Appendix to "Cost pass-through in Commercial Aviation: Theory and Evidence" – Theoretical Derivations

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"Cost Pass-through in Commercial Aviation: Theory and Evidence."

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Abstract

This appendix serves as a supplement to "Cost Pass-through in Commercial Aviation: Theory and Evidence." In this appendix we present the computational details of the theoretical model as well as the model predictions described in the text of the above-mentioned paper. Using a model of air travel demand and supply for an origin-destination market, we derive the closed-form expression for Nash equilibrium airfares, and use the closed-form expression to perform a series of comparative statics exercises. In particular, crucial expressions for obtaining predictions in Table 1 and Table 2 in the paper (Gayle and Lin, 2020) are provided.

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A. Obtaining a Closed-form Solution for Bertrand-Nash Equilibrium Airfares

In this section, we provide the computational details of obtaining the Nash equilibrium for the system of air travel demand and supply equations presented in the theory section of the paper (Gayle and Lin, 2020). As described in Section 2.2, we assume airlines are competing simultaneously and non-cooperatively in a Bertrand-Nash price-setting game, and the Nash equilibrium is a set of prices that solve the following first-order conditions:

$$\begin{bmatrix} 2\beta & -\tilde{\beta} & \cdots & -\tilde{\beta} \\ -\tilde{\beta} & 2\beta & \dots & -\tilde{\beta} \\ \vdots & \vdots & \ddots & \vdots \\ -\tilde{\beta} & -\tilde{\beta} & \cdots & 2\beta \end{bmatrix} \times \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} - \begin{bmatrix} H_1 + \beta c_1 \\ H_2 + \beta c_2 \\ \vdots \\ H_n + \beta c_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{A-1}$$

which can be rewritten as follows:

$$B \times \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} - \begin{bmatrix} H_1 + \beta c_1 \\ H_2 + \beta c_2 \\ \vdots \\ H_n + \beta c_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{A-2}$$

where

$$B = \begin{bmatrix} 2\beta & -\tilde{\beta} & \cdots & -\tilde{\beta} \\ -\tilde{\beta} & 2\beta & \dots & -\tilde{\beta} \\ \vdots & \vdots & \ddots & \vdots \\ -\tilde{\beta} & -\tilde{\beta} & \cdots & 2\beta \end{bmatrix} \tag{A-3}$$

Following the approach illustrated in Wang and Zhao (2007), let $B = \frac{1}{a}[I - bT]$, where $a = \frac{1}{2\beta+\tilde{\beta}}$; $b = a\tilde{\beta} = \frac{\tilde{\beta}}{2\beta+\tilde{\beta}}$; I is an $n \times n$ identity matrix; and T is an $n \times n$ matrix of ones. The inverse of matrix *B* is given by:

$$B^{-1} = a\left[I + \frac{b}{1-nb}T\right] \tag{A-4}$$

We focus on a Nash Equilibrium in which products have strictly positive prices ($P_i > 0$) and production levels ($q_i > 0$). The system of first-order conditions yields the following expression for Nash equilibrium price levels:

$$\begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} = B^{-1} \begin{bmatrix} H_1 + \beta c_1 \\ H_2 + \beta c_2 \\ \vdots \\ H_n + \beta c_n \end{bmatrix} = \begin{bmatrix} a + \frac{ab}{1-nb} & \frac{ab}{1-nb} & \cdots & \frac{ab}{1-nb} \\ \frac{ab}{1-nb} & a + \frac{ab}{1-nb} & \dots & \frac{ab}{1-nb} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{ab}{1-nb} & \frac{ab}{1-nb} & \cdots & a + \frac{ab}{1-nb} \end{bmatrix} \begin{bmatrix} H_1 + \beta c_1 \\ H_2 + \beta c_2 \\ \vdots \\ H_3 + \beta c_n \end{bmatrix} \tag{A-5}$$

For any air travel product i in equation system (A-5), the optimal airfare P_i is given by:

$$P_i = \left(a + \frac{ab}{1-nb}\right) H_i + \frac{ab}{1-nb} \sum_{j \neq i}^{n-1} H_j + \left(a + \frac{ab}{1-nb}\right) \beta c_i + \frac{ab\beta}{1-nb} \sum_{j \neq i}^{n-1} c_j \qquad \text{(A-6)}$$

Substituting $= \frac{1}{2\beta+\tilde{\beta}}$, $b = \frac{\tilde{\beta}}{2\beta+\tilde{\beta}}$ into equation (A-6), we obtain the Nash equilibrium expression for prices as shown in equation (7) in the paper (Gayle and Lin, 2020), given by:

$$P_i = \frac{2\beta-(n-2)\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} H_i + \frac{\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} \left(\sum_{j \neq i}^{n-1} H_j\right) +$$

$$\frac{\beta[2\beta-(n-2)\tilde{\beta}]}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} c_i + \frac{\beta\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} \left(\sum_{j \neq i}^{n-1} c_j\right) \qquad \text{(A-7)}$$

Furthermore, substituting the specifications for H_i and c_i into equation (A-7) yields the following reduced-form equation for Nash equilibrium price for air travel product $i = 1,2,\dots,n$:

$$\boldsymbol{P_i^*} = \boldsymbol{f}(\boldsymbol{\theta}; P_c, Hedge_i, Mkt_{Dist}, IntineraryDist_i, D_i, D_i^c, n_0, n_1, n_2, X_1, X_{2i}, X_{-2i}, Z_1, Z_{2i})$$

$$= \frac{h_0+h_1X_1+\beta\alpha_0+\beta\alpha_1Z_1}{2\beta-(n-1)\tilde{\beta}} + \frac{\left\{\begin{matrix} h_2X_{2i}+h_3X_{-2i}+(\gamma_1Mkt_{Dist}+\gamma_2Mkt_{Dist^2})\delta_0D_i \\ +\beta\alpha_2Z_{2i}+\beta\phi_0(a_0+a_1Hedge_i)+\beta\phi_0D_i^c+\beta\phi_0\alpha_7ItineraryDist_i \end{matrix}\right\}}{2\beta+\tilde{\beta}} +$$

$$\frac{\left\{\begin{matrix} \tilde{\beta}\sum_{j=1}^{n}(h_2X_{2j}+h_3X_{-2j}+\beta\alpha_2Z_{2j}+\beta\phi_0(a_0+a_1Hedge_J)+\beta\phi_0\alpha_7ItineraryDist_j) \\ +\tilde{\beta}[\delta_0h_4(\gamma_1Mkt_{Dist}+\gamma_2Mkt_{Dist^2})+\beta\phi_0\alpha_4]n_0 \\ +\tilde{\beta}[\delta_0h_5(\gamma_1Mkt\_Dist+\gamma_2Mkt\_Dist^2)+\beta\phi_0\alpha_5]n_1 \\ +\tilde{\beta}[\delta_0h_6(\gamma_1Mkt\_Dist+\gamma_2Mkt\_Dist^2)+\beta\phi_0\alpha_6]n_2 \end{matrix}\right\}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} +$$

$$\left\{\frac{\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)+[2\beta-(n-1)\tilde{\beta}]D_i}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}(\gamma_1Mkt\_Dist+\gamma_2Mkt\_Dist^2)\delta_1 + \right.$$

$$\left.\frac{\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2)+[2\beta-(n-1)\tilde{\beta}](D_i^c+(a_0+a_1Hedge_i)+\alpha_7ItineraryDist_i)+\tilde{\beta}\sum_{j=1}^{n}((a_0+a_1Hedge_J)+\alpha_7ItineraryDist_j)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}\beta\phi_1\right\}P_c$$

