TECHNICAL APPENDIX

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Cross-Border Trade in Electricity

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Contents

A Expectation of Quadratic Sum

Let $f(x)$ be a normal probability density function of the random variable x with mean μ and variance σ^2. Then the expectation of a function $g(x)$ is

$$\mathcal{E}\{g(x)\} = \int_{-\infty}^{+\infty} g(x) f(x) dx \tag{TA-1}$$

where $f(x) = \exp[-(x-\mu)^2/(2\sigma^2)]/[\sigma\sqrt{2\pi}]$ is the normal density function. For a quadratic function $g(x)$ with arbitrary parameters a and b,

$$\mathcal{E}\{ax + bx^2\} = \int_{-\infty}^{+\infty} (ax + bx^2) f(x) dx = a\mu + b(\mu^2 + \sigma^2) \tag{TA-2}$$

This principle can be applied to calculating the profits and retail price of the utility. The utility's profits are defined as

$$\pi = \int \left[p q(t) - c(q(t)) \right] \mathrm{d}t \tag{TA-3}$$

Allowing for a fixed mark-up η set by the regulator, the retail price $\bar{p}$ is given by

$$\bar{p} = (1+\eta) \frac{\int c(q(t)) \mathrm{d}t}{\int q(t) \mathrm{d}t} = (1+\eta) \left[c_1 + c_2 \bar{q} + \frac{c_0}{\bar{q}} + \frac{c_2}{2} \left(\left(\frac{s}{\bar{q}} \right)^2 - 1 \right) \bar{q} \right] \tag{TA-4}$$

B Multivariate Normal Affine Transformation

Assume the $\mathbf{x}$ is a vector of random variables which are distribute multivariate normal so that $\mathbf{x} \sim \mathrm{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma})$. Further assume that $\mathbf{b}$ is a vector of constants of the same size a $\mathbf{x}$. The product $z = \mathbf{b}^\intercal \mathbf{x}$ is then univariate normal with $z \sim \mathrm{N}(\mathbf{b}^\intercal \boldsymbol{\mu}, \mathbf{b}^\intercal \boldsymbol{\Sigma} \mathbf{b})$. Consider the bivariate case with vector elements $+b_1$ and $-b_2$. Then z is distributed univariate normal with mean $b_1\mu_1 - b_2\mu_2$ and variance $b_1^2\sigma_1^2 + b_2^2\sigma_2^2 - 2b_1b_2\rho\sigma_1\sigma_2$. The variance will decrease if the two random variables are positively correlated, and will increase if the two random variables are negatively correlated.

C Truncated Normal Distribution

If a random variable z is distributed normally with mean μ and variance σ^2, then the expected values of the left-truncated and right-truncated distribution with truncation point a are:

$$\mathcal{E}\{z | z > a\} = \mu + \sigma \frac{\phi((\mu - a)/\sigma)}{\Phi((\mu - a)/\sigma)} \tag{TA-5}$$

$$\mathcal{E}\{z | z < a\} = \mu - \sigma \frac{\phi((a - \mu)/\sigma)}{\Phi((a - \mu)/\sigma)} \tag{TA-6}$$

The functions $\phi(\cdot)$ and $\Phi(\cdot)$ denote the standard normal probability density function and standard normal probability cumulative density function, respectively. Further note that $\phi(x) = \phi(-x)$ and $1 - \Phi(x) = \Phi(-x)$.

D Alternative Cost Function

An alternative to the quadratic cost function that was used primarily in this paper, it is possible to employ a logarithmic cost function

$$c(q) = -\gamma \ln\left(1 - \frac{q}{K}\right) \tag{TA-7}$$

that depends on the capacity utilization rate q/K. This cost function has a single parameter $\gamma > 0$, and the cost function itself is convex with monotonically increasing marginal cost, i.e., $c'(q) = \gamma/(K-q) > 0$ and $c''(q) = \gamma/(K-q)^2 > 0$, and $\lim_{q\to K} c(q) = \infty$. Instead of transmission costs, exporting incurs transmission losses so that exporting the amount x requires $x(1+\xi)$ of extra generation, with $\xi > 0$. Thus the profit function can be written as

$$\pi^x = px - [C(q + x(1+\delta^x\xi)) - C(q)] \tag{TA-8}$$

where δ^x and δ^m are binary indicators for export and import status, respectively. The utility will export and import when

$$p > \frac{\gamma(1+\xi)}{K-q} \quad \text{for exporting} \tag{TA-9}$$

$$p < \frac{\gamma}{K-q} \quad \text{for importing} \tag{TA-10}$$

The trading price for electricity is

$$p = \frac{(1+\xi)(\gamma^h + \gamma^f)}{(K^f - q^f)(1+\delta^x\xi) + (K^h - q^h)(1+\delta^m\xi)} \tag{TA-11}$$

and the export volume is

$$x^h = \frac{\gamma^f(K^h - q^h)}{(\gamma^h + \gamma^f)(1+\delta^x\xi)} - \frac{\gamma^h(K^f - q^f)}{(\gamma^h + \gamma^f)(1+\delta^m\xi)} \tag{TA-12}$$

Exports and imports will occur when

$$\xi < \frac{\gamma^f(K^h - q^h)}{\gamma^h(K^f - q^f)} \quad \text{for exporting} \tag{TA-13}$$

$$\xi < \frac{\gamma^h(K^f - q^f)}{\gamma^f(K^h - q^h)} \quad \text{for importing} \tag{TA-14}$$

From the above it is clear that x^h is a linear function of q^h and q^f, and thus the integration over the reference time period to find X^h and M^h proceeds in the same fashion as discussed in the paper and B and C.

E Empirical Patterns of North-American Electricity Trade

Table TA-1 shows average annual generation and demand of electricity in the ten Canadian provinces and three territories. In most provinces, output and demand match closely. Most provincial utilities operate under a mandate of self-sufficiency. A few provinces export a

Table TA-1: Average Annual Electricity Generation, Consumption, Exports and Imports by Province (2008-2012)

Province	Output [GWh]	Demand [GWh]	Exports CA[%]	Exports US[%]	Imports CA[%]	Imports US[%]
Canada	585,173	550,163		8.9		3.1
Alberta	61,163	64,228	0.3	0.3	4.2	1.2
British Columbia	64,649	64,670	3.4	13.0	0.3	15.6
Manitoba	33,962	24,426	4.1	26.8	2.8	1.0
New Brunswick	11,830	14,511	11.0	9.9	30.1	5.5
Newfoundland and Labrador	41,000	11,423	72.2		0.2	
Nova Scotia	11,333	11,726	0.1	0.1	1.9	1.6
Northwest Territories	671	671				
Nunavut	166	166				
Ontario	145,075	132,535	3.9	9.7	2.6	2.7
Prince Edward Island	216	1,197	23.3		86.2	
Quebec	193,364	202,835	3.6	10.0	17.1	0.5
Saskatchewan	21,334	21,424	5.2	0.5	4.6	1.5
Yukon	411	411				

Note: Output is total generation of electricity in gigawatthours (GWh). Demand is total electricity available for use with the province in gigawatthours (GWh). Exports are the delivery of electricity to other provinces (CA) and the United States (US). Imports are the receipts of electricity from other provinces (CA) and the United States (US). Exports and imports are expressed in percentages of output and demand, respectively. Source: Statistics Canada CANSIM Table 127-0003.

Table TA-2: Correlation of Monthly Provincial Electricity Demand

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
BC		0.37^b	0.58^d	0.91^d	0.49^d	0.91^d	0.87^d	0.80^d	0.42^c	0.87^d
AB	0.37^b		0.58^d	0.48^d	-.05	0.47^d	0.13	0.03	0.41^c	0.40^b
SK	0.58^d	0.58^d		0.76^d	0.07	0.74^d	0.51^d	0.50^d	0.50^d	0.64^d
MB	0.91^d	0.48^d	0.76^d		0.46^c	0.97^d	0.84^d	0.79^d	0.43^c	0.86^d
ON	0.49^d	-.05	0.07	0.46^c		0.43^c	0.59^d	0.61^d	0.38^b	0.32^b
QC	0.91^d	0.47^d	0.74^d	0.97^d	0.43^c		0.86^d	0.81^d	0.45^c	0.91^d
NB	0.87^d	0.13	0.51^d	0.84^d	0.59^d	0.86^d		0.87^d	0.39^b	0.83^d
NS	0.80^d	0.03	0.50^d	0.79^d	0.61^d	0.81^d	0.87^d		0.41^c	0.70^d
PE	0.42^c	0.41^c	0.50^d	0.43^c	0.38^b	0.45^c	0.39^b	0.41^c		0.36^b
NL	0.87^d	0.40^b	0.64^d	0.86^d	0.32^b	0.91^d	0.83^d	0.70^d	0.36^b	

Note: The numbers in the table are Pearson correlation coefficients based on the 60 monthly observations for the 2008-2012 period. Statistical significance at the 95%, 99%, 99.9% and 99.99% confidence levels are indicated by superscripts ^{a}, ^{b}, ^{c}, and ^{d}, respectively. Source: Statistics Canada CANSIM Table 127-0003.

Table TA-3: Correlation of Monthly Electricity Demand, Canadian Exporter Provinces and US Importer States, 2001–2012

	AB	BC	MB	NB	NS	ON	QC	SK
AK	*0.63*^{d}	**0.84**^{d}	*0.83*^{d}	*0.54*^{d}	*0.62*^{d}	*-.00*	*0.80*^{d}	*0.68*^{d}
AZ	*0.08*	**-.46**^{d}	*-.45*^{d}	*-.68*^{d}	*-.54*^{d}	*-.12*	*-.60*^{d}	*-.20*^{a}
CA	**0.19**^{a}	**-.24**^{b}	*-.30*^{c}	*-.51*^{d}	*-.37*^{d}	*-.01*	*-.41*^{d}	*-.10*
CO	*0.47*^{d}	**-.11**	*0.00*	*-.43*^{d}	*-.27*^{b}	*-.15*	*-.21*^{b}	*0.22*^{b}
IA	**0.46**^{d}	*0.04*	*0.15*	*-.23*^{b}	*-.09*	*0.06*	*-.04*	*0.27*^{b}
ID	**0.31**^{c}	**-.04**	*0.01*	*-.26*^{b}	*-.14*	*0.15*	*-.13*	*0.09*
IL	*0.22*^{b}	*-.09*	*-.02*	*-.22*^{b}	*-.10*	**0.34**^{d}	*-.13*	*0.03*
IN	*0.29*^{c}	**0.08**	*0.14*	*-.07*	*0.09*	**0.39**^{d}	*0.07*	*0.15*
MA	*0.23*^{b}	*0.05*	*0.08*	**-.06**	*0.11*	**0.42**^{d}	**0.05**	*0.09*
MD	*0.01*	*-.05*	*0.05*	**0.04**	*0.14*	*0.52*^{d}	*0.05*	*0.02*
ME	*0.14*	*0.22*^{b}	*0.13*	**0.19**^{a}	**0.25**^{b}	*0.59*^{d}	**0.23**^{b}	*0.10*
MI	*0.07*	*-.13*	*-.15*	*-.22*^{b}	*-.10*	**0.48**^{d}	**-.16**	**-.14**
MN	*0.43*^{d}	*0.11*	**0.17**^{a}	*-.17*^{a}	*0.01*	**0.20**^{a}	*0.02*	**0.23**^{b}
MO	*0.32*^{d}	*0.00*	*0.08*	*-.20*^{a}	*-.06*	**0.20**^{a}	*-.06*	*0.19*^{a}
MT	*0.45*^{d}	**0.67**^{d}	*0.60*^{d}	*0.37*^{d}	*0.51*^{d}	*0.26*^{b}	*0.54*^{d}	*0.40*^{d}
ND	**0.79**^{d}	*0.61*^{d}	**0.79**^{d}	*0.33*^{d}	*0.39*^{d}	*-.19*^{a}	*0.63*^{d}	**0.80**^{d}
NE	*0.45*^{d}	*-.01*	*0.14*	**-.24**^{b}	**-.12**	*0.03*	**-.06**	*0.28*^{c}
NH	*0.28*^{c}	*0.19*^{a}	*0.18*^{a}	**0.06**	*0.21*^{a}	*0.43*^{d}	**0.20**^{a}	*0.14*
NM	*0.40*^{d}	**-.22**^{b}	*-.13*	*-.54*^{d}	*-.39*^{d}	*-.21*^{a}	*-.34*^{d}	*0.12*
NV	*0.12*	**-.40**^{d}	*-.40*^{d}	*-.64*^{d}	*-.50*^{d}	*-.06*	*-.55*^{d}	*-.17*^{a}
NY	*0.08*	*-.19*^{a}	*-.14*	**-.22**^{b}	**-.12**	**0.39**^{d}	**-.21**^{a}	*-.09*
OH	*0.20*^{a}	*0.10*	*0.13*	*0.05*	*0.16*	**0.56**^{d}	*0.10*	*0.06*
OR	**0.44**^{d}	**0.82**^{d}	*0.74*^{d}	*0.67*^{d}	*0.70*^{d}	*0.41*^{d}	*0.79*^{d}	*0.50*^{d}
PA	**0.36**^{d}	*0.30*^{c}	*0.34*^{d}	*0.14*	*0.30*^{c}	**0.40**^{d}	*0.29*^{c}	**0.30**^{c}
TX	*0.15*	**-.48**^{d}	*-.38*^{d}	*-.64*^{d}	*-.53*^{d}	**-.13**	*-.55*^{d}	*-.09*
UT	*0.54*^{d}	**-.00**	*0.10*	*-.35*^{d}	*-.20*^{a}	*-.15*	*-.12*	*0.28*^{c}
VT	*0.36*^{d}	*0.54*^{d}	*0.49*^{d}	*0.41*^{d}	*0.51*^{d}	**0.67**^{d}	**0.50**^{d}	*0.27*^{b}
WA	**0.59**^{d}	**0.73**^{d}	*0.79*^{d}	*0.56*^{d}	*0.60*^{d}	*-.00*	*0.79*^{d}	*0.72*^{d}
WY	*0.69*^{d}	**0.44**^{d}	*0.58*^{d}	*0.07*	*0.21*^{a}	*-.40*^{d}	*0.38*^{d}	*0.68*^{d}

