Reducing Energy Consumption Using Stepped Industrial Rates

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ABSTRACT

In efficient markets, price and quantity respond to changes in demand and supply conditions so that there are no shortages and prices reflect marginal costs of supply. These conditions are often not met in retail electricity markets because electricity is not generally storable, marginal costs of supply vary substantially over time, and most customers face fixed retail rates. This paper reports on an industrial stepped rate which is aimed at overcoming these issues and reducing customers' electricity consumption. The main contribution of this paper is that it appears to be the only econometric study of the impact of a stepped industrial electricity rate.

Introduction

In efficient markets, price and quantity respond to changes in demand and supply conditions so that there are no shortages and prices reflect marginal costs of supply. These conditions are often not met in retail electricity markets due to three main factors: (1) electricity is not generally storable so that stocks cannot be used to buffer demand or supply shocks; (2) marginal costs of supply vary substantially over the course of a year or even over the course of day as high marginal cost peaking plants are dispatched to supplement low marginal cost base load plants; and (3) most customers face fixed retail rates which are set by regulators and do not reflect constantly changing wholesale electricity costs.

The results of these factors are that: (1) shortages can occur in response to extreme demand conditions; (2) marginal costs are below fixed retail prices during periods of low demand so that production and consumption are below socially optimal levels; and (3) marginal costs are above fixed retail prices during periods of high demand so that production and consumption are above socially optimal levels. Social welfare can therefore be increased by mechanisms which produce more responsive electricity demand. These activities can be divided into price-based demand reduction-based activities.

The U. S. Department of Energy (DOE) notes that "price-based demand response refers to changes in usage by customers in the prices they pay and include real-time pricing, critical peak pricing and time-of-use rates" [U. S. Department of Energy (2006)]. Stepped rates are pricing tool which have not yet been widely applied. The DOE further notes that significant price differentials between hours or time periods can lead to substantial changes in energy use and electricity bills. Table 1, which is based largely on references U. S. Department of Energy (20060 and Borenstein et al. (2002), provides summary descriptions, advantages and disadvantages of time of use rates, critical peak pricing, real time pricing and stepped rates.

Table 1. Price-Based Demand Response

	Description	Advantages	Disadvantages
Time of use rate	Rate with different unit prices for usage during different blocks of time	Better price signal than fixed rate, but still relatively simple	Cost of meters higher than for fixed rates Reflect little of the variation in wholesale prices
Critical peak pricing	Rate with basic time of use structure and added provision for higher event price when system has trouble meeting peak demand	Provides stronger response at peak than time of use rates	Prices are preset and don't move with changes in market prices
Real time pricing	Rate where price fluctuates to reflect wholesale electricity price on the market	Provides more accurate price signals than time of use rates or critical peak pricing	Creates higher uncertainty for customers on electricity prices which they will actually pay
Stepped rate	Rate with two or more steps with the customer baseline load rate at the first step and additional load at second step	Provides strong energy conservation impact if step 1 and step 2 prices are significantly different	May do relatively little to reduce peak energy demand even if energy response is significant

Estimating Demand Response

A number of studies have looked at various aspects of demand response for large commercial and industrial customers. The references section includes some of the more prominent studies. Studies of demand response must deal with two separate issues, first, participation (that is, the number of customers enrolling in a rate program or responding to the demand response rate) and, second, response (that is, the quantity and timing of energy or demand reduction). Four main approaches have been developed for the estimation of demand response: (1) customer surveys; (2) benchmarking; (3) engineering approach; and (4) econometric approach [13].

Customer surveys are used to ask customers about their responses to innovative rates and to ask related questions to clarify the context. Survey information on participation and individual demand response is used to estimate rate impacts on the load. The advantage of customer surveys is that they provide highly detailed and customer-specific information. The disadvantage of customer surveys is that they may not know the extent of their participation or the resulting load impacts with an adequate degree of accuracy.

Benchmarking involves applying information from other jurisdictions to the jurisdiction of interest. Participation is often available from administrative records, so the main use of benchmarking is to infer likely load response at the customer level. The advantage of benchmarking is that it is based on actual customer response to demand response rates, in one or more comparable jurisdictions. The disadvantage of benchmarking is that it assumes that market context and individual customer characteristics are of a second order of importance in determining demand response.

