Cost Pass-Through in Commercial Aviation

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Abstract

The significant decline in crude oil price worldwide since the mid-2014 directly resulted in substantial fuel expenses reduction for US airlines; whereas whether an average passenger benefit from airlines’ fuel costs savings has caused much public debate. This paper aims to investigate the market mechanisms through which crude oil price influences airfare as well as factors that may influence the extent to which crude oil price changes affect airfare. We rely on a simple theoretical model of air travel demand following Shubik-Levitan demand formulation and Bertrand type supply to study the market channels through which changes in crude oil price may be reflected in airfares. The simple theoretical model yields clear predictions on the relationship between crude oil price and airfare, as well as reveal factors that may influence the strength of this relationship. Guided by the theoretical model, we subsequently compile a dataset given by the Department of Transportation DB1B databank, then use a simple reduced-form regression analysis to empirically test predictions from the theoretical model. Our empirical results reveal that there is a positive pass-through from changes in crude oil price to airfare, suggesting that a given percentage change in crude oil price translates into a certain percentage change in airfare even if the size of pass-through is relatively small. Furthermore, we find that the pass-through rate depends on several market characteristics. In particular, the magnitude of the pass-through tends to be greater in more competitive markets and it is likely to be smaller in longer distance markets, ceteris paribus.

Keywords: Cost pass-through; Airlines competition

JEL Classification Codes: L93; L13

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1. Introduction

Brent Crude, the energy price index that many airline executives monitor, serves as an important instrument for these executives to predict future fuel costs for their airline because: (i) the index captures price movements of a key component of jet fuel; and (ii) the index is normally highly correlated with prices of its refinery products.\(^1\) Crude oil price has declined from $111.8/barrel in June 2014 to $38.01/barrel in December 2015, an approximate 66% reduction.\(^2\) Consistent with the decline in crude oil price, financial information reported by the four major US airlines, American, Delta, United and Southwest, in their 10-K filings documented to US Securities and Exchange Commission (SEC) shows that all four major airlines experienced a significant decline in their fuel expenses from 2014 to 2015 (see Table 1). For example, American and Delta Airlines reported more than 40% saving in fuel costs, while United and Southwest had over 30% reduction in fuel expenses during this period.\(^3\) In spite of fuel cost savings, industry analysts have pointed out that airfares have been “essentially stable during this period”.\(^4\) Airline price data released by the Bureau of Labor and Statistics (BLS) showed that the monthly average airfare decreased by less than 5%,\(^5\) which is quite trivial compared with the size of reduction in crude oil price as well as jet fuel price over this time period.

\(^1\) The Financial Accounting Standards Board (FASB) Statement 133 requires a hedge must be shown to be highly effective to corporations. A hedge is deemed effective if the ratio of the change in value of the derivative (e.g. crude oil) to that of the hedged item (e.g. jet fuel) falls between 80% and 125%, i.e. “80/125 rule”. Southwest (and many other air carriers) relies on crude oil and/or its refinery products to hedge against the risk of fuel costs fluctuations due to jet fuel price changes.

\(^2\) Oil price is represented by Brent crude oil spot price from Energy Information Administration (EIA): https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=rbrte&f=m.

\(^3\) There are extensive studies that investigate the relationship between crude oil price and prices of its refinery petroleum products. For example, Asche et al (2003) applied multivariate analysis in oil industry in northern Europe and found evidence that prices of crude oil, gasoline and kerosene fuel are proportional with constant spreads. They further pointed out that refinery petroleum industry is an example of “supply driven market integration”. Li (2010) also provided strong evidence that jet fuel price adjusts towards the long-run co-integration with crude oil price.


Table 1: Fuel Expense (% of Operating Expenses) for 4 Major US Airlines

<table>
<thead>
<tr>
<th>Year</th>
<th>American</th>
<th>Delta</th>
<th>United</th>
<th>Southwest</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>35.4%</td>
<td>33.3%</td>
<td>34%</td>
<td>35.1%</td>
</tr>
<tr>
<td>2014</td>
<td>33.2%</td>
<td>35.4%</td>
<td>32%</td>
<td>32.3%</td>
</tr>
<tr>
<td>2015</td>
<td>21.6%</td>
<td>23%</td>
<td>23%</td>
<td>23%</td>
</tr>
</tbody>
</table>

2014-2015 Fuel Expense % Change

<table>
<thead>
<tr>
<th></th>
<th>American</th>
<th>Delta</th>
<th>United</th>
<th>Southwest</th>
</tr>
</thead>
<tbody>
<tr>
<td>-41.2%</td>
<td>-43.9%</td>
<td>-36%</td>
<td>-31.7%</td>
<td></td>
</tr>
</tbody>
</table>

Source: Airlines’ SEC 10-K filings.

To obtain a better picture of how market airfare responded to crude oil and jet fuel prices during this time period, we plot the quarterly percentage change of crude oil price, jet fuel price and industry average airfare from the third quarter of 2013 to the fourth quarter of 2015 in Figure 1. In this price series plot, a notably positive relationship is evident between crude oil price and jet fuel price over the sample period. It is noticeable that crude oil and jet fuel prices start to decline dramatically in mid-2014, whereas industry average airfare shows little or no co-movement with the energy prices during this period. This simple plot suggests that airline fuel cost savings has little or no pass-through to airfare. However, one may argue that an industry average airfare may not be reflective of how air carriers adjust airfare in response to their fuel cost changes. It is possible that airfare tracks crude oil and jet fuel prices better in some air travel markets than others. As such, we select two distinct markets: OAK (Oakland, CA) to GEG (Spokane, WA) and SYR (Syracuse, NY) to PHX (Phoenix, AZ) and plot in the upper panel of Figure 2 the quarterly percentage change of crude oil price, jet fuel price and average airfare in the two markets. Both markets are similar with respect to the number of airlines that compete in the market; specifically, each of the two markets has three competing airlines. However, the two markets differ substantially with respect to travel distance; in particular, OAK-GEG has non-stop flight distance of 723 miles, while SYR-PHX has non-stop flight distance of 2045 miles. In upper panel of Figure 2 it is noticeable that changes in average fare in the OAK-GEG market intimately follows changes in energy prices. However, in the SYR-PHX market, changes in average fare often moves in an opposite direction to changes in energy prices, and the opposite movement becomes more prominent from the third quarter of 2014. In summary,

8 The two markets are chosen to illustrate how airfare may respond differently to energy prices across markets with distinct characteristics.
controlling for the number of competing carriers, the price change plots in the upper panel of Figure 2 suggest that fuel cost pass-through to airfare tends to be larger in the shorter distance market (OAK - GEG) compared to the long distance market (SYR - PHX).

The lower panel of Figure 2 plots quarterly percentage changes in crude oil price, jet fuel price and average airfare in two markets: OAK (Oakland, CA) to GEG (Spokane, WA) and BWI (Baltimore, MD) to MLB (Melbourne, FL). The BWI - MLB has non-stop flight distance of 797 miles, which is comparable to the nonstop flight distance in the OAK - GEG market of 723 miles. However, BWI - MLB is a monopoly market served only by Delta Airlines with one-stop connection flight, whereas OAK - GEG is a market served by three airlines offering multiple competing products. As such, it is reasonable to conjecture that the OAK - GEG market is more competitive than the BWI - MLB market. In the lower panel of Figure 2, while changes in average fare in the OAK - GEG market intimately follows the energy prices change, there is little or no co-movement of changes in airfare and changes in energy prices for the BWI - MLB market. In summary, controlling for market travel distance, the price change plots in the lower panel of Figure 2 suggest that fuel cost pass-through to airfare tends to be larger in the more competitive market (OAK - GEG) compared to the monopoly market (BWI - MLB).

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9 In the OAK-GEG market, Delta and Alaska Airlines consistently provided one-stop connection flights, while Southwest Airlines consistently offered non-stop flights across the whole sample period. In the fourth quarter of 2013 and second quarter of 2014, Southwest exceptionally served two-stop connection flights together with non-stop service.
Figure 1: Energy Prices and Average Airfare across all US Domestic Air Travel Markets

Figure 2: Energy Prices and Airfare in select US Domestic Air Travel Markets
The above observations raise two interesting questions that this paper seeks to answer: (i) what are the market mechanisms through which crude oil price influences airfare?; and (ii) what are the possible factors that may influence the extent to which crude oil price changes affect airfare? To achieve this goal, we first specify a simple theoretical model of air travel demand and supply in an origin-destination market. We rely on this simple theoretical model to study market channels through which changes in crude oil price may be reflected in airfare. The simple theoretical model yields clear predictions on the relationship between crude oil price and airfare, as well as reveal factors that may influence the strength of the relationship. With the theoretical model as a guiding framework, we subsequently compile a data set on information drawn from US domestic air travel markets, then use reduced-form regression analysis to empirically test predictions from the theoretical model.

Key results from the analysis are as follows. First, our theoretical model predicts that there is a positive pass-through (also referred as “price transmission”\(^{10}\)) from crude oil price changes to airfare and the magnitude of this effect, i.e. the “pass-through rate”, depends on several market characteristics. One such market characteristic is the extent of market competition among air carriers. Our theoretical model predicts that the size of pass-through becomes larger when markets are more competitive. Another market characteristic that also plays a role in affecting the size of pass-through is the distance between origin and destination. Consistent with what our theoretical model predicts, our empirical results reveal that there is a positive marginal effect of crude oil price on airfare in US domestic air travel markets. Specifically, we find that for a 10% increase in crude oil price, airfare tends to increase by 0.61% to 0.77% on average. The magnitude of the pass-through rate estimate depends on the competitiveness of the relevant US domestic air travel market. In particular, the pass-through rate tends to be greater in more competitive markets. The empirical results also suggest that the pass-through rate is smaller in longer distance markets.

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\(^{10}\) This term “price transmission” has been used interchangeably with “cost pass-through” in many empirical work that studies the cost-price pass-through relationship in a variety of markets, such as Azzam (1999), Gomez and Koerner (2002), Aguiar and Santana (2002), Krivonos (2004), Frey and Manera (2005), Leibtag et. al. (2007), and Bonnet and Villas-Boas (2016) and many others. However, these studies focus on the asymmetric patterns of cost-price pass-through in their markets of interest, which is not our focus in this paper.
The paper proceeds as follows. In the next section we briefly review the relevant literature. In section 3 we specify and analyze a simple theoretical model of air travel demand and supply in an origin-destination market. Section 4 describes the data used for empirical analysis. Guided by the theoretical analysis, in section 5 we specify, estimate and discuss results from reduced-form regression equations. Concluding remarks are gathered in section 6.