(A-8)

where

$$n_0 = \sum_{i=1}^{n} d_{i0} \qquad \text{(A-9)}$$

$$n_1 = \sum_{i=1}^{n} d_{i1} \qquad \text{(A-10)}$$

$$n_2 = \sum_{i=1}^{n} d_{i2} \qquad \text{(A-11)}$$

$$X_{-2i} = \sum_{j \neq i}^{n-1} X_{2j} \qquad \text{(A-12)}$$

$$\boldsymbol{\theta} \equiv \{\beta_0, \tilde{\beta}, h_0, h_1, h_2, h_3, h_4, h_5, h_6, \gamma_1, \gamma_2, \delta_0, \delta_1, \alpha_0, \alpha_1, \alpha_2, a_0, a_1, \alpha_4, \alpha_5, \alpha_6, \alpha_7, \phi_0, \phi_1\} \qquad \text{(A-13)}$$

The assumption of strictly positive prices and quantities implies that $2\beta - (n-1)\tilde{\beta} > 0$. Implications of the assumption of strictly positive prices and quantities are summarized in **Lemma 1**.

Lemma 1: *The assumption of positive prices and quantities for each product* $i = 1,2, \dots, n$ *in Nash equilibrium, implies that the following inequalities hold simultaneously:*

$$\begin{cases} P_i^* > 0 \\ q_i^* > 0 \\ H_i > c_i > 0 \\ \beta > \tilde{\beta} > 0 \end{cases} \Rightarrow \begin{cases} 2\beta - (n-1)\tilde{\beta} > 0 \\ \sum_{j=1}^{n} H_j + \left[(n-1)\tilde{\beta} - \beta\right]\sum_{j=1}^{n} c_j > 0 \\ H_i > c_i > 0 \\ \beta > \tilde{\beta} > 0 \end{cases} \quad \text{(A-14)}$$

Illustration of Inequalities Suggested in Lemma 1:

Assuming positive price and quantity for each product, we first compute the Nash equilibrium quantity by substituting the equilibrium price into demand function, which gives:

$$q_i^* = \frac{\beta}{2\beta+\tilde{\beta}} \frac{[2\beta-(n-1)\tilde{\beta}]H_i - (\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_i + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} \quad \text{(A-15)}$$

Strictly positive prices and quantities imply the following inequalities:

$$\begin{cases} P_i^* > 0 \\ q_i^* > 0 \\ H_i > c_i > 0 \\ \beta > \tilde{\beta} > 0 \end{cases} \Rightarrow \begin{cases} \frac{[2\beta-(n-1)\tilde{\beta}](H_i+\beta c_i) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} \left(\frac{1}{2\beta+\tilde{\beta}}\right) > 0 \\ \frac{[2\beta-(n-1)\tilde{\beta}]H_i - (\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_i + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} \left(\frac{\beta}{2\beta+\tilde{\beta}}\right) > 0 \\ H_i > c_i > 0 \\ \beta > \tilde{\beta} > 0 \end{cases} \quad \text{(A-16)}$$

For each $i = 1,2, \dots, n$, their positive Nash equilibrium prices imply:

$$\text{If } \begin{cases} P_1^* = \frac{[2\beta-(n-1)\tilde{\beta}](H_1+\beta c_1) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} \left(\frac{1}{2\beta+\tilde{\beta}}\right) > 0 \\ P_2^* = \frac{[2\beta-(n-1)\tilde{\beta}](H_2+\beta c_2) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} \left(\frac{1}{2\beta+\tilde{\beta}}\right) > 0 \\ \vdots \\ P_n^* = \frac{[2\beta-(n-1)\tilde{\beta}](H_n+\beta c_n) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} \left(\frac{1}{2\beta+\tilde{\beta}}\right) > 0 \end{cases} \text{, then } P_1^* + P_2^* + \cdots + P_n^* > 0$$

That is:

$$P_1^* + P_2^* + \cdots + P_n^* = \frac{[2\beta-(n-1)\tilde{\beta}](H_1+\beta c_1) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} + \frac{[2\beta-(n-1)\tilde{\beta}](H_2+\beta c_2) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} +$$

$$\cdots + \frac{[2\beta-(n-1)\tilde{\beta}](H_n+\beta c_n) + \tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} = \frac{\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}} > 0 \quad \text{(A-17)}$$

Given $H_i > c_i > 0\ \forall i$ and $\beta > 0$, $H_j + \beta c_j > 0\ \forall i$, therefore, $2\beta - (n-1)\tilde{\beta} > 0$.

For each $i = 1,2, \dots, n$, their positive Nash equilibrium quantities imply:

$$\text{If}\begin{cases} q_1^* = \frac{[2\beta-(n-1)\tilde{\beta}]H_1-(\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_1+\tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}}\left(\frac{\beta}{2\beta+\tilde{\beta}}\right) > 0 \\ q_2^* = \frac{[2\beta-(n-1)\tilde{\beta}]H_2-(\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_2+\tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}}\left(\frac{\beta}{2\beta+\tilde{\beta}}\right) > 0 \\ \vdots \\ q_n^* = \frac{[2\beta-(n-1)\tilde{\beta}]H_n-(\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_n+\tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}}\left(\frac{\beta}{2\beta+\tilde{\beta}}\right) > 0 \end{cases}, \text{ then } q_1^* + q_2^* + \cdots + q_n^* > 0$$

That is:

$$q_1^* + q_2^* + \cdots + q_n^* = \frac{[2\beta-(n-1)\tilde{\beta}]H_1-(\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_1+\tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}}\left(\frac{\beta}{2\beta+\tilde{\beta}}\right) +$$
$$\frac{[2\beta-(n-1)\tilde{\beta}]H_2-(\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_2+\tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}}\left(\frac{\beta}{2\beta+\tilde{\beta}}\right) + \cdots +$$
$$\frac{[2\beta-(n-1)\tilde{\beta}]H_n-(\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]c_n+\tilde{\beta}\sum_{j=1}^{n}(H_j+\beta c_j)}{2\beta-(n-1)\tilde{\beta}}\left(\frac{\beta}{2\beta+\tilde{\beta}}\right) = \frac{\sum_{j=1}^{n}H_j+[(n-1)\tilde{\beta}-\beta]\sum_{j=1}^{n}c_j}{2\beta-(n-1)\tilde{\beta}}\beta > 0 \quad \text{(A-18)}$$

Given $2\beta-(n-1)\tilde{\beta} > 0$ from the positive prices constraint, the positive quantities suggest $\sum_{j=1}^{n}H_j + [(n-1)\tilde{\beta} - \beta]\sum_{j=1}^{n}c_j > 0$. Therefore, the assumption of strictly positive Nash equilibrium prices and quantities imply the inequalities in (A-14).

B. Model Predictions

In this section, we derive the crude oil-airfare pass-through relationship represented by the partial derivative of Nash equilibrium airfares in equation (A-8) with respect to crude oil price, and on the basis of which, we further conduct comparative statics analysis that facilitates the derivation of several propositions summarized and presented in Table 1 and Table 2 in the paper (Gayle and Lin, 2020).