Note: The numbers in the table are Pearson correlation coefficients based on monthly demand data for Canadian provinces that export electricity to the US, and US states that import electricity from Canada. Coefficients in **boldface** are for actual trade partners; all other correlations are shown in *italics*. Statistical significance at the 95%, 99%, 99.9% and 99.99% confidence levels are indicated by superscripts ^{a}, ^{b}, ^{c}, and ^{d}, respectively. Source: Statistics Canada CANSIM Tables 127-001, 127-0002, and 127-0003; US Energy Information Administration, Electricity Browser.

significant amount of electricity to neighbouring provinces. For example, the province of Newfoundland and Labrador exports most of its electricity to neighbouring Quebec.[1]

Table TA-2 provides simple correlation statistics for electricity demand in the ten provinces (aligned geographically from west to east). In some instances, demand correlation between neighbouring provinces is relatively high and exceeds 0.8. Interestingly, the correlation between two pairs of large provinces are modest: demand in Alberta and British Columbia is correlated at 0.37, and demand in Ontario and Quebec is correlated at 0.43. The point to take away is that correlations are far less than perfect, and this opens up a source for gains from trade.

Table TA-3 extends the correlation analysis to the pairs of eight provinces and 32 US states that are engaged in cross-border electricity trade. Actual trading partners are highlighted in boldface, while hypothetical trading partners are shown in italics. Many of the existing trade partners exhibit positively-correlated electricity demand. As the theoretical section will demonstrate later, lower and negative correlations are associated with a higher potential for trade. In the case of British Columbia, trade with California, Nevada, Arizona, New Mexico, and Texas is particularly beneficial because of the negative correlations. As is easily seen, many pairs with high negative correlations are not engaging in trade—an indication of unrealized trade potential.

Figure TA-1 illustrates the time dimension of electricity trade with the example of British Columbia, which has one 500 kV intertie with the neighbouring province Alberta, and two 500 kV and two 230 kV interties with Washington state. This amounts to an export capacity of 3,150 MW to the United States and 1,200 MW to Alberta. For technical reasons, import capacities are slightly lower. As was indicated in table TA-1, British Columbia's total electricity trade is relatively balanced with a significant amount of imports and exports. On closer inspection, exports and imports exhibit seasonal patterns. Even over the period of a month, British Columbia tends to export and import electricity at the same time. This is in part explained by the fact that there are multiple interties. British Columbia's available generation capacity depends on water levels in the reservoirs of its hydroelectric dams. Thus there is surplus electricity in high-water years. The years 2011 and 2012 exhibited large net exports during the summer months. Electricity trade with Alberta, shown in figure TA-2, contributes relatively little to the overall trade because of the smaller capacity of the interties. The trading pattern is clearly dominated by exports, indicating that British Columbia has a strong comparative advantage in electricity generation with respect to neighbouring Alberta.

One of the peculiarities of international trade in electricity is that the price does not necessarily reflect resource abundance in a conventional Heckscher-Ohlin sense. The price of traded electricity depends as much on long-term comparative advantage as it does on short-term shortages. The result is that electricity—a homogenous commodity—can be priced rather differently depending on which way the electricity flows through an intertie. The 'law of one price' does not apply. Pricing may even reach absurd levels. During the California electricity crisis in 2000/2001, British Columbia exported electricity to California at peak prices of around $800/MWh. And in March 2013, Ontario exported electricity to New York and Michigan at $–128/MWh: a negative price. Dumping electricity across the border was less costly than ramping down generators.

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[1]The Churchill Falls hydroelectric dam in Labrador, with an installed capacity of 5,428 Megawatt from 11 turbines, delivers electricity to the province of Quebec under a long-term power purchasing agreement that is a highly favourable to Quebec at today's prices.

Figure TA-1: British Columbia Total Trade in Electricity, 2008-2012

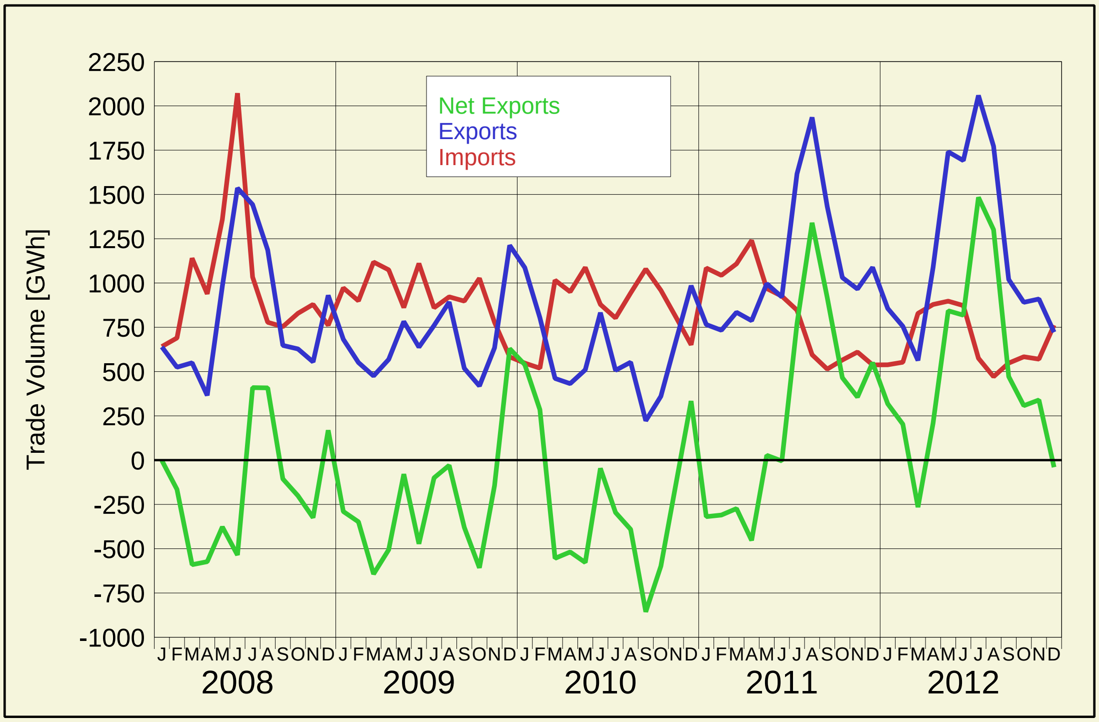
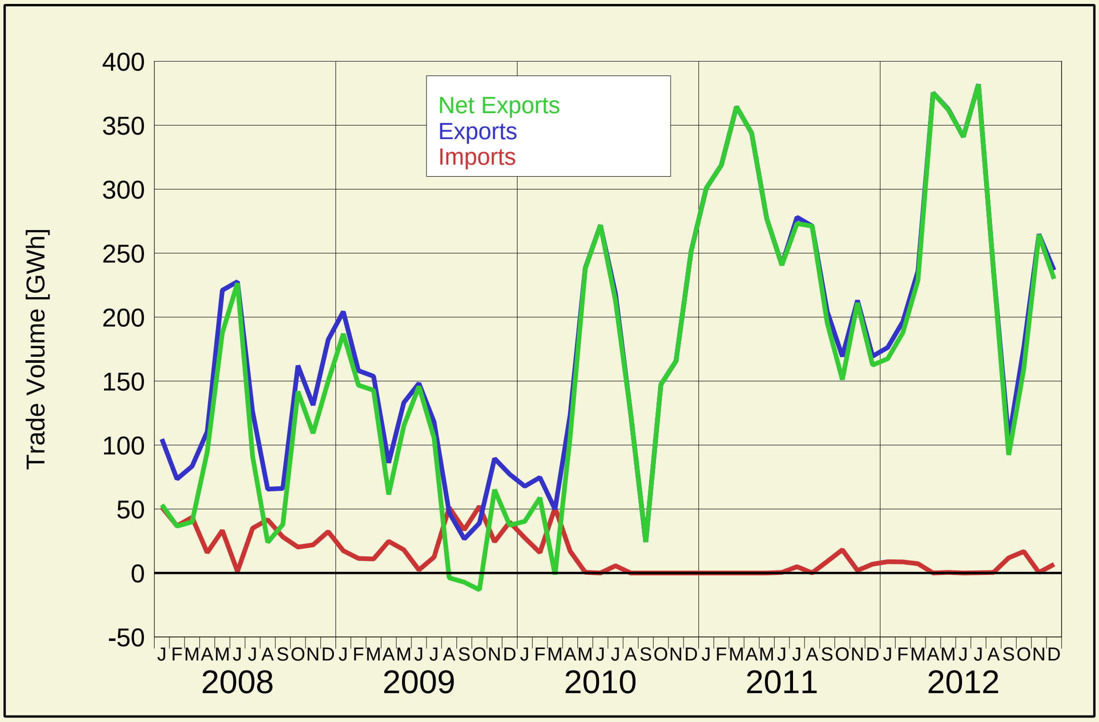


Figure TA-2: British Columbia Interprovincial Trade in Electricity, 2008-2012



Note: Original data from Statistics Canada CANSIM Table 127-0003.

Building interties between jurisdictions is expensive. A double-circuit 500 kV AC line is estimated to cost over $2 million per kilometer [Mason et al., 2012], with each circuit able to carry a 2,000 MW load. At the end of each line, additional substations are needed, each costing about $30 million. However, there are significant economies of scale with respect to the length of the line. High-voltage direct current (HVDC) lines are cheaper for carrying long-distance loads but require more expensive Line Commutated Converters (LCCs) at the end. Recent years have seen many innovations into HVDC technology that will make HVDC technology cheaper and expand its scope of use.[2]

F Decomposing One-Way and Two-Way Trade

The model introduced in this paper allows both for one-way trade (driven by comparative advantage in electricity generation) and two-way trade (driven by the benefits of reciprocal load smoothing). Available trade data aggregates both types of trade into one figure. Can they be decomposed?

