The Residential Energy Savings Effect of a 2-Step Inclining Block Electricity Rate

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ABSTRACT

BC Hydro introduced a 2-Step inclining block rate in October 2008 to replace the existing single rate schedule for residential customers. The purpose of the rate was to encourage conservation by reflecting the legacy cost of energy in the first step and the marginal cost of new energy in the second.

The rate applies two distinct charges separated by a consumption boundary of 1,350 kilowatt-hours per bi-monthly billing period. The first step applies to all energy consumed up to and including the threshold while the second pertains to all consumption above. Since the two charges differ substantially in absolute terms and may be further adjusted by widening the gap between them, a proper accounting of conservation effects requires the estimation of price elasticity of demand within each step. The objective of the analysis described in this paper is to measure the amount of conservation caused by the inclining block rate, where the method used was to estimate relevant price elasticities. The elasticities themselves were estimated by dividing the bi-monthly consumption of each customer by threshold and regressing each consumption block on the logarithm of their corresponding step charges. The expected price elasticity at each step is the regression parameter associated with the natural logarithm of the step price in each of the resulting two equations.

Elasticity values were applied to changes in price at each step to calculate consumption savings in kilowatt-hours. As rate-related savings to the utility are considerable, understanding the effect of the rate structure on conservation is important to energy planning.

Introduction

From 1962 until 1994, BC Hydro used a declining block or tiered rate for residential consumption. The first 275 kWh consumed in a month were priced at one rate while remaining consumption in the month was priced at a lower rate. As directed by the local regulatory body, the utility moved to a flat rate structure on April 1, 1994. This rate remained in effect until October 1, 2008.

In the 2007 Rate Application decision, regulators directed the utility to bring forward its proposal to introduce a Residential Inclining Block Rate (RIBR) with the following attributes:

- The size of the first block should be determined on the basis of the Heritage entitlement and for each customer should be set at about 1600 kWh per bi-monthly billing period;
- All energy consumed in excess of 1600 kWh per bi-monthly billing period should be priced at the marginal cost of supply plus an allowance for distribution losses and
- The rate should be revenue neutral.

Rate Development and Description

The RIBR application was filed with regulators in 2008 and proposed a two-step inclining rate that impacted more than 1.6 million households with average account usage of 11,000 kWh per annum. Following an oral hearing, the local regulatory body determined that it was in the public interest to implement the new rate and ordered that the two-step inclining block structure incorporate the following design principles:

(i) Establish the Step 1 to Step 2 threshold at 1,350 kWh per billing period, which is approximately 90 percent of the median consumption of the utility's residential customers.

(ii) For the period commencing April 1, 2009, establish the Step 2 rate at 8.27 cents per kWh.

(iii) For the period commencing October 1, 2008 through March 31, 2009, establish the Step 1 rate as the above rate less one-half of the difference between that rate and 6.15 cents per kWh.

(iv) Calculate both the Step 1 rate and the Basic Charge residually to achieve revenue neutrality for the residential class.

The utility subsequently filed a revised rate schedule pertinent to the 2010 fiscal year which included: (1) a basic charge of 12.64 cents per day; (2) a Step 1 rate of 5.91 cents per kWh; and (3) a Step 2 rate of 8.27 cents per kWh, all effective April 1, 2009.

Study objective

The objective of this analysis is to measure the reduction in overall energy consumption caused by the inclining block rate. Consumption change was to be measured by estimating relevant price elasticities and applying them to actual annual consumption and price change at each step in the rate structure. Elasticities would be the parametric result of regressing each consumption block on the logarithm of their corresponding step charges.

Method

Data

Price per kWh, heating degree days and unemployment rate are the covariates used in each of two regression equations; one with Step 1 consumption as the dependent variable and the other with Step 2. All other independent variables are categorical. The base categories vary with the regression and are explicitly noted in Table 1. The data is in panel format with i-subscripts referring to cross-sectional observations and t-subscripts to billing periods. There are 4 regions times 5 dwelling types times 2 space heating fuel types for 40 observations per billing period. Data is drawn from bi-monthly billing records extending from April/May 1994 to February/March 2010[1].

Consumption at Step 1 per billing period only includes customers whose usage *never* exceeded the RIBR threshold level whereas Step 2 consumption includes *all* of the consumption of customers whose consumption exceeded the threshold[2]. The fact that Step 2 customers face the Step 1 price below the RIBR threshold is assumed to have a negligible impact on demand[3].

