ELASTICITY OF DEMAND FOR NATURAL GAS IN WESTERN AND CENTRAL CANADA

by

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DEDICATION PAGE

This thesis is dedicated to my parents and sister who are always there for me.

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ABSTRACT

In this paper, we used the Autoregressive Distributed Lag (ARDL) model and the bounds test approach to estimate the elasticity of demand for natural gas in Western and Central Canada. The best model specification selected by Schwarz Information Criterion (SIC) for each province suggests that there exist long-run relationships between the dependent variable and independent variables for all provinces, except Ontario.

Consumption per capita in these provinces can be explained by natural gas prices, electricity prices, income, and heating degree days (a measurement for the weather factor) in levels for the selected specification. The results show that natural gas demand is very inelastic with respect to natural gas prices and also with respect to heating degree days.

LIST OF ABBREVIATIONS USED

ARDL	Autoregressive Distributed Lag
ECM	Error Correction Model
VECM	Vector Error Correction Model
VAR	Vector Autoregression
NGP	Natural Gas Prices
EP	Electricity Prices
HDD	Heating Degree Days
QC	Quebec
ON	Ontario
MB	Manitoba
SK	Saskatchewan
AB	Alberta
BC	British Columbia
OECD	Organisation for Economic Co-operation and Develpment
BP	British Petroleum
GJ	Giga Joules
AIC	Akaike Information Criterion
SIC/BIC	Schwarz Information Criterion/ Bayesian Information Criterion
NP	Nominal Prices
RP	Real Prices

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CHAPTER 1 INTRODUCTION

The fossil fuels are one of the necessities in our economy. They fuel our industries, our homes and, most importantly, our technology, which is paving the way for our advancements. Oil has the biggest share of energy consumption among all fossil fuels. However, there is a new trend showing that more advanced countries around the world are gradually moving towards natural gas as their technology advances. There are many advantages associated with switching to natural gas, such as cost savings and less pollution for the environment. The efficient production of natural gas can also be used as a source of economic power. If a country can produce more than its consumption, not only can it become self-sufficient but it can also export to other countries. In this paper we have investigated the residential natural gas demand elasticity in Western and Central Canadian provinces. We have estimated the long-run demand elasticity of natural gas with regards to natural gas prices, electricity prices, income, and heating degree days using the Autoregressive Distributed Lag (ARDL) model. This is a very crucial subject matter in Canada, yet not much research has been done.

Considering the population of the Organisation for Economic Cooperation and Development (OECD) countries, the per capita demand for oil and natural gas is more than four times higher than demand in non-OECD countries. Based on statistics retrieved from the World Bank, in 2011, the OECD countries only had 17.9 percent of the World's total population while they contributed 65.8 percent of the world's total GDP (Development Data, 2013). Energy demand is an important issue in developed countries. According to the 2012 British Petroleum Statistical review, OECD natural gas consumption in 2011 was 47.7 percent of the World's total natural gas consumption while their share of natural gas production was 35.8 percent. OECD countries' share of crude oil consumption was 51.5 percent of the world's total while their share of production was only 21.7 percent (Statistical Review of World Energy, 2012).

The ratio of natural gas consumption to coal consumption among OECD countries is 1.26 while this ratio for non-OECD countries is only 0.58. Considering the amount of energy consumption in OECD countries, there is a tendency to use cleaner energy sources. Based on British Petroleum (BP) Statistics, in 2011, 87.1 percent of the World's total energy consumption was fossil fuel, while this share for OECD countries was 82.8 percent compared to 90.6 percent in non-OECD countries. Natural gas is the cleanest type of fossil fuel followed by oil while coal is the most polluting type of fossil fuel. Table 1 shows the emissions of different types of fossil fuel (Energy Information Administration (EIA), 1999).

Table 1: Emission levels of fossil fuel (Pounds of air pollutant per billion Btu of energy) (Source: EIA, Natural Gas Issues and Trends 1998)

	Fossil fuel		
Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117000	164000	208000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxides	1	1122	2591

In order to emit less green house gases (GHG), it is necessary to substitute coal with clean energy resources, such as wind, solar, nuclear or natural gas. As we can see, the emissions of natural gas are much lower than the emissions of coal for any kind of pollutant; particularly, the sulfur dioxide emissions are negligible when natural gas is used.

Natural gas is the cheapest type of energy for residential uses. It costs only 32 percent of the cost of electricity in the US (Residential Uses, 2011). Natural gas is widely used for heating and cooking. With the advancement in technology, natural gas can be used in many appliances for heating purposes; these appliances are gaining more popularity, since they are privately cost effective. Space heaters, pool heaters, garage heaters, fireplaces for heating purposes and air conditioning for cooling purposes could be directly powered by natural gas. There is some research on how to use natural gas for generating electricity in appliances with the help of natural gas fuel cells and micro turbines. Therefore, in the future it is likely that residential houses could run their electric appliances independently, only relying on natural gas power and not city electricity (Residential Uses, 2011). However, depending on the energy and materials costs of making this natural gas infrastructure, it may not be worth sinking these capital costs.

According to BP Statistics, natural gas consumption growth in North America grew by 3.2 percent in 2011, which is higher than the world's natural gas consumption growth (2.2 percent). Based on BP statistics, natural gas consumption in Canada grew by 10.3 percent in 2011, which is much higher than the world's average growth. Canada accounts for 3.2 percent of the world's natural gas consumption and for 4.9 percent of the world's natural gas production (Statistical Review of World Energy, 2012), with only 0.5 percent of the world's population (Development Data, 2013). Therefore, the per capita natural gas consumption in Canada is more than six times the world's average. BP statistics also show that natural gas accounted for 28.5 percent of energy consumption in Canada, while the share of natural gas consumption as a share of total energy in the world was 23.7 percent. As a result, natural gas is a very important source of energy in Canada (Statistical Review of World Energy, 2012). Based on the data retrieved from Statistics Canada, 53.7 percent of Canada's residential natural gas consumption in 2011 was consumed in Western provinces, while they only represent 30.7 percent of Canada's population (Statistics Canada, 2014). Thus, the residential natural gas consumption per capita in Western provinces is more than twice that of other provinces and territories. Therefore, finding and analyzing the demand elasticity of residential natural gas in Western provinces is an important topic. We also know that more than half of Canada's population live in Central Canada. Ontario is the biggest consumer of natural gas in Canada. Therefore, in our research, we consider both Western Canada and Central Canada. Some of the main reasons that Western provinces have the higher natural gas consumption per capita are as follows:

1. Western provinces have natural gas resources. They are producers and exporters of natural gas. In contrast, Eastern Canada imports natural gas from Western provinces and the United States.

2. Western provinces, except British Columbia, are colder than Central and Atlantic Canada. Thus, they need more heating resources to warm their houses during winter months.
3. Average income is higher in Western provinces. Western provinces have 37 percent of Canada's GDP, while they account for 31 percent of population. In this research, we have investigated the income elasticity in Western provinces and have compared it with the income elasticity in Central provinces.
4. Price of natural gas per unit of consumption in Western Canada is lower in comparison with the other provinces, e.g. average price of residential natural gas per cubic meter in December 2012 was 20 cents in Alberta compared to 73 cents in Nova Scotia (Statistics Canada, 2014).

These statistics show the importance of natural gas in Western Canadian provinces. In our research we would like to investigate the demand elasticity of natural gas in Western Canadian provinces where they have colder weather and higher income and also investigate the demand elasticity of natural gas in Central provinces where the population is higher.

Since fossil fuels emit greenhouse gases, carbon tax policy is a good idea to motivate the consumers to use clean energy resources. The elasticity estimates for fossil fuels could help policymakers to predict responses to climate change policies, such as carbon taxes. Carbon taxes will increase the relative price of oil and coal generated electricity in comparison to gas generated electricity and gas heating. They would however raise the relative price of natural gas relative to renewable energies like solar, wind, tidal hydro, and also nuclear.

Natural gas may help us to transition to intermittent renewable energies (wind and solar) due to helping to moderate electricity; i.e. gas can be turned on and off quickly when wind or solar turns off and on.

In Section 2, some of the studies about the elasticity of demand for natural gas are discussed. In Section 3, we will describe the data. In Section 4, the econometric model of this paper will be explained, which will lead us to Section 5 where the results of this research will be discussed. Conclusion of this research is located in Section 6. References and appendix are provided for further information.

CHAPTER 2 LITERATURE REVIEW

Bernstein and Madlener (2011) investigated the demand elasticity in twelve OECD countries and found the short-run and long-run demand elasticity of natural gas as a function of disposable income, residential natural gas prices, and weather. According to their research, the magnitude of demand elasticity in the long run for each variable is approximately twice that of the short-run elasticity. In the long-run it is easier to substitute the energy sources. Therefore, the results are more elastic. The long-run elasticity with regards to income is 0.94 compared to 0.45 for short-run; the long-run elasticity with regards to prices is -0.51 compared to -0.24 for short-run; and the long-run elasticity with regards to weather is 1.35 compared to 0.72 for short-run (Bernstein & Madlener, 2011).

The sensitivity of the quantity demanded to price can be measured by the price elasticity of demand. The price elasticity of demand represents the percentage change of the quantity demanded to the percentage change in the price for the good (Besanko & Braeutigam, 2002).

$$\varepsilon_{Q,P} = \frac{\Delta Q}{\Delta P} . \frac{P}{Q}$$

In the equation, $\left(\frac{\Delta Q}{Q}\right) * 100\, percent$ shows the percentage change in quantity and $\left(\frac{\Delta P}{P}\right) * 100\, percent$ shows the percentage change in prices. Since the demand curve is downward sloping, the price elasticity of demand is a negative number. For $-\infty <$

$\varepsilon_{Q,P} < -1$, the demand is elastic; If $\varepsilon_{Q,P} = -1$ the demand is unitary elastic; and for $-1 < \varepsilon_{Q,P} < 0$, the demand is inelastic with respect to prices (Besanko & Braeutigam, 2002).

Figure 1 shows two different demand curves. Since the vertical axis shows the prices and the horizontal axis shows the quantity, the higher absolute value of elasticity corresponds to the flatter demand curve. Therefore, in this figure, the red demand curve represents the more elastic demand and blue curve shows the more inelastic demand curve, provided the same price is specified for both curves.

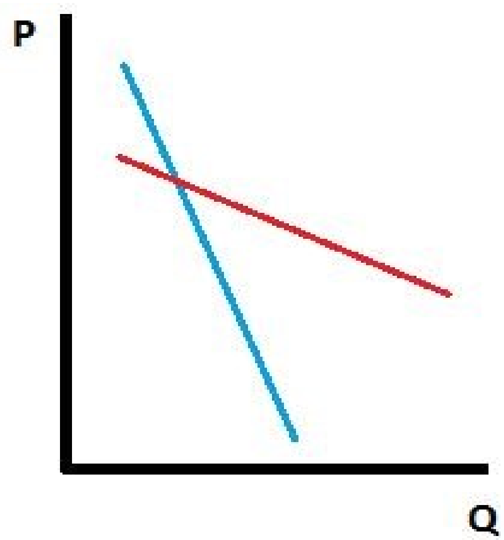

Figure 1: Linear demand

If the demand curve is a linear function, we can write the equation as: $Q = a - bP$.