A conventional measure for measuring the extent of two-way trade is the Grubel and Lloyd [1971] index

$$\text{GL}_t = 1 - \frac{|X_t - M_t|}{X_t + M_t} \tag{TA-15}$$

This means that total trade $X + M$ can be decomposed into one-way trade $|X - M|$ and two-way trade $(X + M) - |X - M|$. Thus the GL index captures the share of two-trade trade. Using the expressions for exports (14) and imports (15), ignoring transportation costs g, and defining the ratio $\theta \equiv |u|/v$ as the normalized trade volume, it can be shown that

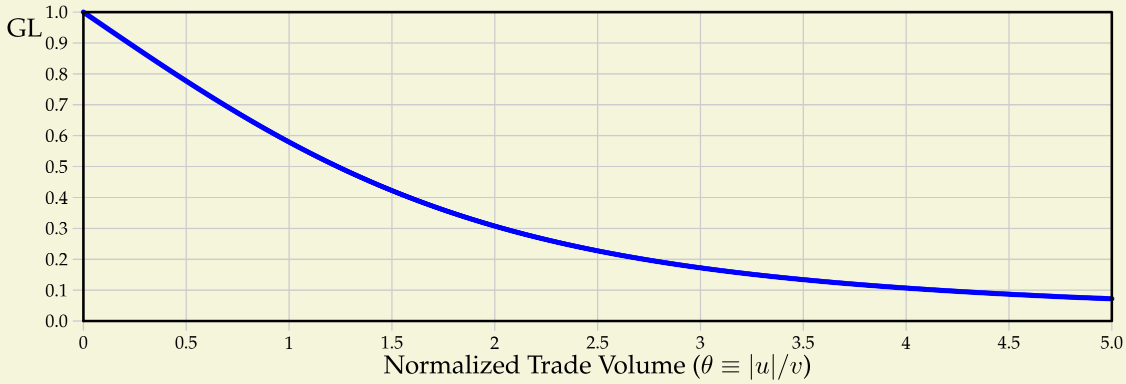
$$\text{GL}(\theta) = 2\Phi(\theta)\left[1 - \theta\frac{1-\Phi(\theta)}{\phi(\theta)}\right] \tag{TA-16}$$

Figure TA-3 visualizes (TA-16). When the trade volume is small relative to the variation in trade volume, virtually all trade is two-way. A high GL index indicates that reciprocal load smoothing dominates as the reason for trade. On the other hand, when comparative advantage dominates and the trade volume is large relative to its variation, one-way trade dominates and the GL index approaches zero.

As the share of two-way trade is computed easily through (TA-15) for a given reference time period, equation (TA-16) provides yet another testable implication of the reciprocal load smoothing model. It needs to be noted, though, that the patterns of one-way and two-way trade do not remain stable over time. The *Technical Appendix* contains figures that depict the share of two-way trade for Ontario, British Columbia and Manitoba during 2003-2012. Over that period, Ontario's two-way trade with the United States has given way to one-way trade, and British Columbia's two-way trade with Alberta has turned into one-way trade.

[2] Notably, ABB's hybrid breakers are considered a 'game changer,' and the voltage-source converter (VSC) technology makes it feasible to use HVDC for lower capacity applications in HVDC 'light' systems. The early 20th-century 'war of the currents' between alternating current (favoured by Tesla and Westinghouse) and direct current (favoured by Edison and General Electric) may well reappear in a new battle over bulk electricity transmission.

Figure TA-3: Index of Two-Way Electricity Trade



G Jurisdictional Integration

How much electricity trade would there be if both jurisdictions were fully integrated? The joint capacity limit is $K^\circ \equiv K^h + K^f$, and joint production is $k^\circ \equiv k^h + k^f$, Demand is now $q^\circ \equiv q^h + q^f$ with expected value $\bar{q}^h + \bar{q}^f$, and at any point in time demand must equal supply: $q^\circ = k^\circ$. However, the new variance of demand is $(s^h)^2 + 2\rho s^h s^f + (s^f)^2$. As the coefficient of correlation varies between $[-1, +1]$, the variance is constrained and ranges between $(s^h - s^f)^2$ at the low end and $(s^h + s^f)^2$ at the high end. For simplicity of exposition, the discussion here will ignore the transmission cost g.

Total cost of the merged utility is determined in such a way that the utility employs the lower cost resources first until it is possible to equate the marginal cost of the original home and foreign resources. Then it employs both resources equally until one of the resources is at full capacity. The remaining capacity, at highest marginal cost, is brought in at the end. The lower and upper thresholds are

$$q_L^\circ \equiv \min\{(c_1^h - c_1^f)/c_2^f, (c_1^f - c_1^h)/c_2^h\} \quad \text{(TA-17)}$$

$$q_H^\circ \equiv \min\{(c_1^h - c_1^f + c_2^h K^h)/c_2^f, (c_1^f - c_1^h + c_2^f K^f)/c_2^h\} \quad \text{(TA-18)}$$

In the region $[q_L^\circ, q_H^\circ]$, the merged marginal costs will be

$$\frac{\mathrm{d}c^\circ(q^\circ)}{\mathrm{d}q^\circ} = \frac{c_1^h c_2^f + c_1^f c_2^h}{c_2^h + c_2^f} + \frac{c_2^h c_2^f}{c_2^h + c_2^f} q^\circ \quad \text{(TA-19)}$$

which is composed of a weighted arithmetic mean of the linear terms c_1 and a harmonic mean for the quadratic terms c_2. When $q^\circ > q_L^\circ$, total supply and individual supply (denoted by k) are related through

$$k^h = \frac{c_1^f - c_1^h + c_2^f q^\circ}{c_2^h + c_2^f} \quad \text{(TA-20)}$$

$$k^f = \frac{c_1^h - c_1^f + c_2^h q^\circ}{c_2^h + c_2^f} \quad \text{(TA-21)}$$

Implied exports of Home and Foreign are $x^h = k^h - q^h$ and $x^f = k^f - q^f$. It is immediately apparent that x^h is the same as (9) without the transmission cost. Exports and imports are thus the same as (14) and (15) without transmission costs. Therefore, in the absence of other economic frictions, the efficient volume of trade in electricity under jurisdictional separation is the same as under jurisdictional integration. This equivalence theorem is fundamental but not unexpected: it is a property of all neoclassical trade models. Trade brings about full efficiency unless dampened by frictions.

In practice, jurisdictional integration has two advantages over jurisdictional separation. First, integration removes the potential conflict over building sufficient intertie capacity. Integration eliminates the negotiation and contracting issues that may arise otherwise. Second, integration also leads to a new price $\bar{p}$, which—as was shown earlier—is influenced by the variance of the distribution of $q(t)$. If demand in both jurisdictions is less than perfectly correlated, integration will lead to a reduction of the joint variance s^2; it will be lower than $(s^h)^2 + (s^f)^2$. This means that the joint price $\bar{p}$ can be lower than the original $\bar{p}^h$ or $\bar{p}^f$ (unless the original price gap was very large). This 'integration bonus' is a true efficiency gain.

H Capacity Constraints

The theoretical model developed so far does not take into consideration that intertie capacity is fixed in the short term. A given intertie has a rated MW capacity for export ($\bar{x}$) and import ($\bar{m}$). These two numbers do not have to be identical for a given intertie because of constraints with transformers and other equipment.[3] A jurisdiction will export or import at maximum intertie capacity when

$$\begin{aligned} p &> c_1 + c_2(q + \bar{x}/2) + g/2 \equiv c_{\bar{x}} \quad \text{exporting} && \text{(TA-22)} \\ p &< c_1 + c_2(q - \bar{m}/2) - g/2 \equiv c_{\bar{m}} \quad \text{importing} && \text{(TA-23)} \end{aligned}$$

When $c^f_{\bar{m}} < c^h_{\bar{x}}$, the home jurisdiction will export electricity at maximum capacity $\bar{x}^h = \bar{m}^f$. The price must fall in the range $c^f_{\bar{m}} < p < c^h_{\bar{x}}$; it is not unique and subject to bargaining. Maximum intertie use for exporting will therefore occur when

$$c^f_2 q^f - c^h_2 q^h > c^h_1 - c^f_1 + g + \bar{x}^h(c^f_2 + c^h_2)/2 \qquad \text{(TA-24)}$$

When foreign and domestic cost factors are the same, then this condition simplifies to $q^f - q^h > \bar{x}^h + g/c_2$. Home exports at maximum capacity as soon as the gap between foreign and domestic load is sufficiently large.

A related question is about the utilization rate of the intertie. How often will the intertie operate under full load? It is again possible to employ the equations for affine transformations in B. Taking expectations on the left-hand side of (TA-24) and abbreviating the term on the right-hand side as $\tilde{c}$, it follows that

$$\begin{aligned} \mathcal{E}\{c^f_2 q^f - c^h_2 q^h\} &= c^f_2 \bar{q}^f - c^h_2 \bar{q}^h \equiv \tilde{u} && \text{(TA-25)} \\ \mathcal{V}\{c^f_2 q^f - c^h_2 q^h\} &= (c^f_2 s^f)^2 - 2\rho c^h_2 c^f_2 s^f s^h + (c^h_2 s^h)^2 \equiv \tilde{v}^2 && \text{(TA-26)} \end{aligned}$$

[3] As a practical example, the *Total Transfer Capability* (TTC) of the Ingledow-Custer intertie (two 500 kV lines) between British Columbia and Washington state is rated at 3,150 MW in the southern direction and 2,000 MW in the norther direction. A figure in the *Technical Appendix* depicts actual utilization hour-by-hour over a few weeks. The frequent reversal of direction is a defining feature of many interties.

The probability that the capacity is fully utilized in the export direction is thus $1 - \Phi((\tilde{c} - \tilde{u})/\tilde{v})$. When both jurisdictions are cost-identical and have demand correlation ρ, the probability of full intertie utilization is

$$\text{Prob}(x = \bar{x}^h) = 1 - \Phi\left(\frac{\bar{x}^h + g/c_2}{s\sqrt{2(1-\rho)}}\right) \tag{TA-27}$$

When both jurisdictions are symmetric, the probability in the expression above cannot exceed 50% because imports and exports are symmetric as well. From the above expression it becomes clear that capacity utilization increases with: a decreasing demand correlation (ρ becomes smaller or negative); a decreasing ratio of intertie capacity to demand variation $\bar{x}^h/s$; and decreasing transportation cost g. Conversely, as $\rho \to 1$, utilization drops to zero. Capacity utilization will increase if the intertie's use is driven by comparative advantage rather than demand fluctuations and reciprocal load smoothing. The larger the comparative advantage $|c_1^f - c_1^h|$, the more the intertie will be used.

I Derivation of the Main Estimating Equation

The main estimating equation is derived directly from the equation that predicts electricity exports as a function of the comparative advantage expression (u), the joint standard deviation (v), and the expression for the truncated normal distribution ($\phi(u/v)/\Phi(u/v)$). The estimating equation is derived by taking logs and using a few subtle transformations and approximations that are explained step-by-step below. The starting point is the export equation

$$X = \left[u + v\frac{\phi(u/v)}{\Phi(u/v)}\right]T \tag{TA-28}$$

Rearranging this gives

$$x = X/T = v\left[\left(\frac{u}{v}\right) + \frac{\phi(u/v)}{\Phi(u/v)}\right] \tag{TA-29}$$

and taking logs yields

$$\ln(x) = \ln(v) + \ln\left(\frac{u}{v} + \frac{\phi(u/v)}{\Phi(u/v)}\right) \tag{TA-30}$$

It turns out that the second term on the right-hand side is in fact nearly linear:

$$\ln\left(\frac{u}{v} + \frac{\phi(u/v)}{\Phi(u/v)}\right) \approx \zeta_0 + \zeta_1(u/v) \tag{TA-31}$$

A regression of the left-hand side of the previous equation on (u/v) in the "typical" range $[-0.5, 2.5]$ with 240 data points yields an R^2 of 0.9996 with $\zeta_0 = -0.220$ and $\zeta_1 = 0.467$. The same regression in the range from -3.5 to $+3.5$ standard deviations still gives an R^2 greater than 99.3%. Substituting approximation (TA-31) back into (TA-30) yields

$$\ln(x) \approx \ln(v) + \zeta_0 + \zeta_1(u/v) \tag{TA-32}$$

This is a highly-accurate approximation, and this turns out to be rather fortuitous for estimation purposes. The terms in the comparative advantage (expected instantaneous export) equation now enter the estimating equation in an additive fashion. In particular, the plus sign in front of $\bar{q}^f$ (for the export destination) and the minus sign in front of $\bar{q}^h$ (for the export source) are preserved exactly.