Proposition 1 (Prediction #1 in Table 1 in the paper (Gayle and Lin, 2020)): crude oil-airfare pass-through relationship

The pass-through rate of airfare to changes in crude oil price level is defined as the marginal effect of crude oil price on the Nash equilibrium airfares of equation (A-8) and derived by taking partial derivative of P_i^* with respect to P_c as shown in equation (13) in the paper (Gayle and Lin, 2020):

$$\frac{\partial \boldsymbol{P_i^*}}{\partial \boldsymbol{P_c}} = \frac{[2\beta-(n-1)\tilde{\beta}]D_i+\tilde{\beta}\sum_{i=1}^{n}D_i}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}\gamma\delta_1 +$$
$$\frac{[2\beta-(n-2)\tilde{\beta}](\alpha_{3i}+D_i^c+\alpha_7 ItineraryDist_i)+\tilde{\beta}\alpha_{-3i}+\tilde{\beta}\sum_{j\neq i}^{n-1}(D_j^c+\alpha_7 ItineraryDist_j)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}\beta\phi_1 \quad \text{(B-1)}$$

where

$$\sum_{i=1}^{n} D_i = h_4 n_0 + h_5 n_1 + h_6 n_2 \tag{B-2}$$

$$\alpha_{-3i} = \sum_{j \neq i}^{n-1} \alpha_{3j} \tag{B-3}$$

Therefore, the pass-through rate of crude oil price to airfare is represented by equation (B-1), with which we derive the conditions for which the hedging parameters, α_{3i} and α_{-3i}, determine the sign of the crude oil-airfare pass-through. Holding everything else constant, we next compute the threshold conditions for α_{3i} and α_{-3i} such that airline i's pass-through rate is zero, i.e. $\frac{\partial P_i^*}{\partial P_c} = 0$.

The α_{3i} and α_{-3i} that satisfy the zero pass-through are determined by the following:

$$\left[2\beta - (n-1)\widetilde{\beta}\,\right]\alpha_{3i}^* + \tilde{\beta}\alpha_{-3i}^* =$$

$$-\frac{1}{\phi_1\beta}\begin{Bmatrix} \left[2\beta - (n-1)\widetilde{\beta}\,\right](\gamma\delta_1 D_i + \phi_1\beta D_i^c + \phi_1\beta\alpha_7 ItineraryDist_i) \\ +\gamma\delta_1\tilde{\beta}(h_4 n_0 + h_5 n_1 + h_6 n_2) + \phi_1\beta\tilde{\beta}(\alpha_4 n_0 + \alpha_5 n_1 + \alpha_6 n_2) \\ +\phi_1\beta\tilde{\beta}\alpha_7 \sum_{j=1}^{n} ItineraryDist_j \end{Bmatrix} \tag{B-4}$$

Define $\Theta(\alpha_{3i}^*, \alpha_{-3i}^*) \equiv \left[2\beta - (n-1)\widetilde{\beta}\,\right]\alpha_{3i}^* + \tilde{\beta}\alpha_{-3i}^*$. According to **Lemma 1**, $2\beta - (n-1)\widetilde{\beta} > 0$, and all other parameters in the right-hand side of equation (B-4) are positive, therefore, $\Theta(\alpha_{3i}^*, \alpha_{-3i}^*) < 0$. It is straightforward to conclude:

(*i*) $\forall i$ and values of α_{3i} and α_{-3i} such that $\left[2\beta - (n-1)\widetilde{\beta}\,\right]\alpha_{3i} + \tilde{\beta}\alpha_{-3i} > \Theta(\alpha_{3i}^*, \alpha_{-3i}^*)$, yield $\frac{\partial P_i^*}{\partial P_c} > 0$;

(*ii*) $\forall i$ and values of α_{3i} and α_{-3i} such that $\left[2\beta - (n-1)\widetilde{\beta}\,\right]\alpha_{3i} + \tilde{\beta}\alpha_{-3i} < \Theta(\alpha_{3i}^*, \alpha_{-3i}^*)$, yield $\frac{\partial P_i^*}{\partial P_c} < 0$.

The above derived conditions for α_{3i} and α_{-3i} determine the sign of the crude oil-airfare pass-through relationship, which we summarize in the following proposition:

Proposition 1: *The pass-through from crude oil price on an airline's optimal airfare can be either positive or negative, depending on the airline's and its rival airlines' fuel hedging strategies. Specifically,* *(i)* $\frac{\partial \boldsymbol{P_i^*}}{\partial \boldsymbol{P_c}} < 0$ *when airline* i *engages in jet fuel hedging contracts such that the associated hedging parameter,* α_{3i}*, satisfies:* $\alpha_{3i} < \frac{\Theta(\alpha_{3i}^*, \alpha_{-3i}^*) - \tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}$ $\forall i$*;*

(ii) $\frac{\partial \boldsymbol{P_i^*}}{\partial \boldsymbol{P_c}} > 0$ *when airline* i *commits no or little jet fuel hedging such that the associated hedging parameter,* α_{3i}*, satisfies:* $\alpha_{3i} > \frac{\Theta(\alpha_{3i}^*, \alpha_{-3i}^*) - \tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}$ $\forall i$*;*

where $\Theta(\alpha_{3i}^*, \alpha_{-3i}^*) \equiv \left[2\beta - (n-2)\tilde{\beta}\,\right]\alpha_{3i}^* + \tilde{\beta}\alpha_{-3i}^*$; and $\alpha_{3i}^*, \alpha_{-3i}^*$ *are the critical values such that the derived pass-through rate equals to zero, that is:*

$$\Theta(\alpha_{3i}^*, \alpha_{-3i}^*) = -\frac{1}{\phi_1\beta}\left\{\begin{matrix} \left[2\beta - (n-1)\tilde{\beta}\,\right](\gamma\delta_1 D_i + \phi_1\beta D_i^c + \phi_1\beta\alpha_7 ItineraryDist_i) \\ +\gamma\delta_1\tilde{\beta}(h_4 n_0 + h_5 n_1 + h_6 n_2) + \phi_1\beta\tilde{\beta}(\alpha_4 n_0 + \alpha_5 n_1 + \alpha_6 n_2) \\ +\phi_1\beta\tilde{\beta}\alpha_7\sum_{j=1}^{n} ItineraryDist_j \end{matrix}\right\}$$

Therefore, Θ *identifies a threshold of the market jet fuel hedging adoptions by airlines for making the crude oil-airfare pass-through positive or negative.*

Proposition 2 (Prediction #2 in Table 1 in the paper (Gayle and Lin, 2020)): the role of airline jet fuel hedging

One of our objectives in the paper (Gayle and Lin, 2020) is to explore the determining roles of several product-specific, firm-specific, and market-specific characteristics on the crude oil-airfare pass-through relationship. Comparative statics analysis facilitates the derivation of such predictions. To examine the impact of jet fuel hedging on the sign and magnitude of the pass-through rate, we take the partial derivative of the pass-through rate defined by equation (B-1) with respect to the hedging variable denoted by $Hedge_i$:

$$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Hedge_i} < 0 = \frac{2\beta-(n-2)\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}a_1\beta\phi_1 \qquad \text{(B-5)}$$

By **Lemma 1**, the above partial derivative is always negative, implying a negative relationship between the hedging ratio and the pass-through rate. **Proposition 2** summarizes the model predicted impact of jet fuel hedging on the pass-through rate:

Proposition 2: *The pass-through rate from changes in crude oil price to an airline's optimal fare is a decreasing function of its jet fuel hedging ratio, i.e.* $\frac{\partial\left\{\frac{\partial \boldsymbol{P_i^*}}{\partial \boldsymbol{P_c}}\right\}}{\partial \boldsymbol{Hedge_i}} < 0$ $\forall i$*. Specifically,* *(i) when airline i's hedging ratio is at a level such that* $\alpha_{3i} < \frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i}) - \tilde{\beta}\alpha_{-3i}}{2\beta - (n-2)\tilde{\beta}}$ $\forall i$, *resulting in a negative pass-through,* $\frac{\partial P^*_i}{\partial P_c} < 0$, *the pass-through rate decreases away from 0 (i.e. increasing in magnitude) as the hedging ratio increases;*

