<u>Supply Function for Electricity Export</u>

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Abstract

Canada is enriched with a lot of hydroelectricity sources. Canada is the second largest hydroelectricity producer in the world. In contrast, the main type of electricity in US is fossil-fuel produced electricity. Hydroelectricity is environmentally better and cheaper than fossil-fuel electricity. Canada is a net exporter of electricity to the United States (US). This paper will look at the electricity export supply function and different factors affecting it, in particular CAD-USD exchange rate. This paper also looks at the nature of marginal price of producing electricity. I also calculate the optimal quantity of electricity for export and compare it to the actual electricity sales at different seasons. I found local electricity demand and availability of water affect electricity export the most. Exchange rate affects electricity export supply function in British Columbia. Marginal price was found to be steady and lower than average price in most cases.

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I. Introduction

Canada is one of the largest electricity producers in the world. In 2012 Canada produced 616 TWh electricity in total, China - 4768 TWh, US - 4048 TWh, Russia - 1012 TWh. In 2012 Canada produced 377 TWh from hydro electrical sources, China - 856 TWh, US - 276 TWh, Russia - 164TW (Energy Information Administration (n.d.) Hydroelectricity is the main type of electricity produced in Canada, which accounts for 63.3% (Canadian Electricity Association, 2014). Hydro-rich provinces are Quebec, Manitoba and British Columbia (Goodman, 2010). Only China produces more hydroelectricity than Canada (Canadian Electricity Association, 2014). In contrast, carbon-intensive coal is the source used for nearly 50% of total electricity production in the United States of America (Goodman, 2010).

. Hydroelectric stations can produce more electricity during high-demand season. For example, demand in Quebec is at its highest during the winter months due to the fact that people need to heat their houses. Hydro-Quebec anticipates high demand during the winter and stores water beforehand to produce enough electricity during winter months. Producers can also and create a surplus over domestic demand over time. In case of US-Canada electricity trade, summer is an off-peak season for Canada while it is on-peak season for the US. The prices for electricity rise in the USA and Canadian producers can anticipate that and store enough water to support domestic off-peak demand and export the surplus to the US.

The USA has been trading electricity with Canada for a long time. Since off-peaks are different in the USA and Canada, each county both imports and exports electricity to/from each other during the year. Overall, Canada is a net exporter.

This paper will look at the electricity export supply function and different factors affecting it, in particular CAD-USD exchange rate. This paper also looks at the nature of marginal price of exporting electricity. I will be calculating the optimal quantity of electricity for export and comparing it to the actual electricity sales at different seasons. In order to accomplish necessary research, the following questions need to be addressed. First, electricity pricing will be discussed. Electricity pricing is affected by different factors such as natural resources prices, generation cost, energy efficiency, etc. Second, electricity surplus generation is a crucial part of this research. It is important to look at when and how electricity producers choose to create a surplus for international trade.

To the best of my knowledge, no papers have been publishing on the nature of electricity export supply function from hydro based system. This paper is organized as following: background and literature review, data analysis and methodology, and conclusion. Detailed table results can be found in Appendixes.

II. Background and Literature review

a. Regulation

The US opened up its electricity market to international competition under FERC order 888 in January 1997. Even before FERC order 888, the USA had been saving $397.2 million per year on electricity cost by importing electricity from Canada. Prices for electricity in 1996 average at 15.2c/kWh in New York and 14.1c/kWh in New England while being 7.3c/kWh in Ontario and 4.9c/kWh in Quebec. Canadian prices are lower due to the public ownership and major reliance on hydroelectricity (Bernard, Clavet, Ondo, 2005). Canadian producers received a required FERC license and were able to export their electricity to the US. The year before the regulation, Canada exported 42.2 TWh of electricity, which is equal to 7.7% of its total production. US savings on electricity almost doubled after 1997. Deregulation allowed Canada to have higher profits due to the price difference. Even though Canadian export to the States increases, it cannot lower marginal cost for electricity in the US because Canadian export is not large enough. Moreover, Canadian producers are behaving as price taker. (Bernard, Clavet, Ondo, 2005).

In 2008, Canada produced 602 TWh of electricity and exported 55.7 TWh of it to the US which valued at CAD 3.8 billion. An average price was $64.91/MWh. Canada's import of electricity from the US was 23.5TWh and valued at $1.33 billion with an average price of $56.59/MWh (Goodman, 2010).

b. Clean Energy

Developed countries are trying to move toward cleaner sources of energy. Climate change concerns are forcing countries to decrease carbon emission and use renewable or nuclear energy. As an example, Ontario government launched a Feed-in Tariff program that would pay up to $0.83/KWh for clean electricity. Clean-energy change is challenging for the USA since nearly a half of its electricity production comes from coal. In Canada, 77% percent of energy generated is low-carbon (Goodman, 2010). The clean energy movements in the USA provide a great opportunity for Canada to increase electricity export to the US.

c. Energy Security

Energy security is another reason for an increased US demand for Canadian hydroelectricity. It became a high priority issue under Obama's administration. Energy security was an issue since the first OPEC crisis in 1973. The geopolitics of oil is not stable and puts the USA in a risky position. Different administrations after OPEC crisis have been trying to become less dependent on foreign oil (Goodman, 2010).

d. Potential Expansion

There is some work that needs to be done in order to support an increasing demand for Canadian energy. New transmission lines are to be built that would benefit Canadian citizens as well. There are still a lot of potential sites to build hydroelectricity stations: Newfoundland and Labrador, Quebec, Ontario, Manitoba, British Columbia, Alberta, and Yukon (Goodman, 2010). Canada is enriched with large wind resources that can be further incorporated in energy production. Canada is famous for its nuclear power technology CANDU. Nuclear energy is also considered low-carbon and as a result be more demanded in the future (Mamay, 2008).

e. Power Industry Ownership Difference

There are some major differences in power industry in the US and Canada. The US power industry is highly fragmented. The two biggest companies produce only 3% of total US electricity. Most of the power-producing companies are privately owned. In contrast, provincial Crown corporations own most of the companies in this industry in Canada. It is regionally fragmented and has fewer players in the market. Increasing electricity trade benefits Canada by supporting economic growth, improving trade balance and job creation (Goodman, 2010).

f. Electricity Pricing

Canadian residents pay one of the lowest electricity rates among industrialized countries. Canadian electricity prices are affected by different factors such as fuel sources, electricity supply, customer service, operation, finance, energy efficiency, and maintenance (Canadian Electricity Association, 2014).

Costs that come from electricity supply are generation, distribution, transmission, operational and maintenance costs. Operational costs are financial, replacement capital, regulatory requirements, and energy efficiency costs. Landscape and population density affects electricity cost as well. There are various provincial and federal taxes in different provinces that influence electricity rates.

Electricity expenditure accounts to about 3% of the average household spending. Electricity prices in Canada are rising these days because electricity companies start investing in new infrastructure to maintain a high reliability status, make Canadian electricity even cleaner and satisfy increasing demand (Canadian Electricity Association, 2014).