The next steps in the derivation require finding expressions for $\ln(v)$ and for u/v to put into equation (TA-32). This involves deriving v and showing how the harmonic mean of the generating capacities appears on the left-hand side of the estimating equation. The identifying assumption introduced in the paper is a normalization of the marginal cost slope parameters c_2. Specifically, it is assumed that $c_2^i q^i$ can be approximated by $\tilde{c}_2^i q^i / K^i$ and that $\tilde{c}_2^i$ is the same across jurisdictions: $\forall i : \tilde{c}_2^i = \tilde{c}_2$. With this assumption in place, the variance equation simplifies as follows:

$$\begin{aligned}
v^2 &= \frac{(c_2^h s^h)^2 - 2c_2^h c_2^f s^h s^f \rho + (c_2^f s^f)^2}{(c_2^h + c_2^f)^2} \\
&= \frac{\tilde{c}_2^2 (s^h/K^h)^2 - 2\tilde{c}_2^2 (s^h/K^h)(s^f/K^f)\rho + \tilde{c}_2^2 (s^f/K^f)^2}{\tilde{c}_2^2 (1/K^h + 1/K^f)^2} \\
&= \left[\left(\frac{s^h}{K^h}\right)^2 - 2\rho \frac{s^h s^f}{K^h K^f} + \left(\frac{s^f}{K^f}\right)^2\right] \left(\frac{K^h K^f}{K^h + K^f}\right)^2 \\
&= \left[\left(\frac{s^h}{K^h}\right)^2 - 2\rho \frac{s^h s^f}{K^h K^f} + \left(\frac{s^f}{K^f}\right)^2\right] \left(\frac{K^{fh}}{2}\right)^2 \equiv \left(\frac{S^{hf} K^{hf}}{2}\right)^2 \qquad \text{(TA-33)}
\end{aligned}$$

where the harmonic mean of capacities of exporting and importing jurisdiction is given by

$$K^{hf} \equiv \frac{2}{1/K^h + 1/K^f} = 2\frac{K^h K^f}{K^h + K^f} \qquad \text{(TA-34)}$$

The square root of (TA-33) yields v. Denote the square root of the expression in square brackets in the last line of (TA-33) as S^{hf}, the joint capacity-adjusted standard deviation of electricity demand. A similar transformation applies to the comparative advantage (instantaneous export) equation:

$$u = \frac{(c_1^f + c_f^2 \bar{q}^f) - (c_1^h + c_2^h \bar{q}^h) - \delta g}{c_2^h + c_2^f} = \frac{K^{hf}}{2}\left[\frac{\bar{q}^f}{K^f} - \frac{\bar{q}^h}{K^h} + \frac{c_1^f - c_1^h - \delta g}{\tilde{c}_2}\right] \qquad \text{(TA-35)}$$

and therefore

$$\frac{u}{v} = \frac{1}{S^{fh}}\left[\frac{\bar{q}^f}{K^f} - \frac{\bar{q}^h}{K^h} + \frac{c_1^f - c_1^h - \delta g}{\tilde{c}_2}\right] \qquad \text{(TA-36)}$$

Note that the harmonic capacity mean K^{fh} cancels out when u and v are divided. The ratio u/v is needed for the linear term in (TA-32). Further taking the square root of (TA-33) and then taking logs, it follows that

$$\begin{aligned}
\ln(v) &= \ln(K^{hf}) + \ln\sqrt{\left(\frac{s^h}{K^h}\right)^2 - 2\rho\frac{s^h s^f}{K^h K^f} + \left(\frac{s^f}{K^f}\right)^2} - \ln(2) \\
&\equiv \ln(K^{hf}) + \ln(S^{hf}) - \ln(2) \qquad \text{(TA-37)}
\end{aligned}$$

where the expression with the square root is defined as S^{hf}, the joint capacity-normalized standard deviation. The $-\ln(2)$ constant is irrelevant for estimation purposes, and the

$\ln(K^{hf})$ term in (TA-37) can be brought to the left side of equation (TA-32) so that $\ln(x^{hf}) - \ln(K^{hf}) = \ln(x^{hf}/K^{hf})$, and thus the estimating equation emerges as

$$\ln\left[\frac{x^{hf}}{K^{hf}}\right] \approx \alpha_4 \ln(S^{hf}) + \alpha_1 \ln\left[\frac{q^f}{K^h}\right] - \alpha_2 \ln\left[\frac{q^h}{K^h}\right] - \alpha_3 \ln(D^{hf}) + \cdots \tag{TA-38}$$

where the $\cdots$ notation symbolizes various fixed effects. Theory clearly predicts all four α coefficients to be positive, and α_4 to be close to unity. Indeed, the key regression in the first column of Table 1 yields an estimate of 0.992.

There is one final approximation introduced into this derivation: using log transformations for individual variables in u/v. Equation (TA-32) is linear in u/v, and thus the estimating equation needs to capture equation (TA-36). As was pointed out earlier, variables in equation (TA-36) enter additively. However, it is expedient to transform the load factors q/K, which are further divided by S^{hf}, into logarithms. This allows pulling out the S^{hf} term and shifting it effectively into the estimate of α_4, which should then be smaller than unity. Also note that S^{hf} has essentially only cross-sectional variation but no time variation, whereas the load ratios and comparative advantage expressions all have significant time variation. Econometrically, the time variation identifies the load ratio parameters α_1 and α_2. Further note that transforming the load ratios into logs is benign. By construction, the load ratios are confined to the $[0, 1]$ interval, and they are usually quite close to the top of this range. The logarithmic transformation is very flat in this range close to one, which makes this transformation rather benign.

The logarithmic transformation of the distance term (D) also provides for an easier interpretation as an elasticity, which in turn allows for comparison with conventional distance effect estimates in gravity equations. More importantly, the effect of distance may not be linear as suggested in the theory. Transmission costs g may indeed be a non-linear function of distance D. Furthermore, taking logs of the load ratios and distance gets around quantifying and explaining the approximation coefficient ζ_1. The estimated coefficients for load ratios and distance are simply elasticities.

The main estimating equation in the paper follows the theory closely. The derivation hinges mostly on the validity of the identifying assumption ($\forall i : \tilde{c}_2^i = \tilde{c}_2$). The logic behind this assumption is that the most marginal power plants are thermal plants with quick ramping-up-and-down, which have similar cost characteristics across jurisidictions. Furthermore, the empirical approximations introduced in the derivation above are minor and arguably benign. Importantly, the derivation of the estimating equation preserves functional form and the signs of the coefficients. In particular, parameter α_4—perhaps the linchpin in the estimation framework—is well identified and derived directly from the theoretical model. Parameter α_4 must be positive and cannot possibly exceed unity. It may be expected to be around $1 - \zeta_1 = 0.553$ if the logarithmic approximation for the variables in u/v was working perfectly. Ultimately, the empirical estimates clearly confirm the validity of the specification that emerged in estimating equation (TA-38).

J Additional Tables and Figures

This section contains a large number of tables and figures that are either ancillary to the main body of the paper or provide robustness checks of empirical results using different specifications or using different subsamples of the data. The are explained below.

Tables TA-4 and TA-5 provide population-weighted distances between Canadian provinces, and between Canadian provinces and US states. Two distance measures were calculated: arithmetic weighted means and harmonic weighted means. The preferred measure is the harmonic mean. Table TA-4 reports both measures (upper right half: arithmetic means; lower left half: harmonic means). Also reported are internal distances for comparison. The computation of distances was carried out through aggregation at the postal code level: forward sortation areas (FSAs) in Canada and zone improvement plan (ZIP) codes in the United States. Canadian population data are from the 2011 Canadian census. US data are from www.unitedstateszipcodes.org and is based on rom authoritative sources including the United States Postal Service (2011), US Census Bureau (2010), and the Internal Revenue Service (2008).

Table TA-6 shows US monthly energy sales by state, in descending order of total sales (mean, in Gigawatthours). Also shown are the standard deviation and the coefficient of variation. Some states have very little variation (e.g., Hawaii) due to climate, whereas others have high variability (e.g., Arizona). The table also shows minimum, median, and maximum sales as an indication of the range of electricity demand.

Table TA-7 is the counterpart for the supply side. It shows the amount of electricity generated in each jurisdiction in descending order of size. It also shows the percentage contributions for each major generation source: coal, natural gas, other fossil fuels, nuclear power, hydro power, and other renewables (solar power, wind power, geothermal power, etc.). Overall, 47% of US electricity is derived from coal, 21% from natural gas, and 20% from nuclear power. During the 2001-2012 averaging period, only 9.5% were derived from renewable sources (including hydro). California and Maine had the highest share of novel types of renewable energy, but Washington, Oregon and Idaho derive the majority of their electricity from (clean) hydroelectricity.

Figures TA-4 and TA-5 show the effects of the California electricity crisis in 2000-01 from the perspective of British Columbia. Clearly visible is the price spike that reached over $800/MWh at the height of the crisis. This translated into substantial windfall profits for electricity exporters; British Columbia alone gained nearly $3 billion dollars in extra revenue.

Figure TA-6 provides an intra-day snapshot of load utilization of the major intertie between British Columbia and the United States. Sampled at 5-minute intervals, the chart shows the capacity limits for exports and imports and the actual utilization (yellow line). It is apparent that two-way trade is happening at very high frequencies even within a day, not just over monthly (or seasonal) periods.

Figures TA-7, TA-8, and TA-9 provide intra-day, intra-week, and seasonal load profiles for British Columbia. The diurnal cycle, shown in percent deviations from the load at midnight, exhibits low demand during the night and two peaks around mid-morning and mid-evening, with somewhat lower demand during the mid-afternoon. Demand is also noticeably lower on weekend days. British Columbia also exhibits a strong seasonal cycle with low demand in the summer and high demand in the winter (due to heating needs).

Figures TA-10, TA-11, and TA-12 show decompositions of trade into one-way and two-way trade using the Grubel-Lloyd index methodology—described earlier in this Technical Appendix—for three exporting provinces: Ontario, British Columbia, and Manitoba. The blue curve shows the decomposition for trade with the United States, and the red curve shows the decomposition for trade with neighbouring provinces. British Columbia (figure TA-11) has very consistent two-way trade with the United States, whereas trade with neighbouring Alberta has transitioned from mostly two-way to mostly one-way since 2008.

The remaining tables provide additional estimates as robustness checks. Table TA-8 provides random effects regressions of the main estimating equation. The columns (A), (B), and (C) provide results for both trade directions (exports and imports), exports by Canadian provinces to US states, and imports from US states into Canadian provinces, respectively. Omitted is the variable for the load variability, which is poorly identified in the presence of fixed or random effects because it has no time variation. When it is included, however, it is positive but not significant.

Tables TA-10 and TA-11 provide robustness checkes for the trade intensity regression. Whereas in the main body of the paper weighted least squares was employed, the two tables here provide ordinary least squares results for comparison. Qualitatively, the results are comparable and where significant provide the correct sign. Overall, weighted least squares provides a better fit and addresses heterogeneity in the data more effectively.

Results shown in table TA-9 investigate the extensive margin of trade. The logistic regression of an indicator variable for non-zero trade captures comparative advantages as well as load smoothing. Similar to table TA-8, table TA-9 reports results for separate trade directions in columns (A)–(C): all US states and Canadian provinces; Canadian provincial exports to US states; and US state exports to Canadian provinces, respectively. Instead of the load variability variable, it includes the demand correlation. Only the distance variable is a strong predictor of who trades with whom. The significant positive estimate of the demand correlation variable in column (A) seems to contradict the theory, but then it is not a direct test because it only focuses on one of the elements (ρ) in the variability term. It may be a statistical artefact, as the two subsamples estimate this variable with no statistical significance. Many of the comparative advantage proxies seem to indicate negative effects, which in turn implies that provinces and states with larger reliance on fossil fuels are more likely to start trading relationships. Again, some of these effects may be affected by the fact that Canadian provinces either fall into the ”large-hydro” or ”diversified” categories. Caution is advised to read too much into the results in table TA-9, other than that distance matters most.

The distribution of export prices by Canadian province and import prices by U.S. state is shown in TA-13. This table is meant to document the great variation in prices that is found in the data. Occasionally, even negative prices are observed when a region encounters an electricity surplus it needs to get rid off, as the alternative of shutting down a baseload power plant may be more expensive than selling electricity at a loss.

Table TA-12 mirrors tables TA-8 and TA-9 by providing results for all exporters and importers in column (A), Canadian exports to US states in (B), and Canadian imports from US states in (C). The elasticities are all positive, which is consistent with theory. The distance effect for exports is positive, but it is negative for imports; in aggregate, it is estimated negatively but weakly. In general, theory suggests that longer distance may lead to higher prices, but to the extent that transmission infrastructure is fixed in the short term, the distance estimates are more likely to capture market structure effects.