Model

This evaluation considers a detailed time-series analysis of aggregated billing data. Regression models estimate price elasticities from electricity consumed by customers at or below 1,350 kWh per billing period (Step 1) and above that level (Step 2).

The regression models for Step 1 and Step 2 consumption are Equations (1) and (2) respectively. Each controls for response variable outliers by applying Huber's Method of Robust Regression (1973). Equation 1 includes interactions (Region 1 x Log Heating Degree Days, Single Family Dwelling x Region 3, Single Family Dwelling x Electric Heat Other Dwelling x Region 1, Apartment x Region 1 and Apartment x Region 2) which are reported in Table 3.2[4]. Equation 2 has no interaction terms and ε is the error term in both equations.

Equation (1)

$$\text{Step 1 Log Consumption}_{it} = \alpha + \beta_1 \text{Region 4}_{it} + \beta_2 \text{Region 3}_{it} + \beta_3 \text{Region 2}_{it} + \beta_4 \text{Mobile Home}_{it} + \beta_5 \text{Other Dwelling}_{it} + \beta_6 \text{Row House}_{it} + \beta_7 \text{Non-Electric Heat}_{it} + \beta_8 \text{Log Step 1 price}_{it} + \beta_9 \text{Billing Period 1}_{it} + \beta_{10} \text{Billing Period 3}_{it} + \beta_{11} \text{Billing Period 4}_{it} + \beta_{12} \text{Billing Period 5}_{it} + \beta_{13} \text{Billing Period 6}_{it} + \beta_{14} \text{Log Unemployment Rate}_{it} + \text{Interactions} + \varepsilon_{it}.$$

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[1] All residential consumption occurring between these dates is included.

[2] In other words, Step 2 consumption includes Step 1 consumption for those customers whose usage exceeded the threshold level.

[3] See the Methodological Discussion for further details.

[4] These interactions are chosen strictly on the basis of statistical significance and contribution to explained variance.

Equation (2)

Step 2 Log Consumption $_{it}$ = $\alpha + \beta_1$ Region 4 $_{it}$ +β_2 Region 3 $_{it}$+β_3 Region 2 $_{it}$ + β_4 Mobile Home $_{it}$ + β_5 Other Dwelling $_{it}$ + β_6 Row House $_{it}$ + β_7 Non-Electric Heat $_{it}$ + β_8 Log Step 2 price $_{it}$ + β_9 Billing Period 2 $_{it}$ + .β_{10} Billing Period 3 $_{it}$ + β_{11} Billing Period 4 $_{it}$ + β_{12} Billing Period 5 $_{it}$ + β_{13} Log Unemployment Rate $_{it}$+ ε_{it}.

Algorithms (1) to (3) below estimate the consumption impact due to price changes within the rate structure. The changes in price (Δ Step 1 and Δ Step 2) are each measured from the price in effect immediately prior to fiscal year 2010. Elasticities are the regression coefficients for the natural logarithm of price in Equations (1) and (2) and account totals are those of March 31, 2010.

(1) Δ Step 1 kWh = Step 1 Elasticity*Δ Step 1 Price *Step 1 Accounts*Average Step 1 Usage per Account

(2) Δ Step 2 kWh = Step 2 Elasticity*Δ Step 2 Price*Step 2 Accounts*Average Step 2 Usage per Account

(3) Δ kWh = Δ Step 1 kWh + Δ Step 2 kWh

Methodology Discussion

The method applied in this paper is new and experimental. There is very little recent literature on estimating demand models and price elasticities under inclining block rates and such that does exist is more concerned with the theoretical difficulties and underpinnings of marginal pricing. Recognizing this problem, the utility sponsored a forum to discuss the theoretical and practical issues of estimating stepped price elasticity[5]. A number of concerns were raised by participants: two are considered here.

The first is the treatment of marginal price: since some customers face both Step 1 and Step 2 charges, it is not strictly true that customers exceeding the RIBR threshold face only one marginal price throughout; namely, the Step 2 charge. The question is whether this concern is of practical rather than theoretical significance; in practical terms, the focus was the accuracy of overall savings calculations.