Engineering approach develops and applies assumed participation rates and demand response to data on local customers including their loads, characteristics and equipment stocks. Response rates are often assumed to be constant and thus unresponsive to prices or to incentive levels. The advantage of the engineering approach is that it is usually grounded in data from other utilities of or expert opinion. The disadvantage of the engineering approach is that for large customers, demand response may be highly dependent on behavioural repose rather than on equipment stocks and related physical factors.

Econometric approach involves estimating demand elasticities from individual customer or aggregate consumption data, and then applying these elasticities to estimate the responsiveness of demand to price and other drivers. The advantages of the econometric method are, first, that it is based on actual customer response and can control for confounding factors such as demand conditions or weather conditions, and, second, that error bands can be calculated using the regression results to quantify uncertainty. The disadvantage of econometric methods is that the estimates may not be robust to changes in the sample used or to changes in the functional form of the estimating equations.

Rate Design

The industrial stepped rate replaced the former transmission rate which was a flat rate, with an energy cost of 2.735 cents per kWh. The stepped rate is an inverted block rate where the first 90% of the Customer Baseline Load (CBL) purchased by a customer is at a lower rate, and the balance consumed is at a higher rate. For the introduction of the rate, the price for Tier 2 energy was set at 5.4 cents per kWh which was BC Hydro's cost to buy electricity from Independent Power Producers. Because the new rate was intended to be revenue neutral, the price for Tier 1 energy was 2.428 cents per kWh (see Table 2). On June 15, 2005, the BC Utilities Commission (BCUC) approved the Negotiated Settlement for BC Hydro's Transmission Service Rate (TSR) Application of March 10, 2005. The Settlement included CBL Guidelines that describe both the criteria and procedures to guide BC Hydro in the determination of the CBL for each customer taking electric service under either the Stepped Rate (RS 1823) or the Time of Use Rate (RS 1825). On December 22, 2005, BC Hydro applied to the BCUC for approval of BC Hydro's proposals respecting outstanding matters from the Settlement including amendments to the CBL Guidelines, and this was approved by the BCUC. BC Hydro subsequently proposed a proposal for settlement of disputes. CBLs were initially notionally set at 100% of 2005 or base year consumption, but there were a number of adjustments made to ensure that the customer baseline loads were as fair as practical. These adjustments included the following: customer buy-back of a BC Hydro Demand Side Management (DSM) project incentive; force majeure; plant capacity increases; BC Hydro funded DSM projects; customer funded DSM projects; load curtailment events; plant down sizing with a new Electricity Service Agreement; plant restarts; variable electricity output generation; and significant recurring downtime.

Table 2. Transmission Service Rate (1821) and Stepped Rate (1823)

Rate	Tier 1 (cents per kWh)	Tier 2 (cents per kWh)
1821, Apr 1, 2005	2.735	2.735
1823, Apr 1, 2006	2.477	5.4
1823, Apr 1, 2007	2.477	5.4
1823, Apr 1, 2008	2.462	7.36

The time of use rate RS 1825 is an optional rate that allows customers to reduce their energy bills by changing when they consume electricity. The time of use rate is designed to encourage customers to shift load from peak periods when expensive to produce at the margin to off peak periods when electricity is less expensive to produce. The time of use rate also has the same Tier 1 and Tier 2 split, but pricing varies by time of day and season of the year as shown in Table 3 (as per the BCUC filing). There are no customers on Time of Use Rates. The initial time of use rate is shown in Table 3.

Table 3. Time of Use Rate (1825)

Period	Tier 1 (cents per kWh)	Tier 2 (cents per kWh)
Winter high load hours	2.348	6.116
Winter low load hours	2.348	5.400
Spring all hours	2.517	4.599
Remainder all hours	2.428	5.400

Recent Sector Developments

Customers' abilities to modify energy consumption and energy demand depends, in large part, on the profiles of energy and demand by end use as well as the availability of technologies to reduce energy and peak consumption at the end use level. This section describes end use energy and peak profiles for the five main transmission sectors as well as summary comments on potential consumption-reducing technologies.