2. Related Literature

Empirical studies that focus on the cost-price pass-through relationship have been done on various industries. In energy sector, Alexeeva-Talebi (2011) examines the impact of introducing the EU Emissions Trading Scheme (ETS) on the unleaded petrol retail prices in 14 EU Member States. In retail food industry, Berck et al (2009) studies the pass-through from price shocks of certain raw commodities (corn, wheat, and gasoline) to supermarket retail prices of ready-to-eat cereals and fresh chicken. Kim and Cotterill (2008) estimates the pass-through rate of increases in milk prices to cheese prices. Bonnet and Villas-Boas (2016) focus on French coffee market and studies the asymmetric pass-through patterns of retail coffee prices in respond to upstream cost shocks. In automobile industry, Gron and Swenson (2000) investigates how exchange rate changes influence the manufacturers’ input market decisions and the importance of accounting for this impact on the estimated pass-through rate as a result of exchange rate changes. Hellerstein and Villas-Boas (2010) studies the relationship between a firm’s degree of vertical integration along the supply chain and its pass-through of exchange-rate-induced cost shocks to the retail prices in the US auto industry.

In airline industry, airline cost structure has been well explored by a considerable number of studies. However, there has been a paucity of studies that focus on the cost-price pass-through relationship. A subset of these airline industry studies are purely

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11 Hirsch (2006) and Neven, Roller, and Zhang (2006) focus on airline labor input and show that labor cost should be endogenous to airline profits as airlines and unions both exhibit some bargaining power in terms of airline workers wage level. Ryerson and Hansen (2013) examine how jet fuel price influences aircraft operating costs using two types of operating cost models and find that fuel price plays a large role in airlines’ decision on choosing the optimal aircraft size in order to minimize operating cost per seat mile. Windle (1991), Zuidberg (2014) and Bitzan and Peoples (2016) also find the positive impact of jet fuel price on airline operating cost.
theoretical analyses, and examine the impact of cost-side shocks to airfare, product quality, airline performance and other market outcome variables. Forsyth (2008) studies the impact of climate change policies, such as carbon taxes or carbon emission permits (referred to as an increase in “effective price of fuel”\textsuperscript{12}) on competition, airfare, and profitability. The author finds the impact differs by market structure. The relevant metric of market structure being whether the airline city pair market is competitive, monopolistic or oligopolistic. The author also argues that airlines are unlikely to be able to pass on the full cost change to airfare in the short run, though in the long run, it is likely that airlines will exit from some city pairs, and this will enable the remaining airlines to raise their fares and restore their profitability. Using a theoretical model, Brueckner and Zhang (2010) examines the effect of airline emission charges on airfare, airline service quality and network structure. They find that an increase in spot market fuel prices, or an equivalent imposition of airline emission charges, will lead to a higher airfare, lower flight frequency, higher load factor, and more fuel-efficient aircraft.

Empirical studies such as Malina et al. (2012), evaluate the economic impact of European Emission Trading Scheme (ETS) on US airlines. They find the impact to be relatively small. The rationale posited is that US airlines may not pass through to airfare the full cost of emission charge since the imperfectly competitive market structure facilitates airlines with market power to absorb part of the cost increase. Koopmans and Lieshout (2016) attempt to identify the most likely pass-through rates for aviation markets for different countries based on previous theoretical findings of pass-through rate in various market settings.\textsuperscript{13} They compute concentration level (measured by Herfindahl-

\textsuperscript{12} Many studies that are conducted with respect to the economic effects of the introduction of European Emission Trading Scheme (ETS) in aviation sector adopt the similar idea, i.e. either increasing spot market jet fuel prices, a carbon-tax scheme or carbon emission permits charge is effectively viewed as equivalent to an increase in jet fuel prices paid by airlines. These studies include but not limited to Forsyth (2008), Brueckner and Zhang (2010), Toru (2011), Malina et al. (2012), Brueckner and Abreu (2016).

\textsuperscript{13} Bulow and Pfeiferer (1983) compute the pass-through rates in a perfect competitive environment and in monopolistic market. They find that an industry-wide cost change will be completely passed along to consumers in a perfect competitive market. A monopolist with a constant marginal cost will pass through 50 percent of a marginal cost change to market price when facing a linear demand. Zimmerman and Carlson (2010) focus on analyzing the role of product differentiation on firm-specific and industry-wide pass-through rates. They find disparate pass-through across the Cournot and Bertrand models. In differentiated oligopoly markets with Cournot type, firm-specific pass-through rates are between 20 percent and 50 percent and sector-wide pass-through rates are greater than the above range. Whereas in Bertrand type market structure, firm-specific pass-through rates are less than 50 percent while greater than 50 percent for sector-wide cost shocks.
Hirschman Index) for each aviation market and suggest that most aviation markets in the world can be characterized as oligopoly with differentiated products. Based on the pass-through rates in differentiated oligopolies computed by Zimmerman and Carlson (2010), Koopmans and Lieshout (2016) further suggest that an airline-specific cost shock is likely to have a less than 50 percent pass-through to airfare, but an industry-wide cost shock will have a larger pass-through to airfare depending on the degree of competition between airlines.

Duplantis (2011) examines conditions under which airline fuel costs are passed on to consumers and estimates the respective fuel cost pass-through rates under these conditions. The author uses reduced-form regression analysis and finds an industry-wide fuel pass-through rate of 0.08 during periods of constant capacity, and 0.89 during periods of changing capacity. This finding is somewhat in line with the argument made by Borenstein and Rose (2007) that fuel cost is relatively fixed unless the airline can quickly adjust capacity with fuel price changes. Toru (2011) studies how airlines fuel cost increase triggered by increasing jet fuel price and environmental policy change is passed through to airfare in EU airline market and its impact on air traffic, airline profits and consumer welfare. Specifically, she uses a structural econometric model with standard logit demand and Bertrand-type market competition to compute the pass-through rates under counterfactual experiments with increases in “effective jet fuel price”. The average estimated pass-through rates under these simulations fall into the range of 0.985 to 0.989 when the corresponding jet fuel price or an equivalent emission charge increase by 50% to 500%. She suggests that the European airline market is highly competitive and airlines are able to pass most of the fuel cost changes to passengers. This result to some extent is close to the finding in PWC (2005), which finds aviation fuel pass-through rates of 90% for low-cost carriers and 105% for full service carriers.14

Our paper is different from the above studies in the following ways. First, unlike previous studies we consider both demand and supply side market channels through which changes in crude oil price pass-through to airfare. On the air travel demand side, changes in crude oil price, through the pressure placed on gasoline price, trigger changes

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14 The results suggest that it takes up to two years for the full pass-through impact to become apparent. (Page 43)
in consumer substitution between air travel and private automobile travel in shorter distance markets. On the air travel supply side, changes in crude oil price spur changes in jet fuel price, which in turn causes airline fuel costs to change. However, the demand-driven price transmission has not been considered in the aforementioned literature.\(^{15}\) Second, unlike previous studies our empirical model allows airline-specific characteristics to affect market airfare level as well as the rate of cost pass-through. In particular, we consider the role that airline jet fuel hedging decisions may play in influencing the size of fuel cost pass-through.\(^{16}\)

3. Theoretical Model

The purpose of this section is to provide a simple theoretical framework to describe market mechanisms through which changes in crude oil price pass through to airfare, as well as to reveal and better understand some underlying factors that may play a role in influencing the size of pass-through. The theoretical model comprises both demand and supply sides of the market for air travel.

To construct our consumer demand function, we consider the potential substitution between air travel and private automobile travel, which depends on the market distance between origin and destination. In line with the argument made by Hayashi and Trapani (1987), the substitutability between flying and driving is influenced by the relevant ground transport cost, determined by gasoline price and time spent driving.\(^{17}\) Following the argument made by Hayashi and Trapani (1987), air travel as well as other modes of mass transit, become relatively cheaper comparing with private automobile travel when there is an increase in gasoline price. Therefore, we introduce gasoline price into the air travel demand equation. In terms of air travel supply, we consider airline fuel cost as a major component of airline operating costs, and therefore directly affected by jet fuel price. Due to the fact that both gasoline and jet fuel are

\(^{15}\) We find one exception by Hayashi and Trapani (1987) who explicitly model the role of energy costs in affecting both demand and supply side of US air travel market.\(^{16}\) Carter, Rogers and Simkins (2004), find that jet fuel hedging is positively related to airline firm value, and “hedging premium” constitutes approximately 12-16% increase in firm value.\(^{17}\) Hayashi and Trapani (1987) consider the total ground transport cost of a trip is the sum of gasoline consumption valued at current cost per gallon, and time cost valued at average hourly earnings of non-supervisory personnel for all industries in the US. However, to simply the analysis in our model, we do not explicitly model the time spent on driving.
petroleum products that are refined from crude oil,\(^{18}\) changes in their prices are driven by changes in crude oil price.

In summary, our discussion above posits that changes in crude oil price affect both the demand and supply sides of air travel markets. In particular, we posit that crude oil price changes affect the demand for air travel via influencing the relative cost of automobile travel through causal changes in gasoline price, while the supply side of air travel is affected due to causal changes in jet fuel price. Consistent with these arguments, Figure 3 and Figure 4 show that crude oil, gasoline and jet fuel prices are positively correlated.

*Figure 3: Energy Prices in Dollar Value*

*Figure 4: Energy Prices in Percentage Change*

3.1 Demand

We think of an air travel market as directional travel between a specific origin and destination, while an air travel product is the specific routing used when transporting passengers from the origin to destination. As such, a given origin-destination market may have several competing products that are differentiated by their routing.

Following from Shubik-Levitan demand, air travel demand among \( n \) differentiated air travel products in a market can be represented by the following system of equations:

\[
\begin{align*}
q_1 &= H - \beta P_1 + \bar{\beta}(P_2 + P_3 + \cdots + P_n) \\
q_2 &= H - \beta P_2 + \bar{\beta}(P_1 + P_3 + \cdots + P_n) \\
&\vdots \\
q_n &= H - \beta P_n + \bar{\beta}(P_1 + P_2 + \cdots + P_{n-1})
\end{align*}
\]

\[
H = h_0 + h_1 X + \gamma P_g
\]

\[
\gamma = e^{-\gamma_0 \text{dist}}
\]

\[
\beta = e^{-\beta_0 \text{dist}}
\]

\[
P_g = \delta_0 + \delta_1 P_c
\]

where \( q_i \) represents the demand level for air travel product \( i \), and \( P_i \) is the associated price level for product \( i = 1,2,\ldots,n \). All other products are considered to be substitute goods to product \( i \), placing an equal weight of impact on product \( i \)’s demand, which is measured by parameter \( \bar{\beta} > 0 \); \( X \) is a vector of variables that influence the level of air travel demand, while \( h_1 \) is a vector of parameters that capture the marginal demand impact of each of the variables in \( X \), respectively; \( P_g \) and \( P_c \) represent gasoline price and crude oil price respectively; while \( \text{dist} \) is a metric of market distance, measured by the non-stop flying distance between the origin and destination of the market.