To test the assumption of accuracy, step elasticity was modelled in a slightly different, but symmetric, manner. Step 1 consumption was re-defined as all Step 1 consumption below the threshold (including that consumed by customers exceeding the threshold) and Step 2 as the residual consumption above the threshold (excluding the first 1,350 kilowatt-hours of Step 1 energy). Since the combined effect of these elasticity values on overall customer consumption (Step 1 and Step 2 usage added together) must equal that of elasticities calculated from the original model, savings results are easily compared. When such a comparison is made, the difference in savings is only 0.35 percent[6]. This finding supports the view that, however we define Step 1 and Step 2 consumption, the calculation of savings attributable to the price structure does not change. As a result, the estimation of a

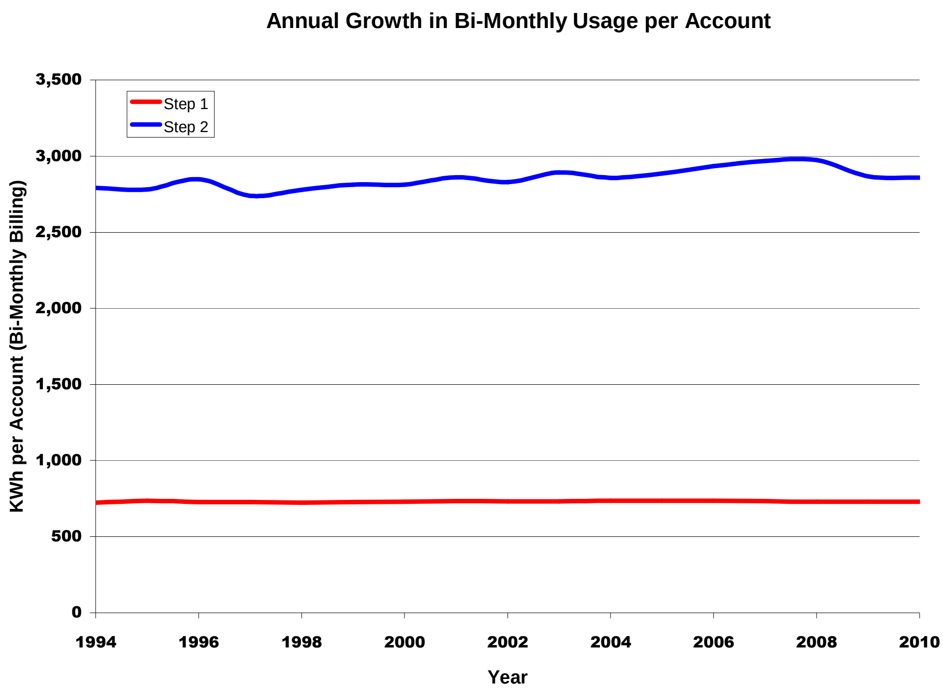
[5] This all-day forum was held October 15 2010. Presenters included Navigant Consulting Inc., Freeman, Sullivan & Co. and Christensen Associates Energy Consulting.

[6] The difference in total energy saving was 229.7 (current model) – 228.9 (alternative model) = 0.8 GWh. This represents a 0.35% variance. More elasticity and usage detail is available from the author.

"pure" marginal price for Step 2 customers appears unnecessary. In other words, the Step 2 charge is the *de facto* unit cost that Step 2 customers currently respond to.

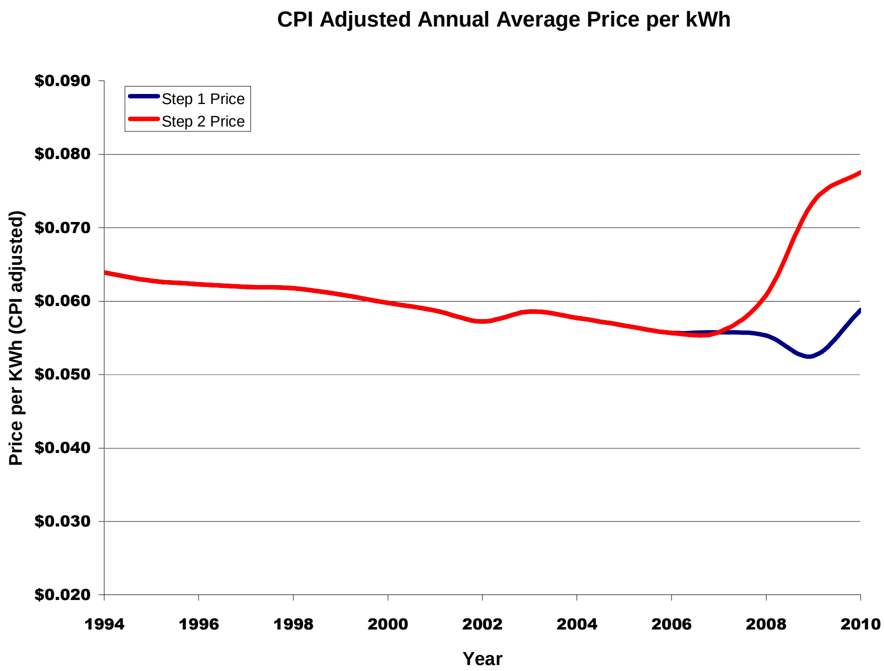
The second concern was time series length. If unduly long, it might introduce unknown sources of variation that affect elasticity estimates in ways that distort customer response to price. It was suggested that multiple analyses of sequentially shorter time periods might reveal the extent to which estimated price elasticities are influenced by declining real prices in the pre-IBR period. However, segmentation of the time series into smaller sequences proved inconclusive. Exploratory work suggested that (a) mean elasticity remains relatively stable throughout the time series[7] and (b) that usage per account was flat in tandem with near-zero price increments. The latter observation is supported by the relationship between annual growth in bi-monthly usage per account (Figure 1) and CPI-adjusted mean price per kilowatt-hour (Figure 2): as average price jumps in 2008 (largely due to the spike in the Step 2 charge), there is a commensurate drop in account usage. Overall trend in the series was not a factor in parametric estimation.