(ii) when airline i's hedging ratio is at a level such that $\alpha_{3i} > \frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i}) - \tilde{\beta}\alpha_{-3i}}{2\beta - (n-2)\tilde{\beta}}$ $\forall i$, *resulting in a positive pass-through,* $\frac{\partial P^*_i}{\partial P_c} > 0$, *the pass-through rate decreases towards 0 (i.e. decreasing in magnitude) as the hedging ratio increases.*

Proposition 2 can also be illustrated using a simple diagram, Figure B1, as follows:

Figure B1: Relationships between model-derived Pass-through Rate and Fuel Hedging Ratios

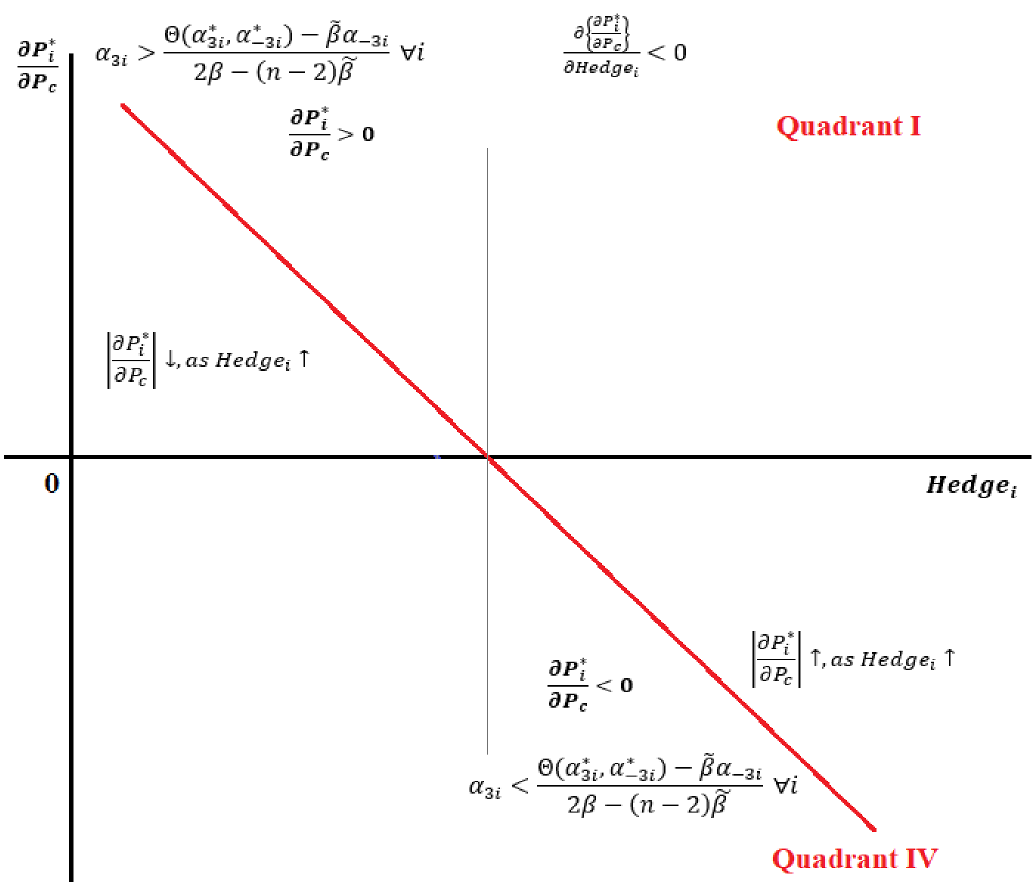

Figure B1 shows that, as fuel hedging ratio increases, the positive crude oil-airfare pass-through rate becomes less positive (decrease in absolute value) in Quadrant I. Whereas, the negative crude oil-airfare pass-through rate becomes more negative (increase in absolute value) in Quadrant IV.

Proposition 3 (Prediction #3 in Table 1 in the paper (Gayle and Lin, 2020)): the role of product itinerary distance

We take the partial derivative of pass-through equation (B-1) with respect to the air travel product's itinerary distance, denoted by $ItineraryDist_i$, to understand the role of a product's actual flying distance in determining the sign and magnitude of crude oil-airfare pass-through:

$$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial ItineraryDist_i} = \frac{2\beta-(n-2)\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}\beta\alpha_7\phi_1 \qquad \text{(B-6)}$$

By **Lemma 1**, the above partial derivative is always positive, implying a positive relationship between the itinerary travel distance and the pass-through rate. This relationship is summarized in **Proposition 3**:

Proposition 3: *The pass-through rate from changes in crude oil price to optimal airfare is an increasing function of the product's itinerary flying distance, i.e.* $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial ItineraryDist_i} > 0\ \forall i$ *. Specifically,*

(i) when airline i *'s hedging ratio is at a level such that* $\alpha_{3i} < \frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}\ \forall i$*, resulting in a negative pass-though,* $\frac{\partial P_i^*}{\partial P_c} < 0$*, the pass-through rate increases towards 0 (i.e. decreasing in magnitude) as the itinerary flying distance increases;*

(ii) when airline i *'s hedging ratio is at a level such that* $\alpha_{3i} > \frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}\ \forall i$*, resulting in a positive pass-through,* $\frac{\partial P_i^*}{\partial P_c} > 0$*, the pass-through rate increases away from 0 (i.e. increasing in magnitude) as the itinerary flying distance increases.*

Proposition 3 can also be illustrated using a simple diagram, Figure B2, as follows:

Figure B2: Relationships between model-derived Pass-through Rate and Itinerary Distance