Table TA-14 provides data that correspond to those reported in the main body of the paper for Canada. It shows the average demand, standard deviation, average supply, surplus, and reserve margin for each US state for the 2003-12 averaging period. Surplus is calculated as the difference between supply and demand. The reserve margin is the ratio of maximum to mean demand, expressed in units of standard deviation. The reserve margin for the US overall is 2.565. It would drop to 2.286 if the entire load was balanced across all states (excluding Hawaii and Alaska). Moreover, the standard deviation would drop from 35,257 GWh per month to 29,567 GWh per month, a 16% drop.

References

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Table TA-4: Population-Weighted Distances Between Canadian Provinces

	AB	BC	MB	NB	NL	NS	NT	NV	ON	PE	QC	SK	YT
AB		734	1,172	3,482	4,101	3,727	2,308	1,856	2,684	3,658	3,015	614	1,646
BC	680		1,799	4,151	4,787	4,395	2,873	2,252	3,299	4,331	3,669	1,240	1,536
MB	1,156	1,783		2,382	3,081	2,623	2,117	2,215	1,541	2,567	1,891	636	2,614
NB	3,478	4,145	2,376		916	283	2,766	3,669	1,114	224	573	2,941	4,600
NL	4,082	4,769	3,059	886		801	2,868	3,918	1,987	730	1,422	3,591	4,986
NS	3,724	4,389	2,618	237	751		2,962	3,891	1,304	191	784	3,185	4,839
NT	2,180	2,775	1,947	2,730	2,811	2,932		1,448	2,771	2,829	2,632	2,126	2,394
NV	1,534	2,078	1,871	3,575	3,853	3,809	1,285		3,378	3,771	3,409	1,923	1,537
ON	2,665	3,282	1,491	1,081	1,959	1,272	2,698	3,201		1,313	598	2,132	4,062
PE	3,655	4,326	2,564	186	700	168	2,799	3,691	1,290		762	3,120	4,735
QC	3,008	3,660	1,879	527	1,379	752	2,578	3,277	449	731		2,466	4,240
SK	563	1,207	583	2,934	3,569	3,179	1,967	1,517	2,101	3,115	2,454		2,083
YT	1,620	1,493	2,606	4,598	4,970	4,839	2,299	1,510	4,053	4,734	4,237	2,064	
(a)	244	215	165	152	284	153	1,134	1,669	215	46	201	280	420
(h)	53	37	22	78	49	42	1,129	1,655	54	23	43	58	381

Note: The upper right half of the table shows arithmetic means and the lower left half of the table shows harmonic means. The latter are preferred as they give greater weight to shorter distances, a notion supported by 'gravity models' of international trade. The diagonal elements correspond to internal distances and are shown as rows (a) for arithmetic means and (h) for harmonic means at the bottom of the table. Population data and geographic locations of postal Forward Sortation Areas (FSAs) were taken from the 2011 Canadian Census. FSAs are the first three letters of a Canadian postal code (e.g., V6T).

Table TA-5: Population-Weighted Distances Between Canadian Provinces and US States

	AB	BC	MB	NB	NL	NS	NT	NV	ON	PE	QC	SK	YT
AK	2,218	1,952	3,258	5,247	5,585	5,486	2,850	1,930	4,719	5,378	4,897	2,700	707
AL	3,051	3,476	2,107	2,298	3,168	2,403	3,880	4,144	1,353	2,478	1,857	2,582	4,662
AR	2,539	2,915	1,724	2,557	3,437	2,707	3,657	3,764	1,485	2,754	2,049	2,116	4,174
AZ	2,112	2,016	2,217	4,123	4,966	4,318	4,148	3,788	3,021	4,328	3,579	2,111	3,542
CA	1,916	1,562	2,418	4,574	5,374	4,788	4,124	3,600	3,502	4,777	4,031	2,125	3,074
CO	1,564	1,777	1,328	3,254	4,078	3,461	3,320	3,075	2,166	3,459	2,707	1,354	3,182
CT	3,292	3,911	2,144	766	1,632	849	3,088	3,740	610	938	510	2,734	4,634
DC	3,190	3,765	2,058	1,223	2,087	1,311	3,306	3,841	609	1,396	861	2,640	4,638
DE	3,256	3,844	2,115	1,098	1,956	1,176	3,276	3,849	616	1,266	771	2,702	4,676
FL	3,802	4,226	2,828	2,471	3,266	2,503	4,483	4,859	1,801	2,612	2,168	3,325	5,409
GA	3,182	3,642	2,179	2,091	2,950	2,180	3,850	4,186	1,230	2,264	1,686	2,689	4,771
HI	5,099	4,409	6,102	8,459	9,163	8,693	7,027	6,100	7,456	8,654	7,933	5,589	4,805
IA	1,940	2,430	984	2,203	3,049	2,402	2,890	2,986	1,100	2,409	1,653	1,443	3,535
ID	853	771	1,495	3,813	4,545	4,045	3,070	2,544	2,819	4,009	3,286	1,107	2,301
IL	2,281	2,805	1,221	1,879	2,745	2,063	2,947	3,187	765	2,084	1,335	1,756	3,830
IN	2,499	3,025	1,428	1,779	2,656	1,944	3,084	3,380	676	1,980	1,253	1,972	4,042
KS	2,048	2,420	1,316	2,631	3,494	2,815	3,311	3,312	1,520	2,836	2,089	1,645	3,684
KY	2,733	3,234	1,691	1,843	2,726	1,981	3,348	3,661	816	2,036	1,355	2,219	4,294
LA	3,008	3,338	2,225	2,802	3,675	2,917	4,146	4,284	1,811	2,986	2,341	2,607	4,647
MA	3,345	3,975	2,199	616	1,480	694	3,033	3,726	679	786	450	2,787	4,648
MD	3,188	3,767	2,052	1,190	2,054	1,278	3,282	3,824	590	1,363	828	2,637	4,628
ME	3,334	3,982	2,201	339	1,250	490	2,853	3,601	759	546	351	2,780	4,566
MI	2,439	3,017	1,304	1,494	2,359	1,679	2,788	3,156	328	1,698	948	1,887	3,913
MN	1,681	2,231	611	2,142	2,942	2,362	2,521	2,601	1,099	2,345	1,597	1,142	3,231
MO	2,274	2,709	1,379	2,310	3,184	2,481	3,282	3,403	1,206	2,513	1,778	1,810	3,891
MS	2,933	3,317	2,062	2,522	3,398	2,640	3,928	4,118	1,525	2,707	2,057	2,494	4,563
MT	602	841	1,060	3,424	4,139	3,661	2,689	2,217	2,458	3,619	2,904	695	2,224
NC	3,269	3,790	2,185	1,654	2,503	1,725	3,646	4,096	944	1,818	1,298	2,740	4,796
ND	1,166	1,717	343	2,520	3,265	2,753	2,341	2,214	1,534	2,718	1,991	625	2,754
NE	1,758	2,174	1,012	2,562	3,401	2,764	3,013	2,981	1,463	2,768	2,013	1,334	3,392
NH	3,285	3,921	2,141	555	1,435	663	2,937	3,636	641	738	351	2,727	4,569
NJ	3,257	3,860	2,111	943	1,806	1,026	3,176	3,784	584	1,114	632	2,701	4,642
NM	2,044	2,131	1,870	3,612	4,466	3,801	3,880	3,636	2,507	3,817	3,071	1,897	3,612
NV	1,703	1,468	2,101	4,238	5,041	4,453	3,866	3,392	3,166	4,442	3,694	1,847	3,007
NY	3,165	3,778	2,011	881	1,753	984	3,052	3,661	398	1,061	514	2,605	4,534
OH	2,702	3,257	1,591	1,497	2,382	1,651	3,070	3,466	419	1,696	986	2,160	4,198
OK	2,292	2,607	1,627	2,831	3,705	2,999	3,633	3,629	1,732	3,033	2,303	1,926	3,932
OR	1,056	521	1,967	4,332	5,027	4,570	3,267	2,623	3,376	4,524	3,817	1,472	2,024
PA	3,076	3,667	1,932	1,099	1,977	1,206	3,136	3,678	448	1,281	705	2,521	4,500
RI	3,372	3,998	2,225	667	1,521	733	3,088	3,774	699	830	504	2,814	4,688
SC	3,307	3,802	2,254	1,866	2,711	1,936	3,801	4,212	1,113	2,030	1,503	2,792	4,864
SD	1,424	1,882	712	2,575	3,377	2,794	2,717	2,622	1,511	2,779	2,027	985	3,056
TN	2,835	3,296	1,850	2,053	2,934	2,176	3,578	3,856	1,069	2,241	1,587	2,345	4,426
TX	2,716	2,950	2,134	3,183	4,063	3,326	4,153	4,143	2,117	3,378	2,681	2,400	4,350
UT	1,310	1,320	1,555	3,728	4,517	3,948	3,376	2,962	2,672	3,931	3,186	1,340	2,815
VA	3,219	3,779	2,097	1,347	2,206	1,427	3,413	3,923	701	1,517	989	2,674	4,693
VT	3,135	3,773	1,993	591	1,479	748	2,807	3,484	505	790	196	2,577	4,416
WA	787	230	1,781	4,157	4,822	4,399	2,975	2,319	3,242	4,345	3,654	1,247	1,784
WI	2,064	2,623	956	1,834	2,672	2,038	2,673	2,897	750	2,039	1,282	1,519	3,585
WV	2,953	3,504	1,843	1,452	2,333	1,571	3,267	3,710	567	1,639	1,004	2,412	4,448
WY	1,164	1,415	1,097	3,247	4,032	3,468	3,008	2,688	2,197	3,449	2,704	996	2,796

Note: Distances are harmonic means based on population data and locations of Canadian postal Forward Sortation Areas (FSAs) and US postal ZIP codes. Canadian data are from the 2011 Canadian census. US data are from www.unitedstateszipcodes.org and is based on rom authoritative sources including the United States Postal Service (2011), US Census Bureau (2010), and the Internal Revenue Service (2008).

Table TA-6: United States Monthly Energy Sales by State

	US State	Mean [GWh]	S.D. [GWh]	C.V. [%]	Min. [GWh]	Median [GWh]	Max. [GWh]
TX	Texas	28,429	4,360	15.3	22,298	27,112	41,679
CA	California	21,296	2,198	10.3	16,963	20,941	27,517
FL	Florida	18,455	2,467	13.4	14,383	17,854	23,677
OH	Ohio	12,901	1,133	8.8	10,882	12,763	15,837
PA	Pennsylvania	12,092	1,019	8.4	10,297	12,044	14,712
NY	New York	12,060	1,111	9.2	10,296	11,895	14,786
IL	Illinois	11,771	1,258	10.7	9,619	11,518	15,555
GA	Georgia	10,930	1,515	13.9	8,434	10,568	14,765
NC	North Carolina	10,617	1,288	12.1	8,541	10,421	13,780
VA	Virginia	8,898	1,056	11.9	7,153	8,727	11,358
MI	Michigan	8,799	784	8.9	7,346	8,690	10,964
IN	Indiana	8,659	761	8.8	7,177	8,534	10,639
TN	Tennessee	8,374	957	11.4	6,861	8,384	10,665
KY	Kentucky	7,389	579	7.8	6,050	7,320	8,805
AL	Alabama	7,248	877	12.1	5,745	7,131	9,505
WA	Washington	7,087	932	13.2	5,172	6,980	9,205
MO	Missouri	6,680	942	14.1	5,172	6,446	9,184
LA	Louisiana	6,662	875	13.1	5,373	6,471	8,778
SC	South Carolina	6,610	763	11.5	5,300	6,440	8,485
NJ	New Jersey	6,483	889	13.7	5,240	6,316	8,913
AZ	Arizona	5,890	1,223	20.8	4,131	5,453	8,808
WI	Wisconsin	5,705	454	8.0	4,894	5,619	7,105
MN	Minnesota	5,463	482	8.8	4,445	5,408	6,755
MD	Maryland	5,429	661	12.2	4,374	5,340	7,036
MA	Massachusetts	4,622	397	8.6	3,931	4,574	5,600
OK	Oklahoma	4,526	770	17.0	3,381	4,336	6,805
CO	Colorado	4,140	426	10.3	3,266	4,077	5,355
MS	Mississippi	3,914	505	12.9	3,140	3,782	5,075
OR	Oregon	3,901	348	8.9	3,329	3,809	4,931
AR	Arkansas	3,771	520	13.8	2,908	3,623	5,147
IA	Iowa	3,610	348	9.6	2,997	3,557	4,668
KS	Kansas	3,225	493	15.3	2,526	3,062	4,558
NV	Nevada	2,735	552	20.2	1,884	2,570	4,197
CT	Connecticut	2,603	277	10.6	2,066	2,580	3,324
WV	West Virginia	2,560	304	11.9	2,084	2,530	3,397
NE	Nebraska	2,302	302	13.1	1,807	2,258	3,368
UT	Utah	2,197	289	13.2	1,654	2,169	2,973
ID	Idaho	1,871	245	13.1	1,487	1,817	2,558
NM	New Mexico	1,763	206	11.7	1,361	1,739	2,306
WY	Wyoming	1,264	156	12.4	1,011	1,273	1,609
MT	Montana	1,136	127	11.2	838	1,122	1,494
ME	Maine	985	81	8.2	824	980	1,282
ND	North Dakota	982	164	16.7	716	950	1,479
DE	Delaware	979	114	11.6	786	968	1,295
DC	District of Columbia	961	118	12.2	714	934	1,251
NH	New Hampshire	907	74	8.2	778	893	1,073
SD	South Dakota	856	120	14.0	633	849	1,135
HI	Hawaii	852	52	6.1	709	852	972
RI	Rhode Island	647	68	10.5	524	632	850
AK	Alaska	502	52	10.5	414	492	623
VT	Vermont	470	34	7.2	408	465	545