As discussed previously, it is expected that consumers’ preference between private automobile travel and air travel depends on the relative cost between the two modes of transportation. We use non-stop flying miles between the market’s endpoints as an index of the market distance. The assumption is that this metric of market distance is positively correlated with driving distance. We also assume that the cost to the consumer of automobile travel, which includes the opportunity cost of time, increases faster with market distance compared to the cost to the consumer of air travel. As such, at any given
gasoline price and jet fuel price, the cost to the consumer of flying relative to driving decreases with market distance. To capture these ideas in the system of air travel demand equations, we assume that $\gamma$, which measures the direct marginal effect of gasoline price on air travel demand, is positive and a decreasing function of market distance since parameter $\gamma_0 > 0$. Through parameter $\delta_1 > 0$, the positive marginal effect of gasoline price on air travel demand is translated into an indirect positive marginal effect of crude oil price on air travel demand.

Therefore, the system of demand equations is specified to capture the fact that automobile travel is normally considered as a closer substitute to air travel at relatively shorter travel distances. Following this rationale, it is likely that gasoline price tends to have a larger impact on the air travel demand in short-haul markets. That is, changes in gasoline price should more heavily influence consumers’ choice between driving and flying in markets with relatively shorter travel distances. However, as the market distance becomes relatively longer, travelers are less likely to switch from flying to driving. In this case, gasoline price changes may have a smaller impact on consumers’ air travel demand, perhaps largely driven by the high opportunity cost of time associated with long-distance travel by driving. It then can be inferred that the crude oil price changes affect short-haul market demand relatively more intensively than longer distance markets demand given the linkage between gasoline price and crude oil price ($\delta_1 > 0$).

Suggested by Gillen et al (2003), to account for the different elasticity of air travel demand in markets of differing in distances, we consider the argument that travelers are likely to be more (less) sensitive to airfare changes in shorter (longer) distance markets. That is, air travel demand tends to be more elastic in shorter-haul markets than it is in longer-haul markets, simply because driving is often considered to be a more realistic alternative in relative shorter distance travel. We capture this effect by specifying $\beta$ to be a decreasing function of market distance based on an exponential functional form with $\beta_0 > 0$. It is easier to see the relationship between market distance and the elasticity of air travel demand through the following inverse demand functions.

$$P_i = \frac{H}{\beta} + \frac{\beta}{\beta} P_{-i} - \frac{1}{\beta} q_i$$

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19 Berry, Carnall and Spiller (1996, Page 13) also make similar arguments.
where \( P_{i-1} = P_1 + P_2 + \cdots + P_{i-1} + P_{i+1} + \cdots + P_n \). Given the above inverse air travel demand equation, notice that when the market distance increases, \( \beta \) is smaller, graphically the demand curve becomes steeper, suggesting a relative inelastic demand in the longer distance markets.

We make a standard assumption consistently made when specifying a system of demand equations, which is that the demand impact of own price changes are greater than cross-price demand impacts, i.e. \( \beta > \tilde{\beta} \), suggesting that own price elasticity is greater than cross price elasticity for given price level.

### 3.2 Supply Relation: Bertrand-Nash Pricing Game

We assume each of the \( n \) differentiated air travel products is offered by a different airline. As such, the system of \( n \) profit functions across competing airlines in the origin-destination market is the following:

\[
\begin{align*}
\pi_1 &= (P_1 - c_1)[H - \beta P_1 + \tilde{\beta}(P_2 + P_3 + \cdots + P_n)] \\
\pi_2 &= (P_2 - c_2)[H - \beta P_2 + \tilde{\beta}(P_1 + P_3 + \cdots + P_n)] \\
&\vdots \\
\pi_n &= (P_n - c_n)[H - \beta P_n + \tilde{\beta}(P_1 + P_2 + \cdots + P_{n-1})]
\end{align*}
\]

We assume that airlines simultaneously and non-cooperatively choose prices, Bertrand-Nash fashion, to maximize profit. The set of prices in a Nash equilibrium must satisfy the following first-order conditions:

\[
B \times \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} - \begin{bmatrix} H + \beta c_1 \\ H + \beta c_2 \\ \vdots \\ H + \beta c_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}
\]

where

\[
B = \begin{bmatrix} 2\beta & -\tilde{\beta} & \cdots & -\tilde{\beta} \\ -\tilde{\beta} & 2\beta & \cdots & -\tilde{\beta} \\ \vdots & \vdots & \ddots & \vdots \\ -\tilde{\beta} & -\tilde{\beta} & \cdots & 2\beta \end{bmatrix}
\]

Following the approach described 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:
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:

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

For any airline \(i\), the optimal airfare \(P_i\) is:

\[
P_i = \left( a + \frac{nab}{1-nb} \right) H + \left( a\beta + \frac{ab\beta}{1-nb} \right)c_i + \left( \frac{ab\beta}{1-nb} \right) \sum_{j \neq i} c_j; \quad i = 1,2,...,n
\]

After substituting \(a\) and \(b\), we obtain:

\[
P_i = \frac{H}{2\beta - (n-1)\bar{\beta}} + \frac{\beta[2\beta - (n-2)\bar{\beta}]}{(2\beta + \bar{\beta})[2\beta - (n-1)\bar{\beta}]}c_i + \frac{\bar{\beta}\beta}{(2\beta + \bar{\beta})[2\beta - (n-1)\bar{\beta}]} \sum_{j \neq i} c_j
\]

The assumption of strictly positive prices and quantities suggests \(2\beta - (n-1)\bar{\beta} > 0\) for any \(n\) number of firms, i.e. \(n=1, 2, ..., \) which we summarize it in the following lemma (see Appendix for the proof).

**Lemma 1:** Assume positive prices and quantities for each firm \(i=1,2,...,n\) in Nash Equilibrium, the following conditions must hold simultaneously:

\[
\left\{ \begin{array}{l}
P_i^* > 0 \\
q_i^* > 0 \\
c_i > 0 \\
H > 0 \\
\beta > \bar{\beta} > 0 \\
\end{array} \right\} \Rightarrow \left\{ \begin{array}{l}
2\beta - (n-1)\bar{\beta} > 0 \\
(2\beta + \bar{\beta})H + \beta[2\beta - (n-1)\bar{\beta}]c_i + \beta\bar{\beta} \left( \sum_{j=1}^{n} c_j \right) > 0 \\
(2\beta + \bar{\beta})H - (\beta + \bar{\beta})[2\beta - (n-1)\bar{\beta}]c_i + \beta\bar{\beta} \left( \sum_{j=1}^{n} c_j \right) > 0 \\
c_i > 0 \\
H > 0 \\
\beta > \bar{\beta} > 0 \\
\end{array} \right\}
\]
We specify airline’s marginal cost functions as:
\[
\begin{align*}
(c_1 &= a_0 + a_{1i}P_f + a_2Z) \\
(c_2 &= a_0 + a_{12}P_f + a_2Z) \\
&\vdots \\
c_n &= a_0 + a_{1n}P_f + a_2Z \\
P_f &= \phi_0 + \phi_1P_c
\end{align*}
\]
where \(c_i\) represents the marginal cost of air travel product \(i = 1, 2, \ldots, n\); \(Z\) is a vector of cost shifting variables that affect airline’s marginal cost; and \(P_f\) represents jet fuel price.

We assume that parameter \(\alpha_{1i} > 0\), which captures the direct positive marginal effect of jet fuel price on airline’s marginal cost; and through the assumption that parameter \(\phi_1 > 0\), this effect translates into the indirect positive marginal effect of crude oil price on airline’s marginal cost.

The Nash price can further be written as:
\[
P_f^*(\theta; P_c, dist, X, Z) = H_0 + \frac{h_1}{2e^{-\beta_{dist} - (n - 1)\beta}}X + \frac{e^{-\beta_{dist}a_2}}{2e^{-\beta_{dist} - (n - 1)\beta}}Z + \frac{\delta_0 + \delta_1P_c}{2e^{-\beta_{dist} - (n - 1)\beta}}e^{-\gamma_{dist}} + \frac{e^{-\beta_{dist}[2e^{-\beta_{dist} - (n - 2)\beta]\alpha_{1i} + \beta e^{-\beta_{dist}}(\sum_{j\neq i}^{n-1} \alpha_{1j})]}}{(2e^{-\beta_{dist} + \beta})[2e^{-\beta_{dist} - (n - 1)\beta}]\phi_1P_c}
\]
where
\[
H_0 = \frac{h_0}{2e^{-\beta_{dist} - (n - 1)\beta}} + \frac{\alpha_0 e^{-\beta_{dist}}}{2e^{-\beta_{dist} - (n - 1)\beta}} + \frac{e^{-\beta_{dist}[2e^{-\beta_{dist} - (n - 2)\beta]\alpha_{1i} + \beta e^{-\beta_{dist}}(\sum_{j\neq i}^{n-1} \alpha_{1j})]}}{(2e^{-\beta_{dist} + \beta})[2e^{-\beta_{dist} - (n - 1)\beta}]\phi_0}
\]
\[
\theta = \{\beta_0, \beta, h_0, h_1, \gamma_0, \alpha_0, \alpha_{1i}, \alpha_{1j}, \alpha_2, \delta_0, \delta_1, \phi_0, \phi_1\}
\]
The expression above that characterizes the Nash equilibrium price level reveals that airline \(i\)’s optimal airfare in a given origin-destination market is determined by:

- \(X, Z\): vectors of demand shifting and cost shifting variables respectively.
- \(dist\): market distance measured by non-stop flying miles.
- \(P_c\): the level of crude oil price, which influences airfare through air travel demand and supply channels.
• $H_0$: a component that comprises a composite of demand and cost factors that determine the mean level of airline $i$’s fare when the variables described in the previous bullet points are counterfactually set equal to zero.