Metal mining. The metal mining sector is dominated by copper and gold mining, but includes a number of other metals usually produced as by-products. The metal mining industry was in a significant decline for a number of years, but it has undergone a major recovery in recent years due to a five-fold increase in the world price of copper. The medium-term outlook for metal mining in British Columbia continues to be positive, given strong and growing demand in China and India, and constraints on increased supply, as few world class deposits have been discovered in recent years. Capacity utilization in metal mining in 2005 was above 90%, and additional mines are ramping up. Table 4 shows that about 87% of the electricity used in the metal mining sector is used by process activities including grinding and ore separation. Opportunities for cost-effective energy reduction include appropriate motor sizing, energy-efficient conveyance, efficient pumping and flotation cell technologies.

Table 4. Metal Mining F2006

End Use	Energy (GWh)	Energy (%)	Demand (MW)	Demand (%)
Pumps	134	5.80	15.4	5.81
Fans and blowers	14	0.061	1.6	0.60
Compressors	7	0.30	0.8	0.30
Materials handling	21	0.91	2.4	0.90
Lighting	118	5.10	13.6	5.13
Process	2,016	87.20	231.2	87.15
Building services	<1	-	0.0	-
Cooling and refrigeration	<1	-	0.0	-
Other	2	0.08	0.3	0.11
Total	2,312	100.00	265.3	100.00

Wood products. The wood products sector operates mainly in the interior and the coastal regions. The interior woods industry has been performing reasonably well, but the coastal wood products industry has faced challenges and is earning relatively low rates of return. The interior industry has relatively high efficiency levels and an abundant supply of low cost, beetle-killed timber. The coastal industry has relatively high harvesting and mill labour costs. Table 5 shows that about 42% of the electricity used in the wood products sector is used by process activities including sawing, cutting and trimming. Opportunities for cost-effective energy reduction include appropriate motor sizing, energy-efficient conveyance, energy-efficient fans, blowers and compressors.

Table 5. Wood Products F2006

End Use	Energy (GWh)	Energy (%)	Demand (MW)	Demand (%)
Pumps	5	0.45	0.7	0.45
Fans and blowers	260	23.42	36.3	23.50
Compressors	127	11.44	17.7	11.46
Materials handling	131	11.80	18.3	11.84
Lighting	65	5.86	9.0	5.83
Process	466	41.98	65.0	42.07
Building services	25	2.25	3.5	2.27
Cooling and refrigeration	3	0.27	0.5	0.32
Other	28	2.53	3.5	2.27
Total	1,110	100.00	154.5	100.00

Pulp and paper. The pulp and paper sector produces and exports a wide variety of products including newsprint, softwood kraft pulp, hardwood kraft pulp, softwood thermo-mechanical pulp and hardwood thermo-mechanical pulp. Although pulp capacity has fallen by about 10% since 2002, the medium-term outlook for the industry appears to be fairly positive as the Asian demand for pulp and paper products remains strong and fibre costs in the interior remain low, due to the availability of beetle-killed timber. Table 6 shows that about 58% of the electricity used in the pulp and paper sector is used by process activities including pulping and drying. Opportunities for cost-effective energy reduction include appropriate motor sizing, energy-efficient conveyance, energy-efficient pumps, fans and blowers. Note that total energy consumption is higher than the reported purchased energy consumption listed above by the amount of self-generation.

Table 6. Pulp and Paper F2006

End Use	Energy (GWh)	Energy (%)	Demand (MW)	Demand (%)
Pumps	2,677	21.37	215.4	14.85
Fans and blowers	1,259	10.05	95.2	6.56
Compressors	343	2.74	22.2	1.54
Materials handling	628	5.01	41.4	2.85
Lighting	257	2.05	14.6	1.01
Process	7,291	58.20	1,056.3	72.83
Building services	69	0.56	4.9	0.34
Cooling and refrigeration	2	0.02	0.2	0.01
Other	3	0.02	0.2	0.01
Total	12,527	100.00	1,450.4	100.00

Chemicals. The chemicals sector includes one chlor-alkali plant, three sodium chloride plant and one hydrogen peroxide plants, which receive electricity at transmission voltage. Electricity typically accounts for 40% to 60% of the costs of these facilities. Table 7 shows that about 93% of the electricity used in the metal mining sector is used by process activities including grinding and ore separation. Opportunities for cost-effective energy reduction include change in appropriate motor sizing, energy-efficient pumps, fans and blowers and electro-chemical technologies.