Note: Source: Energy Information Administration (Electricity Data Browser). Averaging Time Period: 2001/01–2012/12

Table TA-7: United States Monthly Energy Generation and Composition by State

	US State	Generation [GWh]	Coal [%]	N.Gas [%]	F.Fuel [%]	Nuclear [%]	Hydro [%]	Rnwbls. [%]
	United States (All)	333,858	47.1	21.2	2.2	19.7	6.5	3.0
TX	Texas	33,407	36.3	48.7	1.3	9.8	0.3	3.5
PA	Pennsylvania	18,117	51.6	9.4	1.3	35.1	0.9	1.3
FL	Florida	18,082	28.3	44.8	10.1	13.1	0.1	2.0
CA	California	16,787	1.1	52.1	1.8	16.1	16.3	12.4
IL	Illinois	16,160	46.4	3.1	0.3	48.7	0.1	1.4
OH	Ohio	12,152	84.4	3.7	0.9	10.2	0.3	0.4
AL	Alabama	11,848	48.4	18.0	0.3	24.6	6.2	2.3
NY	New York	11,661	12.8	29.6	7.0	29.8	17.8	2.2
GA	Georgia	10,871	57.8	12.0	0.6	25.0	1.9	2.6
IN	Indiana	10,420	92.0	4.0	2.4		0.4	0.9
NC	North Carolina	10,331	57.5	4.6	0.4	32.2	3.5	1.6
MI	Michigan	9,435	58.5	11.7	0.8	26.0	0.4	2.3
AZ	Arizona	8,779	38.7	26.5	0.1	27.5	6.9	0.2
WA	Washington	8,717	7.8	7.6	0.3	7.9	72.4	3.9
SC	South Carolina	8,246	37.7	6.9	0.3	52.4	0.9	1.7
LA	Louisiana	7,970	24.2	49.2	4.7	17.5	1.0	2.8
KY	Kentucky	7,934	92.4	1.4	2.6		3.2	0.4
TN	Tennessee	7,497	58.4	1.7	0.3	30.0	8.6	1.0
MO	Missouri	7,416	82.8	4.6	0.2	10.4	1.6	0.4
WV	West Virginia	7,205	97.3	0.3	0.3		1.5	0.5
VA	Virginia	6,160	41.8	14.4	3.6	36.8	-0.3	3.1
OK	Oklahoma	5,725	50.0	42.9	0.1		3.2	3.8
WI	Wisconsin	5,140	64.7	8.3	1.1	19.9	3.1	2.8
NJ	New Jersey	5,126	13.3	31.8	1.3	51.5	-0.3	1.5
AR	Arkansas	4,527	47.1	16.2	0.4	27.3	5.8	3.0
OR	Oregon	4,450	6.8	23.6	0.1		64.1	5.4
MN	Minnesota	4,417	58.8	5.6	0.8	24.2	1.4	8.5
CO	Colorado	4,173	70.0	22.7	0.1		2.9	4.2
IA	Iowa	4,054	75.5	3.1	0.3	9.5	1.8	9.8
MS	Mississippi	4,018	31.3	43.2	2.1	20.5		2.6
MD	Maryland	3,943	55.8	4.6	4.0	29.6	4.1	1.3
KS	Kansas	3,876	71.5	4.2	0.8	19.6	0.0	3.7
WY	Wyoming	3,831	93.0	1.0	0.5		1.8	3.5
MA	Massachusetts	3,572	22.0	50.2	9.0	12.9	1.1	2.8
UT	Utah	3,377	86.8	10.1	0.1		1.7	1.0
NM	New Mexico	2,958	78.6	17.4	0.1		0.6	3.3
NV	Nevada	2,896	32.1	56.8	0.3		6.0	4.8
NE	Nebraska	2,735	66.5	1.7	0.1	27.6	2.9	1.2
ND	North Dakota	2,707	89.1	0.0	0.3		5.2	5.4
CT	Connecticut	2,707	9.6	29.9	4.8	49.6	1.4	2.2
MT	Montana	2,305	60.8	0.3	1.6		34.8	2.0
NH	New Hampshire	1,742	16.0	23.9	3.1	44.9	6.8	5.0
ME	Maine	1,482	1.6	47.5	5.2		20.7	22.8
ID	Idaho	1,014	0.7	11.9	0.0		79.3	7.5
HI	Hawaii	926	14.1		77.2		0.8	5.9
SD	South Dakota	693	38.7	2.3	0.2		50.4	8.2
DE	Delaware	592	52.3	33.0	13.8			0.9
RI	Rhode Island	584		97.0	0.5		0.0	1.7
AK	Alaska	559	9.2	56.4	13.8		20.6	0.1
VT	Vermont	523		0.0	0.2	73.4	19.4	6.7
DC	District of Columbia	10		5.2	95.5			

Note: 'N.Gas' is natural gas. 'F.Fuel' (other fossil fuels) includes petroleum liquids, petroleum coke, and other gases. 'Rnwbls' are renewables other than hydroelectricity and includes wind, solar, geothermal and biomass. Hydroelectric power includes hydroelectric pumped storage (which may have negative values). Averaging time period: 2001/01–2012/12.

Figure TA-4: British Columbia Exports to California, Monthly Price 1991-2012

Figure TA-5: British Columbia Exports to California, Annual Value 1991-2012

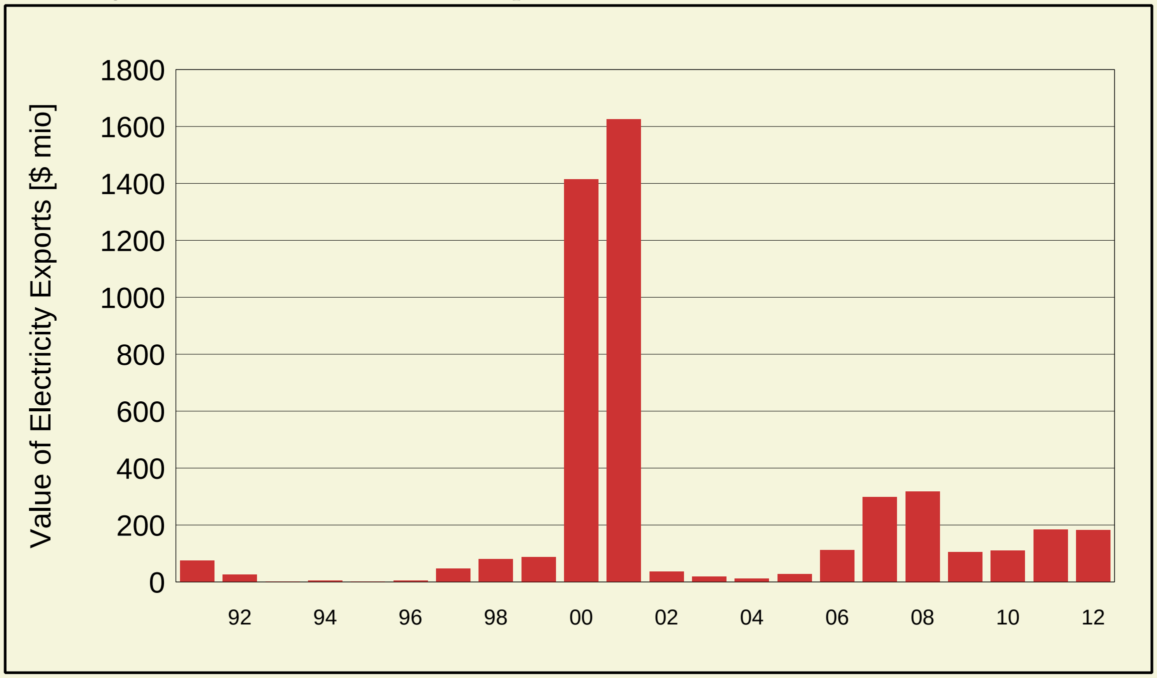
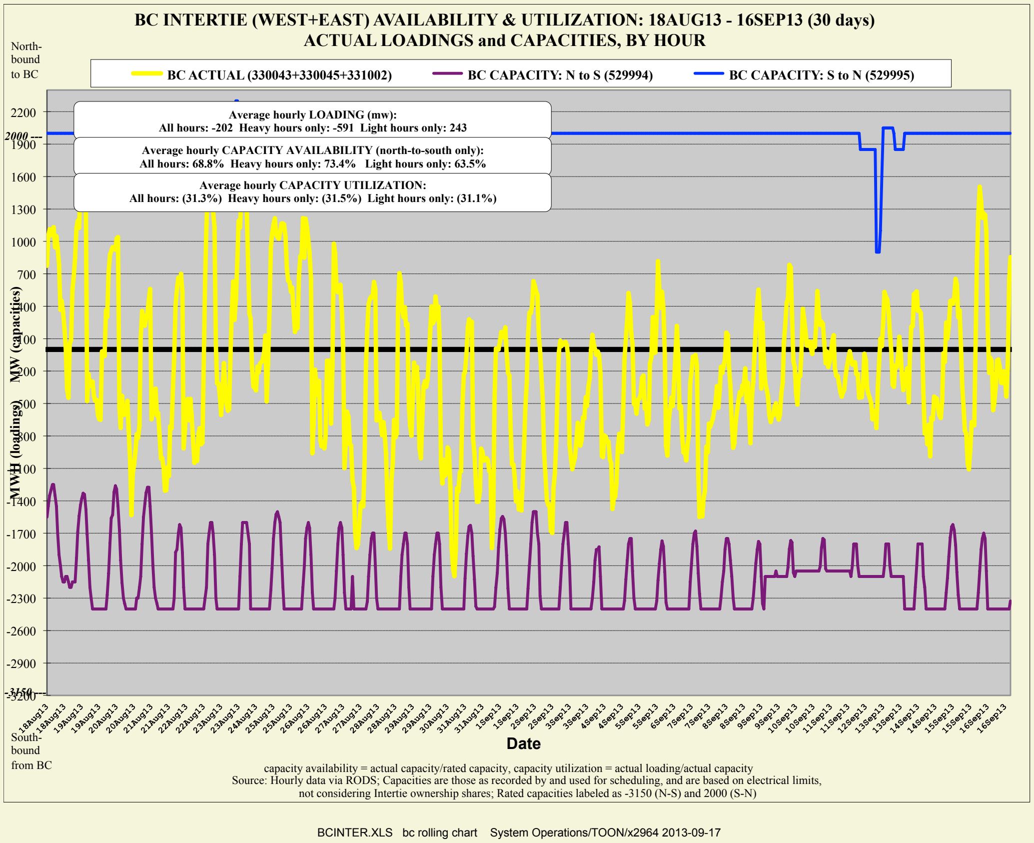


Figure TA-6: British Columbia–United States Intertie Utilization, September 2013



Source: BC Hydro, retrieved from http://transmission.bchydro.com/transmission_system/actual_flow_data/ on September 17, 2013. The instantaneous net actual flow, sampled every five minutes, is displayed for each of the BC-US and BC-Alberta interties. The BC-US intertie is comprised of 5L51, 5L52, 2L112 and Teck Cominco Line 71.