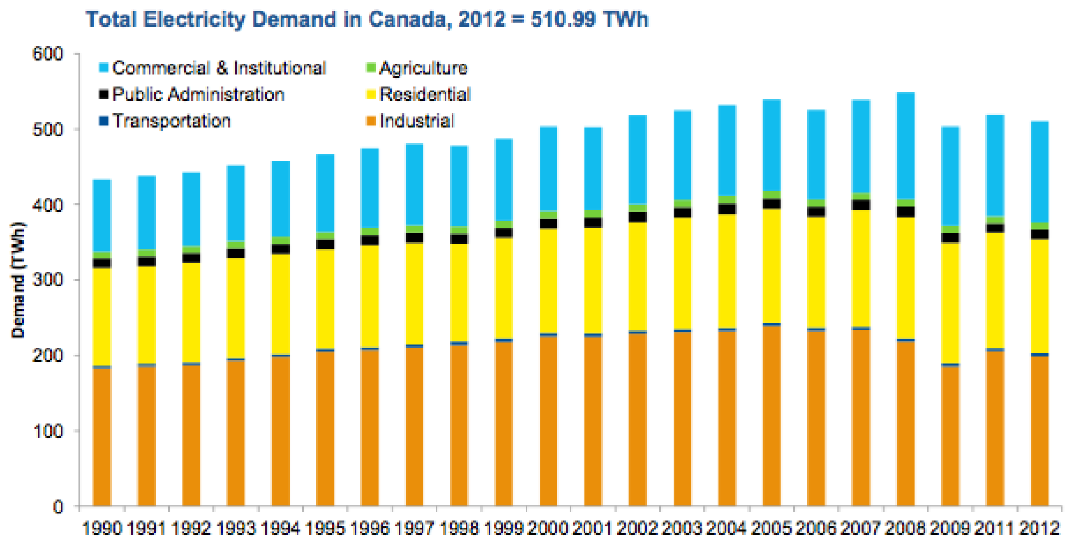
In the U.S. the main factor determining electricity prices is fossil fuel cost. The major type of electricity produced in the States is coal-generated due to its abundance, affordability and reliability. Powder River Basin coal in Wyoming is the main coal supplier in the Midwest. Its prices are lower and stable compared to other regions. Even though there is a lot of coal supply available, prices are expected to rise over time due to higher extraction and environmental compliance costs. (Hydro Manitoba, 2013).

Natural gas supply and prices are the other determinants of the US electricity prices. Latest developments in shale gas extraction increased natural gas availability. It lowered the price of natural gas. Due to the environmental concerns of coal-generated electricity and increased supply of natural gas, the latest is considered to be the main choice for future generations. The Energy Information Administration projects 71% electricity generated will come from gas-fired recourses. Natural gas market in the U.S. is isolated from global market due to the lack of gas terminals. If it was not the case, natural gas prices in the U.S. would adjust to higher global prices. Nevertheless, natural gas prices in the U.S. are projected to grow in the future due to higher demand and increased marginal production cost (Manitoba Hydro, 2013).

Another determinant of electricity pricing in the U.S. is oil pricing. Nowadays, it has a very small impact on electricity sector. Shale gas revolution resulted in low natural gas prices while oil prices were near its historical peak. That made oil economically inefficient electricity source. It is now a backup fuel source in case of a problem of natural gas supply. Moreover, oil prices have been volatile which makes it an even less desirable choice for electricity source. It is hard to estimate future oil prices due to its complex pricing model (Manitoba Hydro, 2013).

g. Electricity Surplus Generation

One of the main factors determining electricity export from Canada to the USA is surplus generation by an electricity producer. Electricity supply estimations are demand-driven (National Energy Board, 2013). It is challenging to understand the nature of electricity surplus. This paper analyzes in particular the impact of exchange rate on electricity trade between Canada and the U.S. It will be necessary to measure electricity surplus for this research. Since the surplus is hard to measure, the following assumption will be used. If there is no change in domestic electricity demand over a certain time period, but electricity supply rises, it means producers intentionally generate electricity surplus. In case of Canadian producers, it might happen because they anticipate demand for Canadian electricity from the U.S. and intentionally create surplus to economically benefit from the trade. Since U.S. electricity is highly dependent to natural resources, mainly coal, and more recently on natural gas Canadian electricity if often a cheaper alternative to domestically produced electricity.



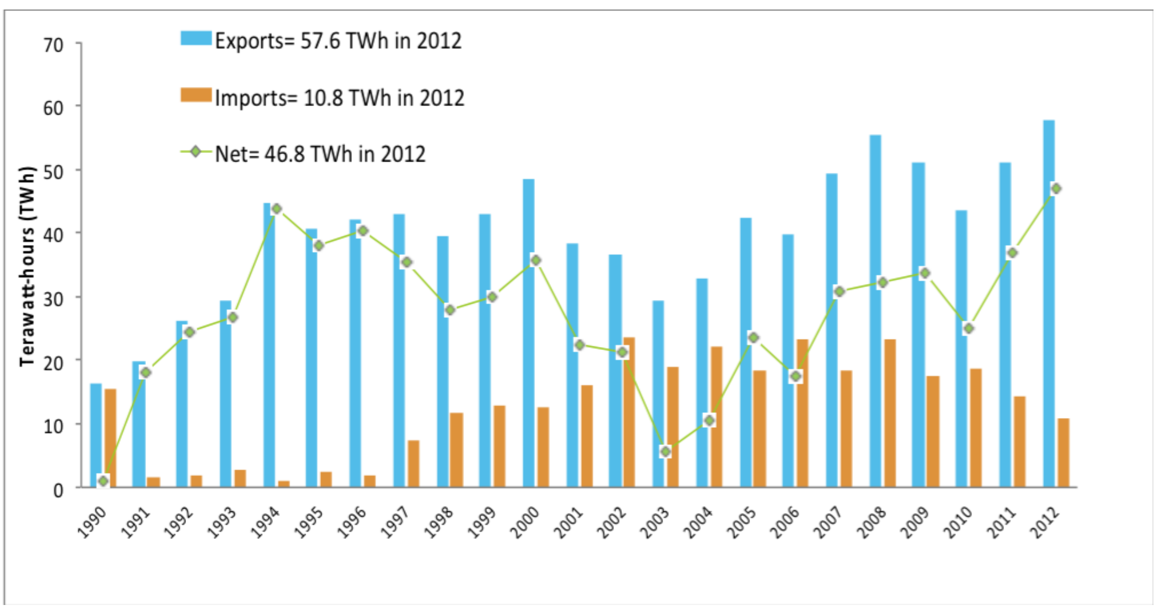
Graph 1: Canadian Electricity Demand (1990-2012) Source: Canadian Electricity Association (2013)

Graph 1 shows Canadian electricity demand over twelve years. Demand is rising but at a slow rate. It is expected to continue growing over the next 35 years in both Canada and the U.S. (Manitoba Hydro).

