Technical Appendix to Accompany
"Load-Following Forward Contracts"
by David P. Brown and David E. M. Sappington

Part I of this Technical Appendix provides additional explanation of the analysis in the Alberta setting. Part II provides additional coefficient estimates for the fringe and import supply function.

I. Additional Explanation of the Analysis in the Alberta Setting.

Setting where Only SFCs are Feasible

We first describe the analysis when SFCs are the only feasible forward contract. Then we review the analysis when both SFCs and LFFCs are feasible. Finally, we note how equilibrium outcomes are characterized when forward contracting is not feasible. We analyze a two-stage game in each of T periods. In each period, generators choose SFCs in the first stage and outputs in the second stage. For notational ease, the following analysis omits the time subscript.

We employ backward induction to characterize the solution to the model. In the second stage, taking its SFCs (S_i) as given, Generator i (Gi) chooses its output (q_i) to maximize:

$$\pi_i(q_1, ..., q_4) \;=\; P(Q, \varepsilon)\,[\,q_i + q_i^{mr} - S_i\,] - C_i(q_i) + p^S\, S_i$$

$$\text{subject to:} \;\; q_i \;\geq\; 0 \qquad (1)$$

where q_i^{mr} denotes Gi's must-run output.

Let $\lambda_i \geq 0$ denote the Lagrange multiplier associated with the constraint in (1). Also let $\perp$ denote complementarity. Then (1) implies that Gi's output decision is characterized by the following mixed complementarity conditions for $i = 1, ..., 4$:

$$\frac{\partial P(\cdot)}{\partial Q}\,[\,q_i + q_i^{mr} - S_i\,] + P(Q, \varepsilon) - C_i'(q_i) + \lambda_i \;=\; 0\,;$$

$$0 \;\leq\; q_i \;\;\perp\;\; \lambda_i \;\geq\; 0\,. \qquad (2)$$

To account for the complementarity constraints in (2) in our two-stage numerical analysis, we follow Xian et al. (2004) and employ a nonlinear complementarity function that has the following property:

$$\psi(a, b) \;=\; \sqrt{a^2 + b^2} - a - b \;=\; 0 \quad \Leftrightarrow \quad a \;\geq\; 0 \;\;\perp\;\; b \;\geq\; 0\,. \qquad (3)$$

(3) implies that for $i = 1, ..., 4$, (2) can be written as:

$$\frac{\partial P(\cdot)}{\partial Q}\,[\, q_i + q_i^{mr} - S_i\,] + P(Q,\varepsilon) - C_i'(q_i) + \lambda_i \;=\; 0\,;$$

$$\sqrt{(q_i)^2 + (\lambda_i)^2} - q_i - \lambda_i \;=\; 0\,. \tag{4}$$

The generators choose SFCs in the first stage. Gi chooses S_i to maximize its expected profit, taking rivals' SFCs as given and anticipating the subsequent wholesale output choices. Gi's problem is:

$$\max_{S_i}\; E\{\, \pi_i(q_1^*(S_1, ..., S_4, \varepsilon), ..., q_4^*(S_1, ..., S_4, \varepsilon), S_i, \varepsilon)\,\} \tag{5}$$

where $q_j^*(S_1, ..., S_4, \varepsilon)$ are characterized by (4) for $j \in \{1, 2, 3, 4\}$.

Define $\vec{q}(\varepsilon) \equiv \{q_1(\varepsilon), ..., q_4(\varepsilon)\}$ and $\vec{\lambda}(\varepsilon) \equiv \{\lambda_1(\varepsilon), ..., \lambda_4(\varepsilon)\}$. We formulate G$i$'s choice of S_i as a stochastic mathematical program with equilibrium constraints (SMPEC) that treats the output conditions in (4) as constraints that must hold for each ε:

$$\max_{S_i,\, \vec{q}(\varepsilon),\, \vec{\lambda}(\varepsilon)} \quad E\{\, \pi_i(q_1, ..., q_4, S_i, \varepsilon)\,\}$$

subject to, for each $\varepsilon \in [\,\underline{\varepsilon}, \overline{\varepsilon}\,]$ and for $j \in \{1, 2, 3, 4\}$:

