The Long-Run Price Elasticity of Demand for Electricity and the Feasibility of Raising Electricity Rates to Finance Muskrat Falls

A Report Prepared

for

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I. Introduction

The Muskrat Falls project is expected to be completed in the third quarter of 2020. At that time, the immediate consequence will be an increase in the cost structure of Newfoundland and Labrador Hydro (Hydro). That is because that utility has entered into long-term arrangements to purchase power from the Muskrat Falls generating plant and to use the new transmission assets associated with that project to supply the island of Newfoundland's interconnected electrical system. Hydro is pre-committed to paying whatever price is needed to cover the MF project's costs regardless of how high those costs turn out to be. In turn, Hydro will pass along the cost burden to ratepayers, which means a huge increase in the wholesale price that it will be charging to Newfoundland Power (NP) the main distributor of electricity on the island. The retail price faced by NP's domestic and commercial customers will rise accordingly. Hydro's own retail customers on the island interconnected system will face the same increase since their rates are, as a matter of public policy, set equal to those of corresponding NP customers. Hydro's industrial customers would presumably face a proportionately similar rate shock.

As yet, it is not known by how much prices will increase. In the June 2017 update on the Muskrat Falls project, Nalcor – the provincial government crown corporation behind the Muskrat Falls project and the owner of Hydro - indicated that Hydro's costs would ratchet up considerably.[1] For 2021, the first full calendar year of Muskrat Falls operations, Nalcor estimated the domestic (i.e., residential) customer cost would be approximately 23 cents per kWh. In contrast, as of July 1, 2018, the domestic residential price was 11.4 cent per kWh. Practically all the potential more-than-100-percent increase in the domestic consumer price would be due to the increase in Hydro's cost structure resulting from its Muskrat Falls commitments. Whether the actual increase will be as large as estimated by Nalcor is uncertain. Nalcor's June 2017 figures were based on the full cost of the Muskrat Falls project being borne by island interconnected ratepayers. However, in its 2017 Budget, the provincial government

[1] See https://muskratfalls.nalcorenergy.com/wp-content/uploads/2017/06/Muskrat-Falls-Project-Update-Presentation-June-23_Final.pdf.

indicated that it intended to take steps to limit the price increase to keep the rates competitive with other Atlantic provinces.[2] Still, even such rate mitigation would entail significant increases in island rates.

The purpose of this report is to assess the impact of higher rates on electricity consumption. If higher electricity rates cause a substantial reduction in electricity consumption then paying for Muskrat Falls by imposing higher rates may not be practical or even feasible. Assessing how much higher rates will reduce consumption requires an assessment of the price-elasticity of demand for electricity.

The remainder of this report is organized as follows. The next section, Section II, defines the price elasticity of demand and provides evidence from various sources in order to ascertain a reasonable estimate of it for interconnected island electricity consumers. Section III then uses estimates of the long-run price elasticity to illustrate the implications that arise from the sorts of rate increases that might occur. Brief concluding remarks are given in Section IV.

II. Price Elasticity of Demand

a) The Concept

The price elasticity of demand is an index of consumers' responsiveness to a price change. Normally, when the price of a commodity goes down consumers will decide to purchase more of it, and if the price goes up then they would purchase less. Price elasticity is a measure of the magnitude of such responses. For example, if the price of electricity went up 10 percent and customers reduce their consumption by just 1 percent then that response would be considered small. In that case, demand for electricity is insensitive, or inelastic, with respect to the price change. The index value of that elasticity is measured by the ratio of the change in the amount purchased (1 percent in this example) to the price change (10 percent); the result is 1/10 or simply 0.1; technically the value takes a negative sign but a widely used convention is to express it in absolute value. In contrast, had the reaction to the price change been a 15 percent reduction in consumption then that would be considered a big response and demand would be

[2] See http://www.budget.gov.nl.ca/budget2018/speech/budget_speech2018.pdf, p.32.

classified as price-sensitive or price-elastic. The index value would then be 15/10 or equivalently 1.5. More generally, the measure of price elasticity (*e*) is calculated as:

e = (percentage change in consumption)/(percentage change in price).