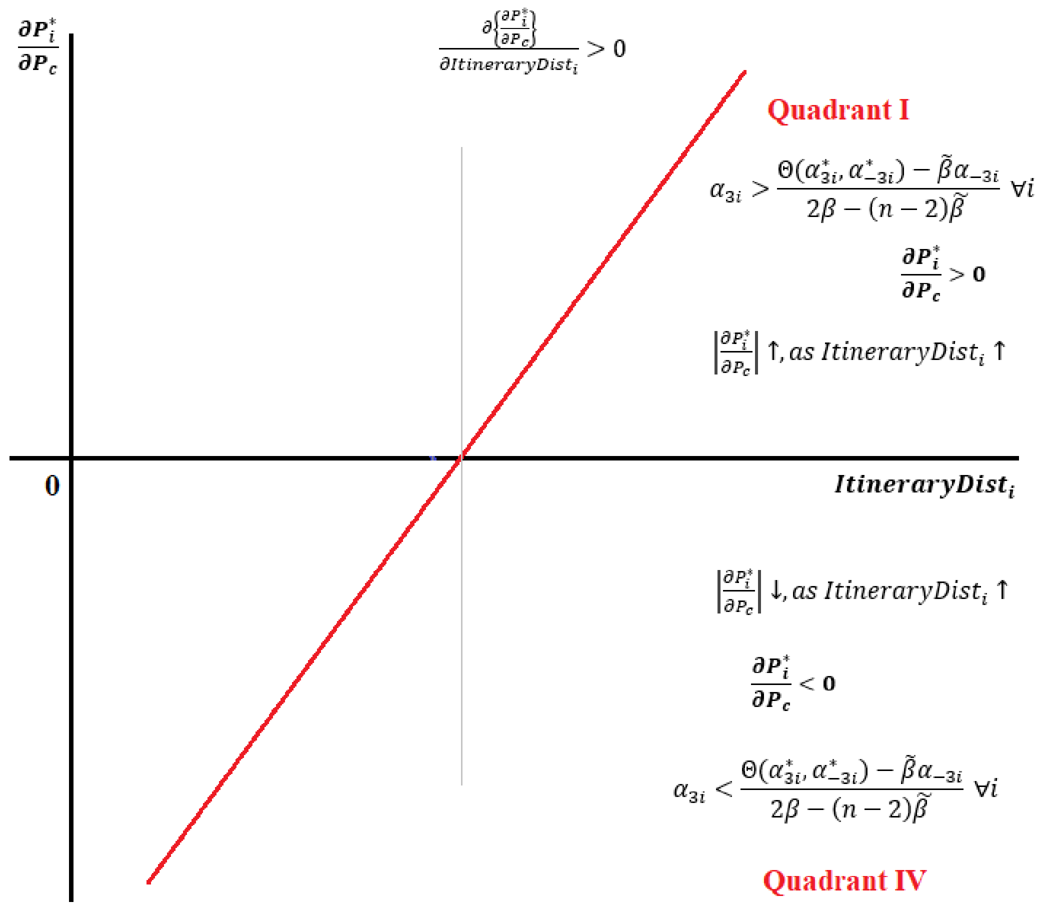

Figure B2 shows that, as a product's itinerary distance increases, the positive crude oil-airfare pass-through rate becomes more positive (increase in absolute value) in Quadrant I, whereas, the negative crude oil-airfare pass-through rate becomes less negative (decrease in absolute value) in Quadrant IV.

Proposition 4 (Prediction #4 in Table 1 in the paper (Gayle and Lin, 2020)): the role of market competition

We take the partial derivative of pass-through equation (B-1) with respect to each of the three measures of market competition, n_0, n_1, n_2, to understand the role of market competition in determining the sign and magnitude of crude oil-airfare pass-through:

$$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} = \underbrace{\frac{[2\beta-(n-1)\tilde{\beta}]h_4+\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]^2}\gamma\tilde{\beta}\delta_1}_{Demand-side\ (+)} +$$

$$\underbrace{\frac{[2\beta-(n-1)\tilde{\beta}]\alpha_4+\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2)+\tilde{\beta}\sum_{i=1}^{n}(\alpha_{3i}+\alpha_7 ItineraryDist_i)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]^2}\tilde{\beta}\beta\phi_1}_{Supply-side\ (+/-)} \quad \text{(B-7)}$$

$$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} = \underbrace{\frac{[2\beta-(n-1)\tilde{\beta}]h_5+\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]^2}\gamma\tilde{\beta}\delta_1}_{Demand-side\ (+)} +$$

$$\underbrace{\frac{[2\beta-(n-1)\tilde{\beta}]\alpha_5+\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2)+\tilde{\beta}\sum_{i=1}^{n}(\alpha_{3i}+\alpha_7 ItineraryDist_i)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]^2}\tilde{\beta}\beta\phi_1}_{Supply-side\ (+/-)} \quad \text{(B-8)}$$

$$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} = \underbrace{\frac{[2\beta-(n-1)\tilde{\beta}]h_6+\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]^2}\gamma\tilde{\beta}\delta_1}_{Demand-side\ (+)} +$$

$$\underbrace{\frac{[2\beta-(n-1)\tilde{\beta}]\alpha_6+\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2)+\tilde{\beta}\sum_{i=1}^{n}(\alpha_{3i}+\alpha_7 ItineraryDist_i)}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]^2}\tilde{\beta}\beta\phi_1}_{Supply-side\ (+/-)} \quad \text{(B-9)}$$

To determine the sign of equations (B-7), (B-8), and (B-9), we set them to zero and derive conditions for values of α_{3i} and α_{-3i} such that $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} = 0, \frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} = 0, \frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} = 0$. The conditions for values of α_{3i} and α_{-3i} such that $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} = 0, \frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} = 0, \frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} = 0$ are the following:

$$\tilde{\beta}\alpha_{3i}^0 + \tilde{\beta}\alpha_{-3i}^0 = -\frac{1}{\phi_1\beta}\left\{\begin{matrix} [2\beta-(n-1)\tilde{\beta}](\gamma\delta_1 h_4+\phi_1\beta\alpha_4) \\ +\gamma\delta_1\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)+\phi_1\beta\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2) \\ +\phi_1\beta\tilde{\beta}\alpha_7\sum_{j=1}^{n} ItineraryDist_j \end{matrix}\right\} \quad \text{(B-10)}$$

$$\tilde{\beta}\alpha_{3i}^1 + \tilde{\beta}\alpha_{-3i}^1 = -\frac{1}{\phi_1\beta}\left\{\begin{matrix} [2\beta-(n-1)\tilde{\beta}](\gamma\delta_1 h_5+\phi_1\beta\alpha_5) \\ +\gamma\delta_1\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)+\phi_1\beta\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2) \\ +\phi_1\beta\tilde{\beta}\alpha_7\sum_{j=1}^{n} ItineraryDist_j \end{matrix}\right\} \quad \text{(B-11)}$$

$$\tilde{\beta}\alpha_{3i}^2 + \tilde{\beta}\alpha_{-3i}^2 = -\frac{1}{\phi_1\beta}\left\{\begin{matrix} [2\beta-(n-1)\tilde{\beta}](\gamma\delta_1 h_6+\phi_1\beta\alpha_6) \\ +\gamma\delta_1\tilde{\beta}(h_4n_0+h_5n_1+h_6n_2)+\phi_1\beta\tilde{\beta}(\alpha_4n_0+\alpha_5n_1+\alpha_6n_2) \\ +\phi_1\beta\tilde{\beta}\alpha_7\sum_{j=1}^{n} ItineraryDist_j \end{matrix}\right\} \quad \text{(B-12)}$$

Define the following:

$$\Psi_0(\alpha_{3i}^0, \alpha_{-3i}^0) \equiv \tilde{\beta}\alpha_{3i}^0 + \tilde{\beta}\alpha_{-3i}^0 \quad \text{(B-13)}$$

$$\Psi_1(\alpha_{3i}^1, \alpha_{-3i}^1) \equiv \tilde{\beta}\alpha_{3i}^1 + \tilde{\beta}\alpha_{-3i}^1 \quad \text{(B-14)}$$

$$\Psi_2(\alpha_{3i}^2, \alpha_{-3i}^2) \equiv \tilde{\beta}\alpha_{3i}^2 + \tilde{\beta}\alpha_{-3i}^2 \quad \text{(B-15)}$$

According to **Lemma 1**, $2\beta - (n-1)\widetilde{\beta} > 0$, and all other parameters in the right-hand side of the above equations (B-10) through (B-12) are positive, therefore, $\Psi_0(\alpha_{3i}^0, \alpha_{-3i}^0) < 0$; $\Psi_1(\alpha_{3i}^1, \alpha_{-3i}^1) < 0$; and $\Psi_2(\alpha_{3i}^2, \alpha_{-3i}^2) < 0$. Therefore, it is straightforward to conclude the following:

(*i*) $\forall i$ and values of $\alpha_{3i}$and α_{-3i} such that $\tilde{\beta}\alpha_{3i} + \tilde{\beta}\alpha_{-3i} < \Psi_0(\alpha_{3i}^0, \alpha_{-3i}^0)$, yield $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} < 0$; conversely, $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}\alpha_{3i} + \tilde{\beta}\alpha_{-3i} > \Psi_0(\alpha_{3i}^0, \alpha_{-3i}^0)$, yield $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} > 0$.

