Pipes, Trains and Automobiles: Supplementary Material

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A Details on the Transportation supply curve abstraction

Given the evidence in BCUC (2019a) and BCUC (2019b), we can consider three types of wholesale gasoline imports to the Vancouver area: pipeline, rail and barge. As explained in the main text, we assume that the marginal cost of production (or procurement in the case of Parkland refinery importing additional volumes) is constant (with respect to output level) and potentially heterogeneous across firms and that the cost of import transportation is common across firms but varies with overall (market level) imports. Abstracting to linear supply functions for these three sources:

$$q_{\text{pipeline}} = \begin{cases} 0 & \text{if } p_{trans} < \tau_p \\ \in (0, K) & \text{if } p_{trans} = \tau_p \\ K & \text{if } p_{trans} > \tau_p \end{cases}$$

$$q_{\text{barge}} = \begin{cases} 0 & \text{if } p_{trans} < \tau_b \\ \dfrac{p_{trans} - \tau_b}{\gamma_b} & \text{if } p_{trans} < \tau_b \end{cases}$$

$$q_{\text{rail}} = \begin{cases} 0 & \text{if } p_{trans} < \tau_r \\ \dfrac{p_{trans} - \tau_r}{\gamma_r} & \text{if } p_{trans} < \tau_r \end{cases}$$

where P_{trans} is the market wide price of the import transportation services; τ_m is the intercept of the inverse supply curve for source $m \in$ {pipeline imports, barge imports, rail imports} and $\gamma_m \geq 0$ is the slope of the inverse supply curve for m. Note that the supply curve for pipeline services is assumed perfectly elastic as in the main text. It follows that the market level inverse supply curve can then be defined over the relative sizes of τ_p, τ_b and τ_r:[1]

- If $\tau_p < \tau_b < \tau_r$:

$$p_{trans} = \begin{cases} \tau_p & \text{if} \quad Q < K \\ \tau_b + \gamma_b \left(Q - K\right) & \text{if} \quad K < Q < K + \dfrac{\tau_r - \tau_b}{\gamma_b} \\ \dfrac{\gamma_r \tau_b + \gamma_b \tau_r}{\gamma_b + \gamma_r} + \dfrac{\gamma_b \gamma_r}{\gamma_b + \gamma_r} \left(Q - K\right) & \text{if} \quad K + \dfrac{\tau_r - \tau_b}{\gamma_b} < Q \end{cases} \tag{A.1}$$

(The case where $\tau_p < \tau_r < \tau_b$ is parallel to this, swapping subscripts r and b.)

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[1]We ignore the cases where $\tau_r < \tau_p$ as they are not empirically relevant given the evidence in BCUC (2019a) and BCUC (2019b) that marginal rail costs are always in excess of pipeline tolls.

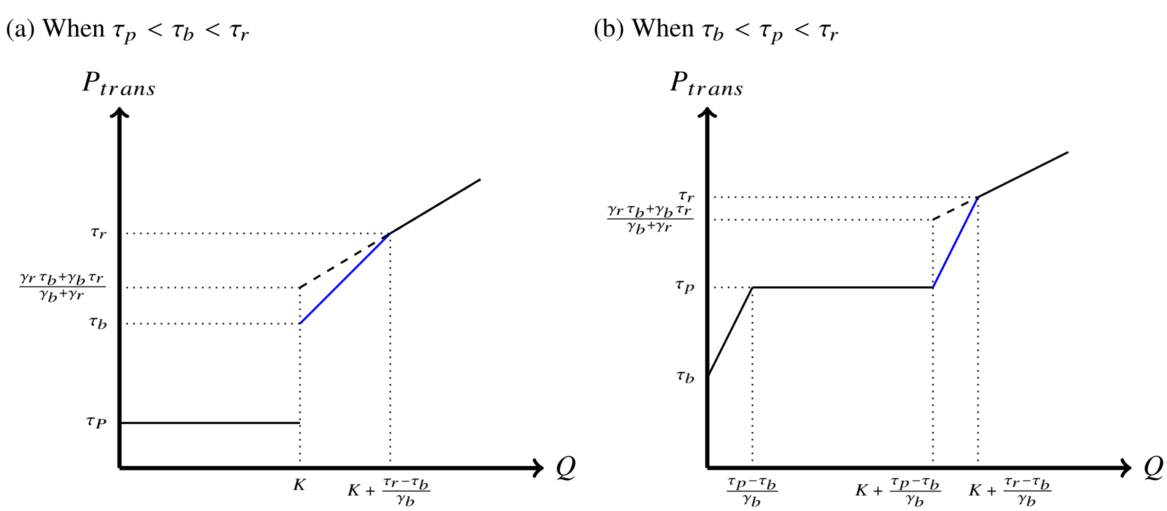
- If $\tau_b < \tau_p < \tau_r$:

$$p_{trans} = \begin{cases} \tau_b + \gamma_b Q & \text{if} \quad Q < \dfrac{\tau_p - \tau_b}{\gamma_b} \\ \tau_p & \text{if} \quad \dfrac{\tau_p - \tau_b}{\gamma_b} < Q < K + \dfrac{\tau_p - \tau_b}{\gamma_b} \\ \tau_p + \gamma_b \left[Q - \left(K + \dfrac{\tau_p - \tau_b}{\gamma_b} \right) \right] & \text{if} \quad K + \dfrac{\tau_p - \tau_b}{\gamma_b} < Q < K + \dfrac{\tau_r - \tau_b}{\gamma_b} \\ \tau_r + \dfrac{\gamma_b \gamma_r}{\gamma_b + \gamma_r} \left[Q - \left(K + \dfrac{\tau_r - \tau_b}{\gamma_b} \right) \right] & \text{if} \quad K + \dfrac{\tau_r - \tau_b}{\gamma_b} < Q \end{cases} \tag{A.2}$$

(The case where $\tau_r < \tau_p < \tau_b$ is parallel to this, swapping subscripts r and b.)

These cases are given graphically in the two panels of Figure A.1. Given the nature of the discussion here, our concern is primarily with the portions of each function where market moves off the pipeline portion of the transportation services supply curve to the right. This is $Q = K$ in Figure A.1(a) and $Q = K + \frac{\tau_r - \tau_b}{\gamma_b}$ in Figure A.1(b).

Figure A.1: Import Transportation Services Inverse Supply Curves



The supply function depicted in Figure 4Assumed Transportation Input Inverse Supply Curvefigure.caption.4 is defined over only 2 sub-domains whereas the supply curves in Figure A.1 are defined over 3 (Panel a) or 4 (Panel b) sub-domains. Nevertheless, we can interpret the parameters in the 2 sub-domain case as a reasonable abstraction of the more complex functions presented here. We know from the evidence in BCUC (2019a) and BCUC (2019b) that barge imports make up a small proportion of total imports. This in turn implies that $\frac{\tau_r - \tau_b}{\gamma_b}$ is small. Given this, we can generally ignore the blue portion of the transportation supply curves in Figure A.1 and interpret the parameters used in the cost function given in the main text as $\tau_r = \frac{\gamma_r \tau_b + \gamma_b \tau_r}{\gamma_b + \gamma_r}$ and $\gamma = \frac{\gamma_b \gamma_r}{\gamma_b + \gamma_r}$. If $\tau_b < \tau_p < \tau_r$ it is also necessary to redefine the measure of capacity K to be equal to $K + \frac{\tau_p - \tau_b}{\gamma_b}$ (the point of discontinuity moving off the portion of the supply function where marginal supply is provided via pipeline).

B Equilibrium when $Q^* = K$

Define $\underline{q_i}$ as the individual firm output that satisfies $\underline{q_i} = K - \sum_{h \neq i} q_h$. Defining firm i's output around this point as $q_i = \underline{q_i} + e$ the firm's profit function around $\underline{q_i}$ can be defined by:

$$\pi_i\left(\underline{q_i} + e\right) = \begin{cases} [a - b(K+e) - \tau_r - \gamma e - c_i]\left(\underline{q_i} + e\right) & \text{iff } e > 0 \\ \left[a - b(K+e) - \tau_p - c_i\right]\left(\underline{q_i} + e\right) & \text{iff } e \leq 0 \end{cases}$$

For $q_i = \underline{q_i}$ to be an optimal choice requires that

$$\frac{\partial \pi_i\left(\underline{q_i} + e\right)}{\partial e} < 0 \;\; \forall e > 0$$
$$\frac{\partial \pi_i\left(\underline{q_i} + e\right)}{\partial e} > 0 \;\; \forall e \leq 0$$

Taken together, these conditions are satisfied if and only if equation (6) is satisfied. Restating equation (6Ranges for K when $N \geq 2$equation.3.6) for convenience.

$$\frac{a - bK - \tau_r - c_i}{b + \gamma} < \underline{q_i} \leq \frac{a - bK - \tau_p - c_i}{b}$$