The calculation is done under the assumption that other influences on consumption decisions, such as income and prices of other commodities, have not changed. In order words, it isolates the impact of a price change on consumption. Whenever the index value is more than 1, demand is classified as price-elastic, or price-sensitive, and the more that it exceeds one the greater is the price elasticity. When the ratio is a fraction then demand is said to be price-inelastic, and the smaller the fraction the more inelastic. Additionally, elasticity is not generally a constant; its value over one price range is usually not the same as over a different price range.

Price elasticity also has a time dimension. When a price changes, consumers are typically limited in how they can react over a short period of time. For example, a higher price of electricity might induce consumers who use electric spacing heating to turn back their thermostats but not much else over the course of a few months. However, if the price increase persists then consumers might over time decide to install more insulation, switch to other space heating sources or replace an electric hot water tank with one that uses propane. Such responses take more time and the consumer must be convinced that the upfront cost is worthwhile, i.e., that the future electricity cost savings would exceed those upfront costs. Thus, the index value of the price elasticity measured over a short period could be quite close to zero but much larger over time. Therefore, there is a distinction between the short-run and long-run price elasticity of demand. In the case at hand, it is the long-run that is relevant. That is because the Muskrat Falls project's high operating costs and debt repayments will continue for decades so pricing based on full or substantial cost recovery would mean persistently higher prices. The long-run is not a specific period of chronological time. Rather, it is the amount of time that consumers take to fully respond to a change in price. As may occur with the Muskrat Falls project, if consumers believe that a large price increase is coming and will persist then they may react at early stages or even prior to a price increase in anticipation of it. For this reason, in the case of Muskrat Falls, the long-run may be a fairly short period of time.

b) Estimates of the Price-elasticity of Demand for Electricity in the Long Run

There is an extensive literature on price elasticities for electricity but there does not seem to be any published estimates available for the island of Newfoundland's interconnected system. However, there is some evidence based on provincial data as well as findings from elsewhere that can provide a reasonable assessment of what that elasticity might be. They are discussed in this subsection.

(i) Some evidence from Newfoundland and Labrador

Domestic, i.e., residential, customers are the largest group of electricity consumers on the island's interconnected grid. They consume between 50 and 60 percent of the electricity delivered over that system. Table 1 provides two possible values for the long-run price elasticity of demand for electricity by island domestic consumers, and both are based on provincial data.

Table 1

Estimates of the Long-Run Price Elasticity

of Average Residential Demand for Electricity

Source	Estimate
Partial Adjustment Model (see Appendix)	0.42
Case Study of South Labrador Coast	1.20

The first estimate presented in Table 1 is 0.42. It was obtained from econometric estimation of a partial adjustment model of residential demand for electricity, the details of which are given in the Appendix to this report. Such a model incorporates the idea that consumers need time to fully adjust to a price change, which is the case with electricity. That model incorporates not just price but other relevant influences on average electricity consumption, notably the price of substitutes and household income, with appropriate adjustments for inflation.[3] Estimation was based on annual data for the average consumption by NP's domestic customers, and who make up the overwhelming majority of interconnected residential electricity consumers on the island. The data covered the years from 1992 to 2016 inclusive.

[3] Total residential consumption is also affected by the number of residential customers, which is influenced by demographics.

The estimate of 0.42 is a long-run figure. It suggests that following a price shock of, for example 20 percent, that, given enough time to fully adjust, a consumer's average annual consumption would fall by 8.4 percent (i.e., 0.42 multiplied by 20 percent); analogously, had the price decreased by 20 percent then an 8.4 percent eventual increase in electricity consumption would be the model's prediction. While a long-run elasticity of 0.4 is plausible, there are reasons to suggest that it may be low when considering a possible future Muskrat Falls price shock. First, that elasticity was estimated based on data from 1992 to 2016. The magnitude of price elasticity depends on the availability of substitutes for the commodity whose price has increased. In the early years of that time period, it may be that substitutes such as mini-splits were not as well-known nor as efficient as they have become in more recent years. Secondly, the figure was estimated based on the range of electricity prices that prevailed during the 1992 to 2016 period. None of those prices was as high as the prices suggested by the provincial government or Nalcor for the post-Muskrat Falls era so the analysis does not capture that high-price experience.