(*ii*) $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}\alpha_{3i} + \tilde{\beta}\alpha_{-3i} < \Psi_1(\alpha_{3i}^1, \alpha_{-3i}^1)$, yield $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} < 0$; conversely, $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}\alpha_{3i} + \tilde{\beta}\alpha_{-3i} > \Psi_1(\alpha_{3i}^1, \alpha_{-3i}^1)$, yield $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} > 0$.

(*iii*) $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}\alpha_{3i} + \tilde{\beta}\alpha_{-3i} < \Psi_2(\alpha_{3i}^2, \alpha_{-3i}^2)$, yield $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} < 0$; conversely, $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}\alpha_{3i} + \tilde{\beta}\alpha_{-3i} > \Psi_2(\alpha_{3i}^2, \alpha_{-3i}^2)$, yield $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} > 0$.

Given the above relationships along with findings in **Proposition 1**, Table B1 summarizes the impact of market competition on the pass-through rate:

Table B1: The Impact of Market Competition on the Pass-through Rate[1]

	Outcomes	**Parameter Restrictions**
$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0}$	$\frac{\partial P_i^*}{\partial P_c} < 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} < 0$	**(1.1)** $\alpha_{3i} < \min\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_0(\alpha_{3i}^0,\alpha_{-3i}^0)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} < 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} > 0$	**(1.2)** $\min\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_0(\alpha_{3i}^0,\alpha_{-3i}^0)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\} < \alpha_{3i} <$ $\max\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_0(\alpha_{3i}^0,\alpha_{-3i}^0)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} > 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} > 0$	**(1.3)** $\alpha_{3i} > \max\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_0(\alpha_{3i}^0,\alpha_{-3i}^0)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1}$	$\frac{\partial P_i^*}{\partial P_c} < 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} < 0$	**(2.1)** $\alpha_{3i} < \min\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_1(\alpha_{3i}^1,\alpha_{-3i}^1)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} < 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} > 0$	**(2.2)** $\min\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_1(\alpha_{3i}^1,\alpha_{-3i}^1)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\} < \alpha_{3i} <$ $\max\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_1(\alpha_{3i}^1,\alpha_{-3i}^1)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} > 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} > 0$	**(2.3)** $\alpha_{3i} > \max\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_1(\alpha_{3i}^1,\alpha_{-3i}^1)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2}$	$\frac{\partial P_i^*}{\partial P_c} < 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} < 0$	**(3.1)** $\alpha_{3i} < \min\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_2(\alpha_{3i}^2,\alpha_{-3i}^2)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} < 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} > 0$	**(3.2)** $\min\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_2(\alpha_{3i}^2,\alpha_{-3i}^2)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\} < \alpha_{3i} <$ $\max\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_2(\alpha_{3i}^2,\alpha_{-3i}^2)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} > 0$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} > 0$	**(3.3)** $\alpha_{3i} > \max\left\{\frac{\Theta(\alpha_{3i}^*,\alpha_{-3i}^*)-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}}, \frac{\Psi_2(\alpha_{3i}^2,\alpha_{-3i}^2)-\tilde{\beta}\alpha_{-3i}}{\tilde{\beta}}\right\}$

From Table B1, $(\alpha_{3i}^0, \alpha_{-3i}^0)$, $(\alpha_{3i}^1, \alpha_{-3i}^1)$, $(\alpha_{3i}^2, \alpha_{-3i}^2)$ represent the critical values such that $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0} = 0$, $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1} = 0$, $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2} = 0$, respectively. Therefore, $\Psi_0(\alpha_{3i}^0, \alpha_{-3i}^0)$, $\Psi_1(\alpha_{3i}^1, \alpha_{-3i}^1)$ and $\Psi_2(\alpha_{3i}^2, \alpha_{-3i}^2)$ identify the thresholds of fuel hedging adoptions by airlines that determines whether the marginal impact of market competition intensity on the crude oil-airfare pass-through rate is positive or

[1] For conditions (1.2), (2.2) and (3.2), we find the signs of $\frac{\partial P_i^*}{\partial P_c}$ and its partial derivatives with respect to n_0, n_1, n_2, respectively, are opposite with two possibilities; however, assuming the pass-through equation to be a continuous and differentiable function with respect to n_0, n_1, n_2, the only possibility is $\frac{\partial P_i^*}{\partial P_c} < 0$ and the relevant partial derivatives are positive, as shown in the table.

negative. Guided by parameter restrictions and associated outcomes reported in Table B1, we summarize the impact of market competition on the pass-through rate in **Proposition 4**:

Proposition 4: *The pass-through from changes in crude oil price to an air travel product's equilibrium airfare can be positively or negatively influenced by the intensity of market competition, depending on the airline's and its rival airlines' fuel hedging strategies:*

(i) when airline i's hedging ratio is at a level satisfying parameter restrictions (1.1), (2.1), or (3.1) in Table B1, there is a negative pass-though; and the negative pass-through rate decreases away from 0 (i.e. increasing in magnitude) with the number of competing products that have the same number of intermediate stops offered in the market. The total effect is negative with the supply-side effect being negative and dominating the positive demand-side effect.

(ii) when airline i's hedging ratio is at a level satisfying parameter restrictions (1.2), (2.2), or (3.2) in Table B1, there is a negative pass-through; and the negative pass-through rate increases towards 0 (i.e. decreasing in magnitude) with the number of competing products that have the same number of intermediate stops offered in the market. The total effect is positive.

(iii) when airline i's hedging ratio is at a level satisfying parameter restrictions (1.3), (2.3), or (3.3) in Table B1, there is a positive pass-through; and the positive pass-through rate increases away from 0 (i.e. increasing in magnitude) with the number of competing products that have the same number of intermediate stops offered in the market. The total effect is positive.

Using $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_0}$ in equation (B-7) as an example, the impact of market competition measured by n_0 on the pass-through in **Proposition 4** can be illustrated using a simple diagram, Figure B3, as follows:

Figure B3: Relationships between model-derived Pass-through Rate and Market Competitiveness