### 3.3 Theoretical analysis

#### 3.3.1 What is the impact of crude oil price on the fare charged by an airline?

The marginal effect of crude oil price on a typical airline’s price level determines the cost pass-through relationship, or price transmission, from changes in crude oil price to changes in airfare. As such, the cost pass-through relationship is derived from our theoretical model based on the following partial derivative:

$$
\frac{\partial P_i^*}{\partial P_c} = \frac{e^{-\gamma_0 \text{dist}} \delta_1}{2e^{-\beta_0 \text{dist}} - (n - 1)\beta} + \frac{e^{-\beta_0 \text{dist}} [2e^{-\beta_0 \text{dist}} - (n - 2)\beta] \alpha_{1i}}{(2e^{-\beta_0 \text{dist}} + \beta) [2e^{-\beta_0 \text{dist}} - (n - 1)\beta]} \phi_1
$$

Demand Effect

$$
\frac{\beta e^{-\beta_0 \text{dist}} (\sum_{j \neq i}^{n-1} \alpha_{1j})}{(2e^{-\beta_0 \text{dist}} + \beta) [2e^{-\beta_0 \text{dist}} - (n - 1)\beta]} \phi_1
$$

Direct Cost Effect

$$
\frac{\beta e^{-\beta_0 \text{dist}} (\sum_{j \neq i}^{n-1} \alpha_{1j})}{(2e^{-\beta_0 \text{dist}} + \beta) [2e^{-\beta_0 \text{dist}} - (n - 1)\beta]} \phi_1
$$

Strategic Cost Effect

The above equation suggests that changes in crude oil price are translated into changes in airfare through two market channels: demand side and supply side. The following provides intuitive descriptions of the demand side effect, as well as the two supply side effects:

- **Demand effect** captures how crude oil price changes affect consumer air travel demand. This effect is positive according to our previous discussion. The reason is that an increase (decrease) in crude oil price pushes up (down) gasoline price, leading to higher (lower) air travel demand as driving becomes relative more (less) costly. The higher (lower) demand for air travel causes airfare to rise (fall). This demand effect is particularly strong in shorter distance markets as driving is a closer substitute to flying in shorter distance travel.

- **Direct cost effect** captures the portion of airline $i$’s optimal airfare response to changes in its own marginal cost, where the marginal cost changes are driven by changes in crude oil price. This direct cost effect is positive, and therefore consistent with the argument that an increase (decrease) in crude oil price causes an increase
(decrease) in jet fuel price, which causes an increase (decrease) in the airline’s own marginal cost, which then causes an increase (decrease) in the airlines optimal airfare.

- **Strategic cost effect** captures the extent to which an airline $i$’s optimal airfare responds to changes in the marginal cost of rival airlines, where the rival airlines’ marginal cost changes are driven by changes in crude oil price. This strategic cost effect results from the strategic interdependence across competing oligopolistic firms in a market, a feature of our model that results from the assumed Bertrand-Nash price-setting game played between airlines. The strategic cost effect is positive, reflecting the argument that an increase (decrease) in crude oil price increases (decreases) the marginal cost and consequently airfare of an airline’s rivals, which causes the airline to increase (decrease) its own airfare in response to the increase (decrease) in airfare of its rivals. Due to the strategic interdependence across competing oligopolistic airlines, it is important to note that the strategic effect facilitates a positive correlation between an airline’s fare and crude oil price, even in an extreme situation in which the airline’s own marginal cost is insensitive to crude oil price changes.

**Proposition 1**: The marginal effect of crude oil price on an airline’s optimal airfare is always positive, i.e., for $i = 1, 2, ..., n$: \( \frac{\partial P_i^*}{\partial P_c} > 0 \).

The inequality in Proposition 1 holds given \( 2\beta - (n - 1)\tilde{\beta} > 0 \) according to Lemma 1 and the positive correlation among energy prices, i.e. \( \delta_1, \phi_1 > 0 \). Proposition 1 implies that as crude oil price increases (decreases), the equilibrium airfare charged by airline $i$ also increases (decreases). As suggested by Zimmerman and Carlson (2010), “a positive cost pass-through rate means that some portion of a marginal cost change will be passed through to price regardless of the level of competition”.

3.3.2 How an airline’s jet fuel hedging decision affects the extent of pass-through from changes in crude oil price to airfare?
We now consider how the size of the pass-through from changes in crude oil price to airfare may be affected by airlines’ fuel hedging strategy. Airline service is heavily dependent on the price and availability of jet fuel. High volatility in fuel costs, increased fuel price, and significant disruptions in the supply of aircraft fuel can have a significant negative impact on airlines’ regular operations. Airlines often enter into fuel hedging contracts, such as forward contracts, futures contracts, options, swaps and collars, to lock in future fuel prices and thus reduce their exposure to rising fuel costs.\textsuperscript{20} We expect airlines that extensively use fuel hedging contracts are likely to experience smaller impact from short-term fuel price swings resulted from crude oil market fluctuation. This effect is captured in our model by a relatively small $\alpha_{1i}$ for airline $i$ in the marginal cost equation. Proposition 2 summarizes how the model captures the impact of airline jet fuel hedging decisions on the size of pass-through from changes in crude oil price to airfare:

**Proposition 2**: The size of pass-through from changes in crude oil price to an airline’s optimal fare is greater the larger is parameter $\alpha_{1i}$ in the airline’s marginal cost function, i.e. for $i, j = 1, 2, ..., n, i \neq j$: $\frac{\partial P_i^*}{\partial P_c} > \frac{\partial P_j^*}{\partial P_c}$, if $\alpha_{1i} > \alpha_{1j}$.

The proof of this proposition follows from the difference in the following partial derivatives:

$$\frac{\partial P_i^*}{\partial P_c} - \frac{\partial P_j^*}{\partial P_c} = \frac{\beta[2\beta - (n - 1)\bar{\beta}]\phi_1}{(2\beta + \bar{\beta})[2\beta - (n - 1)\bar{\beta}]}(\alpha_{1i} - \alpha_{1j}) = \frac{\beta \phi_1}{(2\beta + \bar{\beta})}(\alpha_{1i} - \alpha_{1j})$$

Given that $\beta, \bar{\beta} > 0$ and $\phi_1 > 0$, $\frac{\partial P_i^*}{\partial P_c} - \frac{\partial P_j^*}{\partial P_c} > 0$ holds if and only if $\alpha_{1i} - \alpha_{1j} > 0$.

Alternatively, by Lemma 1, we can describe Proposition 2 using the following equation:

$$\frac{\partial \left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial \alpha_{1i}} = \frac{\beta[2\beta - (n - 2)\bar{\beta}]\phi_1}{(2\beta + \bar{\beta})[2\beta - (n - 1)\bar{\beta}]} > 0; \text{ when } 2\beta - (n - 1)\bar{\beta} > 0$$

\textsuperscript{20} There are considerable studies that focus on how airline fuel hedging strategies affect airlines in terms of firm market value and risk management (see Carter, Rogers and Simkins (2006a, 2006b), Morrell and Swan (2006), Treanor et al. (2014)).
The above equation states that the larger $\alpha_{1i}$ is, the larger the impact of crude oil price on airline $i$’s optimal price level. Intuitively, we may rationalize this effect in the following way: airlines who enter jet fuel hedging contracts, which causes a smaller $\alpha_{1}$, tend to experience smaller changes in their marginal cost from crude oil price shocks compared to airlines that do not use fuel hedging contracts. In this case, the latter airlines are more likely to pass along the crude oil price shocks to consumers through airfare.

### 3.3.3 How market competition impacts size of pass-through from changes in crude oil price to airfare?

We now consider how the size of pass-through from changes in crude oil price to airfare may vary with level of market competition, where degree of market competition is measured in the model by the number of airlines that compete in the market, $n$. The impact of air travel market competition intensity on the size of crude oil price pass-through to airfare is described in the following proposition:

**Proposition 3:** The extent of pass-through from changes in crude oil price to airfare increases with the number of firms in the market, that is, the pass-through rate is greater in more competitive markets than in less competitive markets, i.e. for $i = 1, 2, ..., n$:

$$\frac{\partial \{\partial P_i \}}{\partial n} > 0.$$

The proof of **Proposition 3** follows from the following partial derivative:

$$\frac{\partial \{\partial P_i \}}{\partial n} = \frac{\gamma \bar{\beta} \delta_1}{(2 \bar{\beta} - (n - 1) \bar{\beta})^2} + \frac{\beta \bar{\beta}^2 \phi_1(\sum_{j=1}^{n} \alpha_{1j})}{(2 \bar{\beta} + \bar{\beta}) [2 \bar{\beta} - (n - 1) \bar{\beta}]^2}
$$

$$= \frac{e^{-\gamma_0 \text{dist} \bar{\beta} \delta_1}}{[2e^{-\beta_0 \text{dist}} - (n - 1) \bar{\beta}]^2} + \frac{e^{-\beta_0 \text{dist} \bar{\beta}^2 \phi_1(\sum_{j=1}^{n} \alpha_{1j})}}{(2e^{-\beta_0 \text{dist}} + \bar{\beta})[2e^{-\beta_0 \text{dist}} - (n - 1) \bar{\beta}]^2}$$

It is clear to see that the sign of the above equation is positive given $\beta_0 \bar{\beta} > 0$ and $\gamma, \alpha_{1j}, \delta_1, \phi_1 > 0$, suggesting that an increase in $n$ corresponds to a higher pass-through rate. As the market becomes relative more competitive with a growing number...
of firms, market players are likely to compete on price more aggressively, leaving smaller and smaller profit margins. A profit maximizing firm will quickly adjust its optimal price after a cost shock, holding the belief that its rivals will react similarly to the cost shock. As such, a cost shock is likely to pass-through into new equilibrium prices on a larger scale when markets are more competitive. This interpretation complies with the argument made by Koopmans and Lieshout (2016) and Malina et al. (2012) that when markets become more competitive, profits margins decline, which leaves small room for airlines to absorb costs without passing through costs increase to prices. Thus airlines are more likely to pass cost changes to airfare when market competition is more intense. However, our result contradicts with predictions made by Zimmerman and Carlson (2010). They show that in differentiated Bertrand competition with asymmetric firms (with asymmetric cost structure), pass-through rate is monotonically decreasing in the degree of competition in the markets.