The inverse demand function is: P=a/b – (1/b)*Q

Therefore, the price elasticity of demand is:

$$\varepsilon_{Q,P} = \frac{\Delta Q}{\Delta P}\frac{P}{Q} = -b\frac{P}{Q}$$

As we can see in Figure 2 and based on the elasticity formula, when the demand approaches 0, the price elasticity of demand approaches minus infinity and when the price approaches 0, the price elasticity of demand approaches 0 (Besanko & Braeutigam, 2002).

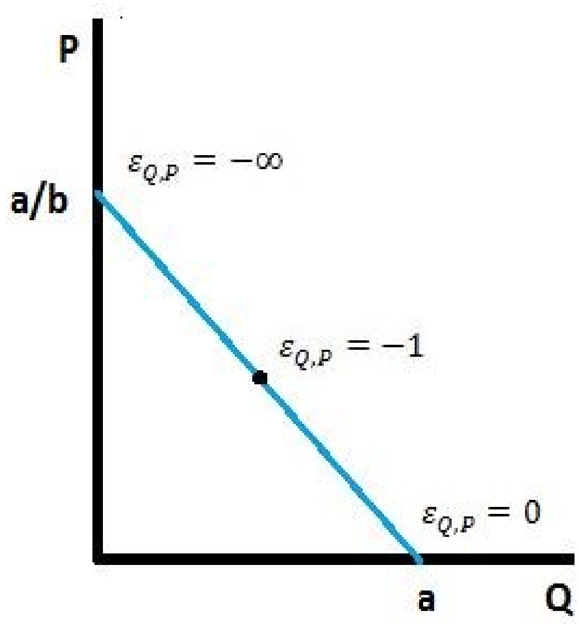

Figure 2: Price elasticity of demand

There is a non-linear form of demand curve where the elasticity remains constant along the curve: $Q^d = aP^{-b}$, where a and b are positive constants. Taking the natural logarithm of both sides, we can derive the log-linear demand curve:

ln Q= ln a – b ln P , where the elasticity is equal to –b (Besanko & Braeutigam, 2002).

The residential natural gas demand elasticity has been studied in some papers. The table below shows the results of previous studies for the residential natural gas demand elasticity. The short-run demand elasticity with respect to variables shows the immediate response if that variable changes. However, the long-run demand elasticity is a measurement for total responses with respect to the independent variable (Bernstein & Madlener, 2011).

Table 2: Elasticity of demand for natural gas (L denotes long-run and S denotes short-run elasticities)

Research	Location	Estimation Method	Data	Income elasticity	Price elasticity	Weather elasticity
Bernstein & Griffin (2006)	Contiguous United States	Fixed effects	1977-2004 (annual)	S:0.26	L:-0.36 S:-0.12	S:0.18
Nilsen et al (2008)	12 European Countries	Shrinkage	1978-2002 (annual)	L:3.32 S:0.81	L:-0.10 S:-0.03	
Joutz et al (2008)	United States	Shrinkage	1980-2006 (monthly)		L:-0.18 S:-0.09	
Maruejols et al (2009)	Canada	LAIDS	1960-2007 (annual)	L:0.90	L:-0.50	
Bernstein & Madlener (2011)	12 OECD Countries	ARDL	1980-2008 (annual)	L:0.94 S:0.45	L:-0.51 S:-0.24	L:1.35 S:0.72
Bernstein & Madlener (2011)	United States	ARDL	1980-2008 (annual)	L:0.03 S:0.03	L:-0.16 S:-0.04	L:0.74 S:0.70
Payne et al (2011)	Illinois, US	ARDL	1970-2007 (annual)	L:0.02	L:-0.26 S:-0.19	L:0.63

Bernstein and Griffin (2006) estimated the natural gas elasticity of demand for 47 states in the contiguous United States. They used the fixed effect method for the panel data. “The fixed effects formulation implies that differences across groups can be captured in differences in the constant term (Greene, 2012, p. 359)”. Fixed effect estimators are also known as within estimators. If the variables are time invariant, they will disappear from the fixed effects econometric model and will be treated as a constant (Kennedy, 2003). Their estimation shows that the long-run price elasticity is -0.36, which is 3 times larger than the short-run price elasticity. The short-run income elasticity is 0.26 and the short-run weather (heating degree days) elasticity is 0.18. Therefore, based on their research, natural gas demand is very inelastic with respect to prices, income and climate in the contiguous United States (Bernstein & Griffin, 2006).

Nilsen et al (2008) used the shrinkage method to estimate the natural gas demand elasticity in 12 European countries. The Shrinkage method is a useful way of estimation when the data is ill-posed. If data is ill-posed the solutions are not reliable and the solutions might not fully depend on the data. When data is ill-posed, arbitrary small changes in data will lead to large changes in solutions. Therefore, in order to obtain reliable solutions, the data should be improved (regularized) (Engl, Kunischt, & Neubauer, 1989). In the shrinkage method, the ill-posed data will be improved to new set of data considering other information, in such a way that new data are not ill-posed. For example, the heat equation may be an ill-posed problem initially, but considering some adjustments could improve the equation to a well-posed problem. Then with the help of shrinkage estimator, new estimates are obtained, where new estimates for new data (prospective fit) are closer to the real value when compared to the original raw estimates (retrospective fit) (Copas, 1983). The shrinkage estimator is the weighted average of 2 different estimators, $\hat{\theta}$ and $\hat{\theta}^{target}$. $\hat{\theta}$ is a high-dimensional estimate with many independent components and $\hat{\theta}^{target}$ is a low-dimensional estimate, but it is more biased. The weights of these 2 components (λ and (1- λ)) in the shrinkage estimator are determined in such a way that the shrinkage estimator has smaller mean square errors (MSE), when it is compared to OLS (Hausser & Strimmer, 2009). Therefore, shrinkage estimators are biased estimators with smaller MSE which give better results than OLS when the data is not well-posed.

According to Nilsen et al (2008), the average income elasticity is 0.81 in the short run and 3.32 in the long run. Therefore, the natural gas demand with respect to income is inelastic in the short run, but it is elastic in the long run. Their research shows the demand elasticity for natural gas with respect to prices is very inelastic both in the short run and the long run. The short-run price elasticity is -0.03 and the long-run price elasticity is -0.10 (Nilsen, Asche, & Tveteras, 2008).

Joutz et al (2008) used the shrinkage method and the US monthly data between 1980 and 2006 to estimate the price elasticities of the demand for natural gas. Their estimation shows that the natural gas demand is very inelastic with respect to prices both in short run (-0.09) and long run (-0.18). As in other studies, the absolute value of the short-run elasticity is smaller than that of the long run. Therefore, the American households are not sensitive to natural gas prices, especially in the short run (Joutz, Shin, McDowell, & Trost, 2008).

Maruejols & Ryan (2009) is one of the few studies which have estimated the demand for natural gas in Canada. They used the Linearly Almost Ideal Demand System (LAIDS) method for their research and their annual data spans from 1960 to 2007. They estimated the long-run income elasticity and long-run price elasticity for Atlantic Canada and all the other provinces individually. According to their research, the median long-run income elasticity in Canada is around 0.9, while the long-run price elasticity is almost -0.50. Furthermore, the price elasticity varies mostly between provinces while most provinces are fluctuating in the narrower range of long-run income elasticity (Maruejols & Ryan, 2009).

LAIDS is a simple demand model which provides a first order approximation in demand and it satisfies the properties of an ideal demand system, such as axioms of choice, budget constraints and linear homogeneity of degree 0 for prices and expenditure. Therefore, when the relative prices of items are unchanged, the relative demand of them will remain unchanged. However, the changes in relative prices will change the demand for each item (Deaton & Muellbauer, 1980).

Bernstein & Madlener (2011) estimated the short-run and long-run elasticities (prices, income, and weather) of natural gas demand based on the Autoregressive Distributed Lagged (ARDL) model for the annual data from 1980 until 2008. Their study shows that the elasticities in the short run are almost half as much as those of the long run. Their research shows the 12 chosen OECD countries on average have inelastic short-run natural gas demand with respect to income, prices, and weather, whereas their long-run demand for natural gas with respect to heating degree days is elastic (1.35). Since the United States is the major market of Canada's natural gas exports, it is interesting to know its demand elasticity with respect to natural gas prices. Bernstein & Madlener (2011) study suggests the natural gas demand in the United States is very inelastic with respect to prices; the short-run price elasticity is -0.04 while the long-run price elasticity in US is four times as much (-0.16).

Payne et al (2011) used the ARDL model to estimate the natural gas demand elasticity in Illinois, US. They used the annual data from 1980 until 2007. Their results are not much different from the elasticities reported by Bernstein and Madlener (2011) for the United States, because both studies are applying the same method of estimation (ARDL). The income elasticity for Illinois estimated by Payne et al (2011) in the long run is 0.02, while Bernstein & Madlener (2011) estimated 0.03 for the United States. Payne et al (2011) estimation for Illinois's natural gas demand price elasticities in the short run and long run are -0.19 and -0.26, the long-run natural gas demand elasticity with respect to climate in Illinois is 0.63 in comparison with 0.74 for the United States (Bernstein & Madlener, 2011). Since Illinois is a northern US state, its weather is colder than the average for the United States. Therefore, the demand for natural gas in Illinois with respect to weather is more inelastic when it is compared to an average state in the United States.

CHAPTER 3 DATA DESCRIPTION

We consider 192 monthly observations for each of the following Canadian provinces: British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), and Quebec (QC). The monthly data ranges from Jan 1997 until Dec 2012 for income, residential natural gas prices, electricity prices, Consumer Price Index (CPI) and Heating Degree Days (HDD).

Statistics Canada provides the monthly data for nominal median wages per week (table 2820073), which is used as the income variable in this paper. There are no direct monthly data available for income at the provincial level.

Statistics Canada provides monthly data (table 1290003) for natural gas prices at the provincial level. However, there are no direct monthly data for residential electricity prices. Statistics Canada only reports the CPI index for electricity (table 3260020) (both residential and non-residential use). To construct the nominal electricity prices at the provincial level, we collect cross sectional data provided by Ontario-Hydro in May 2011, considering the average rate of electricity at 1000 KWH consumption (Electricty Rates by Province, 2011). Then using the electricity CPI index, we obtain the nominal electricity prices between Jan 1997 and Dec 2012 following these steps:

1) Find the electricity price for 1 KWH in May 2011 for each province by dividing the total price of electricity for 1000 KWH consumption by 1000.

$NP_{e,\ pr,\ May\ 2011}$= Price of 1000 KWH consumption/1000, where nominal price per KWH is represented by NP

2) $CPI_{e,t}$ is the index for electricity prices at time t. We can find the nominal price of electricity for each period knowing the prices in one period (May 2011) and the electricity index:

$NP_{e,\ pr,\ t} = NP_{e,\ province,\ May\ 2011} * (CPI_{e,\ pr,\ t} / CPI_{e,pr,\ May2011})$

3) Real prices can be calculated in constant dollars. In this research we converted all the nominal prices to real terms using the Dec 2012 Dollar value:

$RP_{e,\ pr,\ t} = NP_{e,\ pr,\ t} * (CPI_{Dec\ 2012} / CPI_{t})$,

Where RP is real price in 2012 Canadian Dollars

4) Although it is not necessary to convert the units as they could be treated as a constant in log-form, we converted both natural gas prices and electricity prices to the same unit. So later on, we can compare the prices of both types of energy sources with the same unit (dollar/gigajoules). Let $RP_{e,\ province,\ t,\ (\$/GJ)}$ represent real price per gigajoule at time t in the province named, then

$RP_{e,\ province,\ t,\ (\$/GJ)} = 277.7788 * RP_{e,\ province,\ t}$

In the model we use the natural logarithms of all variables.