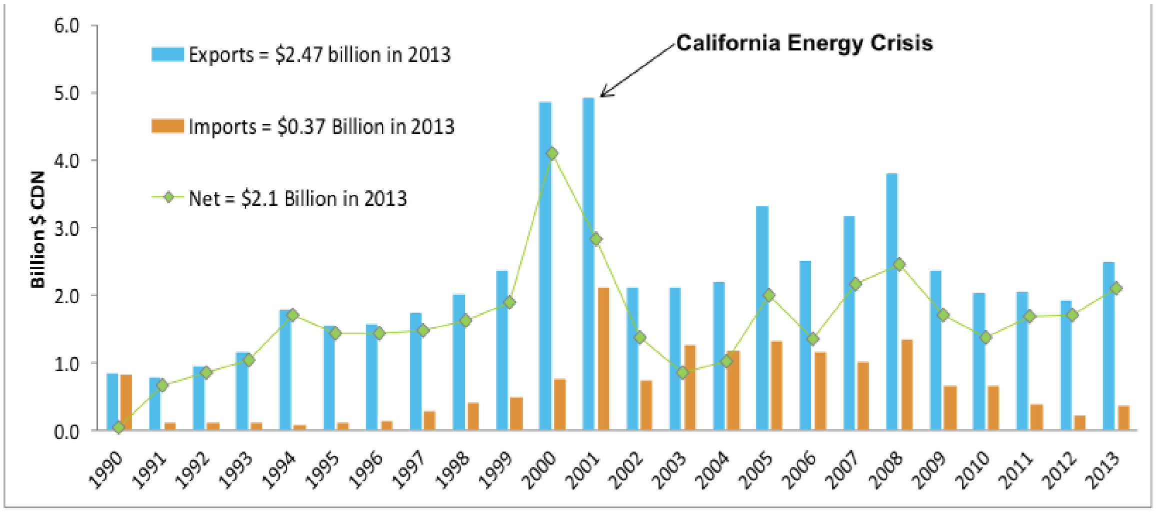
Different factors affect increasing electricity demand. Lower electricity prices in Canada increase demand and discourage electricity efficiency which overtime will increase the prices. Growing population is another reason for increased electricity consumption. There was a 165% population growth from 1946 to 2006. Canadian population is estimated to grow further. Development in battery technology, which is now being implemented in electric vehicles, is projected to increase electricity demand even further (Manitoba Hydro, 2013).

Even though electricity demand has been rising at a very slow rate, electricity exports to the U.S. fluctuated a lot. It can be seen in Graph 2. Revenue from electricity exports activity can be seen in Graph 3. There are peaks and drops in the revenues due to changing electricity prices and output. Overall, it can be said that electricity demand increases at a very slow and stable rate, while electricity export is volatile, and exports revenue is volatile to an even higher degree.

The graphs support my assumption that electricity producers can generate electricity surplus anticipating high demand from the U.S. Since Canadian demand does not change very much over time, while exports fluctuate a lot, it can be concluded that producers create different surpluses depending on anticipated price of electricity in the U.S.



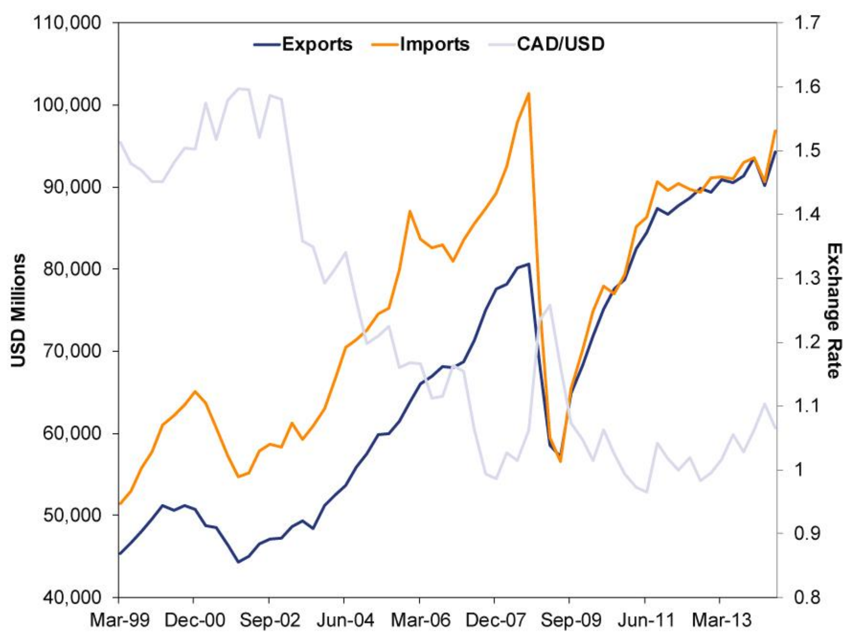
Graph 2: Canada - U.S. Electricity Trade 1990-2010. Source: Canadian Electricity Association (2013)



Graph 3: Canada - U.S. Electricity Trade Revenue 1990-2010. Source: Canadian Electricity Association (2013)

h. Exchange Rate and Trade

According to macroeconomics rules, exchange rate affects trade. When a certain currency becomes cheaper, all other things being equal, export rises because this country's goods or services become cheaper to buy. This rule applies to US-Canada trade (Dion, Laurence, et al., 2005). In 2008, Canada exported $562 billion of products and services which accounted to a third of Canada's GDP (Statictics Canada, National Income). Canada and the USA have been trading goods for centuries. In 2012, US merchandise imports from Canada summed to US$324.2 billion. Exports to Canada were US$292.4 billion (Census, 2012 US Trade in goods with Canada). If we look at Graph 4, we can see that the trade was affected by the exchange rate. When the Canadian dollar appreciates, exports to Canada rise while imports from Canada decrease. The opposite is true when Canadian dollar depreciates. According to historical data, there is an inverse relationship between CAD/USD exchange rate and exports from Canada.



Graph 4: CAD/USD Exchange Rate and Total Exports and Imports of Goods and Services, quarterly, captured at the last day of a quarter (2013)

Source: FactSet and US Bureau of Economic Analysis, as of 10/06/2014.

Electricity trade, like any other trade, should fall under the same macroeconomics rule. The relationship between exchange rate and electricity trade between Canada and the USA will be analyzed in this paper. The assumption is when Canadian dollar depreciates, electricity export to the USA should rise and vice-versa. Canadian producers anticipate an increased demand for electricity from the States when Canadian dollar depreciates. They will generate more electricity since they know it will be demanded. Since the price for electricity in the US is higher, their profit will increase.

No academic articles were found on this specific topic. It might be due to the difficult nature of electricity production. It is problematic to measure the surplus of generated electricity. Nevertheless, some authors analyzed the relationship between USD-CAD exchange rate and natural resources trade.

Bolkedjo and Buongiorno (2006) looked at the US-Canada trade of the main forest products. They found that in the short-run exports are highly elastic to exchange rate while imports are less elastic but still significant. In the long-run, elasticity for both imports and exports decreases but stays noteworthy. That supports a theory that decreasing currency exchange rate leads to higher exports.

Sadorsky (2001) analyzed gas and oil industry return to stock. One of the factors he looked at was the CAD-USD exchange rate. He also mentioned that not a lot of research focusing on exchange rate and oil prices had been done. His results indicate that oil and gas stock returns are affected by the exchange rate. An increase in the exchange rate lowers the return to Canadian oil and gas stocks. In other words, Canadian investors anticipate lower profits when Canadian dollar increases relative to US dollar.

III. Data analysis

a. Data

The time period studied in this paper is from January 2000 to May 2015. All the data used for the research covers this time period. For some variables I need previous year information, that means that I will need to use 1999 data for these variables.