3.3.4 How market distance affects the extent of pass-through from changes in crude oil price changes to airfare?

Our theory suggests that consumer preference between air travel and private automobile travel depends on the relevant ground transport cost in transporting them from origin to destination. An essential factor that determines the ground transport cost is the market distance between the two endpoints of the market. We use the air travel product’s non-stop flying miles to approximate the potential driving distance between the two endpoints. Airline’s optimal pricing suggests that market distance is going to affect both the level of air travel demand (captured by \( \gamma \)) and the elasticity of the air travel demand (captured by \( \beta \)). Hence, we consider the overall effect rendered by market distance to be split into two effects: “level effect” and “elasticity effect”. For a given number of firms in the market, the overall effect is calculated by partially differentiating the pass-through equation with respect to market distance, given by:
\[
\frac{\partial \left\{ \frac{\partial P_i}{\partial P_c} \right\}}{\partial \text{dist}} = \left( \frac{\delta_1}{2\beta - (n-1)\bar{\beta}} \right) \frac{\partial \left\{ e^{-\gamma_0 \text{dist}} \right\}}{\partial \text{dist}} \\
+ \left( \frac{\partial \left\{ \frac{1}{2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta}} \right\}}{\partial \text{dist}} \right) (\delta_1 \gamma) + \left( \frac{\partial \left\{ e^{-\beta_0 \text{dist}} \left[ 2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta} \right] \right\}}{\partial \text{dist}} \right) (\phi_1 \alpha_{1i}) + \left( \frac{\partial \left\{ \frac{\bar{\beta} e^{-\beta_0 \text{dist}}}{2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta}} \right\}}{\partial \text{dist}} \right) (\phi_1 \sum_{j \neq i}^{n-1} \alpha_{1j})
\]

\[
= -\frac{\gamma_0 \delta_1 \gamma}{2\beta - (n-1)\bar{\beta}} + \frac{2\beta_0 \delta_1 \gamma \bar{\beta}}{[2\beta - (n-1)\bar{\beta}]^2} + \frac{(n-1)\beta_0 \bar{\beta}^2 [4\beta - (n-2)\bar{\beta}] \beta \phi_1 \alpha_{1i}}{[2\beta - (n-1)\bar{\beta}]^2} + \frac{\beta_0 \bar{\beta} \left[ 4\beta^2 + (n-1)\bar{\beta}^2 \right] \beta \phi_1 \sum_{j \neq i}^{n-1} \alpha_{1j}}{[2\beta - (n-1)\bar{\beta}]^2}
\]

\[
= -\frac{\gamma_0 \delta_1 \gamma e^{-\gamma_0 \text{dist}}}{2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta}}
\]

\[
+ \frac{2\beta_0 \delta_1 \gamma e^{-\gamma_0 \text{dist}} e^{-\beta_0 \text{dist}}}{[2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta}]^2} + \frac{(n-1)\beta_0 \bar{\beta}^2 \left[ 4e^{-\beta_0 \text{dist}} - (n-2)\bar{\beta} \right] e^{-\beta_0 \text{dist}} \phi_1 \alpha_{1i}}{[2e^{-\beta_0 \text{dist}} + \bar{\beta}]^2 [2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta}]^2} + \frac{\beta_0 \bar{\beta} \left[ 4e^{-2\beta_0 \text{dist}} + (n-1)\bar{\beta}^2 \right] e^{-\beta_0 \text{dist}} \phi_1 \sum_{j \neq i}^{n-1} \alpha_{1j}}{[2e^{-\beta_0 \text{dist}} + \bar{\beta}]^2 [2e^{-\beta_0 \text{dist}} - (n-1)\bar{\beta}]^2}
\]

\text{Level Effect}

\text{Elasticity Effect (–)}

\text{Elasticity Effect (+)}
The first term of the above equation describes how market distance affects how airlines adjust their optimal prices as a response to crude oil price changes when consumers may switch between air travel and private automobile travel due to changes of ground transport cost induced by gasoline price changes. Intuitively, an increase in crude oil price leads to an increase in gasoline price, which makes driving relatively more expensive and air travel relatively cheaper. Air travel in this case becomes more attractive, shifting the demand curve outward as consumers switch from driving to air travel. The magnitude of shift of air travel demand depends on the market distance between origin and destination. It is relatively large for short distance travel compared with long distance travel because it is much easier for consumers to switch between driving and flying when the two cities are close to each other. Thus we would expect there are more consumers switching from driving to flying for short distance travel when gasoline price increases, i.e. gasoline price changes affect more heavily in shorter distance markets.

This effect, which we refer to as a level effect, is negative and can be explained based on the following diagram in Figure 5. In order to focus on the impact of the level effect, we keep the elasticity of air travel demand constant across markets of different distances. A simplified assumption to illustrate this level effect is to let the initial demand curve, $D_0$, represent both the initial short distance and long distance market demand. In addition, the associated equilibrium price level, $P_0$, which is found by equating the initial marginal cost curve, $MC_0$ to the initial marginal revenue curve, $MR_0$ at $E_0$ for a typical oligopolistic firm $i$, represents both the initial short distance and long distance equilibrium market price level. Consider now a positive cost shock from an increase in crude oil price level shifts $MC_0$ upward to $MC_1$, it is expected that this shock is likely to impact more heavily in short distance market by shifting the initial short distance market demand, $D_0$, rightward to $D^S_1$, a larger shift than the resulting new long distance market demand, $D^L_1$. The associated new marginal revenue curves for the new short distance and new long distance market demand are $MR^S_1, MR^L_1$ respectively. The new profit-maximizing price levels, $P^S_1, P^L_1$, corresponding to the new short and long distance market demand are found by equating the new marginal revenue ($MR^S_1, MR^L_1$) to the new marginal cost curves ($MC_1$) at $E^S_1, E^L_1$ respectively. It is clear that a larger right shift of short distance market demand results in a greater equilibrium increase in airfare, i.e.
\( \Delta P^S = P^S_1 - P_0 > \Delta P^L = P^L_1 - P_0 \), suggesting a higher pass-through rate for a given cost shock, \( \Delta MC \), in shorter distance market than it is in longer distance market. Meanwhile, the nature of the oligopolistic market structure suggests that this cost-price pass-through is likely to be incomplete for a typical oligopolistic firm \( i \). That is, the maximum change in equilibrium airfare tends to be less than the change in marginal cost for a given cost shock, i.e. \( \Delta P^S_1 \leq \Delta MC \).

*Figure 5: Illustrating the level effect using a simple diagram*

The last three terms together capture how market distance affects airline’ response to crude oil price changes when consumer may exhibit different sensitivity to the change of airfare. The intuition is that short distance travelers tend to be more sensitive to airfare changes than long distance travelers, simply because driving is often not a realistic alternative to air travel in long distance markets. As such, we would expect airlines to pass along a crude oil price induced cost shock to airfare more heavily to long distance air travelers given their less elastic air travel demand compared to consumers in short-haul markets. Another way to understand airlines pass-through behavior in this analysis is to think about how much output they have to sacrifice to pass on a certain amount of the
change in their marginal costs.\textsuperscript{21} A pass-through will be smaller for the less elastic long distance air travel demand because the reduction of quantity demand is smaller, thus making passing the cost shock through to airfare more attractive.

This effect, which we refer to as an \textit{elasticity effect}, is positive and can be explained based on the following diagram in Figure 6. When we consider the \textit{elasticity effect}, we focus on analyzing the change in elasticity for the air travel demand between short-haul and long-haul markets, assuming no \textit{level effect} induced by the change of market distance. Again, to simplify the illustration, we assume the initial equilibrium airfare for the relative more elastic short distance market is at the same level with the initial equilibrium airfare for the relative less elastic long distance market, $P_0$, which is found by equating their associated marginal revenue curves ($MR_S$, $MR_L$) to the initial marginal cost curve, $MC_0$ at $E_{0}^{S}, E_{0}^{L}$. Consider now a positive cost shock from an increase in crude oil price level shifts $MC_0$ upward to $MC_1$, intercepting the short distance marginal revenue curve $MR_S$ at $E_{1}^{S}$ and the long distance marginal revenue curve $MR_L$ at $E_{1}^{L}$. The resulting new profit-maximizing price level for the long distance market is notably greater than that for the short distance market, i.e. $P_{1}^{L} > P_{1}^{S}$, suggesting a greater equilibrium increase in airfare for the less elastic long distance market demand than it is in the more elastic short distance market for a given cost shock, i.e. $\Delta P_{1}^{L} = P_{1}^{L} - P_{0} > \Delta P_{1}^{S} = P_{1}^{S} - P_{0}$. Similar to the previous discussion, it is expected that the maximum change in equilibrium airfare is less than the change in marginal cost for a given cost shock of $\Delta MC$, i.e. $\Delta P_{1}^{L} \leq \Delta MC$.

\textsuperscript{21} Cost pass-through: theory, measurement, and potential policy implications. RBB Economics, February 2014.
The overall effect of market distance between origin and destination on the size of pass-through from changes in crude oil price to airfare is determined by the relative strength between the two offsetting effects. We summarize the above discussion in the following proposition:

**Proposition 4:** The impact of market distance between origin and destination on the extent of pass-through from changes in crude oil price to airline market fare levels is governed by two offsetting effects: a negative “level effect” and a positive “elasticity effect”, by Lemma 1. The sign of the overall effect is determined by the relative strength of the above two effects.

4. **Data**

We use data from three main sources. The airline ticket information data is the usual one used for studies of US airline industry, the Passenger Origin-Destination Survey of the US Department of Transportation (database DB1B), a 10% quarterly sample of all airline tickets. It provides information on flight fares, itinerary (origin,
destination, and all connecting airports), the ticketing and operating carriers for each segment, the type of ticket (i.e. round-trip or one-way), the number of passengers traveling on the itinerary at a given fare in each origin-destination pair, itinerary miles flown in transporting the passenger from origin to destination, and non-stop flight distance. Following Aguirregabiria and Ho (2012), information on the population of each origin and destination city is based on the Population Estimates Program (PEP) of the US Census Bureau, which produces annual population estimates under the category “Cities and Towns (Incorporated Places and Minor Civil Division)”. We use the energy price data from US Energy Information Administration (EIA) under “short-term energy outlook”, including gasoline, jet fuel and crude oil prices. At last, we collected the information regarding airlines’ jet fuel hedging strategy adopted in our data file from their SEC filings (i.e. 10-K).

4.1 Sample selection

The DB1B raw data file contains millions of tickets for each quarter. For instance, the number of records in the third quarter of 2013 is 5,749,897. To construct our working sample, we focus on the last two quarters of 2013 and all four quarters of 2014 and 2015, a total of ten quarters of data.

We construct our DB1B working sample in the following manner:

- Following Brueckner and Spiller (1994) and Berry, Carnall, and Spiller (2006), we keep only round-trip itineraries within the continental US with at most four segments

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22 The URL of this data source is: http://www.transtats.bts.gov/Tables.asp?DB_ID=125.
23 The URL of this data source is: http://www.census.gov/popest/data/index.html.
24 The URL of the data source is: https://www.eia.gov/forecasts/steo/query/.
25 Crude oil is represented by Brent Crude oil since this is the primary energy index that most US airlines follow for fuel hedging; gasoline is using “all grades retail price including taxes US average”; and jet fuel price is the price of “jet fuel refiner price to end users”. All energy prices are deflated in 2014 dollar using consumer price index (CPI) that was obtained from the Bureau of Labor Statistics (BLS).
26 Before this sample period, American Airlines and US Airways announced plans to merge in February 2013 and was approved by US Airways shareholders in July 2013. This merger was challenged by the Department of Justice August 2013 but soon was settled in November 2013. We assume that the market price change that might be influenced by the AA-US Airways merger was realized when it was announced in the beginning of 2013 and thus our analysis of airline market fare during our sample period avoids the examination of the market price change that may contribute to the increasing market power caused by this merger. The idea is similar to the statement that Kim and Singal (1993) made in their study that “exercise of market power does not have to wait until merger completion,…even without an explicit price-fixing agreement, the mere anticipation of a merger would make the participating firms more cooperative.”
(i.e. no more than three intermediate stops). We eliminate all itineraries with market fares less than $50 or greater than $2,000.