Income, natural gas prices and electricity prices are deflated to real terms with the help of CPI. All of these variables are deflated to real terms based on the dollar value in Dec 2012:

Real Variable = Nominal Variable * ($CPI_{Dec\ 2012}$ / CPI_t)

Environment Canada provides the monthly average temperature for different cities in each province. Since major Canadian cities are close to the US borders and the majority of population in each province is settled in major cities, for calculating the temperature in each province, we relied on the weighted average data of main cities in each province based on their population. British Columbia (BC) temperature is assumed to be the weighted average of Vancouver and Victoria. Alberta (AB) temperature is based on the weighted average temperature of Calgary and Edmonton. Saskatchewan (SK) temperature is the weighted average of Saskatoon and Regina. Winnipeg represents Manitoba (MB) for the climate data here, Ontario's (ON) temperature is the weighted average of temperature in Toronto and Ottawa. For Quebec's (QC) temperature the weighted average temperature of Montreal and Quebec City is considered. Using the data for temperature, we can calculate Heating Degree Days (HDD), which is one of the independent variables in the model. Heating Degree Days shows the difference between the base temperature and recorded temperature on a given day, if and only if the recorded daily temperature is below the base temperature (Temperature is the average of the daytime low and the daytime high). These differences are then summed over the time interval to give the heating degree days used in calculation. The base temperature is usually considered at 18 degree Celsius. In this research we will use the HDD data as a monthly observation based on the base temperature of 18 C. HDD is calculated as follows:

$$HDD = \begin{cases} (18 - T_M) * \left(\frac{365.25}{12}\right) & T_M \leq 18, \\ 0 & Otherwise. \end{cases}$$

where T_M is the monthly average temperature.

Since all variables appear in log-form in our regression model, we have added 1 to all HDD measurement:

$hdd_t = \ln(HDD_t + 1)$.

Figure 3 shows the monthly heating degree days in each province. For all provinces, the HDD peaks in the winter months and has its lowest points in the summer months. British Columbia and central provinces are warmer than Canadian Prairies.

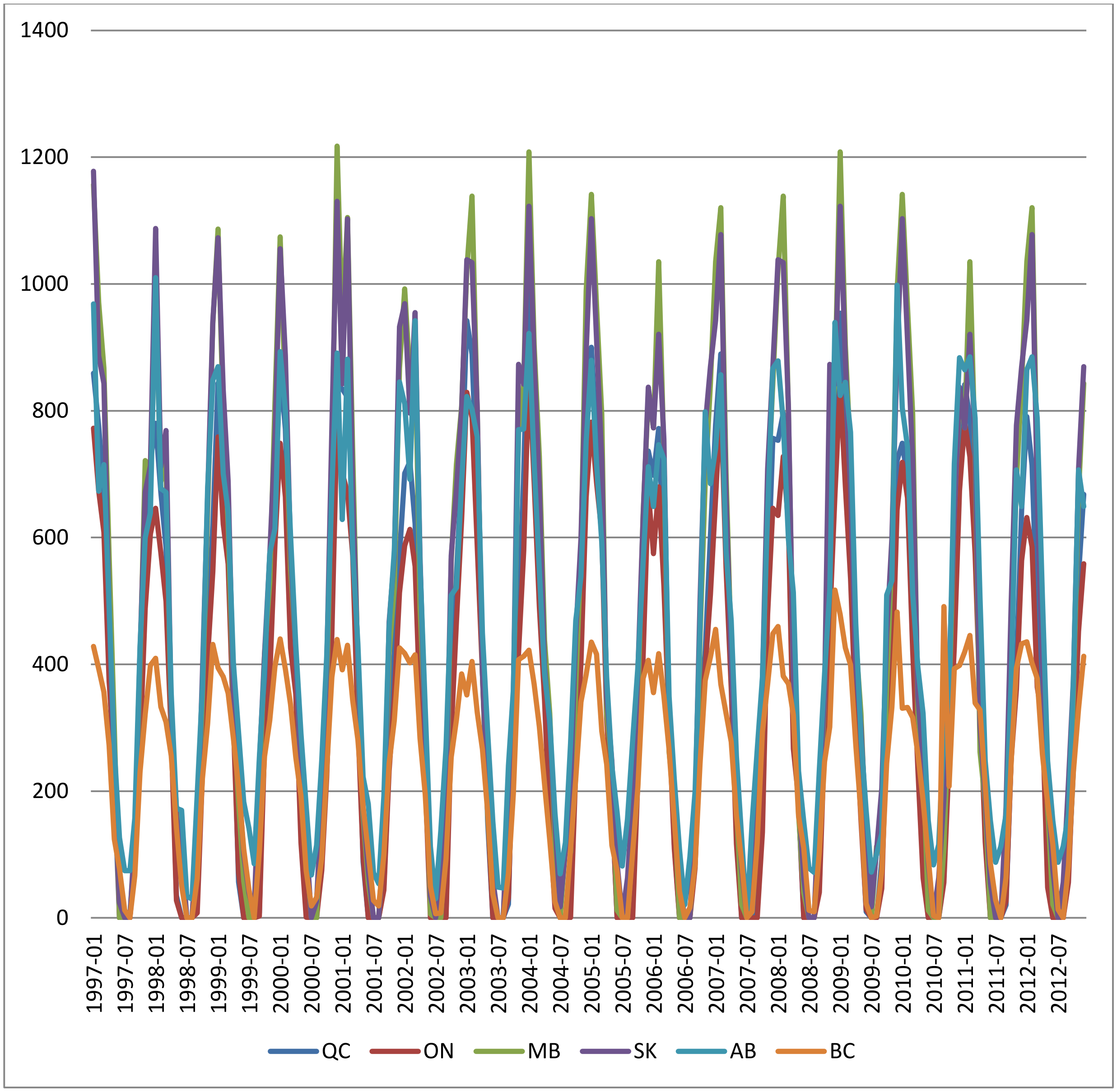

Figure 3: Monthly Heating Degree Days between 1997 and 2012

Figure 4 shows the number of residential natural gas customers for eight provinces. Statistics Canada doesn’t provide data for residential natural gas in Prince Edward Island and Newfoundland. As we can see in the figure, the number of residential natural gas customers in Atlantic Canada is almost negligible. In 2012, there were approximately 10,000 residential natural gas customers in New Brunswick and 2,000 customers in Nova

Scotia[1], while Ontario had more than 3 million customers followed by Alberta, which had more than a million customers[2]. Since the number of residential natural gas customers in Atlantic Provinces is negligible compared to other provinces and at the same time there is not enough data for consumption in Atlantic Canada, this thesis only focuses on natural gas consumers in Western and Central Canadian provinces. These provinces cover more than 99 percent of Canada's residential natural gas customers.

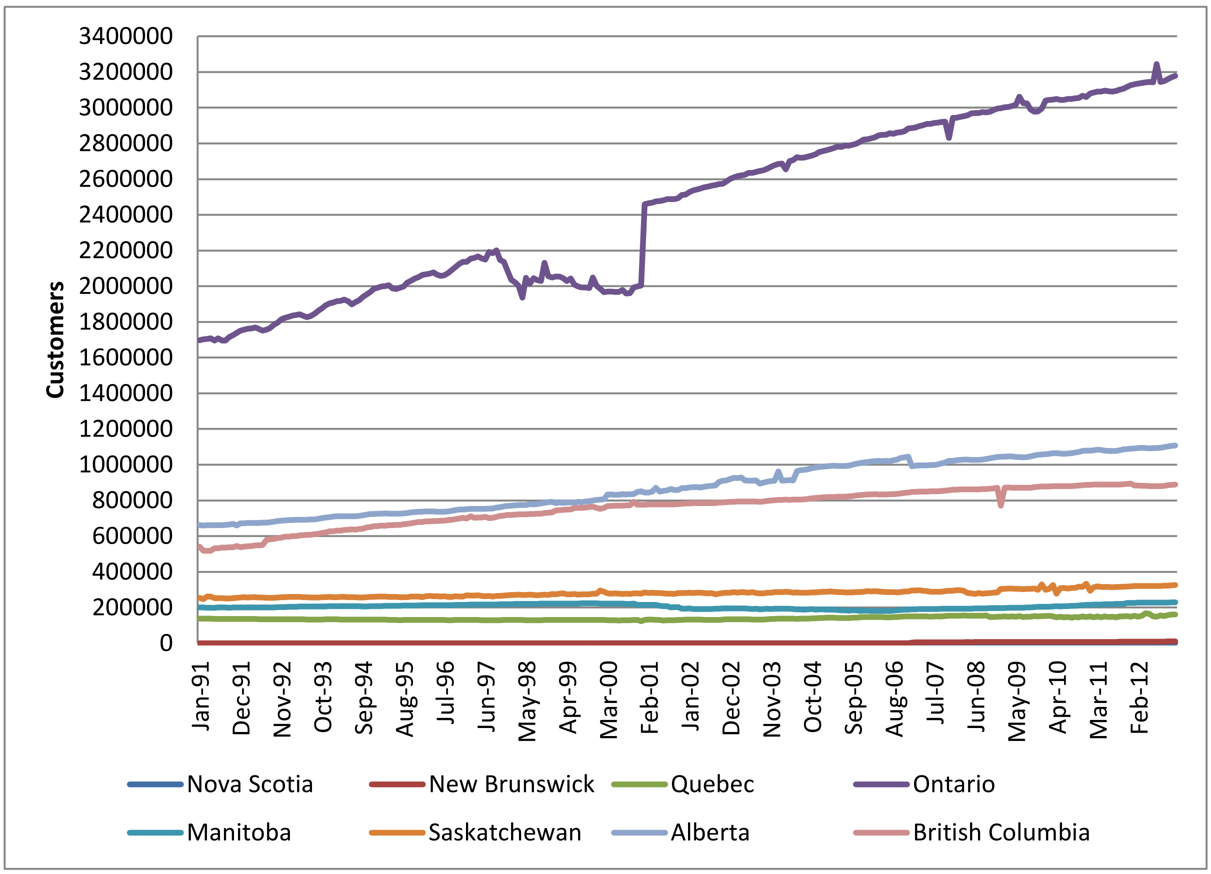

Figure 4: Residential natural gas customers

[1] Nova Scotia and New Brunswick both have small numbers of natural gas customers, which causes both of their graphs to lie very close to horizontal axis.

[2] Notice the striking departure from trend that appears for Ontario from 1997 to 2001. This could be a statistical artifact. It deserves further investigation.

Figure 5 shows monthly residential natural gas consumption per capita in Western Canada and Central Canada. As we can see, the highest natural gas consumption per capita is in Alberta followed by Saskatchewan. Ontario, Manitoba and British Columbia have almost the same level of natural gas consumption per capita. Quebec has the lowest level of per capita natural gas consumption. All the provinces experience a narrow peak in winter months. Therefore, weather (hdd) is one of the main components in natural gas consumption. The natural gas consumption per capita has a significant gap between Alberta and Quebec. This may suggest that residents of Quebec use electricity for heating their houses during winter months.