Figure TA-7: British Columbia – Hourly Intra-Day Load Profile

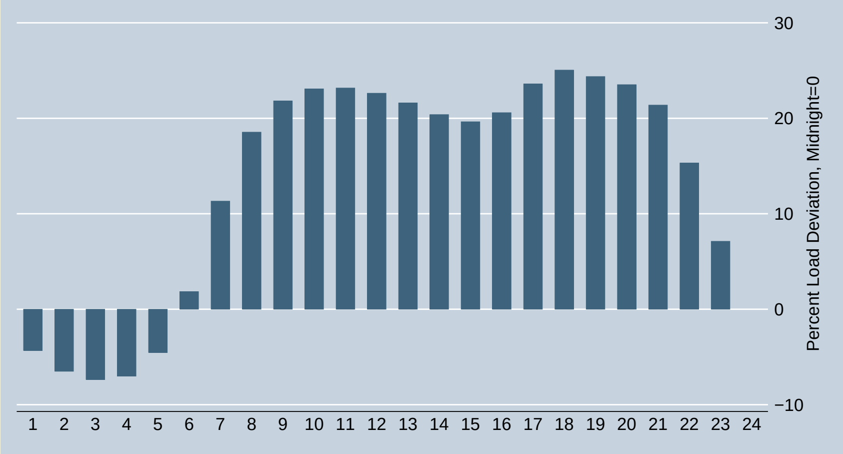


Figure TA-8: British Columbia – Daily Intra-Week Load Profile

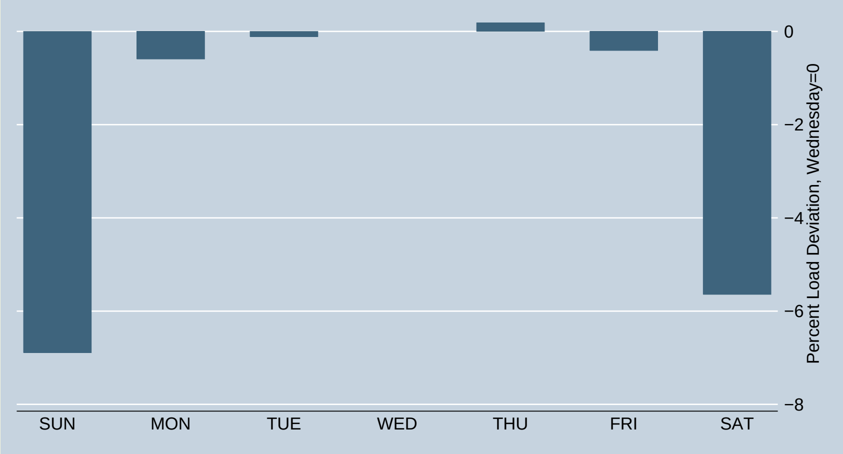
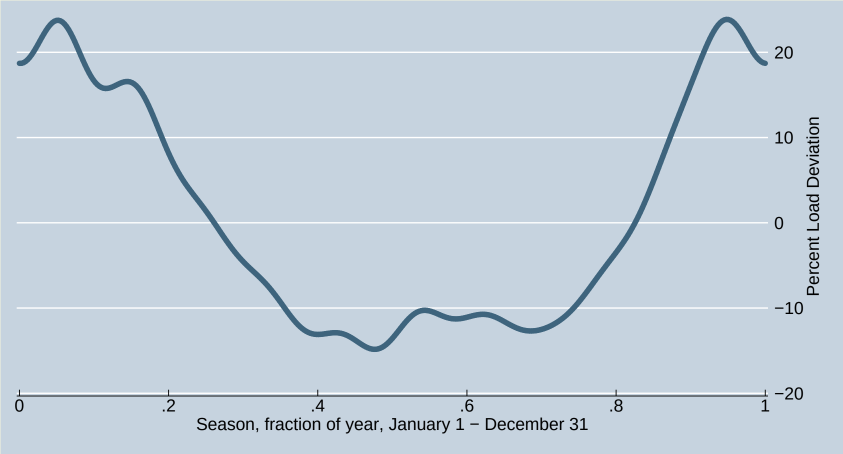


Figure TA-9: British Columbia – Seasonal Load Profile



Source: BC Hydro, based on 2007-2013 hourly data. Seasonal profile using 12th-order Fast Fourier Transform

Figure TA-10: Decomposition of Ontario Electricity Trade

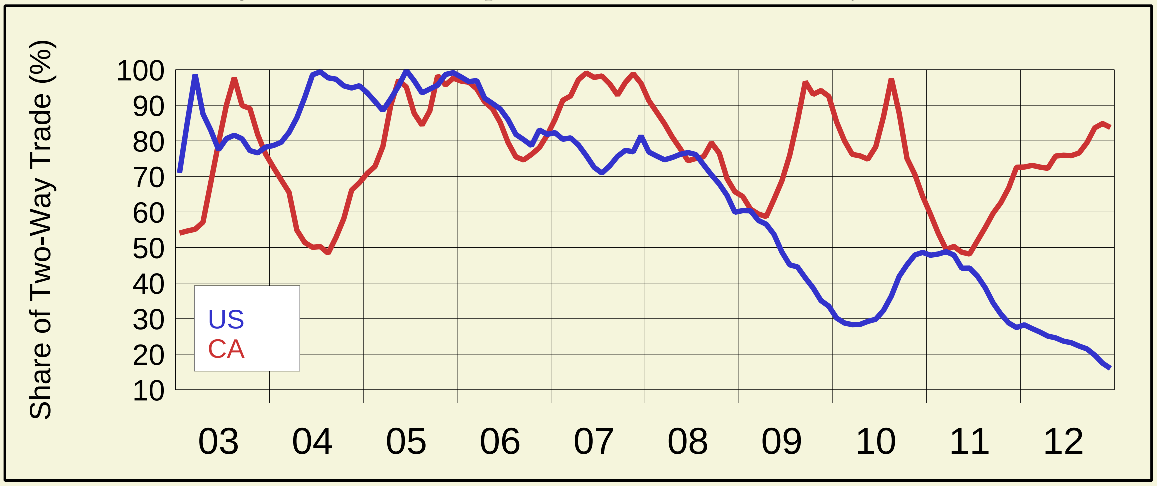


Figure TA-11: Decomposition of British Columbia Electricity Trade

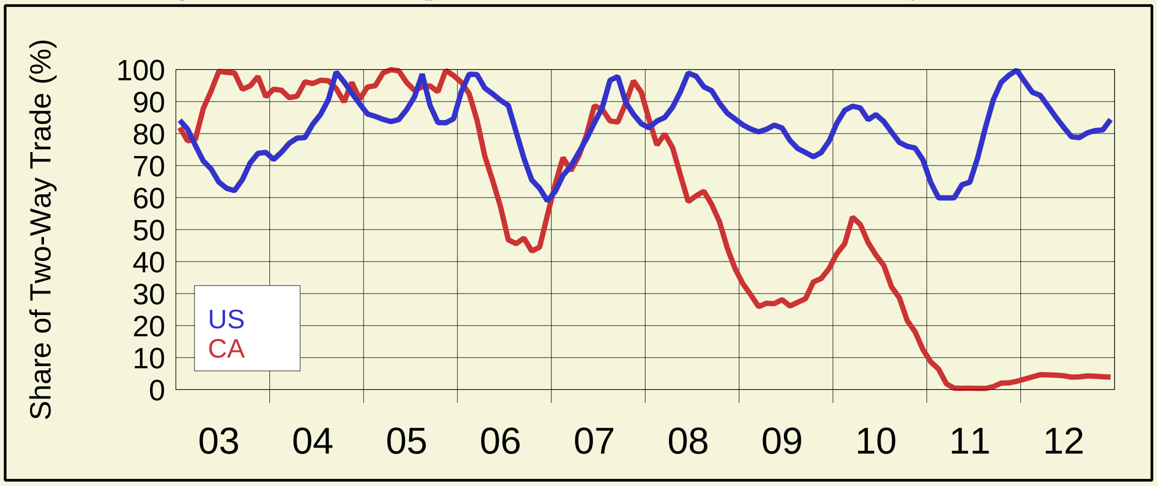
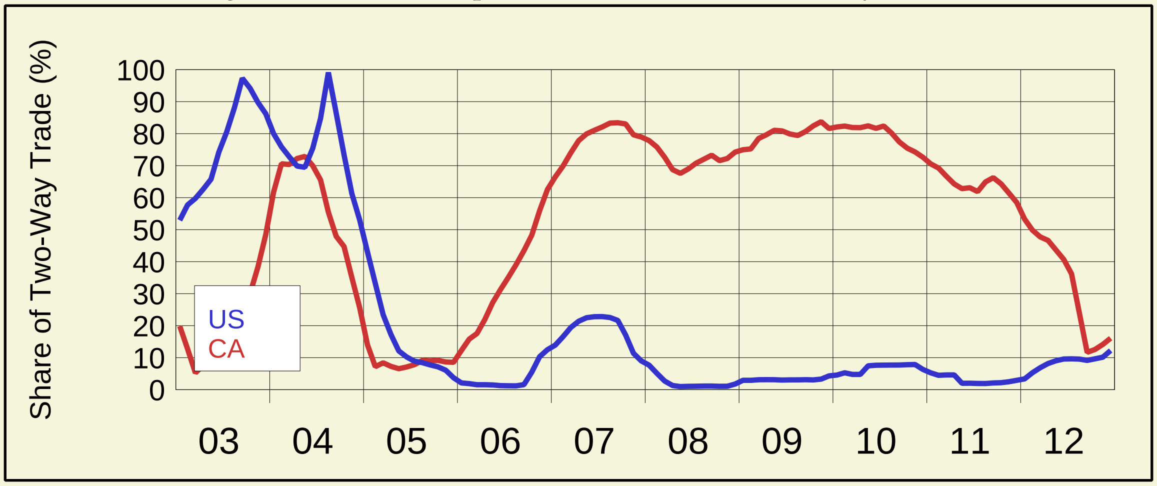


Figure TA-12: Decomposition of Manitoba Electricity Trade



Note: the two-way trade index has been smoothed by aggregating exports and imports over the last twelve months in order to suppress seasonal effects.

Table TA-8: Random Effects Estimation

		(A)		(B)		(C)	
Trade Direction		Exp+Imp		Exports		Imports	
Intercept		-2.196^a	(2.32)	-6.092^c	(3.90)	3.409^a	(2.27)
Importer Load Ratio	$\ln(q_j/K_j)$	1.199^c	(8.67)	1.000^c	(5.67)	1.355^c	(6.18)
Exporter Load Ratio	$\ln(q_i/K_i)$	-0.582^c	(4.23)	-0.483^b	(3.13)	-0.202	(.802)
Transmission Distance	$\ln(D_{ij})$	-2.296^c	(6.73)	-2.546^c	(4.30)	-2.552^c	(4.81)
Demand Variability	$\ln(V_{ij})$	0.498^c	(3.72)	-0.360^a	(2.15)	1.499^c	(6.96)
Importer hydro share	%	-0.017^c	(5.20)	-0.009^a	(2.48)	-0.028^c	(4.32)
Importer nuclear share	%	-0.025^c	(6.05)	0.001	(.255)	-0.038^c	(5.61)
Importer renewables share	%	-0.000^c	(3.86)	-0.088^c	(11.4)	0.000	(.499)
Exporter hydro share	%	0.022^c	(6.60)	0.054^c	(9.85)	0.001	(.178)
Exporter nuclear share	%	0.045^c	(9.95)	0.072^c	(13.7)	-0.021^a	(2.44)
Exporter renewables share	%	-0.000	(1.26)	-0.000^b	(2.67)	-0.055^c	(5.07)
Time trend		-0.008	(1.35)	0.071^c	(8.45)	-0.027	(1.91)
Observations		8,797		4,814		3,983	
Export/Import pairs		146		75		71	
C.S. variance share		0.296		0.144		0.298	
R^2		0.040		0.102		0.068	

Note: Results shown in column (A) were estimated using random effects for the exporter-importer pairs. Statistical significance at the 95%, 99%, and 99.9% confidence levels are indicated by superscripts ^{a}, ^{b}, ^{c}, respectively. Hausman Test statistics cannot be reported because the fixed-effect version of the model is not defined because of the time invariance of key regressors.