- A *market* is defined as a directional pair of an origin and a destination airport. For example, a direct flight from Atlanta to Boston is a different market from Boston-Atlanta. This definition allows for the characteristics of the origin city to affect consumers' air travel demand. As in Berry, Carnall, and Spiller (2006), the geometric mean of the population estimates in 2014 of the end-point cities characterizes the market size.

- A *product* is defined as a unique combination of itinerary-operating carrier. A non-stop flight from Atlanta to Boston operated by American Airline, for instance. We focus on products that use a single operating carrier for all segments of a given itinerary, i.e. pure online products. Table 2 lists the names and associated airline code of the 21 carriers in our sample.

<table>
<thead>
<tr>
<th>Airline Code</th>
<th>Airline Name</th>
<th>Airline Code</th>
<th>Airline Name</th>
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</thead>
<tbody>
<tr>
<td>AA</td>
<td>American Airlines</td>
<td>OO</td>
<td>SkyWest Airlines</td>
</tr>
<tr>
<td>AS</td>
<td>Alaska Airlines</td>
<td>RP</td>
<td>Chautauqua Airlines</td>
</tr>
<tr>
<td>B6</td>
<td>JetBlue Airways</td>
<td>S5</td>
<td>Shuttle America</td>
</tr>
<tr>
<td>DL</td>
<td>Delta Airlines</td>
<td>SY</td>
<td>Sun Country Airlines</td>
</tr>
<tr>
<td>EV</td>
<td>ExpressJet Airlines</td>
<td>UA</td>
<td>United Airlines</td>
</tr>
<tr>
<td>F9</td>
<td>Frontier Airlines</td>
<td>US</td>
<td>US Airways</td>
</tr>
<tr>
<td>FL</td>
<td>AirTran Airways</td>
<td>VX</td>
<td>Virgin America</td>
</tr>
<tr>
<td>G4</td>
<td>Allegiant Airlines</td>
<td>WN</td>
<td>Southwest Airlines</td>
</tr>
<tr>
<td>G7</td>
<td>GoJet Airlines</td>
<td>YV</td>
<td>Mesa Airlines</td>
</tr>
<tr>
<td>HA</td>
<td>Hawaiian Airlines</td>
<td>YX</td>
<td>Midwest Airlines</td>
</tr>
<tr>
<td>NK</td>
<td>Spirit Airlines</td>
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</tbody>
</table>

- *Price* and *quantity* are obtained by averaging the market fare and aggregating the number of passengers according to our definition of product respectively. Thus in the collapsed data, a product is a unique observation during a given time period.

Unfortunately, one limitation of the DB1B data is that it does not contain passenger-specific information and some important elements of product differentiation, such as departure times, how far in advance the ticket is purchased and length-of-stay requirements. The energy price data from EIA is available in daily market spot price. With only quarterly airline data, we restrict our selection of energy prices to also be
quarterly, i.e. the Brent crude oil, jet fuel, and gasoline prices are quarterly averaged market spot prices obtained from EIA database.

4.2 Data summary

Table 3 reports the summary statistics of our sample. Overall, we have 615,242 observations in our sample and 147,073 markets based on our definition of market. The quarterly average airfare, crude oil price, jet fuel price, and gasoline price in the sample are approximately $266, $81.53/barrel (or $1.94/gallon), $2.33/gallon, and $3.07/gallon respectively. The average market distance across all product is around 1414 miles. To control for the macro forces that affect consumers air travel demand, we include the variable of population measured by the geometric mean of the population size in the origin and destination cities. Airfare are affected by market structure, product differentiation and other market or product level characteristics. To control for these market/product level characteristics, we include other variables in the analysis.

$N_{airline\_mkt}$ serves as a measure of actual market competition, calculated by summing the number of distinct carriers serving the market. A monopoly market is the one with only one airline serving the market. There are at maximum 11 airlines competing in one market and on average 4 airlines offering flight services in a market. To control for the potential entry threat that may affect equilibrium market fare level, we include $Threat\_all$ and $Threat\_non\_legacy$, as measures of potential market competition. Following Gayle and Wu (2013) and Goolsbee and Syverson (2008), $Threat\_all$ is obtained by computing the number of all the distinct carriers that are present both endpoints of a market without serving the market; and $Threat\_non\_legacy$ is obtained by computing the number of all the distinct non-legacy carriers that are present both endpoints of a market without serving the market. Following Berry and Jia (2010) and Brueckner, Lee and Singer (2013), carriers that are normally considered as legacy carriers include American Airlines, United, Delta, US Airways, Alaska, Midwest, and Hawaiian Airlines.^{27} Non-legacy carriers include all the carriers that are not the above carriers in

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^{27} To construct all the entry threat variables, we place less restrictions on the DB1B dataset by not solely focusing on roundtrip itineraries. The less restrictive data thus includes carriers that may only place entry threat to the incumbents in a market by providing one-way flights at both endpoints without actually serving the market. These airlines will not be included in our final dataset, but only be useful to measure the potential market competition.
the dataset. The maximum number of carriers that place an entry threat without serving the market is 10, whereas the maximum number of non-legacy carriers that place an entry threat without serving the market is 7. These above three variables capture the market structure and are used to evaluate how market competition affects the market fare level as well as the size of pass-through.

Carriers may offer both non-stop and connecting service. Consumers value the two types of products differently. To capture the difference, we use Interstop to measure the travel itinerary convenience. It is calculated by summing the number of intermediate stops in a product's itinerary. Therefore, it is expected that the more intermediate stops associated with an itinerary, the less convenience the air travel product is considered to be, consumer would be willing to pay a lower price for this product. However, there may exist products that have the same number of intermediate stops in an origin and destination market; but because the location(s) of the intermediate stop airport(s) are different, their associated itinerary flying miles will differ and thus exhibit different relative routing qualities. Following Chen and Gayle (2015), Gayle and Wu (2015), Gayle and Le (2015), we use Inconvenience to measure the product routing quality which is not captured by product characteristics of Interstop. This variable is computed by dividing the itinerary miles flown from origin to destination by its correspondent non-stop radian distance. Thus, if an itinerary is non-stop flight, then its Inconvenience measure is 1. The maximum Inconvenience of a product in the data is about 3.7. This means travelers need to travel 3.7 times longer distance with this product than the direct flight distance.

Origin_Presence is an indicator of airlines' hub premium at the market endpoint cities by aggregating the number of destinations that an airline connects with the origin city using non-stop flights. The greater the airline’s “presence” in the origin airport, the more likely that the origin airport is served as a hub or a focus city by this airline, the better services, such as more frequent and convenient departure times are likely to be offered to consumers. Airlines serve about 26 different cities from the relevant market's origin cities.

Fuel cost is one major component of airlines operating expenses. To protect against sudden losses from rising fuel prices or sudden gains from decreasing fuel prices,
airlines usually use some form of hedging instruments to lock in fuel prices thus stabilize overall airline costs. We use a dummy variable *Hedge*, equals to 1 if the carrier uses jet fuel hedging contacts. On average, about 81% products provided by carriers are under hedging contracts.

### Table 3: Summary Statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>mean</th>
<th>sd</th>
<th>min</th>
<th>max</th>
</tr>
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<tbody>
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<td>Airfare* (dollars)</td>
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<td>107.9482</td>
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<td>Crude Oil Price* (dollars/barrel)</td>
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<td>27.08791</td>
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<td>Jet Fuel Price* (cents/gallon)</td>
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<td>Gasoline Price* (cents/gallon)</td>
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<td>53.20798</td>
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<td>Quantity (numbers of passengers per product)</td>
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<td>375.4612</td>
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<td>10294</td>
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<td>Interstop</td>
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<tr>
<td>Inconvenience</td>
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<td>634.7927</td>
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<td>Population</td>
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<td>Hedge</td>
<td>.8151882</td>
<td>.3881452</td>
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</tbody>
</table>

* Inflation-adjusted in 2014 dollar.

In the next section, we use a simple reduced-form regression to empirically test the impact of crude oil market changes on airfare and factors that affect the extent of pass-through.

### 5. Empirical analysis

Based on our theory, it has been argued that there exists a positive pass-through relationship from changes in crude oil price to airline market fare and the size of this pass-through is affected by some market characteristics. In accordance with our theoretical predictions, we empirically estimate and test how these following variables affect the size of pass-through: airline jet fuel hedging decisions, market competition and market distance between origin and destination. The empirical analysis examines these factors across a sample of US domestic origin-destination air travel markets.

#### 5.1 Reduced-form regression analysis

Our empirical analysis relies on the following two reduced-form model specifications:
• Model I:

\[ \log(P_{tmt}) = \theta_0 + \theta_1 \log(P_{c,mt}) + \theta_2 N_{\text{airline mkt}mt} + \theta_3 \log(P_{c,mt}) \times N_{\text{airline mkt}mt} + \theta_4 \text{Threat all}_{mt} \\
+ \theta_5 \log(P_{c,mt}) \times \text{Threat all}_{mt} + \theta_6 \log(\text{distance}_{mt}) + \theta_7 \log(P_{c,mt}) \times \log(\text{distance}_{mt}) \\
+ \theta_8 \text{Hedge}_{mt} + \theta_9 \log(P_{c,mt}) \times \text{Hedge}_{mt} + \theta_{10} \text{Interstop}_{mt} + \theta_{11} \text{Inconvenience}_{mt} \\
+ \theta_{12} \text{Origin Presence}_{mt} + \theta_{13} \log(\text{Population}_{mt}) + \eta_t + \text{Origin}_{m} + \text{Dest}_{m} + \epsilon_{mt} \]

• Model II:

\[ \log(P_{tmt}) = \theta_0 + \theta_1 \log(P_{c,mt}) + \theta_2 N_{\text{airline mkt}mt} + \theta_3 \log(P_{c,mt}) \times N_{\text{airline mkt}mt} \\
+ \theta_4 \text{Threat non legacy}_{mt} + \theta_5 \log(P_{c,mt}) \times \text{Threat non legacy}_{mt} + \theta_6 \log(\text{distance}_{mt}) \\
+ \theta_7 \log(P_{c,mt}) \times \log(\text{distance}_{mt}) + \theta_8 \text{Hedge}_{mt} + \theta_9 \log(P_{c,mt}) \times \text{Hedge}_{mt} \\
+ \theta_{10} \text{Interstop}_{mt} + \theta_{11} \text{Inconvenience}_{mt} + \theta_{12} \text{Origin Presence}_{mt} + \theta_{13} \log(\text{Population}_{mt}) \\
+ \eta_t + \text{Origin}_{m} + \text{Dest}_{m} + \epsilon_{mt} \]

The dependent variable in each model is the airfare of product \( i \) in market \( m \) at time \( t \). Both model specifications include the following control variables: \( P_c \), \( N_{\text{airline mkt}} \), \text{distance} , \text{Hedge} , \text{Interstop} , \text{Inconvenience} , \text{Origin Presence} , \text{Population} , time fixed effects (\( \eta_t \)), origin and destination fixed effects. Model I and II differ from each other by how potential entry threat is measured. Specifically, in Model I we use the number of all distinct airlines that present both endpoints without serving the market, i.e. \text{Threat all}; while in Model II we use the number of all non-legacy carriers that present both endpoints without serving the market, i.e. \text{Threat non legacy}.