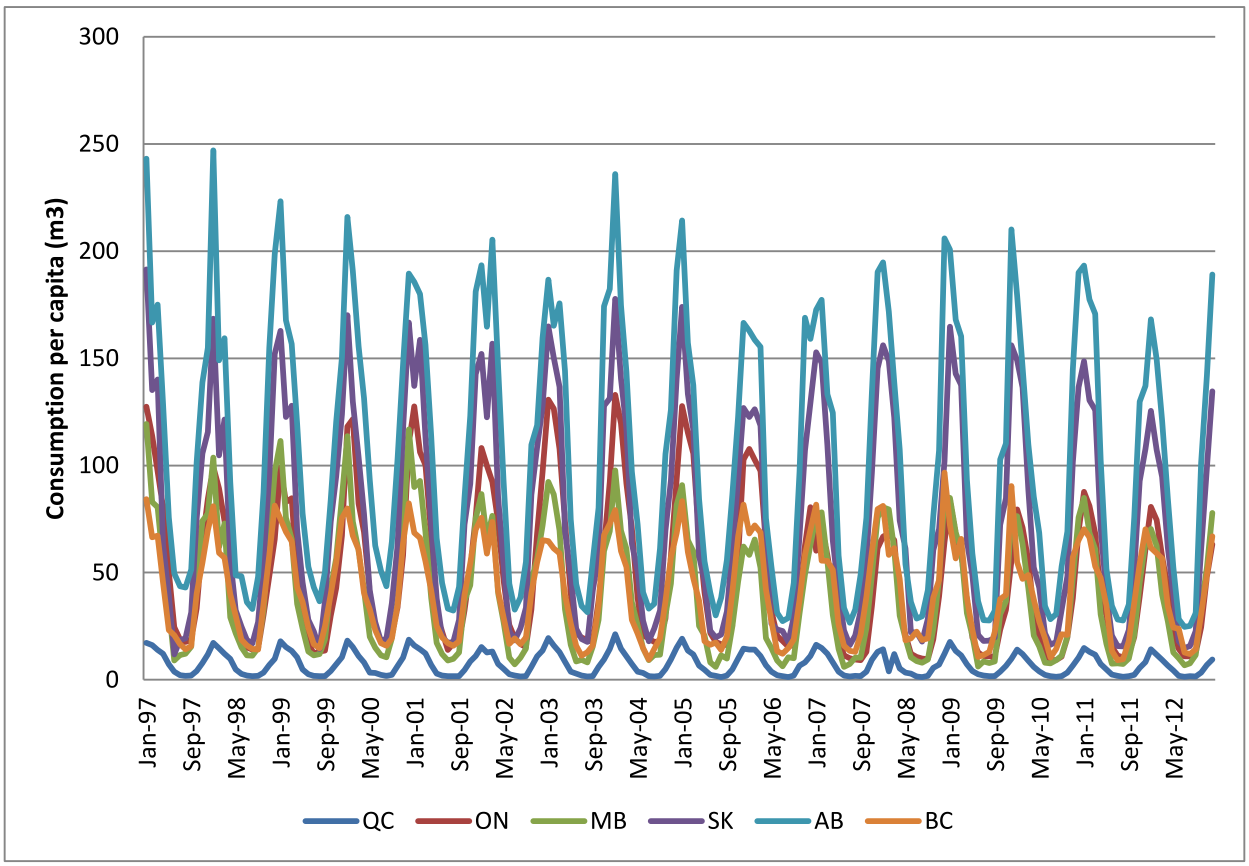

Figure 5: Natural gas consumption per capita between 1997 and 2012

Figure 6 shows the real prices of natural gas. Alberta has the lowest real prices of natural gas followed by Saskatchewan. Ontario, Manitoba and British Columbia have almost the same range of real prices. Quebec has the highest real prices of natural gas. Considering the consumption and real prices between provinces, we can infer that real prices of natural gas have a negative correlation with consumption per capita. This figure also shows that the prices of natural gas per Giga Joules (GJ) of consumption are higher during the summer months and lower during winter months.

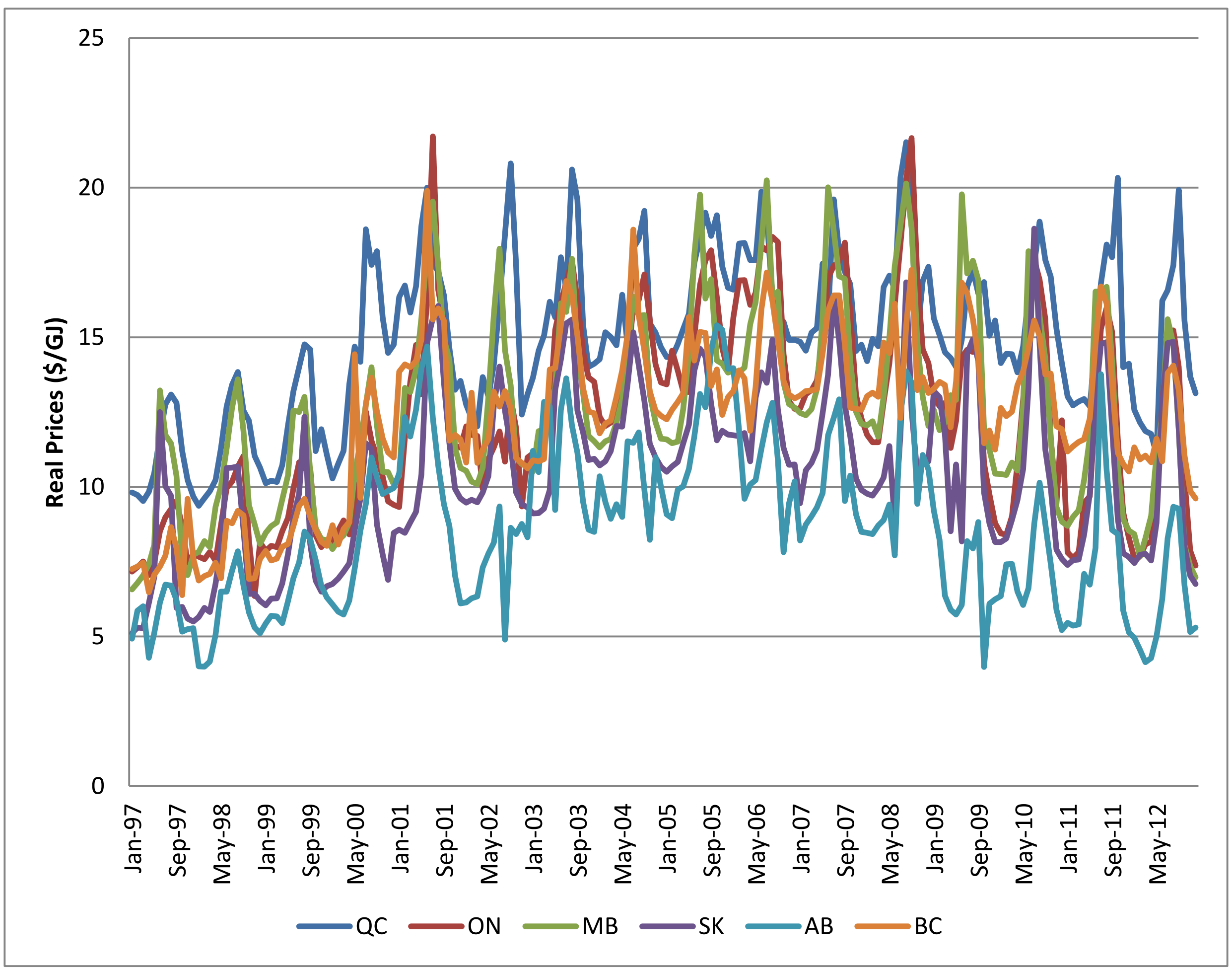

Figure 6: Residential natural gas prices between 1997 and 2012

Figure 7 shows the real electricity prices for Western and Central Canada. The real electricity prices are not fluctuating as much as real natural gas prices. Quebec has the lowest electricity prices while it has the highest real natural gas prices. Price of the energy sources is one of the key factors in consumers' demand. As a result, in Quebec the residential natural gas consumption per capita is lower than in other provinces. Electricity prices are relatively low in Quebec, Manitoba and British Columbia.

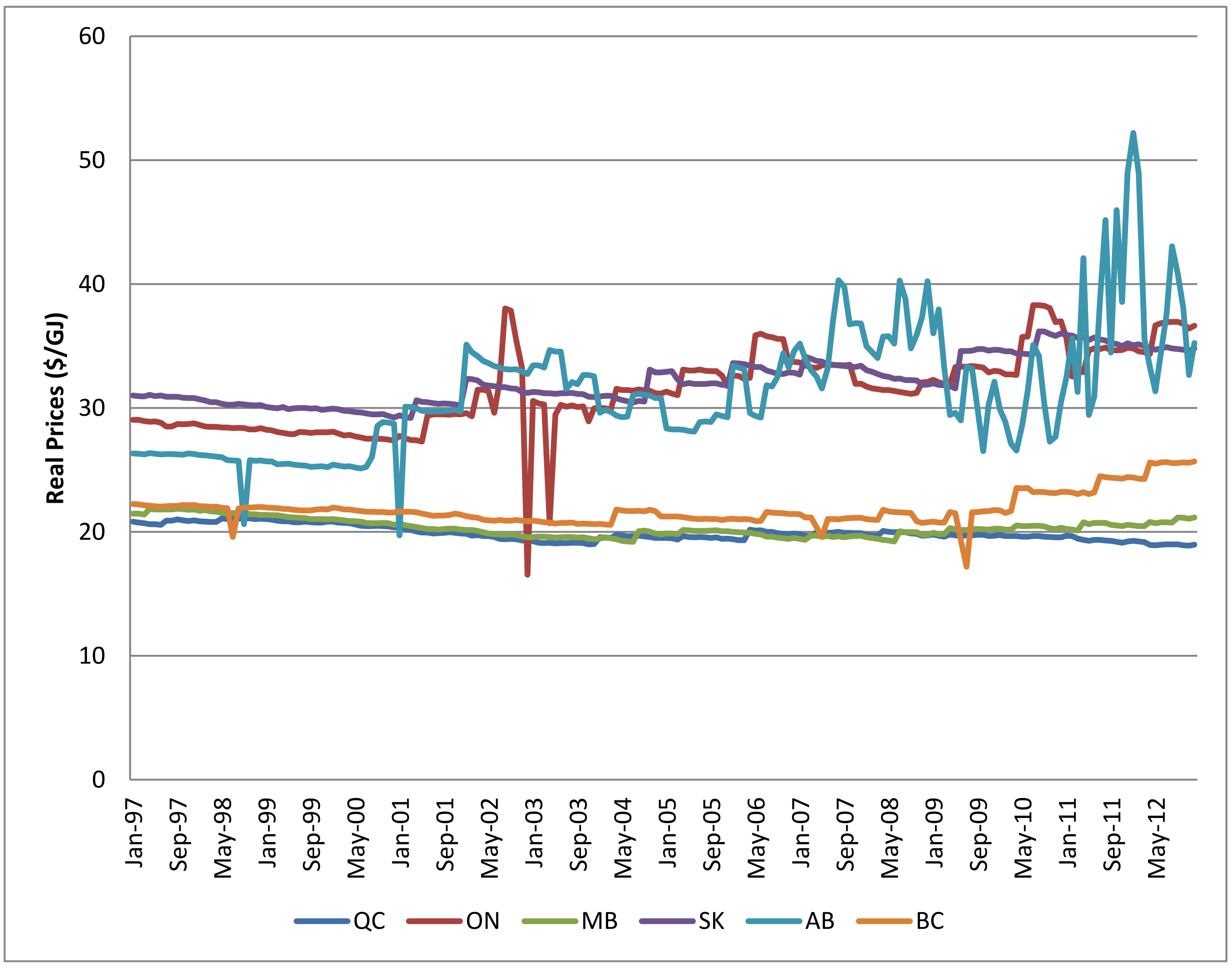

Figure 7: Electricity prices between 1997 and 2012

Table 3: Summary of the data averages between 1997 and 2012 across provinces

Province	Average Real Natural Gas Price ($/GJ)	Average Real Electricity Price ($/GJ)	Average Relative Prices (PNG/PE)	Average Annual HDD	Average of median annual real wages ($)	Average Annual Residential Natural Gas Consumption per Capita (Cubic meter)
QC	14.95	19.90	0.75	4019	34979	87
ON	12.29	31.48	0.39	3455	39637	583
MB	12.52	20.35	0.61	5476	33393	481
SK	10.37	32.22	0.32	5579	35923	909
AB	8.54	31.29	0.27	5360	40769	1255
BC	12.21	21.84	0.56	2798	37875	495