Figure 1



[7] Mean elasticity for the period prior to the RIBR varies between -0.10 and -0.15.

Figure 2



Results

Energy and Peak Savings

Table 1 provides the results of the regression models used in this analysis. Sample sizes and regression parameters are shown in each column[8]. Although a number of approaches were explored, the two models presented in Table 1 are preferred on intuitive and statistical grounds[9]. The elasticity estimates generated in this study are generally comparable to those used in the rate application.

Column 2 presents the results for the Step 1 consumption model. All of the regression coefficients are statistically significant at the five percent level or better, and the explanatory power of the model is excellent with an adjusted R-squared of 0.88. The estimated Step 1 price elasticity is -0.054.

Column 3 presents the results for the Step 2 consumption model. All of the regression coefficients are statistically significant at the five percent level or better, and the explanatory power of the model is also excellent with an adjusted R-squared of 0.91. The estimated Step 2 price elasticity is -0.111.

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[8] A full accounting of tests of significance for the model and individual parameters is available from the author.

[9] These explorations included inclusion of additional variables, generalised estimating equations and fully saturated designs. A sampling of customer level data was also modeled and the results are outlined in Appendix I of this report. Selected example model runs are available from the author. Different definitions of Step 1 and Step 2 consumption were also modeled (see Methodology Discussion).

Table 1 Regression Models

Variable	Step 1 Consumption	Step 2 Consumption
Intercept	6.38	7.55
Region 1	(base)	(base)
Region 4	-0.01*	-0.06
Region 3	-0.02*	-0.08
Region 2	0.04	-0.01
Apartment	(base)	(base)
Mobile Home	0.29	0.22
Other Dwelling	-0.27	0.80
Row House	0.26	0.09
Single Family Dwelling	0.39	0.34
Non-Electric Heat	-0.11	-0.18
Billing Period 1 (April-May)	0.04	(base)
Billing Period 2 (June-July)	(base)	-0.16
Billing Period 3 (August-September)	0.03	-0.14
Billing Period 4 (October-November)	0.06	0.11
Billing Period 5 (December-January)	0.06	0.31
Billing Period 6 (February-March)	0.06	0.21
Log of Heating Degree Days	-0.01	-0.02
Log of Unemployment Rate[10]	-0.01	-0.02
Log of Tier 1 Price	-0.05	-
Log of Tier 2 Price	-	-0.11
Single Family Dwelling x Electric Heat	-0.12	-
Single Family Dwelling x Region 3	0.03	-
Region 1 x Log of HDD	0.01	-
Other Dwelling x Region 1	0.10	-
Apartment x Region 1	-0.10	-
Apartment x Region 2	-0.11	-
Adjusted R^2	0.88	0.91
Durbin-Watson Value	1.97	1.95
Sample size (Observations)[11]	3,800	3,800

Note. All regression parameters are significant at the 5% level or better *except* where indicated with an asterisk (*). Compound variables connected with an "x" are interactions.

[10] Unemployment rate by region is entered as a proxy for income. Good information on disposable income was not available.

[11] There are 4 regions times 5 dwelling types times 2 space heating fuel types for 40 observations per billing period. As data is drawn from 95 billing periods, there are 3,800 observations in total.