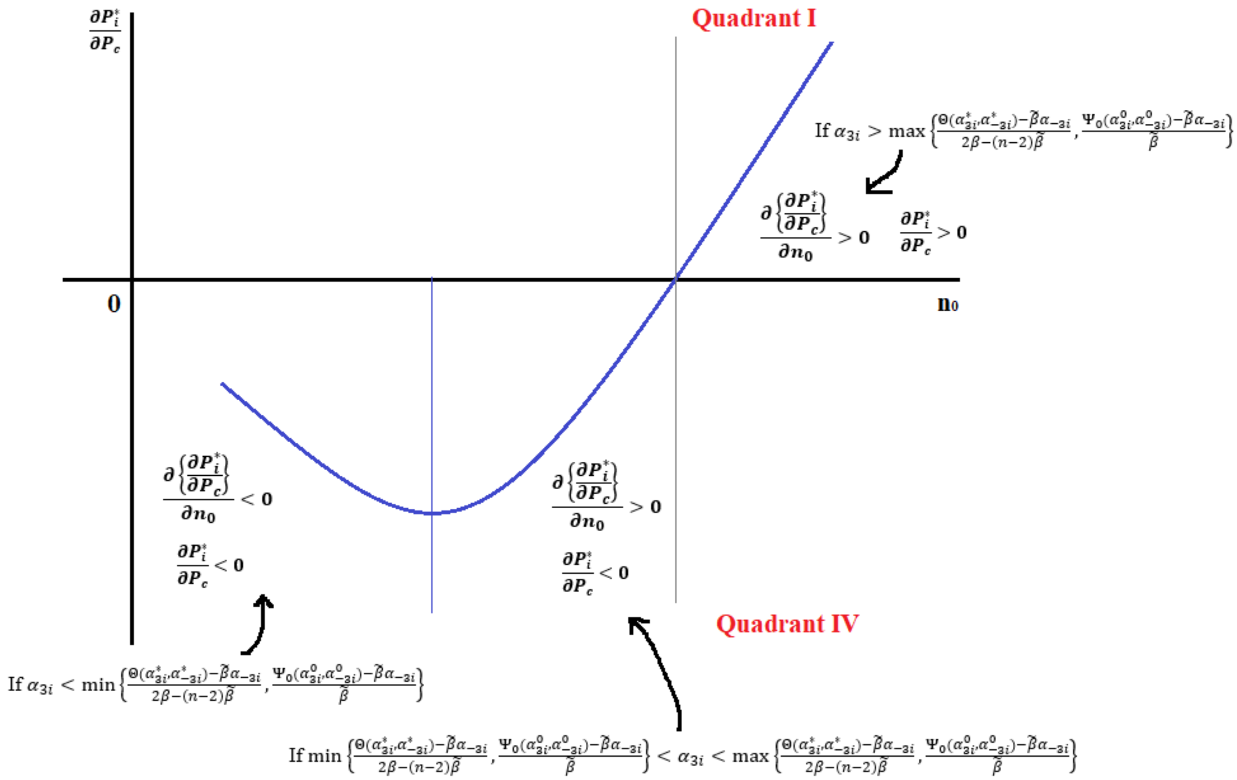

Figure B3 shows that, there is a non-linear relationship between the level of market competition measured by the total number of non-stop products competing in an origin-destination market and the pass-through rate, depending on airlines' adoption of fuel hedging strategies. The above non-linear relationship also applies to $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_1}$ and $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial n_2}$. The relationship between the crude oil-airfare pass-through and market competition illustrated above implies that an additional air travel product offered in the market can have either an upward or a downward pressure on the air travel product's pass-through rate, depending on airlines' hedging ratios, *ceteris paribus*.

Proposition 5 (Table 2 in the paper (Gayle and Lin, 2020)): the role of origin-destination market distance

We take the partial derivative of pass-through equation (B-1) with respect to the origin-destination market distance denoted by Mkt_Dist, to understand the role of market distance in determining the sign and magnitude of crude oil-airfare pass-through:

$$\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist} = \underbrace{\left(\frac{h_4 n_0+h_5 n_1+h_6 n_2}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]}\tilde{\beta} + \frac{D_i}{2\beta+\tilde{\beta}}\right)(\gamma_1 + 2\gamma_2 Mkt\_Dist)\delta_1}_{\text{"Level Effect"}\left(+\text{ if } Mkt\_Dist\in\left(0,-\frac{\gamma_1}{2\gamma_2}\right);\,-\text{ if } Mkt\_Dist\in\left(-\frac{\gamma_1}{2\gamma_2},-\frac{\gamma_1}{\gamma_2}\right]\right)} +$$

$$\underbrace{\left\{\begin{array}{l} 2\gamma\beta\beta_0\delta_1\left(\frac{\tilde{\beta}[4\beta-(n-2)\tilde{\beta}](h_4 n_0+h_5 n_1+h_6 n_2)}{(2\beta+\tilde{\beta})^2[2\beta-(n-1)\tilde{\beta}]^2} + \frac{D_i}{(2\beta+\tilde{\beta})^2}\right) \\ +\tilde{\beta}^2\beta\beta_0\phi_1\frac{(n-1)[4\beta-(n-2)\tilde{\beta}](\alpha_{3i}+D_i^c+\alpha_7 ItineraryDist_i)}{(2\beta+\tilde{\beta})^2[2\beta-(n-1)\tilde{\beta}]^2} \\ +\tilde{\beta}\beta\beta_0\phi_1\frac{[4\beta^2+(n-1)\tilde{\beta}^2]\sum_{j\neq i}^{n-1}(\alpha_{3j}+D_j^c+\alpha_7 ItineraryDist_j)}{(2\beta+\tilde{\beta})^2[2\beta-(n-1)\tilde{\beta}]^2} \end{array}\right\}}_{\text{"Elasticity Effect" }(+/-)} \quad \text{(B-16)}$$

In the above partial derivative, the sign of the "*level effect*" depends on the first derivative of the quadratic function of $\gamma = \gamma_1 Mkt\_Dist + \gamma_2 Mkt\_Dist^2$ as shown by equation (4) in the paper (Gayle and Lin, 2020), which yields the following:

(*i*) If $Mkt\_Dist \in \left(0, -\frac{\gamma_1}{2\gamma_2}\right)$, there is a positive "*level effect*";

(*ii*) If $Mkt\_Dist \in (-\frac{\gamma_1}{2\gamma_2}, -\frac{\gamma_1}{\gamma_2}]$, there is a negative "*level effect*".

The sign of the "*elasticity effect*" depends on airlines' hedging parameters, α_{3i} and α_{-3i}. To determine the sign of the "*elasticity effect*", we set it to zero and derive the condition on values of α_{3i} and α_{-3i}. As such, we have the following:

$$2\gamma\beta\beta_0\delta_1\left(\frac{\tilde{\beta}[4\beta-(n-2)\tilde{\beta}](h_4 n_0+h_5 n_1+h_6 n_2)}{(2\beta+\tilde{\beta})^2[2\beta-(n-1)\tilde{\beta}]^2} + \frac{D_i}{(2\beta+\tilde{\beta})^2}\right) +$$

$$\tilde{\beta}^2\beta\beta_0\phi_1\frac{(n-1)[4\beta-(n-2)\tilde{\beta}](\alpha_{3i}+D_i^c+\alpha_7 ItineraryDist_i)}{(2\beta+\tilde{\beta})^2[2\beta-(n-1)\tilde{\beta}]^2} +$$

$$\tilde{\beta}\beta\beta_0\phi_1\frac{[4\beta^2+(n-1)\tilde{\beta}^2]\sum_{j\neq i}^{n-1}(\alpha_{3j}+D_j^c+\alpha_7 ItineraryDist_j)}{(2\beta+\tilde{\beta})^2[2\beta-(n-1)\tilde{\beta}]^2} = 0 \quad \text{(B-17)}$$

Appropriately rearranging equation B-17 yields:

$$\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]\alpha'_{3i} + [4\beta^2+(n-1)\tilde{\beta}^2]\alpha'_{-3i} =$$

$$-\frac{1}{\phi_1\tilde{\beta}}\left\{\begin{array}{c} 2\gamma\delta_1[2\beta-(n-1)\tilde{\beta}]^2 D_i + 2\gamma\delta_1\tilde{\beta}[4\beta-(n-2)\tilde{\beta}](h_4 n_0+h_5 n_1+h_6 n_2) \\ +\phi_1\tilde{\beta}^2(n-1)[4\beta-(n-2)\tilde{\beta}](D_i^c+\alpha_7 ItineraryDist_i) \\ +\phi_1\tilde{\beta}[4\beta^2+(n-1)\tilde{\beta}^2]\sum_{j\neq i}^{n-1}(D_j^c+\alpha_7 ItineraryDist_j) \end{array}\right\} \quad \text{(B-18)}$$

Then define $\Lambda(\alpha'_{3i}, \alpha'_{-3i}) \equiv \tilde{\beta}(n-1)\left[4\beta-(n-2)\tilde{\beta}\right]\alpha'_{3i} + \left[4\beta^2+(n-1)\tilde{\beta}^2\right]\alpha'_{-3i}$. According to **Lemma 1**, $2\beta-(n-1)\tilde{\beta} > 0$, and the fact that all other parameters of the right-hand side of equation (B-18) are positive, therefore, $\Lambda(\alpha'_{3i}, \alpha'_{-3i}) < 0$.