$$\frac{\partial P(\cdot)}{\partial Q}\left[\, q_j + q_j^{mr} - S_j\,\right] + P(Q,\varepsilon) - C_j'(q_j) + \lambda_j \;=\; 0\,;$$

$$\sqrt{(q_j)^2 + (\lambda_j)^2} - q_j - \lambda_j \;=\; 0\,. \tag{6}$$

Following the stochastic programming literature (e.g., Yao et al., 2007; Birge and Louveaux, 2011), we approximate the solution to the SMPEC in (6) by assuming ε has a discrete uniform distribution with $n < \infty$ equally likely possible values, $\{\varepsilon_1, \varepsilon_2, ..., \varepsilon_n\}$. Using (6), the Discrete SMPEC (D-SMPEC) can be written as:

$$\max_{S_i,\, \vec{q}(\varepsilon),\, \vec{\lambda}(\varepsilon)} \quad \sum_{l=1}^{n} \frac{1}{n}\, \pi_{il}(q_{1l}, ..., q_{4l}, S_i, \varepsilon_l)$$

subject to, for $j \in \{1, ..., 4\}$ and $l \in \{1, ..., n\}$:

$$\frac{\partial P_l(\cdot)}{\partial Q_l}\left[\, q_{jl} + q_j^{mr} - S_j\,\right] + P_l(Q_l, \varepsilon_l) - C_j'(q_{jl}) + \lambda_{jl} \;=\; 0\,;$$

$$\sqrt{(q_{jl})^2 + (\lambda_{jl})^2} - q_{jl} - \lambda_{jl} \;=\; 0\,. \tag{7}$$

The D-SMPEC in (7) is mathematically equivalent to a standard deterministic mathematical program with equilibrium constraints (MPEC). Because Gi's choice of S_i is represented by the MPEC in (7), the overall problem is an equilibrium problem with equilibrium constraints (EPEC) (DeMiguel and Xu, 2009; Leyffer and Munson, 2010). A solution to this EPEC requires the simultaneous solution of the four MPECs.

Following Hu (2002), Hu and Ralph (2007), and DeMiguel and Xu (2009), we characterize the Karush-Kuhn-Tucker conditions associated with (7) for Generators 1, 2, 3, and 4. Formally, let ρ_{ijl} and ψ_{ijl} denote the Lagrange multipliers associated with the first and second constraints in (7), respectively. Then the Lagrangian function for Gi's D-SMPEC in (7) is:

$$\begin{aligned} \mathcal{L}^i \;=\; & \sum_{l=1}^{n} \frac{1}{n}\, \pi_{il}(q_{1l}, ..., q_{4l}, S_i, \varepsilon_l) \\ & + \sum_{j=1}^{4} \sum_{l=1}^{n} \rho_{ijl} \left[\frac{\partial P_l(\cdot)}{\partial Q_l} \left(q_{jl} + q_j^{mr} - S_j \right) + P_l(Q_l, \varepsilon_l) - C_j'(q_{jl}) + \lambda_{jl} \right] \\ & + \sum_{j=1}^{4} \sum_{l=1}^{n} \psi_{ijl} \left[\sqrt{(q_{jl})^2 + (\lambda_{jl})^2} - q_{jl} - \lambda_{jl} \right]. \end{aligned} \tag{8}$$

Recall from the text that in this setting:

$$p^S \;=\; E\{\, P(Q, \varepsilon)\,\} \;\approx\; \frac{1}{n} \sum_{l=1}^{n} P(Q_l, \varepsilon_l)\,. \tag{9}$$

(9) implies that (8) can be written as:

$$\begin{aligned} \mathcal{L}^i \;=\; & \sum_{l=1}^{n} \frac{1}{n} \{\, P_l(Q_l)\,[\, q_{il} + q_i^{mr} \,] - C_i(q_{il}) \,\} \\ & + \sum_{j=1}^{4} \sum_{l=1}^{n} \rho_{ijl} \left[\frac{\partial P_l(\cdot)}{\partial Q_l} \left(q_{jl} + q_j^{mr} - S_j \right) + P_l(Q_l, \varepsilon_l) - C_j'(q_{jl}) + \lambda_{jl} \right] \\ & + \sum_{j=1}^{4} \sum_{l=1}^{n} \psi_{ijl} \left[\sqrt{(q_{jl})^2 + (\lambda_{jl})^2} - q_{jl} - \lambda_{jl} \right]. \end{aligned} \tag{10}$$