In accordance with our theoretical prediction in the model section, we rely on a reduced-form analysis and attempt to estimate the pass-through rate of changes in crude oil price to airfare and examine how market competition, distance and airline-specific decision on hedging influence the size of the pass-through. In particular, we focus on the pass-through rate (PTR) of changes in crude oil price to airfare defined by:

\[ \text{PTR} = \frac{\partial \log(P)}{\partial \log(P_c)} = \theta_1 + \theta_3 N_{\text{airline mkt}} + \theta_5 \text{Threat all} + \theta_7 \log(\text{distance}) + \theta_9 \text{Hedge} \quad \text{(Model I)} \]

\[ \text{PTR} = \frac{\partial \log(P)}{\partial \log(P_c)} = \theta_1 + \theta_3 N_{\text{airline mkt}} + \theta_5 \text{Threat non legacy} + \theta_7 \log(\text{distance}) + \theta_9 \text{Hedge} \quad \text{(Model II)} \]

It is these variables, \( N_{\text{airline mkt}} \), \text{Threat all} , \text{Threat non legacy} , \log(\text{distance}) , and \text{Hedge} that may play a role in influencing the size of pass-through.
Our primary parameters of interest are thus $\theta_1, \theta_3, \theta_5, \theta_7$ and $\theta_9$. In the next section, we focus on interpreting the reduced-form regression results, on which base we will draw some inference to address our research questions.

5.2 Regression results

The reduced-form regression results are reported in Table 4. Given the fact that airlines jet fuel hedging decisions are airline-specific characteristic, airline fixed effect is not included in the regressions.

We use the logarithm of airfare and crude oil price, thus the coefficient of $log(P_c)$ measures the elasticity of airfare to crude oil price, i.e. the percentage change in airfare associated with a given percentage change in crude oil price. The coefficient estimates of $log(P_c)$ in both models have expected positive signs and statistically significant. Without considering the impact of other market characteristics, this estimate implies that, on average, a 10% increase in crude oil price yields about a 0.61~0.77% increase in airfare. Thus, this result provides direct evidence that a given percentage change in crude oil price translates into a certain percentage change in airfare even if this change is relatively small. The rate of pass-through estimated in our models is close to the one obtained by Duplantis (2010), 0.08 during times of constant capacity, but is much smaller than 0.89 during periods when higher fuel costs trigger capacity changes. We therefore conclude that, there is an immediate positive impact of crude oil price shocks on air travel market fare before taking into account other market factors.

The coefficient estimates of $N_{airline_mkt}$ are both statistically significant. This parameter is introduced to capture the role of actual market competition in influencing the market airfare. Both estimates have expected negative signs, suggesting that the more airlines serving the market (thus introducing higher competition in this market), the lower the airfare. For example, the estimated coefficient for $N_{airline_mkt}$ indicates that, on average, one additional carrier active in a market lowers the market equilibrium airfare by 3.5~3.7%. The coefficient estimates of $Threat_all$ and $Threat_non_legacy$ measure the role of potential market competition in influencing the market airfare. It is also expected to have a negative impact on the airfare rationalized by the fact that stronger entry threat from potential entrants exerts stronger potential competition in the market, which places a
downward pressure on the market airfare. The coefficient estimate of Threat_non_legacy has the expected sign and statistically significant, suggesting that one additional non-legacy carrier exhibiting threat to the other market participants lowers the market fare by 2.39% on average. The coefficient estimate of Threat_all does not have expected sign and not significant at conventional level.

In order to assess the role of market competition level in influencing the size of pass-through from changes in crude oil price to airfare, we focus on the interaction terms: \( \log(P_c) \times N_{\text{airline_mkt}} \), \( \log(P_c) \times \text{ Threat_all} \) in Model I and \( \log(P_c) \times N_{\text{airline_mkt}}, \log(P_c) \times \text{ Threat_non_legacy} \) in Model II. The interaction terms of \( \log(P_c) \times N_{\text{airline_mkt}} \) in both models are statistically significant at conventional level. In Model I, the coefficient estimate of \( \log(P_c) \times N_{\text{airline_mkt}} \) suggests that the more airlines competing in a market, the greater the size of pass-through. Specifically, it implies that, on average, one additional air carrier serving a market increases the pass-through elasticity by around 0.006 percentage point. In other words, a 10% increase in crude oil price yields 0.06% higher of airfare for each one additional air carrier in the market, everything else constant. The coefficient estimate of \( \log(P_c) \times \text{ Threat_all} \) in Model I is not statistically significant, so we focus on the interpretation of the coefficient estimate of \( \log(P_c) \times \text{ Threat_non_legacy} \) in Model II, i.e. \( \hat{\theta}_5 \) = 0.00757. This estimate implies that one additional non-legacy carrier placing an entry threat in a market raises the pass-through elasticity by around 0.008 percentage point. Put differently, airfare is likely to be 0.08% higher in respond to 10% increase in crude oil price when there is additional entry threat from a non-legacy carrier, everything else constant. In summary, we consider the above results empirically validate our prediction in Proposition 3 that greater market competition on average produces greater extent of pass-through from changes in crude oil price to airfare.

We now consider how market non-stop flight distance affects market airfare by examining the coefficient estimates of the logarithm market distance, \( \log(\text{distance}) \), in each model. Our regression results show that the coefficient estimates are both significantly different from zero with positive signs, suggesting that the longer the market

\[^{28}\text{This impact of market structure in the pass-through rate is captured by the parameters } \theta_3, \theta_5, \text{ i.e. } \theta_3 = \frac{\partial \text{PTR}}{\partial N_{\text{airline_mkt}}} \text{ in Model I and II, } \theta_5 = \frac{\partial \text{PTR}}{\partial \text{Threat_all}} \text{ in Model I and } \theta_5 = \frac{\partial \text{PTR}}{\partial \text{Threat_non_legacy}} \text{ in Model II.}\]
distance, the higher the airfare in equilibrium. Specifically, a 10% increase in market distance between the origin and destination results in around 4% increase in equilibrium airfare. It seems reasonable as the longer distance of air travel services is normally associated with higher overall flight costs, such as greater fuel burn or longer flight hours for the crew, thus the higher the price level airlines set.

To see how market distance affects the size of pass-through, we now look at the coefficient of the interaction term between crude oil price and logarithm market distance: \(\log(P_c) \times \log(\text{distance})\). Both estimates in Model I and II are statistically significant with negative signs, indicating that the size of pass-through declines with market distance. For example, everything else constant, a 10% increase in an O-D market distance reduces the pass-through elasticity by 0.15-0.16%. The 10% increase in market direct flight distance is approximately 141 miles evaluated at the sample mean. The negative sign suggests that the “level effect” dominates the “elasticity effect” according to our model prediction. It is likely that air travel demand has a relative larger shift for shorter distance travel as switching between driving and flying tend to be much easier in shorter distance in the case of a change in crude oil price. Keeping in view of this, on the supply side, airlines are likely to pass along a cost shock to passengers through airfare in shorter haul markets than they would do in longer haul markets. However, to further examine Proposition 4, a more flexible consumer demand model may be recommended to facilitate more flexible consumer substitution patterns.

We now examine the potential role of airlines’ jet fuel hedging decisions in affecting the equilibrium airfare and the size of pass-through as a result of changes in crude oil price. We first focus on how the Hedge dummy may affect the market airfare. In both models, we see the statistical significant coefficient estimates of Hedge dummy with positive signs, suggesting that the average airfare for hedged air travel products are relatively higher than the average airfare for unhedged air travel products. Specifically, airfare for products under fuel hedging contracts, on average is about 43% higher than otherwise. One plausible explanation is that airlines which use jet fuel hedging contracts

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29 This impact of market distance on pass-through rate is captured by the parameter \(\theta_7\), i.e. \(\theta_7 = \frac{\partial \mu_P}{\partial \log(\text{distance})}\) in Model I and II.

30 Toru (2011) uses both the standard logit demand and nested logit demand to capture consumers’ substitution pattern among differentiated products.
tend to charge higher prices compared with those without hedging contracts owning to the initial investment costs for entering the fuel hedging instruments.

To better understand the jet fuel hedging effect on the pass-through rate, we consider the coefficient estimates for the interaction term between crude oil price and the hedging dummy: $log(P_c) \times \text{Hedge}$. The estimates in Model I and II are both statistically significant at conventional level with negative signs, implying that the adoption of jet fuel hedging contracts places downward pressure on the size of pass-through. Specifically, the pass-through rate for products under fuel hedging contracts, on average, is 0.084 percentage point lower than the pass-through rate for products unhedged. The significance of this estimate in each model suggests that whether airlines entering jet fuel hedging contracts or not has statistical impact on the size of pass-through from crude oil price shocks. This result validates our theoretical prediction in Proposition 2 that fuel hedging provides airlines incentive to reduce the intensity of pass-through to airfare when facing a crude oil price shock. However, as airline fixed effect is excluded from both specifications, we need to be cautious in terms of interpreting the magnitude of hedging effect. It is likely that the $\text{Hedge}$ dummy may have picked up some other effects common to all the hedged airlines more than the pure hedging effect relative to unhedged airlines. The hedging effect on the equilibrium airfare as well as the pass-through elasticity in both models is likely to be overestimated.