Export Quantity and Price for electricity exported paid by US are sourced from National Energy Board (TABLE 2A Export Summary Report by Source, Authorization and Exchange Type). Export Quantity is measured in MW/H. Price to US is measured in Canadian dollars. This data is for interruptible transactions only. The data covers three provinces: Quebec, Manitoba and British Columbia. The main electricity producing and exporting companies in these provinces are Quebec Hydro, Manitoba Hydro – Electricity Board and Powerex Corp (wholly owned by BC Hydro). These companies are the province-owned corporations.

Data for the local electricity demand in Quebec, Manitoba and British Columbia is derived from Statistics Canada’s CANSIM database. The data from two tables was combined: Table 127-0003 (Electric power generation, receipts, deliveries and availability of electricity, monthly (Megawatt hour), Jan 2008 to Apr 2015) and Table 127-0001 (Electric power statistics, monthly (Megawatt hour) *Terminated*, Jan 1950 to Dec 2007).

Net export for the last twelve months attempts to measure the availability of water for hydroelectricity. It is calculated as a weighted average of net export for the last 12 months with the 12^{th} month weighing 12 times more than the 1^{st} month. The data is derived from the same CANSIM tables mentioned above.

In Canada most of electricity comes from hydro and nuclear sources, so coefficients of fossil fuels in Canada are expected to be insignificant. In contrast, the U.S. electricity price is highly dependent on fossil fuels. If fossil fuel prices increase, electricity price in the U.S. increases. In this situation, it is economically beneficial for the U.S. to buy cheaper Canadian electricity, which is not so reliant on fossil fuel prices.

Prices for gas paid by electricity producing companies in US were found in U.S. Energy Information Administration. For Quebec, electricity market, prices in New York were used, for British Columbia – prices in California, and for Manitoba – prices in Texas. Manitoba Hydro sells electricity mainly to Minnesota and North Dakota, but gas prices are unavailable for these states. Texas was chosen due to its geographical location close to Minnesota and North Dakota. Monthly data for 2002-2015 was available. I used linear interpolation to calculate monthly prices for gas for 2000-2001.

Future prices for natural gas were derived from US Energy Administration (New York Mercantile Exchange). “Contract 4” data represents the price for natural gas in 4 months. Prices are measured in dollars per million Btu. I then converted the data in Canadian dollars per million btu.

For an exchange rate between Canadian and US dollar, I used Exchange rate Bank of Canada U.S. dollar at close monthly average.

b. Methodology

At first, I specify a linear regression model for electricity export supply function for three provinces: Quebec, Manitoba and British Columbia. Then I ran the Durbin-Watson Test and Breusch-Godfrey Test for autocorrelation, the tests showed that a positive autocorrelation is present. My model also had heteroscedasticity. In order to correct these problems, I used the regression model with Newey-West standard errors (see Appendices C). Newey-West approach corrects heteroscedasticity and autocorrelation (Newey & West, 1987). I used 12 lags in Newey-West approach because I have monthly data and I assume that previous 12 months have an effect on current month. There is the initial regression model:

$$ex\_i\_q_t = \beta_0 + \beta_1 demand_t + \beta_2 net\_export_t + \beta_3 gas\_p_t + \beta_4 gas\_p\_fut_t + \beta_5 usdcad_t + \beta_6 ex\_f\_q_t + \varepsilon_t$$

There are no previous studies, which talk about nature of the electricity export supply function. I used the same explanatory variables for all three provinces. In my model, the dependent variable, $ex\_i\_q_t$, is interruptible quantity of electricity which is exported to US from each province. For each province I used a separate model with the same explanatory variables.

The first explanatory variable,$demand_t$, is the local demand for electricity in each province. Domestic demand is included in our model because demand for electricity increases with the economic expansion in a region. If there is an economic growth in Canada, domestic demand for electricity increases which results in lower electricity surplus availability. In all three provinces (Quebec, Manitoba and British Columbia) electricity producers are state-owned corporations. The main goal of these corporations is to satisfy local demand in the province they operate. When demand is rising due to the weather conditions (for example cold winter) or increasing population, the electricity surplus that can be sold to US is decreasing. It is also works in the opposite direction: when local demand is lower than expected, there is more available electricity for sale to US.

The second independent variable, net_export_t, is the net export for each province in the last twelve months. The amount of electricity that Quebec, Manitoba and British Columbia can generate is highly dependent on stock of water available for use. It is hard to measure how much water each province has in order to generate electricity but it is an important factor that affects the export quantity of electricity. I am using net export (interprovincial trade and trade with US) of electricity in the last 12 months as an indicator of how much water each province has. If a province has had a positive net export (or higher than usual) in the last twelve months that means they have enough water to produce electricity for export. If province has had a negative net export (or less than usual) then it is more likely that it has a low water stock, and potential quantity of electricity available for export is decreasing. When I ran the Dickey-Fuller unit-root test, the net export alone was not stationary. First difference corrected this problem and now Dickey-Fuller test shows that this variable does not have a unit-root and it is stationary. Note: Quebec always has a negative net export with an exception for few months because of Churchill Falls Generating Station in Newfoundland and Labrador. Quebec has a long-term contract with Churchill Falls Generating Station and in the data it is counted as electricity import for Quebec.

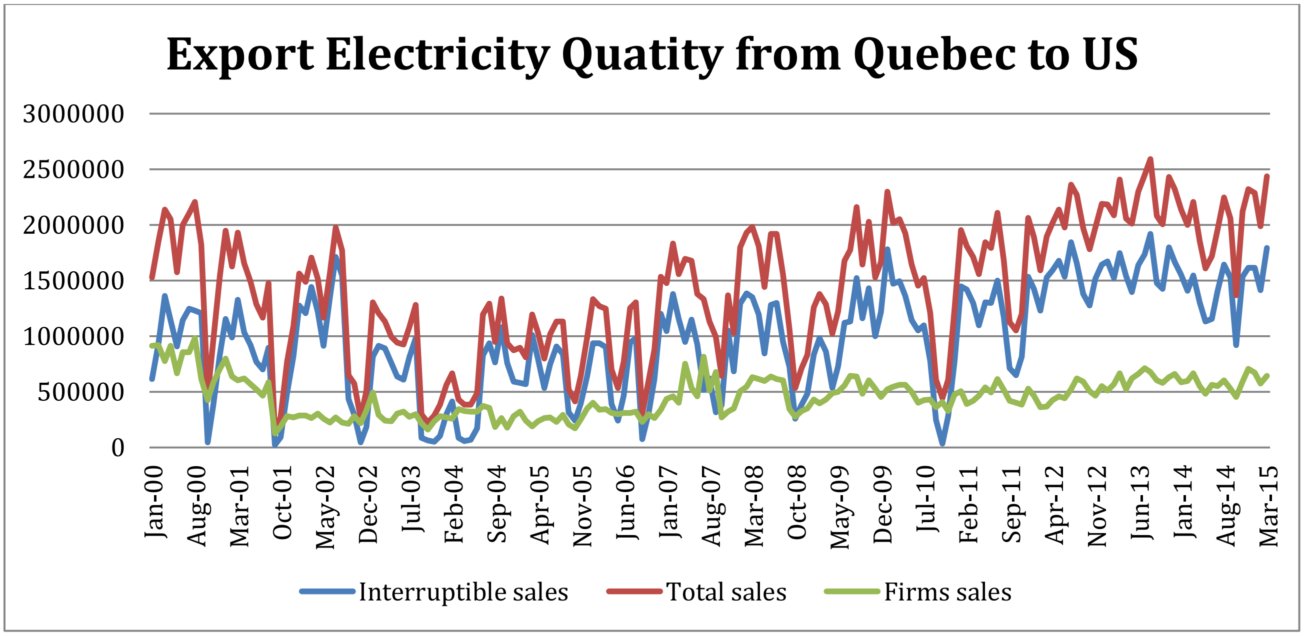
Price of natural gas in US is another factor which might affect the quantity of electricity imported by US from Canada. Coal and natural gas are important resources for electricity generation in the US. Lots of coal is used for production of electricity in the US today. However, the price of gas affects the price of electricity a lot more since it is often the marginal price of electricity generation (Energy Information Administration, 1997).