Recognizing that in equilibrium $\sum_i q_i = Q^* = K$ (where the second equality follows by assumption in this case), aggregating the inequality chain in (6Ranges for K when $N \geq 2$equation.3.6) to the market level yields:

$$\sum_i \left[\frac{a - bK - \tau_r - c_i}{b + \gamma}\right] < K \leq \sum_i \left[\frac{a - bK - \tau_p - c_i}{b}\right]$$

The above can be simplified as in equation (7Ranges for K when $N \geq 2$equation.3.7), restated here for convenience:

$$\frac{n}{(n+1)b + \gamma}\left[a - \tau_r - \frac{\sum c_i}{n}\right] < K \leq \frac{n}{(n+1)b}\left[a - \tau_p - \frac{\sum c_i}{n}\right]$$

For the duopoly case where $N = 2$, this interval simplifies to:

$$\frac{2(a - \tau_r) - (c_1 + c_2)}{3b + \gamma} < K \leq \frac{2\left(a - \tau_p\right) - (c_1 + c_2)}{3b}$$

C Deriving equilibrium quantities (equation 8Market Equilibriumequation.3.8) from best response functions (equations 3A Cournot Oligopoly Model of a Regional Wholesale Gasoline Marketequation.3.3)

Rewriting the equations (3A Cournot Oligopoly Model of a Regional Wholesale Gasoline Marketequation.3.3) in matrix notation the system becomes $\mathbf{Aq} = \mathbf{d}$ where:

$$\mathbf{A} \equiv \begin{pmatrix} 2 & 1 & \cdots & 1 \\ 1 & 2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 1 \\ 1 & \cdots & 1 & 2 \end{pmatrix} \quad \mathbf{q} \equiv \begin{pmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{pmatrix}$$

If we assume that $K > \frac{n}{(n+1)b}\left[a - \tau_p - \frac{\sum_{i\in N} c_i}{n}\right]$, this directly implies that $\sum_{i\in N} q_i > K$, and we define $\mathbf{d}$ as:

$$\mathbf{d} \equiv \begin{pmatrix} \left[a - \left[c_1 + \tau_p\right]\right] / b \\ \left[a - \left[c_2 + \tau_p\right]\right] / b \\ \vdots \\ \left[a - \left[c_n + \tau_p\right]\right] / b \end{pmatrix}$$

If we assume that $K < \frac{n}{(n+1)b+\gamma}\left[a - \tau_r - \frac{\sum_{i\in N} c_i}{n}\right]$, this directly implies that $\sum_{i\in N} q_i < K$, and we define $\mathbf{d}$ as:

$$\mathbf{d} \equiv \begin{pmatrix} \left[a - \left[c_1 + (\tau_r - \gamma K)\right]\right] / \left[b + \gamma\right] \\ \left[a - \left[c_2 + (\tau_r - \gamma K)\right]\right] / \left[b + \gamma\right] \\ \vdots \\ \left[a - \left[c_n + (\tau_r - \gamma K)\right]\right] / \left[b + \gamma\right] \end{pmatrix}$$

Using this notation we can solve for the equilibrium quantities through standard matrix inversion as $\mathbf{q} = \mathbf{A^{-1}d}$. Inverting $\mathbf{A}$:

$$\mathbf{A^{-1}} \equiv \begin{pmatrix} \frac{n}{n+1} & \frac{-1}{n+1} & \cdots & \frac{-1}{n+1} \\ \frac{-1}{n+1} & \frac{n}{n+1} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \frac{-1}{n+1} \\ \frac{-1}{n+1} & \cdots & \frac{-1}{n+1} & \frac{n}{n+1} \end{pmatrix}$$

Such that $\mathbf{q} = \mathbf{A^{-1}d}$ can be written as in equation (8Market Equilibriumequation.3.8).

D Testing the Strategic Over-Nomination Hypothesis for Refined Shippers

Consider a shipper with a desired throughput quantity denoted by $\overline{q_i}$. If the pipeline the shipper uses is over-subscribed (subject to apportionment) and the shipper is free to "over-nominate" the optimal strategy is to try and set a nomination high enough to ensure apportioned throughput is equal to desired throughput ($k_i = \overline{q_i}$). Consider this as a strategic game wherein some subset of shippers face no upper constraints on their nominations. Deriving best response functions based on this proposition:

$$\begin{aligned}
&\text{Starting from equation (1):} && k_i = \eta_i\,(1-\alpha) \\
&\text{Substituting } k_i = \overline{q_i} \text{ and rearranging:} && \eta_i = \frac{\overline{q}_i}{(1-\alpha)} \\
&\text{Substituting for } \alpha: && \eta_i = \frac{\overline{q}_i}{\frac{K}{\eta_i + \sum_{j\neq i}\eta_j}} \\
&\text{Rearranging to isolate for } \eta_i: && \eta_i = \frac{\overline{q}_i}{K-\overline{q}_i}\left(\sum_{j\neq i}\eta_j\right)
\end{aligned}$$

As discussed in section 2.1Pipeline Capacity Constraints and Apportionmentsubsection.2.1 the verification procedure for nominations (prior to the 2015 rule change) constituted a more stringent constraint on nominations for crude oil shipments (as these are larger in total volume and by extension require more storage etc.) compared to the smaller total refined product volumes. Even more generally, if crude oil shippers are not acting strategically in their nominations (whether constrained by the third-party verification or for some other reason), then the above best response function only applies to refined product shippers.