Differentiating (10) provides:

$$\frac{\partial \mathcal{L}^i}{\partial S_i} \;=\; -\sum_{l=1}^{n} \rho_{iil}\, \frac{\partial P(Q_l, \varepsilon_l)}{\partial Q_l} \;=\; 0\,; \tag{11}$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}^i}{\partial q_{il}} \;=\; & \frac{1}{n}\left[\,\frac{\partial P_l(\cdot)}{\partial Q_l}\,[\,q_{il}+q_i^{mr}\,]+P_l(Q_l,\varepsilon_l)-C_i'(q_{il})\,\right] \\
& + \sum_{\substack{j=1\\ i\neq j}}^{4} \rho_{ijl}\,\left[\,\frac{\partial^2 P_l(\cdot)}{\partial Q_l^2}\,[\,q_{jl}+q_j^{mr}-S_j\,]+\frac{\partial P_l(Q_l,\varepsilon_l)}{\partial Q_l}\,\right] \\
& + \rho_{iil}\,\left[\frac{\partial^2 P_l(\cdot)}{\partial Q_l^2}\,[\,q_{il}+q_i^{mr}-S_i\,]+2\,\frac{\partial P_l(Q_l,\varepsilon_l)}{\partial Q_l}-C_i''(q_{il})\,\right] \\
& + \psi_{iil}\left[\,\left(\,[\,q_{il}\,]^2+[\,\lambda_{il}\,]^2\,\right)^{-\frac{1}{2}}\,q_{il}-1\,\right] \;=\; 0 \;\;\text{for}\;\; l \;=\; 1,\ldots,n\,;
\end{aligned}
\tag{12}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}^i}{\partial q_{kl}} \;=\; & \frac{1}{n}\left[\,\frac{\partial P_l(\cdot)}{\partial Q_l}\,(\,q_{il}+q_i^{mr}\,)\,\right] \\
& + \sum_{\substack{j=1\\ j\neq k}}^{4} \rho_{ijl}\,\left[\,\frac{\partial^2 P_l(\cdot)}{\partial Q_l^2}\,\left(\,q_{jl}+q_j^{mr}-S_j\,\right)+\frac{\partial P_l(Q_l,\varepsilon_l)}{\partial Q_l}\,\right] \\
& + \rho_{ikl}\,\left[\,\frac{\partial^2 P_l(\cdot)}{\partial Q_l^2}\,(\,q_{kl}+q_k^{mr}-S_k\,)+2\,\frac{\partial P_l(Q_l,\varepsilon_l)}{\partial Q_l}-C_k''(q_{kl})\,\right] \\
& + \psi_{ikl}\left[\,\left(\,[\,q_{kl}\,]^2+[\,\lambda_{kl}\,]^2\,\right)^{-\frac{1}{2}}\,q_{kl}-1\,\right] \;=\; 0 \\
& \qquad \text{for}\;\; l \;=\; 1,\ldots,n \quad\text{and}\quad k \;=\; 1,\ldots,4\;(k\neq i)\,;
\end{aligned}
\tag{13}
$$

$$
\frac{\partial \mathcal{L}^i}{\partial \lambda_{kl}} \;=\; \rho_{ikl}+\psi_{ikl}\left\{\,\left(\,[\,q_{kl}\,]^2+[\,\lambda_{kl}\,]^2\,\right)^{-\frac{1}{2}}\,\lambda_{kl}-1\,\right\} \;=\; 0
$$

$$
\text{for}\;\; k \;=\; 1,\ldots,4 \;\;\text{and}\;\; l \;=\; 1,\ldots,n\,; \tag{14}
$$

$$
\frac{\partial \mathcal{L}^i}{\partial \rho_{ikl}} \;=\; \frac{\partial P_l(\cdot)}{\partial Q_l}\,[\,q_{kl}+q_k^{mr}-S_k\,]+P_l(Q_l,\varepsilon_l)-C_j'(q_{kl})+\lambda_{kl} \;=\; 0
$$

$$
\text{for}\;\; k \;=\; 1,\ldots,4 \;\;\text{and}\;\; l \;=\; 1,\ldots,n\,; \tag{15}
$$

$$
\frac{\partial \mathcal{L}^i}{\partial \psi_{ikl}} \;=\; \sqrt{(q_{kl})^2+(\lambda_{kl})^2}-q_{kl}-\lambda_{kl} \;=\; 0
$$

$$
\text{for}\;\; k \;=\; 1,\ldots,4 \;\;\text{and}\;\; l \;=\; 1,\ldots,n\,. \tag{16}
$$