Some areas of the province do have high-price experience. The second estimate in Table 1 is relevant in that regard. That elasticity is 1.2, which indicates a high degree of price sensitivity. That figure is not based on an econometric estimate. It is from a recently published case study of residential consumption in communities located on the south Labrador coast. [4] Prior to 1997, all the communities on that coast were serviced by electricity from diesel plants and faced increasing block rates. However, from 1997 onwards, the communities in the L'Anse au Loup area of that coast began to be serviced from a nearby hydro plant in Quebec. As a result, their residential rates were reduced to those of island interconnected customers. Communities on that South Labrador coast further to the north remained on diesel rates. As of July 1, 2017 the rate for electricity per kWh for electricity in excess of 1,000 kWh in the isolated communities was 16.3 cents while those in the L'Anse au Loup system paid 10.6 cents.[5] That higher rate of 16.3 cents is similar to what the provincial government was alluding to in Budget 2018 for post-Muskrat Falls rates. The study showed that from 1992 to 1997 the two sets of

[4] James P. Feehan (2018) "The long-run price elasticity of residential demand for electricity: Results from a natural experiment," *Utilities Policy*, April.
[5] See https://nlhydro.com/wp-content/uploads/2018/07/July-1-2018-Rates-Rules-Regulationsv2.pdf

communities had very similar electricity consumption patterns but following the reduction in rates for L'Anse au Loup domestic customers in 1997 those patterns diverged. By 2016, average consumption was much higher among L'Anse au Loup customers – approximately double - and at least 50 percent of them had installed electric heat as their primary source of space heating. Before the price change, neither set of communities had significant use of electric heating and that has remained the case in the isolated diesel communities. The observed change in electricity consumption led to the 1.2 elasticity result.

While the south Labrador coast experience may not carry over exactly to communities on the island, the differences in distance and climate are not especially great. If the price elasticity on the island is similar then the implications are profound. For example, with an elasticity of 1.2, a 50 percent increase in price would imply a 60 percent reduction in consumption. Since, in proportions, the reduction in consumption exceeds the price increase, that would mean that the utilities would actually see a decline in their residential sales revenues; selling 60 percent less at a 50 percent higher price implies a revenue drop of approximately 10 percent.

(ii) Estimates from other Jurisdictions

Moving beyond Newfoundland and Labrador, there are many estimates of price elasticities. For example, in one study, by Espey and Espey, found from their survey of various sources that estimates of long-run price elasticities for residential electricity range from approximately 0 to 2.25 with an average of 0.85 and a median of 0.81.[6] This wide range is in part the result of the differences across various study areas and time periods. Climate, availability of substitutes, income levels, and pricing regimes all tend to influence price elasticity. Nevertheless, the Espey and Espey survey illustrates that the provincial values identified in the preceding subsection are generally consistent with results found elsewhere.

Another report, from the Electric Power Research Institute (EPRI), has a somewhat narrower range of values for long-run residential elasticities than in Espey and Espey. That may

[6] See James Espey and Molly Espey (2004) "Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities," *Journal of Agricultural and Applied Economics*, Volume 36 (1), p.66.

be the result of EPRI surveying a smaller number of selected studies. Their findings are summarized in Table 2.[7]

Table 2

Long-Run Price Elasticities from Selected Studies: EPRI

	Mean	Low	High
Residential	0.9	0.7	1.4
Commercial	1.1	0.8	1.3
Industrial	1.2	0.9	1.4

The EPRI survey is interesting because it includes estimates for commercial and industrial customers, and their mean values imply that those groups are price sensitive. However, it is important to stress that the selected studies underlying them are from various areas and not from Newfoundland and Labrador. Both the industrial and commercial customers on the island are likely to have very different characteristics than elsewhere, so significantly higher or lower values for Newfoundland are possible.