We turn next to analyze how the other factors affect the airfare in the model. The coefficient estimates of $\text{Interstop}$ in both models are statistically significant with expected signs. The positive sign implies that one additional intermediate stop that a product has increases average airfare by about 8.4%. It makes sense as more intermediate stops that a product has imply longer itinerary flying miles thus higher fuel costs associated with the product. The same rationale applies to the coefficient estimates of $\text{Inconvenience}$, another measure of product travel convenience, computed by dividing the itinerary flying distance by non-stop flight distance of two endpoints cities. It is reasonable to expect the greater the product’s $\text{Inconvenience}$, the more the itinerary flying miles relative to the product’s non-stop flight miles, the higher the fuel costs are

\[31\] The jet fuel hedging impact on pass-through rate is measured by the parameter $\theta_9$: $\text{PTR}$ evaluated at $\text{Hedge} = 1$ represents the difference in impact on the pass-through elasticity for products under hedging contracts as opposed to products without hedging.
likely to incur, the higher the ticket price that airlines need to charge for. The sign for the coefficient estimates of $Origin\_Presence$ are both positive and significantly different from zero. Since this coefficient estimate measures airline airport prominence or “hub premium”, we expect the greater the airline presence in an origin airport (thus a larger “hub premium”), the greater impact of airlines may have on the market fare. One the other hand, consumers may also value more on services offered by airlines in their hub/focus cities with more non-stop connections. At last, to control for the impact of the potential consumer demand on airfare, we introduce the geometric mean of the population size in origin and destination cities in the regression. The coefficient estimates of logarithm $Population$ are both statistically significant with positive signs in Model I and II, suggesting that the larger the market size, the greater the potential demand and thus the higher equilibrium airfare will be.

With the key pass-through parameter estimates in hand, we may move a further step to assess the overall impact of crude oil price shocks on airline market fare by computing the average rate of pass-through. The last row of Table 4 lists the overall pass-through rates using the parameter estimates of $\hat{\theta}_1, \hat{\theta}_3, \hat{\theta}_5, \hat{\theta}_7, \hat{\theta}_9$ from the regressions and variables of $N\_airline\_mkt$, $Threat\_all$, $Threat\_non\_legacy$, $distance$ at their sample mean, and hedging dummy evaluated at 1. Evaluated at the sample mean before considering the hedging effect, the average pass-through rate suggests that, on average, a 10% increase in crude oil price will be translated into a 0.4~0.5% increase in airfare. Taking into account the hedging effect, we find out that every 10% increase in crude oil price leads to 0.35~0.44 percentage points lower in airfare for products under hedging as compared to products without hedging. This estimate suggests that average rate of pass-through for hedged products is about 0.4% lower than that for unhedged products. This result validates the role of jet fuel hedging in mitigating air carriers’ incentive to pass along any positive cost shocks to consumers through higher airfare. According to our theoretical model, this price transmission resulted from crude oil price changes is likely to be attributed to either the demand-side consumer substitution pattern between driving and flying or the supply-side airline’s cost pass-through owing to higher fuel costs, or both. The reduced-form approach however is not sufficient to disentangle the demand-side effect from the supply-side effect and vice versa. We leave it for future extension.
Table 4: OLS Regression Results

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<th>Model I</th>
<th>Model II</th>
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<tbody>
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<td></td>
<td>log(P)</td>
<td>log(P)</td>
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<tr>
<td>log(P_c) (θ₁)</td>
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<td>0.0611***</td>
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<td></td>
<td>(0.0187)</td>
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<tr>
<td>N_airline_mkt (θ₂)</td>
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<td>-0.0350***</td>
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<tr>
<td></td>
<td>(0.00263)</td>
<td>(0.00266)</td>
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<tr>
<td>log(P_c) × N_airline_mkt (θ₃)</td>
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<td>0.00554***</td>
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<td>Threat_non_legacy (θ₆)</td>
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<td>log(distance) (θ₆)</td>
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<td>(0.00239)</td>
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<td>Hedge (θ₈)</td>
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<td>log(P_c) × Hedge (θ₉)</td>
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<td>Interstop (θ₁₀)</td>
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<td>(0.000859)</td>
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<td>Inconvenience (θ₁₁)</td>
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<td>Origin_Presence (θ₁₂)</td>
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<td>constant (θ₀)</td>
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<td></td>
<td>(3375.8)</td>
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<td>PTR</td>
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</tbody>
</table>

Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Year and quarter dummies, origin and destination dummies are included in both Model I and II.

* PTR = \( \hat{\beta}_1 + \hat{\beta}_3 \times N_{airline\_mkt} + \hat{\beta}_5 \times \text{Threat\_all} + \hat{\beta}_7 \times \log(\text{distance}) \)

* PTR = \( \hat{\beta}_1 + \hat{\beta}_3 \times N_{airline\_mkt} + \hat{\beta}_5 \times \text{Threat\_non\_legacy} + \hat{\beta}_7 \times \log(\text{distance}) + \hat{\theta}_9 \)

* PTR = \( \hat{\beta}_1 + \hat{\beta}_3 \times N_{airline\_mkt} + \hat{\beta}_5 \times \text{Threat\_all} + \hat{\beta}_7 \times \log(\text{distance}) + \hat{\theta}_9 \)

* PTR = \( \hat{\beta}_1 + \hat{\beta}_3 \times N_{airline\_mkt} + \hat{\beta}_5 \times \text{Threat\_non\_legacy} + \hat{\beta}_7 \times \log(\text{distance}) + \hat{\theta}_9 \)
6 Conclusion

The purpose of this paper is to examine the market mechanisms through which crude oil price may influence airfare and investigate the possible market characteristics that may influence the extent to which crude oil price affect airfare. Guided by a simple theoretical model and comparative analysis on the equilibrium fare level, we rely on the reduced-form analysis to empirically estimate the extent of pass-through to airline market fares of changes in crude oil price. Our empirical result reveals the average pure crude oil effect on airfare is that a 10% increase in crude oil price yields a 0.7% increase in airfare before considering any other market effects. This result provides a direct empirical evidence that a given percentage change in crude oil price translates into a certain percentage change in airfare even if this change is relatively small. This incomplete cost pass-through for the U.S. airlines suggests the incomplete competing nature of the U.S. domestic air travel market. Our regression results deliver another important message that airline-specific jet fuel hedging decisions have statistically significant impact on the size of this price transmission even though this estimate may be overestimated as this estimate may have picked up some other airline-specific effects. Specifically, we find that airlines with hedging contracts are likely to pass along airfare change to passengers by 0.84 fewer percentage point than unhedged airlines, facing every 10% increase in crude oil price. Our empirical results in terms of the impact of market competition on the strength of pass-through validates our theoretical predictions. The market competition due to the entry threats from all other non-legacy air carriers and due to the actual competing rivals both shows statistically significant impact on the size of pass-through. Last, the estimate of market distance on the pass-through elasticity suggests the relative dominance of “level effect”, indicating airlines’ greater pass-through in short-haul markets. On average, 141 miles increase in market distance tends to reduce the extent of pass-through by 0.15 percentage points.

One key contribution of this paper is that it provides concrete empirical estimates of the size of pass-through from changes in crude oil price to US domestic air travel market fare, which has not been well studied in literature. Furthermore, our empirical analysis is built on a theoretical framework that considers both demand and supply side market channels through which changes in crude oil price may be passed through to
airfare onto consumers. To best of our knowledge, this analysis of market mechanism has not been studied by any previous literature that focused on the cost-price pass-through analysis in airline industry. Relying on a reduced-form analysis, however, we are unable to disentangle the demand side from the supply side effect on the size of pass-through. As such, we will consider a structural econometric model in the future, which enables us to unpack the reduced-form analysis and examine the relative importance of each potential market channel.
References


Gayle, Philip G., and Huubinh B. Le. Measuring merger cost effects: evidence from a dynamic structural econometric model. working paper, Kansas State University, Department of Economics, 2013.


Appendix:

Proof of Lemma 1

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

\[
q^*_i = \frac{\beta}{2\beta - (n-1)\bar{\beta}} H - \frac{\beta(\beta + \bar{\beta})}{2\beta + \bar{\beta}} c_i + \frac{\beta^2 \bar{\beta}}{2\beta + \bar{\beta}} \left(\sum_{j=1}^n c_j\right)
\]

\[
= \frac{(2\beta + \bar{\beta}) H - (\beta + \bar{\beta})(2\beta - (n-1)\bar{\beta}) c_i + \beta \bar{\beta} \left(\sum_{j=1}^n c_j\right)}{2\beta - (n-1)\bar{\beta}} \left(\frac{\beta}{2\beta + \bar{\beta}} \right)
\]

The sufficient and necessary conditions for strictly positive price and quantity require the following simultaneous inequalities hold:

\[
\begin{align*}
P^*_i > 0 \\
q^*_i > 0 \\
c_i > 0 \\
H > 0 \\
\beta > \bar{\beta} > 0
\end{align*}
\]

The right-hand side system of inequalities suggests the following two scenarios:

\[
(1) \quad \begin{cases}
2\beta - (n-1)\bar{\beta} > 0 \\
(2\beta + \bar{\beta}) H + \beta [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j > 0 \\
(2\beta + \bar{\beta}) H - (\beta + \bar{\beta}) [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j > 0 \\
c_i > 0 \\
H > 0 \\
\beta > \bar{\beta} > 0
\end{cases}
\]

\[
(2) \quad \begin{cases}
2\beta - (n-1)\bar{\beta} < 0 \\
(2\beta + \bar{\beta}) H + \beta [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j < 0 \\
(2\beta + \bar{\beta}) H - (\beta + \bar{\beta}) [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j < 0 \\
c_i > 0 \\
H > 0 \\
\beta > \bar{\beta} > 0
\end{cases}
\]

The set (2) conditions have contradiction, as \(H > 0, \beta > 0\), marginal costs \(c_i\) are non-negative. If \(2\beta - (n-1)\bar{\beta} < 0\), this contradicts with \(2\beta + \bar{\beta}) H - (\beta + \bar{\beta}) [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j < 0\). Therefore, we conclude that to have positive Nash price and quantity requires the following conditions (necessary conditions) hold:

\[
\begin{align*}
2\beta - (n-1)\bar{\beta} > 0 \\
(2\beta + \bar{\beta}) H + \beta [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j > 0 \\
(2\beta + \bar{\beta}) H - (\beta + \bar{\beta}) [2\beta - (n-1)\bar{\beta}] c_i + \beta \bar{\beta} \sum_{j=1}^n c_j > 0 \\
c_i > 0 \\
H > 0 \\
\beta > \bar{\beta} > 0
\end{align*}
\]