are significant at the one percent level. The model says that a one million dollar increase in program budget increases energy savings by 5.4 GWh per year and having a broader breadth of lighting products increases energy savings by 89.6 GWh per year.

Model 2 includes the program budget and the depth of marketing as independent variables. The model has good explanatory power with an adjusted R-squared of 0.68, and the regression coefficients on the budget is significant at the one percent level but the regression coefficient on the depth of marketing variable is not significant. The model says that a one million dollar increase in program budget increases energy savings by 6.0 GWh per year.

Model 3 includes the program budget, the breadth of lighting products, and the depth of marketing as the independent variables. The model has good explanatory power with an adjusted R-squared of 0.72, and the regression coefficients on the budget and breadth of program variables are significant at the one percent level and the five percent level respectively, but the regression coefficient on the depth of marketing variable is not significant. The model says that a one million dollar increase in program budget increases energy savings by 5.6 GWh per year and having a wider range of product offerings increases energy savings by 77.3 GWh per year.

Table 3. Determinants of Residential Lighting Savings (GWh/year)

	Model 1	Model 2	Model 3
Constant	-18.8 (19.3)	12.5 (8.9)	-20.0 (19.5)
Budget	5.4*** (0.85)	6.0*** (0.99)	5.6*** (0.90)
Breadth of products	89.6*** (35.0)	-	77.3** (33.9)
Depth of marketing	-	76.4 (56.4)	33.6 (58.8)
Adjusted R-squared	0.73	0.68	0.72
F statistic	26.9 (0.00)	21.2 (0.00)	17.5 (0.00)

Note. Standard errors for regression coefficients and significance of a linear regression for the F test are shown in parentheses. One, two or three asterisks indicate that the regression coefficient is statistically significant at the ten percent, five percent or one percent level respectively.

Determinants of Utility Cost Effectiveness

Table 4 shows the results of the regression modeling of the determinants of utility cost of conserved energy. The dependent variable is energy savings in the cost of conserved energy. As before, the standard errors for the regression coefficients are shown in parentheses below the regression coefficients, and the levels of significance for the F-tests are shown below the F statistics in parentheses, and the reported regression use White's heteroscedasticity adjusted least squares. The key findings for the regression models are as follows.

Model 1 includes the program budget and the breadth of the program as independent variables. The model has limited explanatory power with an adjusted R-squared of 0.18, and the regression coefficients on the program budget and the breadth of product variables are significant at the ten percent and the five percent level respectively. The model says that a one million dollar increase in program budget increases the cost of conserved energy by $0.0084 per kWh and having a broader breadth of lighting products reduces the cost of conserved energy by $0.054 per kWh.

Model 2 includes the program budget and the depth of marketing as independent variables. The model has very poor explanatory power with an adjusted R-squared of 0.01, and the regression coefficients on the budget is significant at the ten percent level but the regression coefficient on the depth of marketing variable is not significant. The model says that a one million dollar increase in program budget increases the cost of conserved energy savings by $0.00060 per kWh.

Model 3 includes the program budget, the breadth of lighting products, and the depth of marketing as the independent variables. The model has limited explanatory power with an adjusted R-squared of 0.14, and the regression coefficients on the budget and breadth of program variables are significant at the five percent level respectively, but the regression coefficient on the depth of marketing variable is not significant. The model says that a one million dollar increase in program budget increases the cost of conserved energy by $0.00091 per kWh and having a wider range of product offerings reduces the cost of conserved energy by $0.054 per kWh.

Table 4. Determinants of Cost of Conserved Energy (dollars per kWh)

	Model 4	Model 5	Model 6
Constant	0.054** (0.023)	0.031*** (0.013)	0.054*** (0.023)
Budget	0.00084* (0.00046)	0.00060* (0.00056)	0.00091** (0.00046)
Breadth of products	-0.049** (0.025)	-	-0.054** (0.026)
Depth of marketing	-	-0.015 (0.015)	0.015 (0.010)
Adjusted R-squared	0.18	0.01	0.14
F statistic	3.0 (0.07)	0.71 (0.50)	2.00 (0.15)

Note. Standard errors for regression coefficients and significance of a linear regression for the F test are shown in parentheses. One, two or three asterisks indicate that the regression coefficient is statistically significant at the ten percent, five percent or one percent level respectively.

Conclusions

Residential lighting programs have been the most important source of residential energy savings for many utilities in Canada and the United States. These programs have encouraged residential customers to purchase energy efficient lighting products primarily through upstream incentive programs, which provide financial incentives to firms in the manufacturing and distribution stream, and downstream incentives programs, which provide financial incentives directly to customers. The purpose of this paper is to examine the role and impact of various utility marketing activities on residential electricity savings for lighting. This paper has the following conclusions.

First, utility residential lighting programs vary substantially in terms of the marketing mix. For the twenty programs for which comprehensive information could be found, average annual budgets were about $11.8 million, about 60% of programs featured other energy efficient lighting products in addition to CFLs, and about 20% of programs employed multi-level incentives (both upstream and downstream). Product give away was common in the earlier development of residential lighting programs, but it is now significant only in specialized programs targeting hard-to-reach customers.

Second, standard engineering algorithms were used to estimate energy savings. Although there are common elements in the estimation and reporting of energy savings, there are also some differences. To ensure that the basis of comparison was valid across utilities, the algorithms and data used were examined in detail with adjustments made as appropriate. For the twenty programs examined, average energy savings were 98.9 GWh per year.

Third, cost effectiveness was estimated using the utility cost of conserved energy. Again, although cost reporting across utilizes has similarities, there are some differences. So again to ensure comparability across utilities, detailed estimates were made using data at the utility level using a common methodology. For the twenty programs examined, the cost of conserved energy was $0.035 per kWh.

Fourth, the determinants of energy savings were estimated using appropriate cross-section regression modeling. The estimated models had a high degree of explanatory power. The models confirmed that the size of program budgets and the breadth of the offer were significant determinants of program savings, but disconfirmed an impact of the depth of the program marketing on energy savings.

Fifth, the determinants of the cost of conserved energy were also estimated using appropriate cross-section regression modeling. The estimated models had a low degree of explanatory power. The models confirmed that the size of program budgets and the breadth of the offer were significant determinants of the cost of conserved energy, but disconfirmed an impact of the depth of the program offering on cost of conserved energy.

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