Closer to Newfoundland in terms of both geography and climate, is Quebec. The result of two analyses of residential electricity demand there are summarized in Table 3 below. In both cases, the values are practically identical and greater than one. They indicate that electricity demand in Quebec is price-elastic.

Table 3

Estimates of the Long-Run Price Elasticity:

Residential Demand for Electricity in Quebec

Authors	Estimate
Bernard and Genest-Lapante (1995)[8]	1.33
Bernard, Bolduc and Yameogo (2011)[9]	1.32

[7] See EPRI (2008) "Price Elasticity of Demand for Electricity: A Primer and Synthesis," p.20. Available at https://www.epri.com/#/pages/product/1016264/

[8] J.T. Bernard and E. Genest-Laplante (1995) Les élasticités-prix et revenu des demandes sectorielles d'électricité au Québec: revue et analyse. Rapport final de recherche soumis à Hydro-Québec.

[9] Bernard, Jean-Thomas, Denis Bolduc and Nadège-Désirée Yameogo (2011) "A pseudo-panel data model of household electricity demand," *Resource and Energy Economics*, 33 (1):315-325.

It is possible to find many studies that present lower estimates of residential price elasticities than in Tables 1, 2 and 3. However, the range of estimates in those tables provide evidence that island residential customers may be quite price sensitive. A long-run elasticity similar to that found for the south Labrador coast or in Quebec is a distinct possibility for island residential customers.

(iii) Substitution Incentives and the Price of Electricity

The price elasticity of demand for a commodity depends on how important it is to the consumer and on the availability of substitutes for it, and, in particular, on the net savings that would result from substitution. Over a short period of time, a price increase may have little impact on consumption. That is because there may not be enough time to switch to a substitute or the consumer may be uncertain as to whether the price increase is permanent, in which case if there is a cost of substituting then the consumer may wait until convinced that the change is going to be long-lasting. Under the plan to incorporate Muskrat Falls costs into island electricity rates, customers will perceive any significant increase in price as long-lasting. That would provide an incentive for them to investigate alternatives. Generally, the more the alternatives, the greater the price elasticity. Tables 4 and 5 illustrate the possible alternatives for residential customers. The tables show the estimated annual costs of the different options available to customers. The costs are solely for fuel and do not include the upfront costs of installation/switching and maintenance or fixed charges.

Table 4 deals with space heating. It is based on the energy requirements for heating a 2,000 square foot house in St. John's built after 1990; the energy requirement is 80 million BTUs.[10] The table is also adapted from Efficiency Nova Scotia's energy conversion ratios used in its cost comparison methodology.[11] Table 4 shows the annual fuel costs of different types of space heating sources based on three different prices of electricity for residential customers on the island grid: the July 1, 2018 price of 11.4 cents per kWh, and then 17 cents, which is used as the approximation for a mitigated price, and 23 cents, the price that would otherwise be

[10] Natural Resources Canada gives 85 Gigajoules as being needed to heat such a dwelling, which is approximately 80.5 million BTUs. The calculations in Table 4 are based on 80 million BTUs. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/files/pdf/publications/Heating_with_Electricity.pdf Table 3, p.37.

[11] See Efficiency Nova Scotia, https://www.efficiencyns.ca/guide/heating-comparisons/ (For February 2018)

implemented following completion of the Muskrat Falls project. Other fuel costs are those that prevailed in St. John's during mid-July 2018: 97.1 cents per litre for furnace oil and 79.6 cents per litre for propane.[12] Data on firewood costs was not readily available so prices from Nova Scotia were used: $246.96 per cord of wood and $312.99 per ton of pellets.