Indexing refined shippers by j and crude oil shippers by m this set of best response functions can be written using matrix notation as: $\mathbf{Ab} = \mathbf{c}$ where $\mathbf{b}$ is a vector of values η_i, $\mathbf{c}$ is a vector of the same length with all values equal to $\sum_m \eta_m$ and A is a square matrix with values $\frac{K-\overline{q}_i}{\overline{q}_i}$ along the principal diagonal and -1 elsewhere. It follows that the existence of a meaningful equilibrium (one where $\eta_i > 0\ \forall i$) implies that optimal strategic nominations are an increasing linear function of non-strategic nominations. That is: $\frac{\partial \eta_i}{\partial \sum_m \eta_m} > 0$ and by extension $\frac{\partial \sum_i \eta_i}{\partial \sum_m \eta_m} > 0$.[2]

Alternatively, if refined product shippers nominate their true demanded capacity or otherwise fail to engage in strategic over-nomination, aggregate refined product nominations should be exogenous with respect to aggregate crude product nominations, establishing a testable hypothesis:

$$\frac{\partial\left(\sum_i \eta_i\right)}{\partial\left(\sum_m \eta_m\right)}\begin{cases} > 0 & \text{if strategic over-nomination circumvents apportionment} \\ = 0 & \text{if nominations are not strategic}\end{cases}$$

Using available data on TMPL throughput and apportionment, it is possible to test the hypothesis that refined shipper nominations are a function of non-refined shippers nominations prior to May 2015, and only prior to May 2015. I test this hypothesis by fitting the following regression equation.

$$\left(\sum_i \eta_i\right)_t = \widehat{\beta_0}\left[(1-\delta)\sum_m \eta_m\right]_t + \widehat{\beta_1}\left[(\delta)\sum_m \eta_m\right]_t + X_t + e_t \tag{D.1}$$

where $\delta = 1$ after, and only after, May 2015 and X_t is a matrix of controls (which vary across sensitivity analysis).[3]

[2]The existence of this equilibrium does not require any shippers in set m to nominate their true demand ($\eta_m = \overline{q_m}$). It only requires that they face some other constraint such that in equilibrium $\sum_m \eta_m$ is exogenous with respect to the strategic interaction.

[3]Hats imply parameters to be estimated. e_t is the usual error term.

Table D.1: Refined Throughput Regression Results

VARIABLES	(1)	(2)	(3)	(4)
$(1-\delta)\sum_m \eta_m$	0.185***	0.225***	0.194***	0.231***
	(0.0350)	(0.0413)	(0.0338)	(0.0417)
$\delta \sum_m \eta_m$	0.0638	-0.103	0.0942	-0.0592
	(0.101)	(0.0633)	(0.0985)	(0.0586)
δ (= 1 post rule change)		16.96***		15.58***
		(4.799)		(4.877)
DATE	-0.00205	-0.0443	-0.0151	-0.0536
	(0.0453)	(0.0524)	(0.0447)	(0.0528)
Constant	5.448	27.96	14.97	35.29
	(25.61)	(29.30)	(25.40)	(29.51)
R-squared	0.675	0.694	0.733	0.748
Monthly Fixed Effects	No	No	Yes	Yes

169 Monthly Observations: January 2006 to February 2020 Excluding May 2015
112 Months pre rule change ($\delta = 0$). 57 Months post Rule Change ($\delta = 1$)
Newey West Standard Errors with maximum 3 lag autocorrelation in Brackets
(*** p<0.01, ** p<0.05, * p<0.1)

Table D.1 shows the fitted parameter estimates of equation D.1 and their sensitivity to Monthly fixed effects and post rule change dummy controls. All results are exactly as expected. Estimates of β_0 (first row) are statistically significant and positive while estimates of β_1 (second row) are all within 1 standard deviation of 0. This strongly supports the hypothesis that refined product shippers were exercising strategic over-nomination but that the practice ended with the May 2015 rule change.