The solution to the EPEC is characterized by solving the conditions in (11) – (16) for Generators $1, 2, 3$, and 4 simultaneously. There are $4 + 40\,n$ endogenous variables: (i) the 4 generators' forward quantities (S_1, S_2, S_3, S_4); (ii) the $4\,n$ realized outputs $(q_{11}, \ldots, q_{1n}, \ldots,$

$q_{41}, ..., q_{4n}$); (iii) the $4\,n$ Lagrange multipliers $\{\lambda_{11}..., \lambda_{1n}, ..., \lambda_{41}, ..., \lambda_{4n}\}$; and (iv) the $32\,n$ Lagrange multipliers $(\{\rho_{111}, ..., \rho_{11n},\ \rho_{121}, ..., \rho_{44n};\ \psi_{111}, ..., \psi_{11n},\ \psi_{121}, ..., \psi_{44n}\})$. There are also $4 + 40\,n$ unique equations because equations (15) and (16) are the same in the MPECs of Generators 1, 2, 3, and 4. Thus, we have a square constrained non-linear system where the number of conditions equal the number of endogenous variables. This system can be solved using the PATH algorithm using the GAMS software.

Setting where SFCs and LFFCs are Feasible

We analyze a two-stage game in each of T periods. In each period, generators choose SFCs and LFFCs in the first stage and outputs in the second stage. For notational ease, the following analysis omits the time subscript.

We employ backward induction to characterize the solution to the model. In the second stage, taking its SFCs and LFFCs (S_i and L_i) as given, Generator i (Gi) chooses its output (q_i) to maximize:

$$\pi_i(q_1, ..., q_4) \;=\; P(Q, \varepsilon)\,[\,q_i + q_i^{mr} - \alpha\, L_i\, Q - S_i\,] - C_i(q_i) + p^L\, \alpha\, L_i\, Q + p^S\, S_i$$

$$\text{subject to:} \quad q_i \;\geq\; 0\,. \tag{17}$$

Let $\lambda_i \geq 0$ denote the Lagrange multipliers associated with the first and second constraints in (17), respectively. Also let $\perp$ denote complementarity. Then (17) implies that Gi's output decision is characterized by the following mixed complementarity conditions for $i = 1, ..., 4$:

$$\frac{\partial P(\cdot)}{\partial Q}\,[\,q_i + q_i^{mr} - \alpha\, L_i\, Q - S_i\,] + P(Q, \varepsilon)\,[\,1 - \alpha\, L_i\,] - C_i'(q_i) + p^L\, \alpha\, L_i + \lambda_i \;=\; 0\,;$$

$$q_i \;\geq\; 0 \quad \perp \quad \lambda_i \;\geq\; 0\,. \tag{18}$$

Following Xian et al. (2004), we utilize the transformation in (3) to write (18) as:

$$\frac{\partial P(\cdot)}{\partial Q}\,[\,q_i + q_i^{mr} - \alpha\, L_i\, Q - S_i\,] + P(Q, \varepsilon)\,[\,1 - \alpha\, L_i\,] - C_i'(q_i) + p^L\, \alpha\, L_i + \lambda_i \;=\; 0\,;$$

$$\sqrt{(q_i)^2 + (\lambda_i)^2} - q_i - \lambda_i \;=\; 0 \quad \text{for } i \;=\; 1, ..., 4\,. \tag{19}$$

Gi chooses S_i and L_i to maximize its expected profits, taking rival's SFCs and LFFCs as given and anticipating the subsequent wholesale output choices. Gi's problem is:

$$\max_{S_i,\, L_i}\; E\{\, \pi_i(q_1^*(S_1, ..., S_4, L_1, ..., L_4, \varepsilon), ..., q_4^*(S_1, ..., S_4, L_1, ..., L_4, \varepsilon), S_i, L_i, \varepsilon)\,\} \tag{20}$$

where $q_j^*(S_1, ..., S_4, L_1, ..., L_4, \varepsilon)$ are characterized by (19) for $j = 1, ..., 4$.