Table 7. Industrial Chemicals F2006

End Use	Energy (GWh)	Energy (%)	Demand (MW)	Demand (%)
Pumps	66	3.78	7.2	3.78
Fans and blowers	20	1.15	2.2	1.16
Compressors	5	0.29	0.6	0.31
Materials handling	1	0.06	0.1	0.05
Lighting	5	0.29	0.5	0.26
Process	1,617	92.72	176.6	92.70
Building services	3	0.17	0.4	0.21
Cooling and refrigeration	27	1.55	2.9	1.52
Other	<1	-	-	-
Total	1,744	100.00	190.5	100.00

Coal mining. The coal mining sector produces mainly metallurgical coal for export to Japan and China, so the industry is heavily influenced by industrial output trends in these two countries. Demand has recently been strong. Table 8 shows that about 50% of the electricity used in the coal mining sector is used by process activities including ore separation. Opportunities for cost-effective energy reduction include appropriate motor sizing, energy efficient conveyance, energy efficient pumps, fans and blowers.

Table 8. Coal Mining F2006

End Use	Energy (GWh)	Energy (%)	Demand (MW)	Demand (%)
Pumps	101	19.92	11.8	19.93
Fans and blowers	51	10.06	5.9	9.97
Compressors	10	1.97	1.2	2.03
Materials handling	76	14.99	8.9	15.00
Lighting	10	1.97	1.2	2.03
Process	254	50.10	29.6	50.00
Building services	<1	-	0.0	-
Cooling and refrigeration	<1	-	0.0	-
Other	5	0.99	0.6	1.01
Total	507	100.00	59.2	100.00

Results

The main purpose of the econometric analysis was to quantify the impact of the TSR on purchased electricity consumption. The key point is to estimate the price elasticity of demand, which is defined as the percentage change in purchased electricity consumption divided by the percentage change in price. Because TSR customers are subjected to two prices – the Tier 1 price and the Tier 2 price – both prices need to be included in the model. We use two indicators of economic activity, shipments of durable goods and industrial sector employment. Finally, because purchased electricity consumption is affected by Power Smart activity, we use adjusted purchased electricity consumption which is defined as the sum of actual purchases plus estimated Power Smart savings.

The model is estimated using 83 months of data from April 2002 through February 2009. Actual consumption is the sum of monthly consumption aggregated across TSR customers. Power Smart savings are amortized estimates of savings adjusted for persistence and aggregated across TSR customers. Tier 1 price and Tier 2 price are from BC Hydro data. Durable shipments and industrial employment are from BC Statistics.

The basic method for the impact analysis uses time-series regression modelling in log linear form. Log linear models have the advantage of having coefficients that are interpretable as elasticities. In the fullest version of the model, we assume that log of consumption is a linear function of a constant, the log of Tier 1 price, the log of Tier 2 price, the log of durables output, the log of industrial sector employment, and an error term as shown in Equation (1). The impact of stepped rates is then given by the Tier 2 price elasticity γ times the relative change in the Tier 2 price from the base year times Tier 2 consumption lagged one year as given by Equation (2). Note that we measure the price change from the base period rather than from the previous year, because changing industrial energy consumption in response to a price change is a lengthy process that is unlikely to be completed within a year.