When the price of natural gas is high in the US, the country is more interested in Canadian electricity because the high price of natural gas in US does not affect the price of Canadian electricity. I am expecting to see that increasing price of natural gas in US is causing the export of electricity from Canada to increase. The same relation should work in the opposite case.

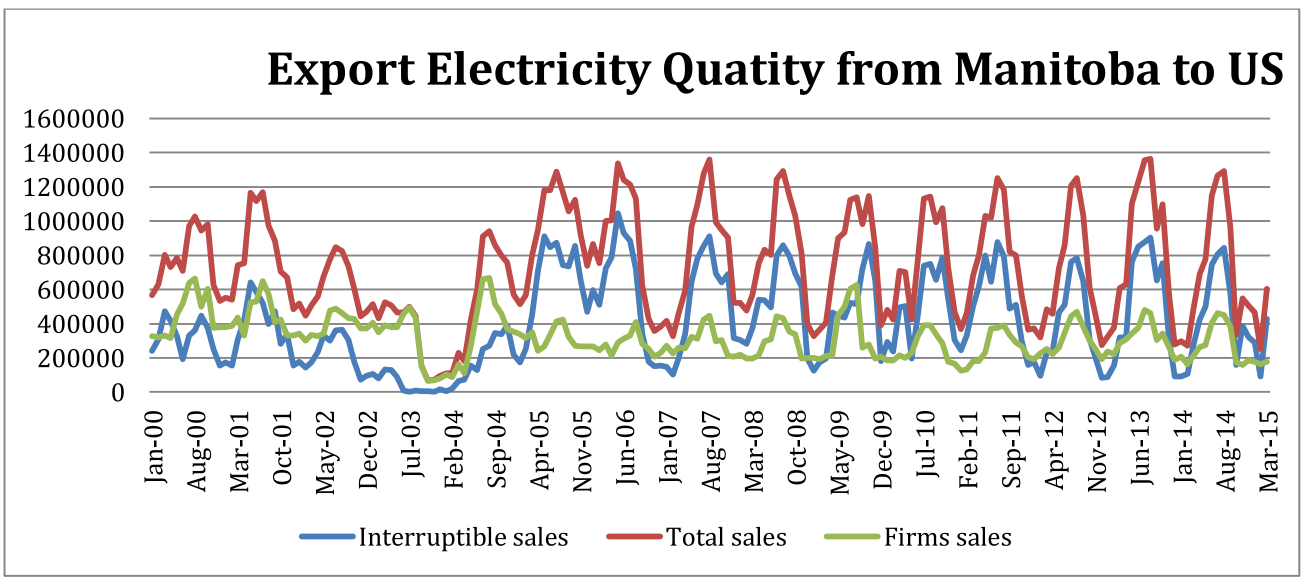
Another variable is the future price of natural gas. Previously in this paper I have made the assumption that generation of electricity surplus highly depends on expectations. When Canadian hydro producers expect the price of natural gas in US to increase in the future (which will cause electricity prices in US to increase as well), then Canadian electricity producers will decrease the electricity surplus today in order to keep the water for later and generate electricity for sale when the price in US will be higher. When the future price of gas is expected to be low in the future, Canadian Hydro Corporations will try to generate more and sell more electricity as soon as possible because they expect lower prices in the future.

The exchange rate, $usdcad_t$, is another variable of interest. The variable represents the value of one US dollar in Canadian dollars. The intuition behind the exchange rate coefficient is based on macroeconomic theory of a negative relationship between an exchange rate and export. When Canadian dollar depreciated against the U.S. dollar, Canadian goods and services become cheaper for Americans to buy compared to domestic goods and services. Electricity is a traded good and export is expected to increase under the same rule. The coefficient for exchange rate is anticipated to be negative. The US is paying for electricity using US dollars. When state-owned producers in Canada convert the currency, they receive higher revenue when Canadian dollar is lower compared to the US dollar. This factor might force Canada to export more electricity when Canadian dollar is low. This variable is in form of the first difference of the USD/CAN exchange rate. I did it in order to eliminate the unit-root from the variable as I did with net export variable described above. The variable for the natural gas price is affected by exchange rate because natural gas prices in US have been converted to Canadian dollars.

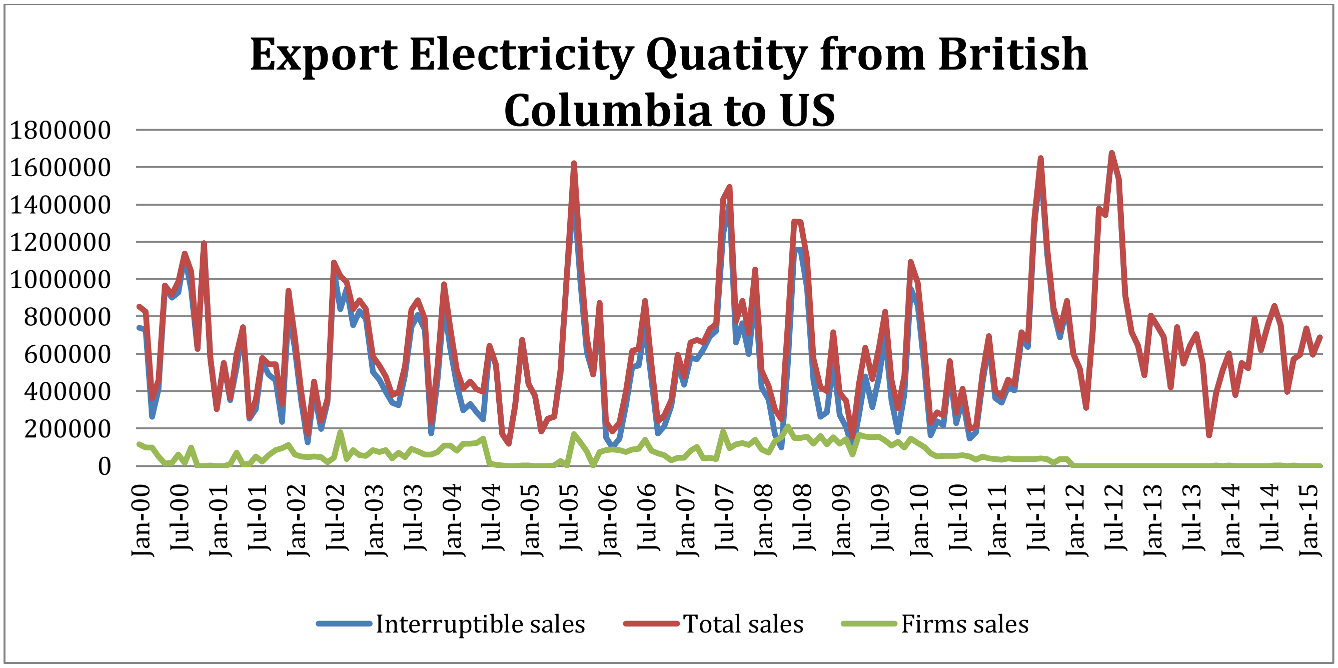
Export quantity for firm sales,$ex\_f\_q_t$, is another explanatory variable. My dependent variable is only a fraction of total export of electricity to US. I am working only with interruptible sales. Firm sales go under the contracts where price and quantity are fixed and my explanatory variables do not play a big role. It can be the case that in the summer when electricity price is high in US, there are more firm sales and less interruptible sales. In this case, total export is high but interruptible sales are low due to more firm sales. This variable should isolate this effect. As you can see in the tables below, every province has a different proportion of interruptible sales.