It is straightforward to conclude the following:

(*i*) $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}(n-1)\left[4\beta-(n-2)\tilde{\beta}\right]\alpha_{3i} + \left[4\beta^2+(n-1)\tilde{\beta}^2\right]\alpha_{-3i} < \Lambda(\alpha'_{3i}, \alpha'_{-3i})$, yield a negative "*elasticity effect*";

(*ii*) $\forall i$ and values of α_{3i} and α_{-3i} such that $\tilde{\beta}(n-1)\left[4\beta-(n-2)\tilde{\beta}\right]\alpha_{3i} + \left[4\beta^2+(n-1)\tilde{\beta}^2\right]\alpha_{-3i} > \Lambda(\alpha'_{3i}, \alpha'_{-3i})$, yield a positive "*elasticity effect*".

Given the above relationships along with findings in **Proposition 1**, Table B2 summarizes the impact of market distance on the pass-through rate:

Table B2: The Impact of Market Distance on the Pass-through Rate[2]

	Outcomes	Parameter Restrictions
$\boldsymbol{Mkt\_Dist} \in \left(\mathbf{0}, -\frac{\boldsymbol{\gamma_1}}{\mathbf{2}\boldsymbol{\gamma_2}}\right)$	$\frac{\partial P_i^*}{\partial P_c} < 0$ Level Effect> 0; Elasticity Effect< 0 $\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist}$ either $(+/-)$	**(1.1)** $\alpha_{3i} < \min\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} < 0$ Level Effect> 0; Elasticity Effect> 0 $\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist} > 0$	**(1.2)** $\min\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\} <$ $\alpha_{3i} < \max\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} > 0$ Level Effect> 0; Elasticity Effect> 0 $\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist} > 0$	**(1.3)** $\alpha_{3i} > \max\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\}$
$\boldsymbol{Mkt\_Dist} \in (-\frac{\boldsymbol{\gamma_1}}{\mathbf{2}\boldsymbol{\gamma_2}}, -\frac{\boldsymbol{\gamma_1}}{\boldsymbol{\gamma_2}}]$	$\frac{\partial P_i^*}{\partial P_c} < 0$ Level Effect< 0; Elasticity Effect< 0 $\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist} < 0$	**(2.1)** $\alpha_{3i} < \min\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} < 0$ Level Effect< 0; Elasticity Effect> 0 $\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist}$ either $(+/-)$	**(2.2)** $\min\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\} <$ $\alpha_{3i} < \max\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\}$
	$\frac{\partial P_i^*}{\partial P_c} > 0$ Level Effect< 0; Elasticity Effect> 0 $\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Mkt\_Dist}$ either $(+/-)$	**(2.3)** $\alpha_{3i} > \max\left\{\frac{\Theta(\alpha^*_{3i},\alpha^*_{-3i})-\tilde{\beta}\alpha_{-3i}}{2\beta-(n-2)\tilde{\beta}},\frac{\Lambda(\alpha'_{3i},\alpha'_{-3i})-[4\beta^2+(n-1)\tilde{\beta}^2]\alpha_{-3i}}{\tilde{\beta}(n-1)[4\beta-(n-2)\tilde{\beta}]}\right\}$

[2] For conditions (1.2) and (2.2), we find the signs of $\frac{\partial P_i^*}{\partial P_c}$ and its partial derivatives with respect to market distance are opposite with two possibilities; however, assuming the pass-through equation to be a continuous and differentiable function with respect to market distance, the only possibility is $\frac{\partial P_i^*}{\partial P_c} < 0$ and the relevant partial derivatives are positive, as shown in the table.

From Table B2, $\alpha'_{3i}, \alpha'_{-3i}$ are the critical values such that the "*elasticity effect*" is zero. Therefore, $\Lambda(\alpha'_{3i}, \alpha'_{-3i})$ identifies the threshold of fuel hedging adoptions by airlines that determines whether the "*elasticity effect*" portion of the marginal impact of market distance on the crude oil-airfare pass-through rate is positive or negative.

Based on parameter restrictions and associated outcomes reported in Table B2, we summarize the impact of market distance on the crude oil-airfare pass-through rate in **Proposition 5**:

Proposition 5: *The impact of market distance between the origin and destination on the pass-through from changes in crude oil price to airfare is governed by two effects: "level effect" and "elasticity effect". Furthermore, the "elasticity effect" depends crucially on consumers' differing sensitivities to changes in airfare across markets of differing distances, as well as the airline's and its rival airlines' fuel hedging strategies:*

(i) when $Mkt\_Dist \in \left(0, -\frac{\gamma_1}{2\gamma_2}\right)$ *and airline* i*'s hedging ratio is at a level satisfying (1.1) in Table B2, a positive "level effect" counters a negative "elasticity effect", and the overall impact of market distance on the negative pass-through rate depends on the relative strengths of the two countervailing effects;*

(ii) when $Mkt\_Dist \in \left(0, -\frac{\gamma_1}{2\gamma_2}\right)$ *and airline* i*'s hedging ratio is at a level satisfying (1.2) in Table B2, a positive "level effect" reinforces a positive "elasticity effect", strengthening the overall positive impact of market distance on the negative pass-through rate. Specifically, the negative pass-through rate increases toward 0 (i.e. decreasing in magnitude) with longer market distances;*

(iii) when $Mkt\_Dist \in \left(0, -\frac{\gamma_1}{2\gamma_2}\right)$ *and airline* i*'s hedging ratio is at a level satisfying (1.3) in Table B2, a positive "level effect" reinforces a positive "elasticity effect", strengthening the overall positive impact of market distance on the positive pass-through rate. Specifically, the positive pass-through rate increases away from 0 (i.e. increasing in magnitude) with longer market distances;*

(iv) when $Mkt\_Dist \in (-\frac{\gamma_1}{2\gamma_2}, -\frac{\gamma_1}{\gamma_2}]$ *and airline* i*'s hedging ratio is at a level satisfying (2.1) in Table B2, a negative "level effect" reinforces a negative "elasticity effect",*

strengthening the overall negative impact of market distance on the negative pass-through rate. Specifically, the negative pass-through rate further decreases away from 0 (i.e. increasing in magnitude) with longer market distances;

(v) when $Mkt\_Dist \in (-\frac{\gamma_1}{2\gamma_2}, -\frac{\gamma_1}{\gamma_2}]$ *and airline* i*'s hedging ratio is at a level satisfying (2.2) in Table B2, a negative "level effect" counters a positive "elasticity effect", the overall impact of market distance on the negative pass-through rate depends on the relative strengths of the two countervailing effects;*

(vi) when $Mkt\_Dist \in (-\frac{\gamma_1}{2\gamma_2}, -\frac{\gamma_1}{\gamma_2}]$ *and airline* i*'s hedging ratio is at a level satisfying (2.3) in Table B2, a negative "level effect" counters a positive "elasticity effect", the overall impact of market distance on the positive pass-through rate depends on the relative strengths of the two countervailing effects.*

References

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