Table 3 is derived from the real term monthly data. It shows the averages of the real term variables on annual basis between 1997 and 2012. The last column contains the annual average consumption per capita for each province. Alberta has the highest residential natural gas consumption per capita followed by Saskatchewan. The per capita consumption of natural gas in these provinces more than 10 times exceeds that of Quebec. Comparing the real average prices and also the relative prices, we can see why residents of Alberta have more incentives to use natural gas compared to residents of Quebec. The average real-term natural gas price in Quebec is 75 percent higher than in Alberta. Therefore, the real natural gas prices have direct effect on consumption per capita. On top of that, the average real electricity price in Quebec is 36 percent cheaper than that of Alberta. Therefore, the low prices of electricity in Quebec have an indirect effect on lowering the natural gas consumption by substituting it with electricity sources.

As we can see, both natural gas prices and electricity prices have a strong effect on natural gas demand. Although the direct effect of natural gas prices is a stronger determinant of natural gas consumption compared to electricity, for better understanding of the consumption through prices we have shown the relative price of natural gas to electricity for the same unit of consumption. The lower the relative price is, the higher the consumption per capita.

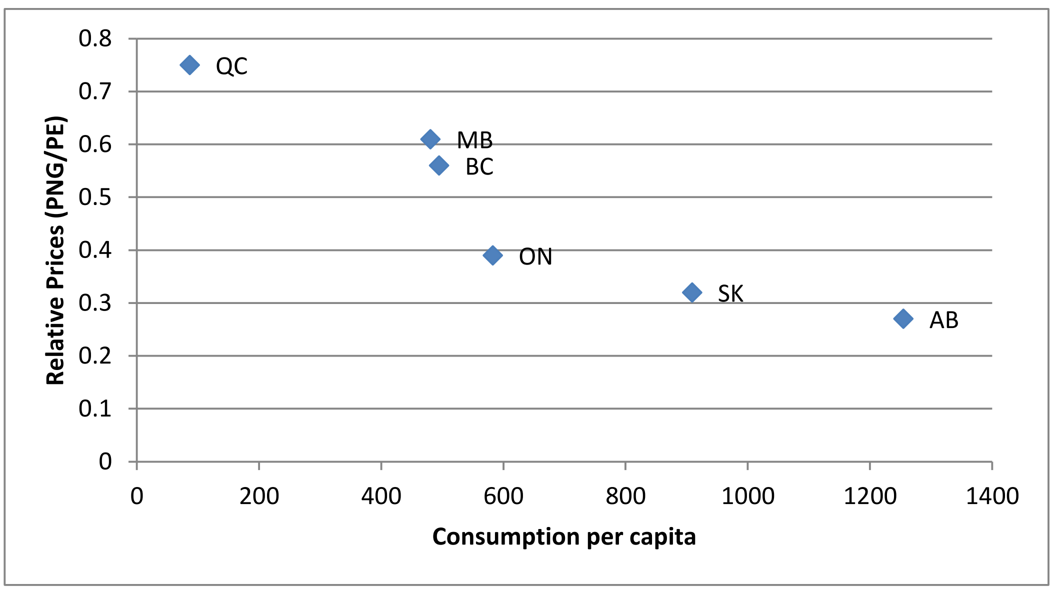

Figure 8: Relative prices and consumption per capita of natural gas by province

As we can see in the table, the average of relative prices in Alberta is the lowest one at 0.27. This means that for a given level of electricity consumption, if Albertans use natural gas, they should only pay 27 percent as much if they had to heat their houses by electricity. This average relative price is the highest in Quebec at 0.75, which has the lowest consumption per capita of residential natural gas. Highlighting all the relative prices, we can see Saskatchewan has the second lowest relative prices and also the second highest natural gas consumption per capita. Ontario, British Columbia and Manitoba ranked 3rd to 5th when they are compared for their low relative prices and they have exactly same ranking in residential natural gas consumption per capita. Comparing the per capita residential natural gas consumption in British Columbia and Manitoba, we can see these 2 provinces have almost the same amount of consumption, while the average relative price in BC is 5 percent cheaper than that of Manitoba. This mainly happens as a result of weather factor. Therefore, the suppliers of natural gas in Manitoba have more power in determining the prices for natural gas compared to their fellow BC suppliers.

Given that the relative price of natural gas (in comparison to electricity) is less than one in all provinces, why doesn't everyone use only natural gas? This is mainly due to two facts: First, electricity has a broader range of residential use. Thus, the natural gas is not a perfect substitute for electricity; Second, natural gas has pipeline installation cost.

CHAPTER 4 METHODOLOGY

In this paper we use the Autoregressive Distributed Lag (ARDL) model. We follow the notation from Heij, Boer, Franses, Kloek, & Van Dijk (2004).

The general form of an ARDL model with one variable is:

$$\varphi(L)y_t = \alpha + \beta(L)x_t + \varepsilon_t,$$

where $\varphi(L) = 1 - \sum_{k=1}^{p} \varphi_k L^k$ and $\beta(L) = \sum_{k=0}^{r} \beta_k L^k$. If the AR model is stationary, then all the roots of $\varphi(L) = 0$ are greater than 1 in absolute value. The change in x_t has a short-run (β_0) and long-run effect (λ) on y_t over time. The long-run multiplier shows the cumulative effect on the expected value of y_t coming from a permanent change in x_t, which is equal to $\lambda = \frac{\beta(1)}{\varphi(1)}$; since in stationary AR model $\varphi(1) \neq 0$, the long-run multiplier can be measured (Heij et al, 2004).

The ARDL model can be written in terms of first differences; it is called the Error Correction Model (ECM). The ECM for the one variable ARDL (1, 1) (p=1 and r=1) is:

$$\Delta y_t = \beta_0 \Delta x_t - (1 - \varphi)(y_{t-1} - \lambda x_{t-1} - \delta) + \varepsilon_t,$$

where $\delta = \alpha/(1 - \varphi)$ and $\lambda = (\beta_0 + \beta_1)/(1 - \varphi)$. The ECM for a stationary ARDL model shows that the change in the dependent variable is explained by the changes in explanatory variable and also through the deviation from the long-run equilibrium (Heij et al, 2004).

The general ECM of ARDL (p, q) is:

$$\Delta y_t = \beta_0 \Delta x_t - \varphi(1)(y_{t-1} - \lambda x_{t-1} - \delta) + \sum_{k=1}^{p-1} \varphi_k \Delta y_{t-k} + \sum_{k=1}^{r-1} \beta_k \Delta x_{t-k} + \varepsilon_t,$$

where $\varphi(1) = 1 - \sum_{k=1}^{p} \varphi_k$, $\delta = \alpha/\varphi(1)$ and the log-run multiplier is $\lambda = \frac{\beta(1)}{\varphi(1)}$ (Heij et al, 2004).

The standard assumptions for the ARDL model include stationarity of the regressors and dependent variable (Heij et al, 2004). If the variables are non-stationary, the usual solution is to use a model with several equations, namely, VAR (vector autoregressive model) or VECM (vector error-correction model). However, Pesaran, Shin and Smith (2001) proved that it is possible to apply the ARDL specification to possibly nonstationary data. Below we give a brief introduction to the VAR and VECM models (following Heij et al (2004)) and explain the Pesaran-Shin-Smith method, which is used in this paper.

Consider a two-variable Vector Autoregressive model (VAR):

$$\begin{pmatrix} y_{t1} \\ y_{t2} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{pmatrix} \begin{pmatrix} y_{t1-1} \\ y_{t2-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}, \qquad \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \sim IID\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} \right)$$

VAR(1) model for m variables can be written in matrix form as:

$$Y_t = \alpha + \Phi Y_{t-1} + \varepsilon_t, \;\; \varepsilon_t \sim IID(0, \Omega),$$

where Y_t is the m x 1 vector of variables, α is the m x 1 vector of constants, Φ is the m x m matrix of AR coefficients, and Ω is the m x m matrix of disturbance terms. When m>1, in order to have the stationary time series, all the eigenvalues of matrix Φ should be inside the unit circle.

This model can be extended to the order p:

$$Y_t = \alpha + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \cdots + \Phi_{\mathrm{p}} Y_{t-p} + \varepsilon_t, \ \ \varepsilon_t \sim IID(0, \Omega).$$

The stationarity condition for VAR(p) is that when det $(\Phi(\mathrm{z}))$ has all of its roots outside the unit circle, where $\Phi(\mathrm{z}) = \mathrm{I} - \Phi_1 \mathrm{z} - \cdots - \Phi_{\mathrm{p}} z^p$.

The VAR(1) model could be converted to the Vector Error Correction Model (VECM). For VAR(1) model, with $\alpha = (I - \Phi)\,\mu$, ΔY_t could be obtained:

$$\Delta Y_t = Y_t - Y_{t-1} = (I - \Phi)\mu + \Phi Y_{t-1} + \varepsilon_t - Y_{t-1}$$

Simplifying this equation, the Vector Error Correction Model is:

$$\Delta Y_t = (\Phi - \mathrm{I})(Y_{t-1} - \mu) + \varepsilon_t$$

The Vector Error Correction Model (VECM) for p lags can be written as follows:

$$\Delta Y_t = -\Phi(1)(Y_{t-1} - \mu) + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-1} + \varepsilon_t,$$

where μ is the means vector and $\Gamma(\mathrm{z}) = 1 - \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-1}$ is an m x m polynomial matrix of order (p-1). The equation shows $-\Phi(1)$ is correcting the deviation of

Y_{t-1} from vector of means. In VECM all the variables are affected by the correction process (Heij et al, 2004).

In order to find the true lag order (p) we can minimize either Akaike Information Criterion (AIC) or Schwarz Information Criterion (SIC). The VECM with m variables can be written as:

$$\Delta Y_t = \Phi(1)\mu + \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + \cdots + \Gamma_{p-1} \Delta y_{t-p+1}, \;\; t = p+1, \dots, n$$

If all the individual variables of Y_t $(\mathrm{m \times 1})$ in the VECM model are integrated of either order of 0 or 1, the rank of matrix Π could help the researcher to decide which model is appropriate for Y_t (VAR, VECM, or the first difference model). If the variables are all stationary, then the matrix has a full rank ($rank\Pi = \mathrm{m}$) and VAR model is applicable. If all of the variables are non-stationary and not cointegrated ($rank\Pi = 0$), then the first difference should be applied. However, when $rank\Pi$=r, where 0 < r < m, then there exist r different cointegration relations and the VECM model should be estimated. The VECM models both short-run effects and long-run (cointegration) effects. The true value of r could be investigated by applying the Johansen trace test for incremental values of r until the null hypothesis of at most r cointegration relations is not rejected (Heij et al, 2004).