Graph 5



Graph 6



Graph 7

Export price of electricity paid by US was omitted for several reasons. First reason is that electricity is seasonal. Prices in the summer are expected to be higher than in the winter. For this reason we can expect Canada exporting more in the summer. However, due to the nature of electricity supply, it is not necessarily the case. It can be a very cold winter in Quebec where people heat their houses using hydro, which means the local consumption of electricity is high. When the summer comes, there is no water available for extra electricity, which can be sold to US. Another example is winter in Manitoba with not much snow. That means they do not have a lot of water in spring, so they cannot generate extra electricity for export. Second reason is related to my assumption about expectations. Canadian producers know from past years there are peak and off-peak prices. They try to save significant amount of water for the summer because they expect prices to be high. However, due to some other factors the price in the summer might be lower than expected and not the highest of the year. Since Canadian producers can adjust water level only over one year, they will still generate electricity and sell to US even when the price is not the highest.

c. Results

The results will describe the models which analyze the level of export in each province. Most of explanatory variables resulted in similar values across all three provinces and some variables were contrary between different models.

The variable coefficient for “local demand” in Manitoba and British Columbia is negative as expected. When local consumption increases in these two provinces export quantity of electricity from Manitoba and British Columbia fall. It is statistically significant at 10% level in British Columbia. The coefficient is not statically significant for Manitoba. However, the coefficient for Quebec is positive and statistically significant which looks puzzling.

Net export over the last 12 month is positive and statistically significant at 1% level for Quebec, Manitoba and British Columbia. This variable is used as an indicator of availability of water in each province. When a province has a positive sign for this variable, it means that they have higher ability to generate and sell electricity to US. Higher net export over the last 12 month is positively correlated with higher export quantity.

Coefficients for prices of natural gas and future prices of natural gas in US are not consistent with my expectations. Coefficients for current prices of natural gas are positive for Manitoba but not statistically significant. The same coefficients for Quebec and British Columbia are negative and not statistically significant.

Coefficient for future prices of natural gas has a negative sign for Manitoba and positive sign for Quebec and British Columbia. However, all three coefficients are not statistically significant.

In British Columbia the variable USD/CAD exchange rate has a positive sign. When Canadian dollar depreciate against US dollar quantity of electricity export is increasing in this province. This value is statistically significant at 10% level of significance. The coefficients are not statistically significant for Quebec and Manitoba.

The sign for the firm sales variable was negative but not statistically significant for British Columbia and Manitoba. However, firm sales quantity is positive and statistically significant at 1% level in Quebec. The meaning behind it might be that when Quebec signs a lot of firm sale contracts, it expects to produce extra electricity. Since they expect to produce more electricity, interruptible sales also go up.

The ratio between interruptible and total electricity export is positive and significant at 1% level in all three provinces. When the fraction of interruptible export increases compared to firm sale, export interruptible quantity increases as well.

TABLE A (Quebec)

newey qc_i_q qc_demand qc_net_weigh_dif gas_p_ny_can gas_p_fut_can_dif usdcaddiff qc_f_q , lag(12)

Regression with Newey-West standard errors
maximum lag:12

Number of obs	183
F(6, 176)	17.61
Prob > F	0.0000

qc_i_q	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
qc_demand	.076005	.0123416	6.16	0.000	.0516484	.1003617
qc_net_weigh_dif	1.222075	.1865754	6.55	0.000	.8538622	1.590288
gas_p_ny_can	-53625.91	17071.28	-3.14	0.002	-87316.67	-19935.14
gas_p_fut_can_dif	84402.6	29433.75	2.87	0.005	26314.08	142491.1
usdcaddiff	-243402.5	817361.9	-0.30	0.766	-1856494	1369689
qc_f_q	1.170106	.3451143	3.39	0.001	.4890108	1.851201
_cons	-438436	220514.2	-1.99	0.048	-873628.4	-3243.513

TABLE B (Manitoba)

newey man_i_q man_demand man_net_weigh_dif gas_p_texas_can gas_p_fut_can_dif usdcaddiff man_f_q , lag(12)

Regression with Newey-West standard errors	Number of obs	183
maximum lag: 12	F(6, 176)	7.00
	Prob > F	0.0000

man_i_q	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
man_demand	-.1652399	.1066439	-1.55	0.123	-.3757053	.0452255
man_net_weigh_dif	2.126623	.6638171	3.20	0.002	.8165567	3.436689
man_p_texas_can	884.5168	14237.73	0.06	0.951	-27214.14	28983.17
man_p_fut_can_dif	-26236.89	19749.06	-1.33	0.186	-65212.34	12738.56
usdcaddiff	128589.9	859476.8	0.15	0.881	-1567617	1824797
man_f_q	-.2500119	.2659396	-0.94	0.348	-.7748528	.274829
_cons	812411.1	281935.7	2.88	0.004	256001.4	1368821

TABLE C (British Columbia)

newey bc_i_q bc_demand bc_net_weigh_dif gas_p_cal_can gas_p_fut_can_dif usdcaddiff bc_f_q , lag(12)

Regression with Newey-West standard errors	Number of obs	183
maximum lag:12	F(6, 176)	4.61
	Prob > F	0.0002

bc_i_q	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
bc_demand	-.0697522	.0385356	-1.81	0.072	-.1458034	.0062991
bc_net_weigh_dif	1.371044	.2972874	4.61	0.000	.7843374	1.957751
bc_p_cal_can	-1478.258	11881.27	-0.12	0.901	-24926.35	21969.83
bc_p_fut_can_dif	40047.36	30527.7	1.31	0.191	-20200.09	100294.8
usdcaddiff	1402840	832157.7	1.69	0.094	-239451.7	3045132
bc_f_q	-.3038697	.5929026	-0.51	0.609	-1.473983	.866244
_cons	986296	279089.1	3.53	0.001	435504	1537088

d. Marginal Price of Electricity

I conducted a separate analysis of average and marginal electricity price. The data used for this analysis consists of monthly average electricity sale for the 2000-2015 time period. I ran a regression with electricity quantity sold being an explanatory variable for average electricity price. Price of natural gas was involved in calculating y-intercept. I used the same Newey-West methodology described in Part B (see Appendix C). The data for average price was given separately for three seasons: winter (December-March), summer (July-August), off-peak season (September-November and April-June). I used different lags depending on the season. Number of lags was chosen based on the number of consecutive months minus one. Only results for Manitoba were statistically significant. That is why I worked with data for Manitoba to conclude marginal price analysis.