Table 4

Comparison of Annual Spacing Heating Fuel Costs (HST of 15% Included):

2,000 Square Foot Detached House Built after 1990 – St. John's

	Electricity Price at 11.4 cents/kWh	Electricity Price at 17 cents/kWh	Electricity Price at 23 cents/kWh
Electric Baseboard heat	$3,074	$4,584	$6,202
Electric Heat Pumps: Air-to-Air	$1,618	$2,413	$3,264
Electric Heat Pumps: Mini-splits	$1,230	$1,834	$2,481
Heat Pumps-Geothermal	$1,025	$1,528	$2,067
Oil Furnace: old at 70% efficiency	$3,497	$3,497	$3,497
Oil Furnace: new at 85% efficiency	$2,880	$2,880	$2,880
Propane (fireplace) at 70% efficiency	$4,305	$4,305	$4,305
Propane furnace at 80% efficiency	$3,767	$3,767	$3,767
Wood stove/furnace at 55% efficiency	$1,723	$1,723	$1,723
Wood stove/furnace at 70% efficiency	$1,353	$1,353	$1,353
Wood Pellets at 75% efficiency	$2,400	$2,400	$2,400

Table 4 shows that, at 11.4 cents per kWh, electric baseboard heating is more costly in terms of annual fuel cost than wood fueled heating and the other electricity-fueled, but more efficient, heat pump options, but less costly than alternatives fueled by either oil or propane. However, at 17 cent per kWh, electric baseboard heating would have the highest annual fuel

[12] See Petroleum Pricing Order of July 12, 2018, http://pub.nl.ca/orders/ppo/oil/HO-180712.pdf

costs of all the options in the table. The margins are quite large. For example, while electricity for baseboard heaters would cost $4,584 annually, the fuel cost for a new furnace would be $2,880 and even electricity for a mini-split would be $1,834. At 23 cents/kWh, as shown in the last column of Table 4, electric baseboard heating would be even more unattractive compared to all the other listed alternatives. In short, the figures in Table 4 suggest that even at 17 cents per kWh all the alternatives to electric baseboard heating offer large annual fuel costs savings, all of which being achieved through less consumption of electricity. At present, approximately 70 percent of residential customers on the island of Newfoundland have electric space heating. Thus, there is considerable room for reductions in residential electricity consumption.

Table 5, which is also adapted from Efficiency Nova Scotia's comparison tables. It is based on a four-person household shows that consumes 240 litres daily. The table shows electric hot water heating offers generally favourable annual costs compared to the oil or propane fired alternatives at 11.4 cent/kWh. However, at higher electricity prices, both propane and oil fueled alternatives offer annual fuel cost savings.

Table 5

Comparison of Annual Hot Water Heating Fuel Costs: 240 Litres Daily

	Electricity Price at 11.4 cents/kWh	Electricity Price at 17 cents/kWh	Electricity Price at 23 cents/kWh
Electric Hot Water Heater (old) at 85% efficiency	$701	$1,046	$1,415
Electric Hot Water Heater (new) at 90% efficiency	$663	$988	$1,337
Oil Stand-alone water heater at 55% efficiency	$ 868	$868	$868
Propane Stand-alone water heater at 55% efficiency	$1,068	$1,068	$1,068
Propane stand-alone/on-demand/ heater-high at 93% efficiency	$632	$632	$632

Tables 4 and 5 illustrate that there are substantial annual savings from switching either to less electricity-intensive space and water heating or to non-electric alternatives but customers will be aware that there are capital costs of doing so. The same observation applies to new construction. If the annual savings are large and expected to persist then the customer would have a very strong incentive to act. If the price increase is anticipated then the action may be taken in advance. In such circumstances the long-run for the price elasticity of demand may not be a lengthy period of chronological time, and that elasticity might be quite large. Furthermore, substitution possibilities go beyond space and water heating. Better house insulation and windows, and replacement of electric lights and appliances with more efficient ones would also be actions that customers could take.