$$(1)\ logGWh_t = \alpha + \beta\ logP1_t + \gamma\ logP2_t + \delta\ logdur_t + \zeta\ logemploy_t + error_t$$

$$(2)\ \Delta GWh_t = \gamma * \Delta rate_t * Tier2\_consumption_{t-1}$$

Table 9 presents the results of three nested econometric models. Model 1 includes only price variables and excludes other economic drivers of the load. The sign of the coefficient on the log of Tier 1 price is negative as expected and it is statistically significant, but the coefficient on the log of Tier 2 price is not statistically significant. Model 2 includes the price variables as well as durables shipments as drivers. The sign of the coefficient on the log of Tier 1 price is negative as expected, and it is statistically significant, but again the coefficient on the log of Tier 2 price is not statistically significant. Model 3 includes the price variables as well as durables shipments and employment as drivers. Now, the sign of the coefficients on the log of both Tier 1 price and Tier 2 price are negative as expected and they are statistically significant, and the coefficients on the log of durable shipments and the log of employment are positive as expected and are statistically significant. The preferred regression is Model 3, which has the greatest explanatory power and for which the signs on the price variables meet a priori expectations. We therefore use the results from Model 3 in the subsequent analysis.

Table 9. Regression Results

	Model 1	**Model 2**	**Model 3**
Constant	20.5857*** (0.0193)	11.6596*** (1.4848)	6.5693*** (1.8247)
LogP1	-0.1694*** (0.0393)	-0.1914*** (0.0326)	-0.2069*** (0.02990)
LogP2	0.0791 (0.0751)	0.0614 (0.0632)	-0.1627** (0.0789)
Log durable shipments	-	0.6145*** (0.1014)	0.5601*** (0.0931)
Log employment	-	-	0.9250*** (0.2231)
Adjusted R^2	0.71	0.82	0.85
Sample size	83	83	83

Note. Standard errors are in parentheses. One, two or three asterisks means significance at the 10%, 5% or 1% level.

Table 11 provides the details of the impact analysis. As indicated above, the impact of the TSR is given by the Tier 2 price elasticity γ times the relative change in the Tier 2 price from the base year times Tier 2 consumption lagged one year. The estimated run rate impact of TSR is a reduction in purchased electricity of 236 GWh for F2007, 126 GWh for F2008, and 113 GWh for F2009 for a total of 474.7 GWh over three years. It should be noted that the reduction in Tier 2 energy is also driven by two other factors which are included in the statistical model, the level of economic activity as reflected by the log of durable shipments and the log of employment in the industrial sector.

Table 11. Impact Analysis by Fiscal Year

	Tier 2 price	ΔP2/P2	Tier 2 energy lagged	Price elasticity	ΔGWh per year
F2006	2.735	-	-	-	-
F2007	5.4	0.9744	1,488	-0.1627	235.9
F2008	5.4	0.9744	795	-0.1627	126.0
F2009	7.36	1.6910	410	-0.1627	112.8
Total	-	-	-	-	474.7

Conclusions

The industrial load is a major part of the domestic load for many large electric utilities, often representing 30%-40% of the total domestic load. In order to provide additional value to large customers, and to improve the cost effectiveness of their supply and delivery systems, many utilities offer innovative rate options such as time of use rates and critical peak pricing to their largest customers. These rates help to shape the demand profile to reduce the costs of electricity supply, but they may do relatively little to encourage energy conservation.

A new rate option for industrial customers, which does offer the potential to significantly increase energy conservation, industrial customers is the stepped rate. Under a stepped rate, customers pay a relatively low rate for an initial step of consumption and higher rate for a second step of consumption. Consumers have a strong financial incentive to undertake hard-wired investments and changes to operation and maintenance practices which will reduce expensive second step consumption. The stepped rate can be designed to meet both equity and efficiency objectives, while being revenue neutral with respect to the previous rate.

BC Hydro's industrial stepped rate was designed to provide a cost-effective alternative to the previous program of industrial financial incentives, which were aimed at increasing energy efficiency and reducing energy consumption. In other words, the industrial stepped rate replaces financial incentives with appropriate price signals to encourage energy conservation.

This study has examined the impact of BC Hydro's industrial stepped rate using econometric models. Over three years, the stepped rate led to a direct reduction in the industrial load of 474.7 GWh per year, on an annualized run-rate basis. The stepped rate has been very cost effective for BC Hydro, since implementation of the rate has been managed by just three program staff with additional support from Key Account Managers who explain and market the rate and assist industrial customers in the identification and implementation of energy conservation activities.

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