Since I had data for average price only, I needed to do the following calculations to figure out the marginal price:

$$Marginal\ price = a' + b'GasPrice + c'Q + f'Q^2$$

To find total revenue we need to integrate the function of marginal price with respect to Q:

$$Total\ revenue = \int_0^Q (a' + b'GasPrice + c'Q + f'Q^2)dQ$$

$$Total\ revenue = (a' + b'GasPrice)Q + \frac{c'}{2}Q^2 + \frac{f'}{3}Q^3$$

To find average price we need to divide total revenue by Q

$$\frac{Total\ revenue}{Q} = (a' + b'GasPrice) + \frac{c'}{2}Q + \frac{f'}{3}Q^2$$

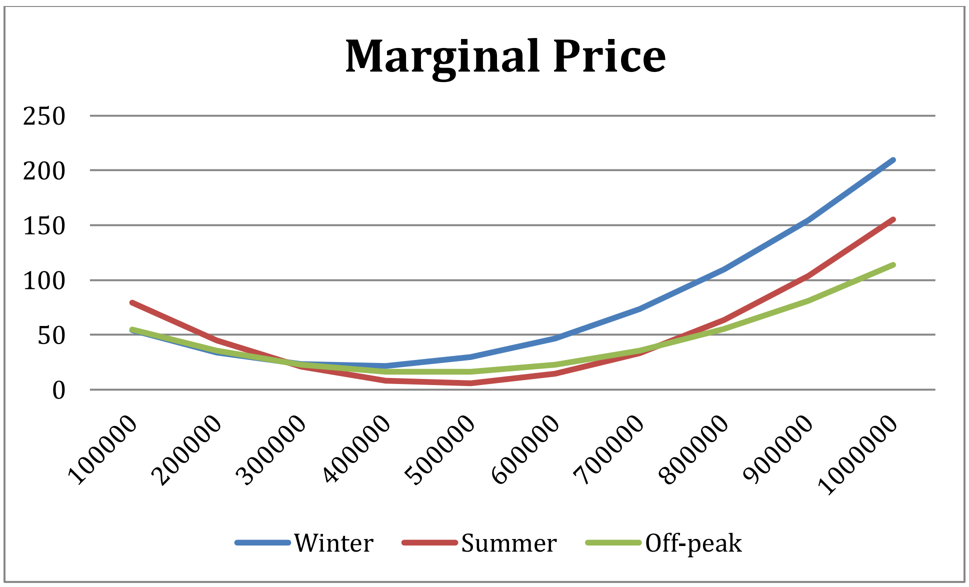
$$Average\ price = a + bGasPrice + cQ + fQ^2$$

We set,

$$a' = a, \quad b' = b, \quad c' = 2c, \quad f' = 3f$$

This is the equation is estimated and used to recover the coefficients of the marginal price curve

$$Marginal\ Price = a + bGasPrice + 2 * cQ + 3 * fQ^2$$



Graph 8

The graph 8 is constructed by using an average price of gas and different export quantities. Coefficients were taken from Marginal Price regression described above to see pattern of Marginal Price curves in different seasons. Price of natural gas was found to have a positive effect on electricity export price.

We are interested in the part of the graph up till the point the slope becomes positive. The slope is decreasing at the diminishing rate. The optimal point for electricity sales is considered to be the point at which the slope is zero. It is clear from the graph that the optimal quantity for winter season is less than the optimal quantities for other two seasons. It might be due to a higher local demand in Manitoba during winter months and lower electricity demand in US. If we look at the average exported electricity for three seasons from our data, it is close to what has been found to be an optimal quantity for each season.

To check marginal price coefficients, I looked at electricity sales from June 2004 to May 2005. As expected, marginal price was lower than average price for most months (see Appendix D). For the months when marginal price was higher than average price, electricity quantity was either very high or very low. That might be due to external factors which are not included in this model. Overall the marginal price is fairly consistent over these 12 months.

Conclusion

Electricity is an important good in any industrialized economy. Canada is enriched with a lot of hydroelectricity sources. Canada is the second largest hydroelectricity producer in the world. In contrast, the main type of electricity in US is fossil-fuel produced electricity. Hydroelectricity is environmentally better than coal-generated electricity due to its lower carbon emissions. Moreover, hydroelectricity has been a cheaper option over the last years. All the developed countries are making effort to move towards green electricity sources and decrease carbon emissions. The U.S.A. is not an exception. Geographical nearness, environmental movement and economic benefit of Canadian hydroelectricity result in electricity trade between two countries. Canada is a net exporter. This paper analyzed electricity export supply function and the several factors affecting it. It was found that availability of water has a positive effect on electricity export from Canada to US. Local demand is negatively correlated with electricity export in Manitoba and British Columbia. No relationship was found between price of natural gas in US and electricity export. Coefficient for an exchange rate in British Columbia shows when Canadian dollar depreciates, electrify export to US increases..

Marginal price for Manitoba electricity sales was analyzed. It was found that marginal price is lower than average price in most cases. Marginal price was fairly consistent when we looked at 12 months' time span.

Appendix A DATA

VARIABLE	EXPLANATION	SOURCE
QC_I_Q	Interruptible electricity export quantity from Quebec to U.S.	National Energy Board
MAN_I_Q	Interruptible electricity export quantity from Manitoba to U.S.	National Energy Board
BC_I_Q	Interruptible electricity export quantity from British Columbia to U.S.	National Energy Board
QC_I_P	Price paid for electricity exported from Quebec (in Canadian dollars)	National Energy Board
MAN_I_P	Price paid for electricity exported from Manitoba (in Canadian dollars)	National Energy Board
BC_I_P	Price paid for electricity exported from British Columbia (in Canadian dollars)	National Energy Board
QC_demand	Local electricity demand in Quebec	Statistics Canada's CANSIM
MAN_demand	Local electricity demand in Manitoba	Statistics Canada's CANSIM
BC_demand	Local electricity demand in British Columbia	Statistics Canada's CANSIM
QC_net_weigh_DIF	Quebec net export for the last 12 months (first difference)	Statistics Canada's CANSIM
MAN_net_weigh_DIF	Manitoba net export for the last 12 months (first difference)	Statistics Canada's CANSIM
BC_net_weigh_DIF	British Columbia net export for the last 12 months (first difference)	Statistics Canada's CANSIM
GAS_P_NY_CAN	Price for natural gas paid by electricity producing companies in New York (in Canadian dollars)	U.S. Energy Information Administration
GAS_P_TEXAS_CAN	Price for natural gas paid by electricity producing companies in Texas (in Canadian dollars)	U.S. Energy Information Administration
GAS_P_CAL_CAN	Price for natural gas paid by electricity producing companies in California (in Canadian dollars)	U.S. Energy Information Administration
GAS_P_FUT_CAN	Future price for natural gas in four months (in Canadian dollars)	U.S. Energy Information Administration
USDCANDIFF	USD/CAD exchange rate (first difference)	Bank of Canada
qc_f_q	Firm electricity export quantity from Quebec to U.S.	National Energy Board
man_f_q	Firm electricity export quantity from Manitoba to U.S.	National Energy Board
bc_f_q	Firm electricity export quantity from British Columbia to U.S.	National Energy Board