In this paper we test the existence of long-run relationships between the dependent variables and the regressors in an ARDL model using bounds testing approach by Pesaran et al (2001). It offers a one-equation robust alternative specification to the multi-equation VECM. For many time series in economics, it is difficult to establish the exact order of integration. P-values of conventional tests for unit root depend on the number of lags and quite often fluctuate around the conventional critical values. The method proposed by Pesaran et al (2001) allows us to estimate both short-run and long-run relations between variables in the absence of reliable information about the order of integration. The authors obtained critical values for the cases of I(0) and I(1), which are respectively known as lower bound and upper bound. The lower bound shows the case where all variables are integrated of order 0 and the upper bound represents the case where all variables are of order 1. In this method (the bounds testing approach), if the F-statistic is above the upper bound, then the null hypothesis of no cointegration between variables will be rejected. In contrast, if the F-statistic is less than the lower bound, the null-hypothesis is not rejected. If the F-statistic is between lower bound and upper bound, then the test for cointegration between variables is inconclusive, given that the order of integration of individual variables is unknown. If the test shows a significant cointegration, the optimal ARDL specification could be selected with the help of Akaike Information Criterion (AIC) or Schwarz Information Criterion (SIC) (Bernstein & Madlener, 2011). In brief, Pesaran et al (2001) showed that only when the results are inconclusive we need to find the integration order of individual variables. Otherwise, their bounds testing approach could explain a reliable relationship between variables without knowing the integration order of each individual variable (Pesaran, Shin, & Smith, 2001).

In this paper, we estimate the long-run demand elasticity of natural gas in Western and Central Canadian provinces using the Cobb-Douglas specification:

$$G_t = \beta_0 \exp(\beta_1 t)\, P_{e,t}^{\beta_2} P_{ng,t}^{\beta_3} Y_t^{\beta_4} HDD_t^{\beta_5}$$

where G_t is consumption per capita, t is time trend, $P_{e,t}$ is electricity prices, $P_{ng,t}$ is natural gas prices, Y_t is income, and βs are coefficients.

Let $g_t = \ln(G_t)$, $y_t = \ln(Y_t)$, $p_{ng,t} = \ln(P_{ng,t})$, $p_{e,t} = \ln(P_{e,t})$, and $hdd_t = \ln(HDD_t + 1)$.

First, we estimate by OLS the conditional ECM similar to the specification in Bernstein and Madlener (2011):

$$\Delta g_t = c + dt + \phi_1 g_{t-1} + \phi_2 p_{e,t-1} + \phi_3 p_{ng,t-1} + \phi_4 Y_{t-1} + \phi_5 hdd_{t-1} + \sum_{i=1}^{k-1} \varphi_{1,i} \Delta g_{t-i} + \sum_{i=0}^{l-1} \varphi_{2,i} \Delta p_{e,t-i} + \sum_{i=0}^{m-1} \varphi_{3,i} \Delta p_{ng,t-i} + \sum_{i=0}^{n-1} \varphi_{4,i} \Delta y_{t-i} + \sum_{i=0}^{o-1} \varphi_{5,i} \Delta hdd_{t-i} + u_t\,,$$

where c is a drift, k, l, m, n and o are numbers of lags, ϕ’s are long term multipliers and φ′s are short-run coefficients. (Bernstein & Madlener, 2011) The optimal model is selected based on the Schwartz Information Criterion (SIC) and the requirement of no serial correlation in residuals.The bounds approach by Pesaran et al (2001) is applied to test for the absence of a relationship in levels between g_t and y_t, $p_{ng,t}$, $p_{e,t}$, and hdd_t.

H_0: $\phi_1 = \phi_2 = \phi_3 = \phi_4 = \phi_5 = 0$ (no relationship in levels),

H_a: $\phi_1 \neq 0, or\ \phi_2 \neq 0, or\ \phi_3 \neq 0, or\ \phi_4 \neq 0, or\ \phi_5 \neq 0$.

After comparing the F-statistic with critical values associated with upper bound and lower bound provided in Pesaran et al (2001), we can decide whether to reject the null hypothesis of no level relationship or not, as long as the test-statistic does not lie between the upper bound and lower bound, which gives an inconclusive result.

Then if there is a significant long-run equilibrium relationship/cointegration between variables, we can model consumption as a function of prices, income, and HDD using an ARDL specification in levels:

$$g_t = \alpha_c + \alpha_d . t + \sum_{i=1}^{k} \alpha_{1,i} . g_{t-i} + \sum_{i=0}^{l} \alpha_{2,i}\, p_{e,t-i}$$
$$+ \sum_{i=0}^{m} \alpha_{3,i} . p_{ng,t-i} + \sum_{i=0}^{n} \alpha_{4,i} . y_{t-i} + \sum_{i=0}^{o} \alpha_{5,i} hdd_{t-i} + w_t$$

W_t is an error term and k, l, m, n and o are numbers of lags of the variables.

$$\beta_0 = \frac{\alpha_c}{1 - \sum_{i=1}^{k} \alpha_{1,i}},$$

$$\beta_1 = \frac{\alpha_d}{1 - \sum_{i=1}^{k} \alpha_{1,i}},$$

$$\beta_j = \frac{\sum_{i=0}^{q} \alpha_{j,i}}{1 - \sum_{i=1}^{k} \alpha_{1,i}},$$

where j = {2, 3, 4, 5} and q = {k, l, m, n, o} and β_js are the long-run slope coefficients (Bernstein & Madlener, 2011).

CHAPTER 5 EMPIRICAL RESULTS

In this section, we discuss our estimated results of the long-run demand elasticity for natural gas. As mentioned in the methodology section, the first step is making sure that all of the variables are either level stationary or first difference stationary. We applied the augmented Dickey-Fuller unit root test and our results show that all the variables for each province are either integrated of order 0 or 1. The unit root test tables are available in the appendix (Tables 5 – 10).

We have chosen the best specification (best number of lags in the ARDL model for each variable) for each province based on SIC. Choosing the best specification for monthly data was the most challenging (and time consuming) part of this research paper. Because monthly data has seasonality and 12 extra lags may be required to properly model it, for this research we had to examine at least 75 different specifications for each of the provinces to get a general idea of the best lag specification. Most of the previous studies have worked with annual data, and therefore, they do not encounter the seasonality effect. So their variables do not need many lags in the ARDL model. For example the best number of lags for consumption per capita ranges between 3 in Ontario and 13 in Saskatchewan and the heating degree days lags ranges between 1 in Saskatchewan and 11 in British Columbia. The AIC is not consistent in suggesting the best lag specification. Therefore, we relied on the SIC to find the best lag specification. The suggested results of lags based on SIC for different lags of each variable and also the chosen ARDL model are given in the appendix (Table 11). None of the ARDL specifications has the serial dependence of the error terms (Table 14 in Appendix).

We applied the Johansen's test of cointegration to see if the variables in the ARDL model are cointegrated of order 1. We found that the chosen specifications of all provinces are cointegrated of order 1. The only exception is the case of consumption per customer in Manitoba, in which case the model was found to be cointegrated of order 2. The tables 12 and 13 of Johansen's test results are given in the appendix.

In the next step, we calculated the error correction model for the provinces. Then we performed the bounds test from Pesaran et al (2001) to see if there exists a long-run relationship (Table 15 in Appendix). The F-test rejects the null hypothesis of no cointegration at 1 percent level for all provinces, except Ontario. In Ontario, the F-statistic shows there are no long-run relationship in levels at 1 percent and 5 percent level for the specification in which the dependent variable is consumption per capita. The bounds test results for Ontario also show that if the dependent variable is consumption per customer, there is no long-run relationship at the 1 percent level, and at the 5 percent level the F-statistic lies between the upper bound and lower bound. Therefore, at the 5 percent level we cannot confirm or reject the null hypothesis.

Therefore, in this paper the ARDL model in levels is available for Quebec, Manitoba, Saskatchewan, Alberta and British Columbia. Table 16 in Appendix reports the estimated coefficients of ARDL models, their significance and standard errors. Based on Table 16, the long-run demand elasticity of natural gas is calculated, which is shown in Table 4. Most previous studies estimated the natural gas demand elasticity based on the annual data. However, since our data are monthly, the estimated coefficients are expected to be more inelastic, when it is compared with other studies. For example, Joutz et al (2008) and Bernstein and Griffin (2006) both estimated the long-run demand elasticity of natural gas in the United States. To contrast, the short periods used in our study provides less latitude for substitution. Since the data in the first study are monthly and in the second study are annual, the long-run elasticity is considerably different. Joutz et al (2008) estimated that the long-run natural gas demand elasticity with respect to prices is -0.18 while that of Bernstein and Griffin (2006) is twice as much at -0.36.

Table 4: Long-run demand elasticity of natural gas in different provinces

Variable	Quebec		Manitoba		Saskatchewan		Alberta		British Columbia	
	Consumption per capita	Consumption per customer	Consumption per capita	Consumption per customer	Consumption per capita	Consumption per customer	Consumption per capita	Consumption per customer	Consumption per capita	Consumption per customer
natural gas prices	-0.092	-0.158	-0.192	-0.133	0.189	0.157	0.001	-0.063	-0.148	-0.197
electricity prices	-0.886	-1.802	-0.781	-2.279	0.651	0.245	0.006	0.018	-0.652	-0.564
income	-1.344	-0.492	0.934	0.445	0.426	0.563	-0.648	-0.358	-0.466	-0.418
heating degree days	0.260	0.257	0.063	0.079	0.150	0.134	0.138	0.128	0.226	0.217

The long-run demand elasticity for natural gas with respect to its own prices is very inelastic for all provinces. When the dependent variable is consumption per capita the long-run demand elasticity of natural gas with respect to its own price ranges between -0.192 in Manitoba and 0.189 in Saskatchewan. Therefore, in the long run, a 1 percent increase of the natural gas prices will decrease the consumption per capita by 0.19 percent in Manitoba and will increase the consumption per capita by 0.19 percent in Saskatchewan. The long-run demand elasticity for natural gas with respect to its own prices in Alberta is 0.001, which shows that in the long run, the residents of Alberta do not adjust their consumption of natural gas in response to the natural gas price changes. This is mainly due to very low level of residential natural gas prices in Alberta within the price range examined. If the dependent variable is consumption per customer, in the long run, a 1 percent increase in natural gas prices in Alberta will decrease the consumption per customer by 0.06 percent. In contrast, in British Columbia, where the winters are considerably warmer, when the natural gas prices increase by 1 percent, the consumption per customer decreases by 0.20 percent. In Quebec, if the natural gas prices increase by 1 percent, the customers decrease their consumption of natural gas by 0.16 percent.