The focus of Tables 4 and 5 has been on residential consumption. However, commercial (general service) customers of NL Hydro and NP as well as NL Hydro's industrial customers would have similar incentives to find less expensive alternative sources of energy if the price of electricity increases substantially for the long term. That would be especially so for those businesses for which electricity is a major component of their cost structure.

c) Overall Assessment of Elasticity

The evidence in the preceding subsections is not sufficient to establish a single estimate for the long-run price elasticity of demand for electricity on the island. However, based on that evidence, that elasticity is likely more than 0.4 and possibly more than 1.0 at current prices.

III. Implications

The range of values for the long-run price elasticity that has been suggested above has far-reaching implications for the post Muskrat Falls period.

a) Electricity Consumption

In 2017, the total customer load for NL Hydro island interconnected system was approximately 7 million megawatt hours (MWh), of which approximately 1.8 million were provided by its oil-fueled generating plant at Holyrood. Nalcor and government statements regarding Muskrat Falls have suggested that the price of electricity could rise by either 50 percent (to about 17 cents/kWh for residential customers) with rate mitigation or 100 percent (to about 23 cents/kWh for residential customers) otherwise, relative to current rates. Even values of the elasticity selected from the lower end of the range suggested herein have substantial implications for future electricity consumption. Table 6 shows how much NL Hydro's customer load might change as a result of the price increases currently in the public discourse and based on the long-run elasticity being either 0.4 or 0.6.

Table 6

Change in NL Hydro Customer Load Due to Electricity Price Increases,

at Selected Values of the Long-Run Price Elasticity of Demand

	Elasticity of 0.4	Elasticity of 0.6
50% Price Increase	-1.4 million MWh	-2.1 million MWh
100% Price Increase	-2.8 million MWh	-4.2 million MWh

Even with the low value of 0.4 for the elasticity and the smaller rate increase of 50 percent, Table 6 indicates that the reduction in customer load due to the price increase would be quite large, at 1.4 million MWh. At a 0.6 elasticity, which might well be lower than the true value, a 50 percent price increase, implies a 2.1 million MWh decrease in consumption. Higher price increases or greater elasticity would lead to even bigger reductions in customer loads. One caveat here is that other considerations will also influence electricity consumption. For instance, changes in income, prices of alternative fuels, technology and demographics would come into play. Some might exert upward movement on consumption and others might tend to lower consumption further. Those influences are not embodied in Table 6, which focuses exclusively on the impact of price changes.

b) Muskrat Falls Energy

Table 6 implies that if electricity prices increase by the magnitudes that have been discussed herein then the resulting fall in consumption could be nearly as large as or even much larger than the amount of energy produced at the Holyrood generating facility, which was approximately 1.8 million MWh in 2017. That is to say, the decline in consumption brought on by the price increase would make Holyrood largely redundant. Winter demand might require the plant to operate at times but, in net terms, the energy from Muskrat Falls could be largely or even totally unneeded to displace Holyrood. The implication is that Muskrat Falls would become primarily or entirely an export project. Practically all the energy that would be in excess of what has already been committed to Nova Scotia would also have to be exported since there would be no market for it on the island at high end-user rates. This is a perverse result because the rationale for the project was to displace Holyrood and meet growth in island electricity consumption.

Island customers would be consuming little or none of Muskrat Falls electricity, in net terms, but would be paying much higher prices for the purpose of financing it. Additionally, island consumers would be burdened with the cost associated with converting to other energy sources and NL Hydro would experience little in the way of revenue increases from island sales as customers there substitute away from electricity. Complicating the revenue challenges would be low prices for exports of energy in accessible external wholesale markets if prices there remain as low as they currently are. So the higher prices may also fail to generate sufficient funds to pay for Muskrat Falls, even with the sort of price mitigation suggested in Budget 2018.

c) Rate Design

The counterproductive impacts of raising electricity rates following completion of Muskrat Falls are a signal that simply raising the price-per-kWh is an incorrect approach to rate design. Setting prices in that way is not related to the core economic principle of marginal cost pricing and, as demonstrated herein, it fails to take account of consumer response to higher prices. The higher rates for island customers would push them away from consuming electricity even though the benefits to island consumers from using that electricity may well exceed the export revenue it earns.