Table 2 provides a simulation of the effect of the Residential Conservation Rate structure on total energy consumption based on the estimated price elasticities shown in Table 1. That is, the calculated percentage changes in the Step 1 and Step 2 prices[12] are multiplied by the respective price elasticities, and then in turn by the number of accounts on each step and their average annual consumption. The resulting simulated changes in consumption, shown in the last column, are an increase in consumption of Step 1 customers of 2.2 GWh, and a reduction in consumption by Step 2 customers of 231.9 GWh. The net effect is a reduction in estimated consumption of 229.7 GWh[13].

Table 2 Fiscal Year 2010 Residential Inclining Block Rate Energy Savings

Step	**Price Elasticity (δ)**	**Change in Rate (Δ)[14]**	**δ x Δ Rate**	**Number of Accounts**	**Mean kWh per Account**	**GWh Savings**
1	-0.054	-0.0117	0.0006	851,768	4,572	**2.2**
2	-0.111	0.1470	-0.0169	768,089	17,909	**-231.9**
Both				1,619,857	10,896	**-229.7**

Limitations

Residential electricity consumption is undoubtedly affected by factors not explicit to the model. One possible source of unwanted variation is the increase in the total number of electronic products over time; another is the increased energy efficiency of certain significant end uses such as refrigeration. The collective impact of such factors on the residential load is not well understood but obviously affects elasticity estimates in a given fiscal year[15]. These factors likely affected consumption during the long time period in which consumers faced a flat rate. The short period since implementing the 2-Step rate (October 2008) also coincided with the recent economic slowdown.

Conclusions

Separate regression models of customer electricity use above and below a threshold value may be employed to estimate price elasticity of demand at each step in a 2-step inclining block rate. These results may then be used to calculate the total energy saved as a result of one or more changes to the rate structure.

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[12] Note that changes in price are calculated by observing the difference in price that occurred at each step. No comparison with a hypothetical equivalent flat rate is made.

[13] All savings calculations are based on Equations (1) to (3) in an earlier section of this report.

[14] Values in the Change in Rate column refer to percentage changes in price per kWh at April 1, 2009 for each stepped rate.

[15] Concurrent residential programs are another possible source of variation. The percentage impact of such program savings on overall consumption is small (less than 1 percent) but does affect the price elasticity parameters estimated in the models. However, the fact that price variables are regressed on actual residential consumption implies that underlying elasticity estimates reflect customer response to price *net* of DSM program effects.

Continuing to inform the models on an annual basis with the latest available consumption data will ensure that stepped elasticity values reflect the most recent customer experience with the rate.

Further exploration of customer level data will also allow more opportunity to explore the effects of rate awareness and the number of billings generally required to register a price signal. As more information on customer response to price at each step becomes available, it should become possible to understand how conservation behaviour is affected by changes in the rate.

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APPENDIX I A LOOK AT CUSTOMER LEVEL DATA

A separate analysis of customer level billing data was conducted on 1,000 randomly selected customers to check the consistency of preliminary results. Equal samples were drawn from each service regions with the proviso that each customer be active as of March 31, 2010 and bi-monthly consumption readings restricted to April 1994 or later[16]. Fifty percent of customers (the two middle quartiles) had between 25 and 75 bi-monthly readings. During the modelling process, variable categories and covariates proved similar to those used in the top-down (aggregate) model presented in Table 2

Analysis of Covariance (ANCOVA) was applied to control for customer (within group) variation. Consumption at each step in the rate was modeled separately as before with Step 1 at or below 1,350 kWh per billing and Step 2 above. Functional forms were very similar to those presented in Equations (1) and (2) and produced results statistically identical with those realised in the model based on aggregate data[17].

Customer level data has the advantage of permitting separate modeling of individual customer demand schedules and shedding light on the nature of the price signal. For example, it was found that models based on this data produced good elasticity results provided that the number of bi-monthly billings per customer (lag) was sufficient to register a response to the price variable[18]. Whereas the top-down (aggregated) model captures all demand and hence all customer behaviour contributing to that demand, some individual customers may lack a sufficient number of bi-monthly consumption readings to evoke a price signal. For these customers, there was either insufficient exposure to billing information or too low a price to evoke a measurable consumption response.

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[16] Not all customers have records going back this far in the past; on average (depending on region) each customer had between six and 10 years of billing history. Note also that April 1 1994 is the date that the single (flat) rate structure was introduced; prior to this time a declining block structure was in effect.

[17] Elasticity estimates were in the neighbourhood of -0.06 to -0.07 for Step 1 and -0.11 and -0.12 for Step 2.

[18] Exploratory modeling showed that, on average six to ten years of bi-monthly billing information was required to register a statistically significant price response in terms of elasticity parameters.