Table TA-9: Extensive Margin of Canada-US Electricity Trade

		(A)		(B)		(C)	
Trade Direction		Exp+Imp		Exports		Imports	
Intercept		7.502^c	(6.12)	15.465^c	(4.63)	12.529^c	(5.00)
Transmission Distance	$\ln(D_{ij})$	-2.396^c	(9.20)	-3.278^c	(6.63)	-2.345^c	(6.40)
Demand Correlation		1.133^a	(2.50)	0.095	(.113)	0.591	(.876)
Importer hydro share	%	-0.022^b	(3.09)	0.002	(.110)	-0.075^c	(4.09)
Importer nuclear share	%	-0.024^b	(2.83)	-0.012	(.990)	-0.058^c	(3.70)
Importer renewables share	%	-0.003^c	(4.48)	0.050	(1.08)	-0.006^c	(4.40)
Exporter hydro share	%	-0.023^b	(3.14)	-0.084^c	(3.41)	-0.008	(.650)
Exporter nuclear share	%	-0.010	(1.26)	-0.047^a	(2.44)	-0.009	(.885)
Exporter renewables share	%	-0.003^c	(4.75)	-0.008^c	(3.94)	0.015	(.373)
Observations		1,020		510		510	
Exporters		61		10		51	
Importers		61		51		10	
Export/Import pairs		1,020		510		510	
Positive Responses	%	8.92		8.24		9.61	
Log Likelihood	$-2\ln(\mathcal{L})$	227.8		147.2		113.7	

Note: Logistic regressions with an indicator for positive exports as the dependent variable. The values in parentheses are z-values (square roots of the Wald-χ^2 statistics). Statistical significance at the 95%, 99%, and 99.9% confidence levels are indicated by superscripts ^{a}, ^{b}, ^{c}, respectively.

Table TA-10: Trade Intensity Regressions—Canada / OLS

Sample Selection		All		TI<120%		TI>0%	
Estimation Method		OLS		OLS		OLS	
Intercept		-43.24^c	(5.15)	-19.93^c	(6.38)	270.01^c	(24.6)
Share of Hydro	%	0.531^c	(13.4)	0.056^c	(3.68)	1.279^c	(32.7)
Share of Nuclear	%	-0.191^a	(1.97)	-0.063	(1.76)	1.043^c	(12.4)
Share of Renewables	%	0.001^c	(13.6)	0.001^c	(32.0)	-0.000	(1.92)
Demand Coeff. of Var.	–	2.838^c	(7.50)	1.270^c	(9.00)	-0.636	(1.85)
Log Average Demand		2.267^b	(3.18)	2.940^c	(11.1)	-34.74^c	(31.3)
Time Trend	a^{-1}	-0.863^b	(2.75)	-0.653^c	(5.39)	-0.573^a	(1.97)
Observations		2,319		2,152		1,816	
Weights		none		none		none	
R^2		0.193		0.332		0.538	

Table TA-11: Trade Intensity Regressions—United States / OLS

Sample Selection		All		TI<120%		TI>1%	
Estimation Method		OLS		OLS		OLS	
Intercept		155.85^c	(35.9)	83.975^c	(33.3)	158.03^c	(35.8)
Share of Hydro	%	-0.243^c	(8.99)	0.031^a	(1.96)	-0.247^c	(8.99)
Share of Nuclear	%	-0.318^c	(11.8)	0.011	(.691)	-0.326^c	(11.9)
Share of Renewables	%	-0.518^c	(5.15)	-0.186^b	(3.21)	-0.546^c	(5.36)
Demand Coeff. of Var.	–	2.573^c	(16.5)	0.905^c	(9.71)	2.585^c	(16.3)
Log Average Demand		-16.88^c	(35.0)	-8.177^c	(29.0)	-17.02^c	(34.5)
Time Trend	a^{-1}	-0.119	(.898)	0.193^a	(2.52)	-0.096	(.708)
Observations		7,956		7,443		7,712	
Weights		none		none		none	
R^2		0.197		0.115		0.199	

Note: Statistical significance at the 95%, 99%, and 99.9% confidence levels are indicated by superscripts ^{a}, ^{b}, ^{c}, respectively. TI stands for trade intensity. Standard scores (unsigned z-values) are shown in parentheses.

Table TA-12: Export Prices — Robustness Checks

Estimation Method	OLS		OLS		OLS	
Price Variable	Exp+Imp		Exports		Imports	
Intercept	4.349^c	(105.)	3.973^c	(79.2)	4.684^c	(79.1)
Log Load Ratio Exporter	0.811^c	(26.0)	0.457^c	(10.9)	0.686^c	(8.73)
Log Load Ratio Importer	0.361^c	(11.6)	0.624^c	(12.5)	0.674^c	(10.4)
Log Distance	-0.046^a	(2.13)	0.125^c	(4.51)	-0.170^c	(5.75)
Time Trend	-0.056^c	(33.8)	-0.047^c	(27.7)	-0.055^c	(20.0)
Observations	8,550		4,679		3,871	
Exporter+Importer F.E.	43		41		40	
R^2	0.250		0.330		0.378	

Note: Statistical significance at the 95%, 99%, and 99.9% confidence levels are indicated by superscripts ^{a}, ^{b}, ^{c}, respectively. The excluded groups for the export and importer jurisdiction indicator variables are Ontario and New York. Importers are prefixed 'M'; exporters are prefixed 'X.' The dependent variable is the logarithm of the price.

Table TA-13: Distribution of Export Prices by Province (Canada) and Import Prices by State (United States)

Province	Mean	Wgtd.	Min.	Q1	Median	Q3	Max.
Alberta	47.70	44.93	1.99	32.02	43.80	55.54	238.90
British Columbia	64.12	52.28	2.78	45.68	65.68	77.43	227.38
Manitoba	48.97	43.18	1.00	35.18	46.65	55.43	162.71
New Brunswick	71.70	66.25	25.96	58.47	67.47	79.08	197.83
Nova Scotia	84.60	61.36	16.73	45.31	57.03	72.82	990.07
Ontario	49.65	45.07	-57.62	35.41	47.05	59.18	202.15
Quebec	57.63	53.81	4.30	36.91	50.50	72.39	200.68
Saskatchewan	54.97	55.84	4.61	34.00	50.87	65.04	510.00
Alaska	71.73	71.72	71.47	71.58	71.58	71.58	72.58
Arizona	66.58	56.98	21.95	43.79	66.46	83.78	161.30
California	56.06	52.74	18.06	42.63	57.72	67.28	116.27
Colorado	96.39	88.48	42.32	71.68	88.87	113.59	227.38
Connecticut	66.84	65.90	7.68	42.75	56.22	77.41	990.07
Idaho	62.40	77.05	2.78	45.48	65.47	78.02	178.89
Illinois	54.85	45.15	24.33	43.26	50.27	61.98	126.70
Indiana	62.92	50.68	17.69	38.83	54.29	72.84	510.00
Kansas	45.83	45.83	45.83	45.83	45.83	45.83	45.83
Massachusetts	67.75	65.88	7.68	43.84	60.50	77.15	990.07
Maryland	40.06	37.79	4.49	34.61	39.18	46.17	69.08
Maine	63.21	60.31	16.73	48.04	60.49	74.73	245.37
Michigan	47.98	40.99	4.61	34.18	45.89	56.27	200.68
Minnesota	46.46	43.21	-57.62	31.84	44.52	55.25	162.71
Missouri	48.35	37.90	14.86	31.14	46.23	54.31	152.00
Montana	50.89	47.86	9.44	33.56	51.22	65.88	140.78
North Dakota	50.84	45.54	9.91	34.41	48.32	59.76	172.78
Nebraska	73.97	70.70	55.99	61.64	74.66	86.31	90.59
New Jersey	40.06	37.79	4.49	34.61	39.18	46.17	69.08
New Mexico	70.42	75.09	23.13	51.47	69.47	85.38	159.00
Nevada	67.10	77.07	4.21	44.43	70.34	83.33	155.18
New York	54.17	50.82	1.99	35.48	49.39	63.44	197.83
Ohio	62.50	54.50	16.04	48.57	59.84	68.93	171.16
Oregon	55.53	57.26	6.53	40.13	52.32	69.73	123.51
Pennsylvania	57.94	47.32	27.24	39.87	55.54	66.61	238.90
South Dakota	34.62	34.62	34.62	34.62	34.62	34.62	34.62
Tennessee	64.41	64.41	64.41	64.41	64.41	64.41	64.41
Texas	47.12	46.95	1.00	32.16	45.41	62.00	106.31
Utah	71.31	76.18	22.43	54.85	72.08	86.27	184.98
Vermont	40.02	37.01	14.40	33.39	35.72	39.55	151.61
Washington	42.43	47.53	5.38	29.45	43.35	53.46	112.88
Wisconsin	58.72	37.39	37.19	37.19	37.26	101.71	101.71
Wyoming	74.87	90.24	8.11	56.03	74.58	87.56	183.86

Note: All prices are expressed in Canadian Dollars per megawatthour ($/MWh). 'Wgtd.' is the price weighted by trade volume; Q1 and Q3 are the first and third quartiles.

Table TA-14: Load Pooling in United States

State	Demand	Std.Dv.	Supply	Surplus	Margin
Alabama	7,345	861	12,065	4,720	2.509
Arkansas	3,823	514	4,642	819	2.574
Arizona	6,027	1,238	9,001	2,974	2.245
California	21,530	2,219	16,954	-4,575	2.698
Colorado	4,216	409	4,237	21	2.785
Connecticut	2,611	285	2,734	123	2.502
Delaware	980	115	604	-376	2.733
Florida	18,719	2,466	18,412	-307	2.010
Georgia	11,103	1,499	11,005	-98	2.443
Iowa	3,662	330	4,171	509	3.050
Idaho	1,897	251	1,057	-840	2.635
Illinois	11,837	1,246	16,331	4,494	2.984
Indiana	8,731	753	10,436	1,705	2.535
Kansas	3,265	483	3,885	620	2.678
Kentucky	7,473	549	7,958	485	2.424
Louisiana	6,712	881	8,040	1,328	2.346
Massachusetts	4,661	392	3,615	-1,046	2.393
Maryland	5,431	654	3,921	-1,511	2.336
Maine	986	83	1,428	442	3.584
Michigan	8,833	780	9,408	575	2.734
Minnesota	5,532	458	4,456	-1,076	2.668
Missouri	6,781	935	7,559	778	2.570
Mississippi	3,948	502	4,019	71	2.242
Montana	1,160	118	2,351	1,191	2.829
North Carolina	10,726	1,292	10,381	-345	2.363
North Dakota	1,011	161	2,735	1,724	2.904
Nebraska	2,343	294	2,765	422	3.490
New Hampshire	915	73	1,832	917	2.164
New Jersey	6,548	896	5,143	-1,405	2.638
New Mexico	1,800	197	3,015	1,215	2.568
Nevada	2,804	551	2,925	121	2.528
New York	12,041	1,131	11,630	-411	2.426
Ohio	12,904	1,136	12,171	-733	2.582
Oklahoma	4,605	764	5,916	1,311	2.880
Oregon	3,922	334	4,572	651	3.019
Pennsylvania	12,218	1,006	18,400	6,181	2.478
Rhode Island	652	69	580	-72	2.874
South Carolina	6,660	771	8,347	1,687	2.369
South Dakota	880	112	706	-174	2.268
Tennessee	8,429	961	7,394	-1,036	2.326
Texas	28,791	4,390	33,770	4,979	2.936
Utah	2,249	281	3,449	1,200	2.579
Virginia	9,035	1,039	6,149	-2,886	2.235
Vermont	470	35	536	66	2.150
Washington	7,222	851	8,912	1,690	2.305
Wisconsin	5,744	446	5,191	-553	3.054
West Virginia	2,604	302	7,174	4,570	2.628
Wyoming	1,301	143	3,859	2,558	2.150
All United States	303,141	35,257	335,845	32,704	2.565
(pooled)		29,567			2.286

Note: Analysis is based on 2003-2012 period using monthly data. All but the last columns report figures in GWh per month. Hawaii, Alaska, and the District of Columbia were excluded from the analysis (the latter because of incomplete data).