Define $\vec{q}(\varepsilon) = \{q_1(\varepsilon), ..., q_4(\varepsilon)\}$ and $\vec{\lambda}(\varepsilon) = \{\lambda_1(\varepsilon), ..., \lambda_4(\varepsilon)\}$. We formulate G$i$'s choice of S_i and L_i as a stochastic mathematical program with equilibrium constraints (SMPEC) that treats the wholesale output conditions in (19) as constraints that must hold for each possible realization of ε:

$$\max_{S_i,\, L_i,\, \vec{q}(\varepsilon),\; \vec{\lambda}(\varepsilon)} \; E\{\, \pi_i(q_1, ..., q_4, S_i, L_i, \varepsilon)\,\}$$

subject to, for each $\varepsilon \in [\,\underline{\varepsilon}, \overline{\varepsilon}\,]$ and for $j \in \{1, 2, 3, 4\}$:

$$\frac{\partial P(\cdot)}{\partial Q}\left[\, q_j + q_j^{mr} - \alpha\, L_j\, Q - S_j\,\right] + P(Q, \varepsilon)\,[\, 1 - \alpha\, L_j\,] - C_j'(q_j) + p^L\, \alpha\, L_j + \lambda_j \;=\; 0\,;$$

$$\sqrt{(q_j)^2 + (\lambda_j)^2} - q_j - \lambda_j \;=\; 0\,. \tag{21}$$

Following the stochastic programming literature (e.g., Yao et al., 2007; Birge and Louveaux, 2011), we approximate the solution to the SMPEC in (21) by assuming that ε has a discrete distribution with $n < \infty$ possible equally likely realizations, $\{\varepsilon_1, \varepsilon_2, ..., \varepsilon_n\}$. Using (21), the discrete SMPEC (D-SMPEC) can be written as:

$$\max_{S_i,\, L_i,\, \vec{q}(\varepsilon),\, \vec{\lambda}(\varepsilon)} \; \sum_{l\,=\,1}^{n} \frac{1}{n}\; \pi_{il}(q_{1l}, ..., q_{4l}, S_i, L_i, \varepsilon_l)$$

subject to, for $j \in \{1, ..., 4\}$ and $l \in \{1, ..., n\}$:

$$\frac{\partial P_l(\cdot)}{\partial Q_l}\left[\, q_{jl} + q_j^{mr} - \alpha\, L_j\, Q_l - S_j\,\right] + P_l(Q_l, \varepsilon_l)[\, 1 - \alpha\, L_j\,] - C_j'(q_{jl}) + p^L\, \alpha\, L_j + \lambda_{jl} \;=\; 0$$

$$\sqrt{(q_{jl})^2 + (\lambda_{jl})^2} - q_{jl} - \lambda_{jl} \;=\; 0\,. \tag{22}$$

The D-SMPEC in (22) is mathematically equivalent to a standard deterministic mathematical program with equilibrium constraints (MPEC). Because Gi's choices of S_i and L_i are represented by the MPEC in (22), the overall problem is an equilibrium problem with equilibrium constraints (EPEC) (DeMiguel and Xu, 2009; Leyffer and Munson, 2010). A solution to this EPEC requires the simultaneous solution of the four MPECs.

Following Hu (2002), Hu and Ralph (2007), and DeMiguel and Xu (2009), we characterize the Karush-Kuhn-Tucker conditions associated with (22) for the generators. Let ρ_{ijl} and ψ_{ijl} denote the Lagrange multipliers associated with the first and second constraints in (22), respectively. Then the Lagrangian function for Generator i's D-SMPEC in (7) is:

$$
\begin{aligned}
\mathcal{L}^i \;=\; & \sum_{l=1}^{n} \frac{1}{n}\, \pi_{il}(q_{1l}, ..., q_{4l}, S_i, L_i, \varepsilon_l) \\
& + \sum_{j=1}^{4} \sum_{l=1}^{n} \rho_{ijl} \left\{ \frac{\partial P_l(\cdot)}{\partial Q_l} \left[q_{jl} + q_j^{mr} - \alpha\, L_j\, Q_l - S_j \right] \right. \\
& \qquad \left. + \; P_l(Q_l, \varepsilon_l) \left[1 - \alpha\, L_j \right] - C_j'(q_{jl}) + p^L\, \alpha\, L_j + \lambda_{jl} \right\} \\
& + \sum_{j=1}^{4} \sum_{l=1}^{n} \psi_{ijl} \left[\sqrt{(q_{jl})^2 + (\lambda_{jl})^2} - q_{jl} - \lambda_{jl} \right]. \qquad (23)
\end{aligned}
$$

Recall from the text that in the present setting:

$$
\begin{aligned}
p^S \;&=\; E\left\{ P(Q^*, \varepsilon) \right\} \;=\; \frac{1}{n} \sum_{l=1}^{n} P(Q_l, \varepsilon_l)\,; \quad \text{and} \\
p^L \;&=\; \frac{E\left\{ P(Q^*, \varepsilon)\, Q^* \right\}}{E\left\{ Q^* \right\}} \;=\; \frac{\sum_{l=1}^{n} P_l(Q_l, \varepsilon_l)\, Q_l}{\sum_{l=1}^{n} Q_l}\,. \qquad (24)
\end{aligned}
$$

(24) implies:

$$
\frac{\partial p^L}{\partial q_{jl}} \;=\; \left[\frac{1}{\sum_{k=1}^{n} Q_k} \right]^2 \left[\left(\frac{\partial P_l(\cdot)}{\partial Q_l}\, Q_l + P_l(\cdot) \right) \sum_{k=1}^{n} Q_k - \sum_{k=1}^{n} P_k(\cdot)\, Q_k \right]. \qquad (25)
$$

(24) implies that (23) can be written as:

$$
\begin{aligned}
\mathcal{L}^i \;=\; & \sum_{l=1}^{n} \frac{1}{n} \left[P(Q_l, \varepsilon_l) [\, q_{il} + q_i^{mr}\,] - C_i(q_{il}) \right] \\
& + \sum_{j=1}^{4} \sum_{l=1}^{n} \rho_{ijl} \left\{ \frac{\partial P_l(\cdot)}{\partial Q_l} \left[q_{jl} + q_j^{mr} - \alpha\, L_j\, Q_l - S_j \right] \right. \\
& \qquad \left. + \; P_l(Q_l, \varepsilon_l) \left[1 - \alpha\, L_j \right] - C_j'(q_{jl}) + p^L\, \alpha\, L_j + \lambda_{jl} \right\} \\
& + \sum_{j=1}^{4} \sum_{l=1}^{n} \psi_{ijl} \left[\sqrt{(q_{jl})^2 + (\lambda_{jl})^2} - q_{jl} - \lambda_{jl} \right]. \qquad (26)
\end{aligned}
$$

The corresponding solution to firm i's D-SMPEC is characterized by:

$$
\frac{\partial \mathcal{L}^i}{\partial S_i} \;=\; - \sum_{l=1}^{n} \rho_{iil}\, \frac{\partial P(Q_l, \varepsilon_l)}{\partial Q_l} \;=\; 0\,; \qquad (27)
$$

$$\frac{\partial \mathcal{L}^i}{\partial L_i} \;=\; -\sum_{l=1}^{n} \rho_{iil} \left[\frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} \, \alpha \, Q_l + P(Q_l, \varepsilon_l) \, \alpha - \alpha \, p^L \right] \;=\; 0\,; \tag{28}$$