IV. Concluding Remarks

This report has presented an assessment of relevant long-run price elasticities for electricity and fuel substitution possibilities. Based on that assessment, it appears that a large increase (e.g., by 50 percent or more) in the per-kWh price of electricity would be problematic. Not only would it be a burden to all island interconnected customer groups, it would cause a large decline in electricity consumption by those consumers. That would impede Nalcor's efforts to raise revenue through Hydro's rates to pay for Muskrat Falls. Island consumption could fall by so much that Muskrat Falls could become solely an export project. Since there has been no indication that such pricing is based on economic principles, there is no reason to believe that these outcomes are consistent with optimal economic use of the province's electrical energy.

APPENDIX

Estimating the Price Elasticity of Demand for Electricity by Households in Newfoundland:
A Partial Adjustment Model

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Introduction

Table 1 of the report refers to a 0.42 estimate for the long-run price elasticity of residential demand for electricity on the Newfoundland interconnected grid and indicates that it was obtained from a partial adjustment model. This appendix explains the methodology that was used to determine that estimate.

The Data

All interconnected residential customers on the island of Newfoundland face the same price of electricity even though areas are served by two utilities; Newfound Power serves the vast majority of customers while Newfoundland and Labrador Hydro serves the remainder. The data on consumption that is used in this exercise corresponds to that for Newfoundland Power's residential customers and was provided by Newfoundland Power on request. There is little reason to expect the NL Hydro's own customers' consumption patterns to be much different from NP's, given that they face the same prices and live on the same island.

In addition to consumption, expressed as average annual consumption per residential customer, the other core variables used are the price of electricity, the price of heating fuel and per capita personal disposable income (PDI). In the analysis that follows, the prices and income are all expressed in real terms (i.e., 2002 constant prices) using Statistics Canada's Consumer Price Index for Newfoundland and Labrador. The data for the price of heating fuel in the province and personal disposable income were obtained from Statistics Canada as well. While most of the data was available on a monthly basis, personal disposable income was annual and thus annual data was used for this exercise. The years covered were 1992 to 2016, inclusive. Table A1 describes the data.

Table A1
Core Data: 1992-2016

Variable	Mean	Std. Dev.	Minimum	Maximum
Weather –Adjusted Average Consumption in kWh	15309	529.6	14588	16206
Real Price of Electricity in cents per kWh	8.55	0.54	7.7	9.2
Real Price of Heating Fuel in cents per litre	62.9	18.4	37.9	95.7
Real Personal Disposable income per capita	$18,447	$3,979.5	$13,886	$24,945

Partial Adjustment Model

In general terms, a household's desired choice of electricity consumption Q^* is determined by the price of electricity (*P*), the price of any substitute (*PF*), and income (*I*). Thus,

$$(1) \qquad Q^* = f(P, PF, I)$$

where *f* denotes the functional relationship between Q^* and the variables that determine it; the other notation in the equation is as given in Table 1. That functional relationship may be written as:

$$(2) \qquad Q^* = a + bP + cPF + dI + u$$

where *a* is a constant and *b*, *c*, and *d* are coefficients, while *u* represents the impact of other possible factors and assumed to be a random error with a zero mean and constant variance.

In equations (1) and (2), Q^* denotes the household's choice but at any point in time achieving it may not be feasible. If the price or some other relevant variable changes then it may take some time for a household to fully adjust. Some actions can be undertaken fairly quickly, e.g., turning down thermostats when the price increases. However, other reactions take time because capital investment, e.g., switching from furnace to electric heat or purchasing electricity-efficient appliances, is costly and may not be undertaken until the price change is perceived as permanent. Such circumstances can be described by a partial adjustment process as below:

$$(3) \qquad Q_t - Q_{t-1} = \lambda(Q_t* - Q_{t-1}).$$

where the subscripts denote time periods. Equation (3) says that the actual change in consumption over one period, $Q_t - Q_{t-1}$, is proportional to any gap between the desired level of consumption and last period's actual consumption, $(Q_t* - Q_{t-1})$. The Greek letter λ denotes the adjustment parameter and would take the value of zero if complete adjustment takes place instantly. When that is not possible the adjustment parameter must be a positive number. It is assumed to be a fraction; otherwise the model would be unstable in the sense that consumption would never converge to the household's desired level. By substituting the expression for Q^* from (2) into (3), and simplifying yield the following:

$$(4) \qquad Q_t = \alpha + \beta P_t + \gamma PF_t + \delta I_t + \varepsilon Q_{t-1} + v_t$$

where $\alpha = a/\lambda$, $\beta = b/\lambda$, $\gamma = c/\lambda$, $\delta = \lambda d$, $\varepsilon = (1- \lambda)$, and $v = \lambda u$.

Equation (4) is the basis for the estimation undertaken in the next section. A double-logarithm specification is used; i.e., the variables in equation (4) are expressed in terms of their logarithmic values.

Results

Table 2 provides the results of the Ordinary Least Squares (OLS) estimation using the 1992-2016 dataset on the functional form given in equations (4). The results are quite good. All the right-hand-side variables are statistically significant; see the corresponding *t* values, all of which are statistically significant. Additionally, the regression test statistics are encouraging; the adjusted R^2 implies a good overall fit, with the regression accounting for 96 percent of the variation in consumption, and Durbin's h statistic suggests that the null hypothesis of no autocorrelation cannot be rejected. [13] Crucially the coefficient on the lag of consumption is a positive fraction, which means the model is stable. Perhaps most importantly, the signs of the coefficients are consistent with basic theory: the coefficient on the price of electricity is negative, the coefficient on the substitute fuel is positive and the coefficient on income is both positive and fractional, which is consistent with electricity being a normal necessity.[14]

[13] With time-series estimation, as this is, there is always a concern that a strong fit may be the result of spurious correlation. That means that the variables move along similar time trends but there is no causal relationship in play. This does not appear the case here because even though the variables are not stationary i.e., do have trends, the residuals from the regression appear to be stationary. Additionally, going beyond the statistical issues associated with spurious correlation, economic theory provides a sound theoretical foundation for consumption varying with the right-hand-side variables of equation (4) in a pattern consistent with the regression results.

[14] When an increase in consumers' income causes an increase in consumption of a good or service, but by less than the percentage increase in income, then that good or service is classified as a normal necessity.

Table A2

OLS Estimation Results

	Double-log Function
Dependent Variable	(Q)
Explanatory Variables	**Coefficients (t values)**
Constant	2.98 (3.27)
Price of Electricity	-0.15 (-2.93)
Price of Fuel	0.023 (2.33)
Disposable Income Per Capita	0.073 (3.39)
Lagged Consumption	0.64 (5.70)
Regression Test Statistics	
Adjusted R^2	0.96
Durbin's h statistic	Prob> chi^2 = 0.61

Based on the results in Table A2, it is straightforward to determine the implied short-run and long-run price elasticities of demand for electricity. These are presented in Table A3 below.

Table A3

Estimates of Price Elasticities from the OLS Results

Short-run Elasticity	-0.15
Long-run Elasticity	-0.417

The short-run price elasticity corresponds directly to the coefficient on the price of electricity as given in Table A2. (Analogously, the coefficient on income is the short-run income elasticity and the coefficient on the price of heating fuel is the short-run cross elasticity for that substitute.) Obtaining the long-run elasticity involves the coefficient on lagged consumption. When full adjustment is achieved, that lagged consumption and current consumption coincide so bringing like terms together and simplifying yields a long-run elasticity of -0.15/(1 - .64) = -0.417 or approximately -0.42.

Following a widely used convention, the short-run and long-run elasticities may be expressed in their absolute values of 0.15 and 0.42, respectively. The latter figure corresponds to the partial adjustment model estimate given in Table 1.