In all provinces, the long-run demand elasticity for natural gas with respect to electricity prices is more elastic than the demand elasticity of natural gas with respect to its own price. Quebec has the most elastic demand elasticity of natural gas with respect to electricity prices. If electricity prices increase by 1 percent, natural gas customers in

Quebec will decrease their natural gas consumption by 1.8 percent. The long-run demand elasticity for natural gas with respect to electricity prices is insignificant in Quebec. If the dependent variable is consumption per capita instead, then a 1 percent increase in electricity prices will decrease the per capita consumption by 0.89 percent. This difference between coefficients is explained by the huge gap between the Quebec population and the number of natural gas customers. The number of natural gas customers in Quebec fluctuated between 130,000 to 170,000 with an upward trend while the population grew steadily from 7.2 million until 8.1 million during the data interval. The demand elasticity for natural gas with respect to electricity prices is very inelastic and positive in Alberta. In Alberta, if the electricity prices increase by 1 percent, the per capita natural gas consumption increases by 0.006 percent. In Saskatchewan, a 1 percent increase in electricity prices will increase the per capita natural gas consumption by 0.65 percent.

The long-run demand elasticity for natural gas with respect to income is very different among provinces. The demand elasticity for natural gas with respect to income is statistically insignificant. In Manitoba and Saskatchewan, the higher income (real wages) is associated with a higher consumption in the long run. In Quebec, Alberta, and British Columbia as income increases, the long-run consumption per capita decreases. The natural gas demand elasticity with respect to income is inelastic for all specifications, except in Quebec where the dependent variable is consumption per capita. Note that the income coefficients are significant only for Quebec (Table 16).

Heating degree days is the most important variable. The long-run demand elasticity for natural gas with respect to heating degree days is very inelastic for all provinces. Since Prairie Provinces (Manitoba, Saskatchewan, and Alberta) are colder than Quebec and British Columbia, they have a more inelastic natural gas demand with respect to climate. If heating degree days increase by 1 percent in Manitoba, the consumption per capita increase only by 0.06 percent; in contrast the consumption per capita in Quebec increases by 0.26 percent. The long-run demand (consumption per capita) elasticity for natural gas with respect to heating degree days in Saskatchewan, Alberta, and British Columbia are 0.15, 0.14, and 0.23 respectively. These magnitudes are considerably smaller than other studies. Bernstein and Madlener (2011) estimated the OECD's long-run demand elasticity with respect to heating degree days at 1.35. Their estimation for the long-run demand elasticity for natural gas in the United States is 0.74, which is much more elastic than our results. Comparing our results with other studies, we can infer that the bigger ranges of average temperature associate with the more inelastic coefficients.

The time trend shows that both consumption per capita and consumption per customer decreased gradually during the time interval (1991-2012). This might be due to improvement in technologies that optimize consumption, efficient furnaces, double glazed windows with energy efficiency certifications, etc. However, the estimators are significant only in two specifications (Table 16).

We also have calculated the specifications with sales taxes. The results are very similar to the discussed specifications and there is no significant difference between the corresponding coefficients. Therefore, we have not reported the results in this paper.

CHAPTER 6 CONCLUSION

In this paper, we estimated the long-run demand elasticity for natural gas with respect to its own prices, electricity prices and heating degree days using an ARDL model. Our results show that the per capita natural gas consumption is very inelastic with respect to the natural gas prices and also the temperature factor (heating degree days) for Western Canada and Quebec. Our ARDL model could explain 95 percent to 98 percent of variation in our data for consumption per capita for different provinces while the residuals are not serially correlated and there is only 1 cointegration relationship between the variables for each province. The bounds test approach confirms that the ARDL model is valid in levels for Western Canada and Quebec.

Since our data are monthly, the coefficients we obtained are very inelastic and they are different from other studies, which usually estimate the elasticity of demand based on annual data. The price inelasticity for monthly data is striking and deserves further investigation. At the same time our long-run price elasticity coefficients are comparable to those obtained by Nilson et al (2008), Joutz et al (2008), and Payne et al (2011). Our results for elasticity of demand with respect to weather differ even more from all other studies. This is because changes in the average temperature in monthly data are much more than the changes of the average temperature in annual data, which were used in other studies. Therefore, our results show that demand is very inelastic with respect to heating degree days. Our natural gas demand coefficients are not as inelastic with respect to the weather factor in other studies, because they are using annual data.

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APPENDIX

Table 5: Unit root test for Quebec at 1 percent significance level

variable	number of lags: level	number of lags: first difference	t-statistics	p-value	trend p-value	stationarity type
electricity prices	0		-1.943	0.628	0.147	first difference
		0	-14.615	0.000	0.920	
consumption per capita	11		-2.723	0.229	0.044	first difference
		10	-15.712	0.000	0.890	
consumption per customer	11		-2.429	0.364	0.048	first difference
		10	-15.280	0.000	0.951	
heating degree days	11		-3.157	0.097	0.851	first difference
		10	-20.871	0.000	0.965	
natural gas prices	10		-1.203	0.906	0.225	first difference
		9	-10.634	0.000	0.018	
income	0		-4.402	0.003	0.000	level

Table 6: Unit root test for Ontario at 1 percent significance level

variable	number of lags: level	number of lags: first difference	t-statistics	p-value	trend p-value	stationarity type
electricity prices	0		-9.385	0.000	0.000	level
consumption per capita	12		-1.741	0.729	0.291	first difference
		11	-5.196	0.000	0.872	
consumption per customer	12		-1.988	0.604	0.117	first difference
		11	-5.090	0.000	0.832	
heating degree days	11		-3.476	0.045	0.410	first difference
		10	-20.772	0.000	0.816	
natural gas prices	12		-1.339	0.875	0.376	first difference
		11	-4.319	0.004	0.094	
income	0		-5.505	0.000	0.000	level

Table 7: Unit root test for Manitoba at 1 percent significance level

variable	number of lags: level	number of lags: first difference	t-statistics	p-value	trend p-value	stationarity type
electricity prices	0		-0.940	0.948	0.273	first difference
		0	-15.750	0.000	0.051	
consumption per capita	11		-2.344	0.408	0.070	first difference
		10	-13.808	0.000	0.467	
consumption per customer	11		-2.473	0.341	0.038	first difference
		10	-13.914	0.000	0.934	
heating degree days	11		-2.825	0.190	0.780	first difference
		11	-13.049	0.000	0.546	
natural gas prices	0		-6.213	0.000	0.431	level
income	0		-4.777	0.001	0.000	level

Table 8: Unit root test for Saskatchewan at 1 percent significance level

variable	number of lags: level	number of lags: first difference	t-statistics	p-value	trend p-value	stationarity type
electricity prices	0		-3.595	0.033	0.001	first difference
		0	-14.588	0.000	0.673	
consumption per capita	11		-2.151	0.513	0.049	first difference
		10	-15.448	0.000	0.282	
consumption per customer	11		-2.222	0.474	0.030	first difference
		10	-15.222	0.000	0.433	
heating degree days	11		-2.672	0.250	0.594	first difference
		10	-17.693	0.000	0.782	
natural gas prices	12		-0.897	0.953	0.072	first difference
		11	-6.960	0.000	0.007	
income	0		-4.368	0.003	0.000	level

Table 9: Unit root test for Alberta at 1 percent significance level

variable	number of lags: level	number of lags: first difference	t-statistics	p-value	trend p-value	stationarity type
electricity prices	0		-6.038	0.000	0.000	level
consumption per capita	10		-3.398	0.055	0.006	first difference
		10	-12.681	0.000	0.810	
consumption per customer	10		-3.166	0.095	0.011	first difference
		10	-12.474	0.000	0.881	
heating degree days	11		-2.668	0.251	0.936	first difference
		10	-18.436	0.000	0.679	
natural gas prices	0		-3.815	0.018	0.797	first difference
		0	-14.658	0.000	0.551	
income	0		-4.138	0.007	0.000	level

Table 10: Unit root test for British Columbia at 1 percent significance level

variable	number of lags: level	number of lags: first difference	t-statistics	p-value	trend p-value	stationarity type
electricity prices	3		-1.059	0.932	0.044	first difference
		2	-12.198	0.000	0.081	
consumption per capita	11		-2.695	0.240	0.064	first difference
		11	-12.034	0.000	0.770	
consumption per customer	12		-2.251	0.458	0.097	first difference
		11	-12.190	0.000	0.862	
heating degree days	12		-1.981	0.607	0.957	first difference
		10	-25.397	0.000	0.951	
natural gas prices	0		-3.910	0.013	0.098	first difference
		12	-4.361	0.003	0.032	
income	0		-4.372	0.003	0.000	level

Table 11: ARDL model selected by SIC

	consumption per capita	natural gas prices	electricity prices	income	heating degree days
Quebec	6	1	1	1	10
Ontario	3	1	3	1	11
Manitoba	4	0	0	1	11
Saskatchewan	13	2	2	0	1
Alberta	5	1	4	0	11
British Columbia	10	2	0	0	11

Table 12: Johansen's cointegration test with trend for provinces

Table A8: Johansen's test with trend for provinces

Province	lags	dependent variable	max rank	trace statisitic	5 percent critical value	cointegration order
QC	10	Consumption per capita	0	140.0003	77.74	1
			1	44.1833*	54.64	
		Consumption per customer	0	133.3887	77.74	1
			1	40.0849*	54.64	
ON	11	Consumption per capita	0	95.1095	77.74	1
			1	41.8512*	54.64	
		Consumption per customer	0	90.6283	77.74	1
			1	41.0483*	54.64	
MB	11	Consumption per capita	0	106.502	77.74	1
			1	50.1030*	54.64	
		Consumption per customer	0	120.8072	77.74	2
			1	67.7708	54.64	
			2	23.9603*	34.55	
SK	13	Consumption per capita	0	82.1934	77.74	1
			1	53.6642*	54.64	
		Consumption per customer	0	89.8841	77.74	1
			1	54.3237*	54.64	
AB	11	Consumption per capita	0	86.4032	77.74	1
			1	44.9578*	54.64	
		Consumption per customer	0	79.2763	77.74	1
			1	41.3673*	54.64	
BC	11	Consumption per capita	0	133.0085	77.74	1
			1	43.9655*	54.64	
		Consumption per customer	0	128.9505	77.74	1
			1	44.8661*	54.64	

Table 13: Johansen's test: cointegrating vectors

Province	lags	dependent variable	rank	electricity prices	natural gas prices	income	heating degree days	trend
QC	10	Consumption per capita	1	-0.660 (0.874)	0.473 (0.146)	4.714 (1.494)	-0.800 (0.072)	-0.002
		Consumption per customer	1	-0.005 (1.082)	0.651 (0.181)	4.471 (1.842)	-0.943 (0.089)	-0.002
ON	11	Consumption per capita	1	-4.598 -(1.043)	-0.109 -(0.178)	18.3 -(3.612)	-1.276 -(0.208)	0.004
		Consumption per customer	1	-4.416 -(1.188)	0.044 -(0.212)	17.783 -(4.219)	-1.412 -(0.241)	0.005
MB	11	Consumption per capita	1	-5.862 (1.747)	-0.260 (0.251)	6.434 (2.038)	-0.886 (0.124)	-0.007
		Consumption per customer (the dependent variable is omitted for rank 2)	1	-1.908 (1.146)	-0.222 (0.164)	3.723 (1.341)	-0.528 (0.081)	-0.003
			2	1.000 .	0.075 (0.027)	-1.011 (0.262)	0.125 (0.018)	0.001
SK	13	Consumption per capita	1	-0.095 (2.147)	-0.713 (0.457)	-3.611 (3.511)	-0.182 (0.156)	0.008
		Consumption per customer	1	0.291 (0.555)	-0.644 (0.114)	-3.562 (0.872)	-0.154 (0.040)	0.008
AB	11	Consumption per capita	1	-0.316 (0.707)	-0.008 (0.145)	0.259 (1.109)	-0.393 (0.051)	0.002
		Consumption per customer	1	-0.564 (0.172)	0.109 (0.057)	-0.292 (0.702)	-0.603 (0.096)	0.003
BC	11	Consumption per capita	1	1.134 (0.116)	0.322 (0.034)	2.038 (0.261)	-0.330 (0.016)	-0.001
		Consumption per customer	1	1.018 (0.113)	0.366 (0.033)	1.813 (0.255)	-0.308 (0.016)	-0.001