$$\begin{aligned}
\frac{\partial \mathcal{L}^i}{\partial q_{il}} \;=\; & \frac{1}{n} \left[\frac{\partial P_l(\cdot)}{\partial Q_l} \, [\, q_{il} + q_i^{mr} \,] + P_l(Q_l, \varepsilon_l) - C_i'(q_{il}) \right] \\
& + \sum_{\substack{j=1 \\ i \neq j}}^{4} \rho_{ijl} \left\{ \frac{\partial^2 P_l(\cdot)}{\partial Q_l^2} \left[\, q_{jl} + q_j^{mr} - L_j \, \alpha \, Q_l - S_j \,\right] + \frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} \, [\, -\alpha \, L_j \,] \right. \\
& \qquad \left. + \frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} \, [\, 1 - \alpha \, L_j \,] + \frac{\partial p^L}{\partial q_{il}} \alpha \, L_j \right\} \\
& + \rho_{iil} \left\{ \frac{\partial P_l^2(\cdot)}{\partial Q_l^2} \, [\, q_{il} + q_i^{mr} - L_i \, \alpha \, Q_l - S_i \,] + 2 \, \frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} \, [\, 1 - \alpha \, L_i \,] \right. \\
& \qquad \left. - \; C_i''(q_{il}) + \frac{\partial p^L}{\partial q_{il}} \alpha \, L_i \right\} \\
& + \; \psi_{iil} \left[\left([\, q_{il} \,]^2 + [\, \lambda_{il} \,]^2 \right)^{-\frac{1}{2}} \; q_{il} - 1 \right] \;=\; 0 \quad \text{for } \; l \;=\; 1, ..., n \;;
\end{aligned} \tag{29}$$

$$\begin{aligned}
\frac{\partial \mathcal{L}^i}{\partial q_{kl}} \;=\; & \frac{1}{n} \, \frac{\partial P_l(\cdot)}{\partial Q_l} [\, q_{il} + q_i^{mr} \,] \\
& + \sum_{\substack{j=1 \\ j \neq k}}^{4} \rho_{ijl} \left\{ \frac{\partial^2 P_l(\cdot)}{\partial Q_l^2} \, [\, q_{jl} + q_j^{mr} - \alpha \, L_j \, Q_l - S_j \,] + \frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} [\, -\alpha \, L_j \,] \right. \\
& \qquad \left. + \frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} \, [\, 1 - \alpha \, L_j \,] + \frac{\partial p^L}{\partial q_{kl}} \, \alpha \, L_j \right\} \\
& + \rho_{ikl} \left\{ \frac{\partial^2 P_l(\cdot)}{\partial Q_l^2} \, [\, q_{kl} + q_k^{mr} - \alpha \, L_k \, Q_l - S_k \,] + 2 \, \frac{\partial P_l(Q_l, \varepsilon_l)}{\partial Q_l} \, [\, 1 - \alpha \, L_k \,] \right. \\
& \qquad \left. - \; C_k''(q_{kl}) + \frac{\partial p^L}{\partial q_{kl}} \, \alpha \, L_k \right\} \\
& + \psi_{ikl} \left\{ \left[\, (\, q_{kl} \,)^2 + (\, \lambda_{kl} \,)^2 \right]^{-\frac{1}{2}} \; q_{kl} - 1 \right\} \;=\; 0 \\
& \qquad \text{for } \; l \;=\; 1, ..., n \;\; \text{and} \;\; k \;=\; 1, ..., 4 \; (k \neq i)\,;
\end{aligned} \tag{30}$$

$$\frac{\partial \mathcal{L}^i}{\partial \lambda_{kl}} \;=\; \rho_{ikl} + \psi_{ikl} \left[\left([\, q_{kl} \,]^2 + [\, \lambda_{kl} \,]^2 \right)^{-\frac{1}{2}} \; \lambda_{kl} - 1 \right] = \; 0 \qquad \text{for } \; k \;=\; 1, ..., 4 \;\; \text{and} \;\; l \;=\; 1, ..., n\,; \tag{31}$$

$$\frac{\partial \mathcal{L}^i}{\partial \rho_{ikl}} = \frac{\partial P_l(\cdot)}{\partial Q_l} [\, q_{kl} + q_k^{mr} - \alpha\, L_k\, Q_l - S_k \,] + P_l(Q_l, \varepsilon_l)\, [\, 1 - \alpha\, L_k \,] - C_j'(q_{kl})$$

$$+ \, p^L \alpha\, L_j + \lambda_{kl} = 0 \quad \text{for } k = 1, ..., 4 \text{ and } l = 1, ..., n\, ; \tag{32}$$

$$\frac{\partial \mathcal{L}^i}{\partial \psi_{ikl}} = \sqrt{(q_{kl})^2 + (\lambda_{kl})^2} - q_{kl} - \lambda_{kl} = 0$$