Appendix B Regression Table

TABLE D (Manitoba Winter)

newey man_i_p man_i_q man_i_q2 gas_p_texas_can, lag(3)

Regression with Newey-West standard errors
maximum lag: 3

Number of obs	63
F(2, 59)	12.43
Prob > F	0.0000

man_i_p	Coef.	Srd. Err.	t	P>|t|	[95% Conf. Interval]	
man_i_q	-0.000171	0.0000742	-2.3	0.025	-0.0003195	-0.0000224
man_i_q2	1.56E-10	1.05E-10	1.49	0.142	-5.38E-11	3.67E-10
gas_p_texas_can	6.509883	1.475803	4.41	0.000	3.556808	9.462958
_cons	38.07234	12.52338	3.04	0.004	13.01311	63.13158

TABLE E (Manitoba Summer)

newey man_i_p man_i_q man_i_q2 gas_p_texas_can, lag(1)

Regression with Newey-West standard errors
maximum lag: 1

Number of obs	30
F(2, 26)	54.53
Prob > F	0.0000

man_i_p	Coef.	Srd. Err.	t	P>|t|	[95% Conf. Interval]	
man_i_q	-0.000253	0.0000323	-7.83	0.000	-0.0003196	-0.0001867
man_i_q2	1.79E-10	2.79E-11	6.41	0.000	1.22E-10	2.36E-10
gas_p_texas_can	4.066354	0.6755596	6.02	0.000	2.677721	5.454987
_cons	96.28731	9.63323	10	0.000	76.48593	116.0887

TABLE F (Manitoba Off-peak)

newey man_i_p man_i_q man_i_q2 gas_p_texas_can, lag(2)

Regression with Newey-West standard errors	Number of obs 90
maximum lag: 2	F(2, 86) 43.29
	Prob > F 0.0000

man_i_p	Coef.	Srd. Err.	t	P>|t|	[95% Conf. Interval]	
man_i_q	-0.000145	0.0000391	-3.73	0.000	-0.0002233	-0.0000679
man_i_q2	1.08E-10	3.41E-11	3.15	0.002	3.97E-11	1.75E-10
gas_p_texas_can	3.743866	0.4701765	7.96	0.000	2.809186	4.678546
_cons	54.57346	10.46662	5.21	0.000	33.76651	75.38041

APPENDIX C: DIAGNOSTIC TESTS

a) Dickey-Fuller test

I used Dickey-Fuller test to see if a variable has unit-root process.

The null hypothesis is: H_0= The series has a unit root

The alternative hypothesis is H_1=The series does not have a unit root (stationary)

Most variables are significant at 1% significance level and few are significant at 5% and 10% levels.

```
dfuller qc_i_q
dfuller man_i_q
dfuller bc_i_q
```

Dickey-Fuller test for unit root					
Interruptible Export of Electricity			Critical value		
Quebec	Manitoba	British Colombia	1%	5%	10%
-4.634	-4.133	-6.368	-3.483	-2.885	-2.575

```
dfuller qc_demand
dfuller man_demand
dfuller bc_demand
```

Dickey-Fuller test for unit root					
Local demand for elecrticity			Critical value		
Quebec	Manitoba	British Colombia	1%	5%	10%
-4.669	-4.67	-5.226	-3.483	-2.885	-2.575

```
dfuller qc_net_weigh_dif
dfuller man_net_weigh_dif
dfuller bc_net_weigh_dif
```

Dickey-Fuller test for unit root					
Net export for the last 12 month (first difference)			Critical value		
Quebec	Manitoba	British Colombia	1%	5%	10%
-5.372	-4.229	-8.092	-3.483	-2.885	-2.575

dfuller gas_p_ny_can
dfuller gas_p_texas_can
dfuller gas_p_cal_can

Dickey-Fuller test for unit root					
Price for natural gas paid by electricity producing companies			Critical value		
New York	Texas	California	1%	5%	10%
-3.412	-3.54	-2.631	-3.483	-2.885	-2.575

dfuller qc_ratio
dfuller man_ratio
dfuller bc_ratio

Dickey-Fuller test for unit root					
Firm quantity			Critical value		
Quebec	Manitoba	British Colombia	1%	5%	10%
-4.656	-4.417	-5.070	-3.483	-2.885	-2.575

dfuller gas_p_fut_can_diff

Dickey-Fuller test for unit root			
Furure price of natural gas in US (in CAD) (first difference)	Critical value		
-9.449	1%	5%	10%
	-3.483	-2.885	-2.575

dfuller usdcaddif

Dickey-Fuller test for unit root			
USD/CAD exchange rate (first difference)	Critical value		
-9.434	1%	5%	10%
	-3.483	-2.885	-2.575

dfuller qc_i_p
dfuller man_i_p
dfuller bc_i_p

Dickey-Fuller test for unit root					
Price paid by US for Electricity (CAD)			Critical value		
Quebec	Manitoba	British Colombia	1%	5%	10%
-6.317	-5.332	-2.869	-3.483	-2.885	-2.575

b) Breusch-Godfrey Test

I used Breusch-Godfrey test to see if there is an autocorrelation in regressions.

The null hypothesis is: H_0= There is no serial correlation in regression
The alternative hypothesis is H_1= There is a serial correlation in regression

If chi-value is less than chi2-value, there is no serial correlation at a specific level of significance. Results show that all variables have serial correlation.

Breusch-Godfrey Test for Export Quantity

Regression	lags(p)	chi2	df	Prob > chi2
Quebec	12	74.927	12	0.0000
Manitoba	12	111.301	12	0.0000
British Columbia	12	55.403	12	0.0000

Breusch-Godfrey Test for Marginal Price in Manitoba

Regression	lags(p)	chi2	df	Prob > chi2
Winter	3	7.539	3	0.0566
Summer	1	0.388	1	0.5331
Off-peak	2	10.473	2	0.0053

c) The Durbin-Watson

I used Durbin-Watson test to see if there is an autocorrelation in regressions.

The null hypothesis is: H_0= There is no autocorrelation in regression

The alternative hypothesis is H_1= There is positive or negative autocorrelation

If there is positive autocorrelation at 5% significance level, d value is less than dL value.

If there is negative autocorrelation at 5% significance level, (4-d) value is less than dL value.

If d value is more than dU or (4-d) value is more than dU, autocorrelation is not statistically significant at 5%.

In all other cases, the test cannot be performed.

Durbin-Watson Test for Export Quantity

The Durbin-Watson	N of Obs.	N of Var.	d	Critical values	
				dL	dU
Quebec	183	7	0.7974388	1.69091	1.82617
Manitoba	183	7	0.5994944	1.69091	1.82617
British Columbia	183	7	1.120437	1.69091	1.82617

Durbin-Watson Test for Marginal Price in Manitoba

The Durbin-Watson	N of Obs.	N of Var.	d	Critical values	
				dL	dU
Winter	63	4	1.445371	1.49433	1.69321
Summer	30	4	1.778446	1.2138	1.64981
Off-peak	90	4	1.435808	1.58893	1.72642

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