Table 14: Test for serial correlation of error terms

Province	dependent variable	lags	chi2	df	Prob > chi2	serial correlation at 5 percent level
QC	Consumption per capita	10	13.557	10	0.1942	No
	Consumption per customer		11.972		0.2869	No
ON	Consumption per capita	11	12.271	11	0.3436	No
	Consumption per customer		12.831		0.3045	No
MB	Consumption per capita	11	11.318	11	0.417	No
	Consumption per customer		17.011		0.1076	No
SK	Consumption per capita	13	17.623	13	0.1724	No
	Consumption per customer		18.203		0.15	No
AB	Consumption per capita	11	18.234	11	0.0763	No
	Consumption per customer		19.042		0.0603	No
BC	Consumption per capita	11	18.228	11	0.0764	No
	Consumption per customer		17.724		0.0882	No

Table 15: Bounds test results for provinces

province	dependent variable	F-statistic	0.01		0.05		long-run relationship	
			I(0)	I(1)	I(0)	I(1)	1 percent level	5 percent level
QC	consumption per capita	15.67	4.4	5.72	3.47	4.57	Yes	Yes
	consumption per customer	13.68	4.4	5.72	3.47	4.57	Yes	Yes
ON	consumption per capita	3.33	4.4	5.72	3.47	4.57	No	No
	consumption per customer	3.75	4.4	5.72	3.47	4.57	No	Inconclusive
MB	consumption per capita	12.07	4.4	5.72	3.47	4.57	Yes	Yes
	consumption per customer	14.6	4.4	5.72	3.47	4.57	Yes	Yes
SK	consumption per capita	6.11	4.4	5.72	3.47	4.57	Yes	Yes
	consumption per customer	6.11	4.4	5.72	3.47	4.57	Yes	Yes
AB	consumption per capita	11.55	4.4	5.72	3.47	4.57	Yes	Yes
	consumption per customer	10.37	4.4	5.72	3.47	4.57	Yes	Yes
BC	consumption per capita	8.7	4.4	5.72	3.47	4.57	Yes	Yes
	consumption per customer	11.03	4.4	5.72	3.47	4.57	Yes	Yes

Table 16: ARDL specifications for provinces

Variable	lag	Quebec		Manitoba		Saskatchewan		Alberta		British Columbia	
		consumption per capita	consumption per customer	consumption per capita	consumption per customer	consumption per capita	consumption per customer	consumption per capita	consumption per customer	consumption per capita	consumption per customer
consumption per capita	1	0.225*** (0.0739)		0.149** (0.0730)		0.0505 (0.0753)		0.314*** (0.0765)		0.175** (0.0798)	
	2	0.0407 (0.0718)		0.303*** (0.0747)		0.198*** (0.0675)		0.184** (0.0762)		-0.0849 (0.0843)	
	3	0.0782 (0.0713)		-0.0218 (0.0747)		-0.0521 (0.0677)		0.0172 (0.0773)		-0.0301 (0.0751)	
	4	-0.165** (0.0694)		-0.361*** (0.0725)		-0.0649 (0.0689)		-0.193** (0.0778)		-0.264*** (0.0749)	
	5	-0.181** (0.0716)				-0.0225 (0.0669)		-0.188** (0.0759)		-0.0305 (0.0738)	
	6	-0.267*** (0.0719)				-0.113* (0.0665)				-0.325*** (0.0744)	
	7					-0.0321 (0.0691)				-0.147* (0.0757)	
	8					-0.0713 (0.0657)				-0.00190 (0.0755)	
	9					-0.0326 (0.0680)				0.0367 (0.0763)	
	10					0.172** (0.0662)				-0.200*** (0.0762)	
	11					0.112 (0.0688)					
	12					0.199*** (0.0694)					
	13					0.0821 (0.0698)					
natural gas prices	0	-0.730*** (0.170)	-0.758*** (0.173)	-0.179** (0.0750)	-0.139* (0.0717)	-0.165 (0.106)	-0.165 (0.106)	-0.258*** (0.0692)	-0.301*** (0.0694)	-0.749*** (0.140)	-0.792*** (0.136)
	1	0.614*** (0.169)	0.576*** (0.173)			-0.115 (0.133)	-0.119 (0.134)	0.259*** (0.0689)	0.250*** (0.0698)	0.273* (0.148)	0.213 (0.146)
	2					0.388*** (0.103)	0.384*** (0.103)			0.199 (0.142)	0.162 (0.139)
electricity prices	0	6.133** (2.545)	5.262** (2.590)	-0.727 (0.601)	-2.371*** (0.613)	-1.017 (0.904)	-1.297 (0.907)	0.235* (0.127)	0.261** (0.127)	-1.220*** (0.309)	-1.198*** (0.295)
	1	-7.258*** (2.561)	-7.344*** (2.619)			-0.0262 (1.222)	-0.0341 (1.222)	-0.130 (0.143)	-0.142 (0.144)		

	2					1.417	1.486	-0.0913	-0.0965		
						(0.917)	(0.919)	(0.141)	(0.142)		
	3							0.155	0.176		
								(0.141)	(0.142)		
	4							-0.163	-0.183		
								(0.126)	(0.127)		
income	0	-4.928***	-4.719***	-1.069	-1.124	0.244	0.357	-0.561	-0.291	-0.872	-0.887
		(1.743)	(1.776)	(1.185)	(1.149)	(0.615)	(0.607)	(0.456)	(0.455)	(0.738)	(0.719)
	1	3.223*	4.150**	1.938	1.588						
		(1.776)	(1.808)	(1.189)	(1.153)						
heating degree days	0	0.0630***	0.0598***	0.0468***	0.0506***	0.0474***	0.0481***	0.117***	0.113***	0.111***	0.108***
		(0.0173)	(0.0176)	(0.0148)	(0.0144)	(0.0127)	(0.0127)	(0.0187)	(0.0187)	(0.0191)	(0.0185)
	1	0.0737***	0.0706***	0.0366**	0.0443***	0.0386***	0.0371***	0.0298	0.0247	0.0547***	0.0538***
		(0.0177)	(0.0180)	(0.0153)	(0.0151)	(0.0132)	(0.0132)	(0.0207)	(0.0207)	(0.0195)	(0.0189)
	2	0.0192	0.0121	0.0236	0.0321**			0.0110	0.00738	0.0555***	0.0572***
		(0.0164)	(0.0165)	(0.0160)	(0.0156)			(0.0211)	(0.0211)	(0.0207)	(0.0200)
	3	0.0450**	0.0434**	-0.0160	-0.00761			-0.0526**	-0.0549**	0.00909	0.0148
		(0.0178)	(0.0181)	(0.0161)	(0.0158)			(0.0212)	(0.0213)	(0.0213)	(0.0207)
	4	-0.00850	-0.0150	-0.0201	-0.0160			-0.0150	-0.0173	0.0237	0.0280
		(0.0190)	(0.0192)	(0.0162)	(0.0157)			(0.0215)	(0.0217)	(0.0209)	(0.0202)
	5	-0.00741	-0.0105	-0.0201	-0.0179			0.0000313	-0.00348	0.00881	0.0131
		(0.0179)	(0.0182)	(0.0159)	(0.0153)			(0.0214)	(0.0215)	(0.0208)	(0.0203)
	6	0.0757***	0.0723***	-0.00855	-0.00978			0.0175	0.0149	0.0475**	0.0505**
		(0.0182)	(0.0186)	(0.0150)	(0.0146)			(0.0203)	(0.0204)	(0.0202)	(0.0197)
	7	-0.00684	-0.0127	-0.0202	-0.0238*			-0.0102	-0.0113	0.0109	0.0180
		(0.0188)	(0.0191)	(0.0144)	(0.0140)			(0.0193)	(0.0194)	(0.0208)	(0.0202)
	8	0.0258*	0.0246	-0.0393***	-0.0429***			-0.0449**	-0.0417**	0.0227	0.0287
		(0.0155)	(0.0159)	(0.0148)	(0.0144)			(0.0184)	(0.0185)	(0.0205)	(0.0200)
	9	0.0107	0.0119	0.00289	-0.00185			-0.0440**	-0.0406**	-0.0184	-0.0124
		(0.0177)	(0.0181)	(0.0145)	(0.0141)			(0.0190)	(0.0190)	(0.0201)	(0.0196)
	10	0.0391**	0.0400**	0.0409***	0.0390***			0.0497***	0.0520***	0.0711***	0.0734***
		(0.0172)	(0.0176)	(0.0140)	(0.0136)			(0.0187)	(0.0187)	(0.0196)	(0.0191)
	11			0.0320**	0.0361**			0.0611***	0.0616***	0.0256	0.0278
				(0.0144)	(0.0139)			(0.0185)	(0.0186)	(0.0182)	(0.0178)
trend	0	-0.00109	-0.00258***	-0.00325***	-0.00270***	-0.00174	-0.00202	-0.000561	-0.00115	-0.0000978	-0.000893
		(0.000899)	(0.000962)	(0.000999)	(0.000953)	(0.00126)	(0.00124)	(0.000784)	(0.000804)	(0.000547)	(0.000555)
consumption per customer	1		0.262***		0.107		0.0599		0.334***		0.142*
			(0.0743)		(0.0720)		(0.0755)		(0.0768)		(0.0788)
	2		0.0533		0.279***		0.192***		0.186**		-0.113
			(0.0734)		(0.0728)		(0.0685)		(0.0767)		(0.0822)
	3		0.0742		-0.0392		-0.0554		0.0203		-0.0488
			(0.0730)		(0.0726)		(0.0685)		(0.0778)		(0.0732)
	4		-0.160**		-0.387***		-0.0702		-0.192**		-0.287***
			(0.0709)		(0.0705)		(0.0694)		(0.0782)		(0.0730)

	5		-0.155**				-0.0319		-0.160**		-0.0517
			(0.0726)				(0.0674)		(0.0757)		(0.0724)
	6		-0.230***				-0.105				-0.337***
			(0.0722)				(0.0672)				(0.0728)
	7						-0.0496				-0.168**
							(0.0696)				(0.0741)
	8						-0.0748				-0.0432
							(0.0667)				(0.0742)
	9						-0.0303				0.0152
							(0.0685)				(0.0748)
	10						0.161**				-0.232***
							(0.0668)				(0.0747)
	11						0.111				
							(0.0693)				
	12						0.189***				
							(0.0698)				
	13						0.0705				
							(0.0698)				
constant	0	18.03**	16.72**	-1.115	8.971	-1.471	-0.522	7.758*	6.566*	16.07**	20.75***
		(8.266)	(8.453)	(5.811)	(5.831)	(5.955)	(6.091)	(3.951)	(3.954)	(6.285)	(6.311)
N		182	182	181	181	179	179	181	181	181	181
adj. R-sq		0.960	0.958	0.958	0.959	0.965	0.964	0.961	0.961	0.948	0.951

standard errors in parentheses; * P<0.10, **<p<0.05, ***p<0.01