$$\text{for } k = 1, ..., 4 \text{ and } l = 1, ..., n\, . \tag{33}$$

The solution to the EPEC is characterized by solving the conditions in (27) – (33) for Generators $1, 2, 3$, and 4 simultaneously. There are $8 + 40\, n$ endogenous variables: (i) the generators' SFCs (S_1, S_2, S_3, S_4) and LFFCs (L_1, L_2, L_3, L_4); (ii) the $4\, n$ realized outputs $(q_{11}, ..., q_{1n}, ..., q_{41}, ..., q_{4n})$; (iii) the $4\, n$ Lagrange multipliers $(\{\lambda_{11} ..., \lambda_{1n}, ..., \lambda_{41}, ..., \lambda_{4n}\})$; and (iv) the $32\, n$ Lagrange multipliers $(\{\rho_{111}, ..., \rho_{11n}, \rho_{121}, ..., \rho_{44n}; \psi_{111}, ..., \psi_{11n}, \psi_{121}, ..., \psi_{44n}\})$. There are also $8 + 40\, n$ unique equations because equations (32) and (33) are the same in the MPECs of Generators 1, 2, 3, and 4. Thus, we have a square constrained non-linear system with the same number of conditions and endogenous variables. This system can be solved using the PATH algorithm using the GAMS software.

To characterize equilibrium outcomes in the setting where forward contracting is not feasible, it is only necessary to identify the generators' equilibrium wholesale outputs. These outputs are characterized by the mixed complementarity problem (MCP) in (2) when $S_i = 0$ for $i = 1, 2, 3, 4$. We solve this MCP using the PATH solver in GAMS.

II. Additional Coefficient Estimates for the Fringe and Import Supply Function.

	OLS Q_t^f	IV First Stage p_t	IV Second Stage Q_t^f
Price	0.3074***		9.6954***
	(0.1295)		(1.7319)
Import Capacity - BC	-0.2125	-0.0469	0.2910
	(0.1503)	(0.0395)	(0.3506)
Import Capacity - SK	0.0440	-0.0418	0.8106
	(0.4324)	(0.0618)	(0.5766)
Import Capacity - MT	0.0486	-0.0761	0.6057
	(0.3524)	(0.0914)	(0.8469)
HD - SK	14.6686***	0.9855	-2.2009
	(4.6029)	(0.8686)	(8.6216)
HD^2 - SK	0.0862	-0.0274	0.3727*
	(0.0874)	(0.0200)	(0.2022)
CD - SK	30.2307**	3.6731	-12.5904
	(13.4403)	(6.3067)	(58.5129)
CD^2 - SK	-1.7684	0.6998	-8.2693
	(1.4619)	(0.8120)	(7.1783)
HD - BC	-27.7370***	-7.4652***	41.5022
	(8.7672)	(2.5316)	(25.4536)
HD^2 - BC	1.7276***	0.2850**	-1.2647
	(0.3508)	(0.1186)	(1.1710)
CD - BC	37.5805*	3.9337	-11.8414
	(19.4069)	(9.1085)	(89.8061)
CD^2 - BC	-0.2593	0.4034	-3.6596
	(2.47406)	(1.9700)	(19.4238)
HD - MT	7.7825	-2.5974**	34.9410***
	(4.8434)	(1.2509)	(12.2839)
HD^2 - MT	-0.3359***	0.0945***	-1.3569***
	(0.1127)	(0.0366)	(0.3652)
CD - MT	10.8734	-5.5025*	58.7032**
	(8.8343)	(2.8991)	(28.1174)
CD^2 - MT	-0.2121	0.0654	-1.1185
	(0.5287)	(0.2004)	(1.9303)
Demand Forecast		0.0489***	
		(0.008)	
K-P Wald Statistic		37.34***	
Calendar Fixed Effects	Y	Y	Y
Temperature Controls	Y	Y	Y
Sample Size	8,760	8,760	8,760

Notes. BC denotes British Columbia, SK denotes Saskatchewan, MT denotes Montana. HD denotes heating degrees and CD denotes cooling degrees. The calendar fixed effects include Hour, Month, Day (of the week), and Holiday. Standard errors appear in parentheses. ***, **, * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table TA1: Coefficient Estimates for the Fringe and Import Supply Function.

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