Cost Pass-through in Commercial Aviation: Theory and Evidence

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Abstract

The significant worldwide decline in crude oil price beginning in mid-2014 through to 2015, which resulted in substantial fuel expense reductions for airlines, but no apparent commensurate reductions in industry average airfares has caused much public debate. This paper examines the market mechanisms through which crude oil price may influence airfare, which facilitates identifying the possible market and airline-specific characteristics that influence the extent to which crude oil price changes affect airfare. Interestingly, and new, our analysis reveals that the crude oil-airfare pass-through relationship can be either positive or negative, depending on various market and airline-specific characteristics. We find evidence that airline-specific jet fuel hedging strategy and market origin-destination distance contribute significantly to pass-through rates being negative. Specifically, the value of pass-through rate decreases with airline fuel hedging ratios and with market origin-destination distance, but increases with competition in origin-destination markets. Even when the pass-through relationship is positive, suggesting that a portion of airlines' fuel cost savings is passed on to consumers via lower airfares, this research reveals the market and airline-specific factors that limit the size of these savings passed on to consumers via lower airfares.

Keywords: Crude oil-Airfare Cost Pass-through; Jet fuel hedging
JEL Classification Codes: L93; L13

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1. Introduction

Crude oil price declined from \$111.8/barrel in June 2014 to \$38.01/barrel in December 2015, an approximate 66% reduction.[1] Unsurprisingly, financial reports of the four major U.S. airlines – American, Delta, United, and Southwest – show that they all experienced more than 30% reduction in fuel expenses from 2014 to 2015.[2] In spite of airline fuel cost savings, industry analysts argued that airfares have been "essentially stable during this period." [3] Airline price index data released by the Bureau of Labor and Statistics showed that the monthly average airfare decreased by less than 5% during this period. This evidence suggests that airline fuel cost savings have little or no pass-through to airfare, which is disturbing for many consumers of air travel. However, one may argue that an industry average airfare may not be sufficiently informative 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, this paper seeks to answer two key questions: (*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 theoretical model of air travel demand and supply in an origin-destination market. We rely on this theoretical model to study market channels through which changes in crude oil price may be reflected in airfare. The theoretical model yields clear predictions of the relationship between crude oil price and airfare, as well as reveals factors that may influence the strength of the relationship. With the theoretical model as a guiding framework, we subsequently compile a data set of information drawn from U.S. domestic air travel markets, then use reduced-form regression analysis to empirically test predictions from the theoretical model.

Empirical studies that focus on the cost-price pass-through relationship have been done on various industries. In the energy sector, Alexeeva-Talebi (2011) examined the

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[1] Oil price is represented by Brent crude oil spot price from U.S. Energy Information Administration (EIA).

[2] For example, American and Delta reported more than 40% jet fuel expense saving, while United and Southwest had over 30% reduction in fuel costs, according to these airlines' 10K reports.

[3] The New York Times. http://www.nytimes.com/2016/02/07/business/energy-environment/airlines-reap-record-profits-and-passengers-get-peanuts.html?_r=0. Similar arguments made by other interested business analysts exist in other media sources, such as CNN-Business, Washington Post, and Forbes. Relevant articles are easily searchable in these websites; thus, we decide not to list them all in the paper.

impact of introducing the European Union (EU) Emissions Trading Scheme on unleaded petrol retail prices in fourteen EU member states. Fabra and Reguant (2014) estimated the channels affecting pass-through of emissions costs to electricity prices and found a complete pass-through of costs to prices. In the retail food industry, Berck et. al. (2009) studied the pass-through from price shocks of raw commodities (corn, wheat, and gasoline) to supermarket retail prices of ready-to-eat cereals and fresh chicken. Kim and Cotterill (2008) estimated the pass-through rate of increases in raw milk prices to cheese prices. Bonnet and Villas-Boas (2016) focused on the French coffee market and studied the asymmetric pass-through patterns of retail coffee prices in response to upstream cost shocks. In the automobile industry, Gron and Swenson (2000) investigated how exchange rate changes influence the manufacturers' input market decisions and the importance of accounting for this impact on the estimated pass-through rate driven by the exchange rate changes. Hellerstein and Villas-Boas (2010) studied 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 retail prices in the U.S. auto industry. The above-listed studies have all paid particular attention to the supply-side pass-on effects to product price levels from cost shocks.

While the cost-price pass-through relationship is well examined in many sectors of our economy, there has been a scarcity of relevant studies in commercial aviation. A subset of these studies contains purely theoretical analyses that examine the impact of cost-side shocks to airfare, product quality, and airline performance measures. Forsyth (2008), for instance, studied the impact of climate change policies, such as carbon taxes or emission permits,[4] on airline market competition, airfare, and profitability. The author found that the impact differs depending on whether the market structure is competitive, monopolistic or oligopolistic. Using a theoretical model, Brueckner and Zhang (2010) argue that an increase in jet fuel price leads to higher airfare, lower flight frequency, and a higher load factor.

Empirical studies, such as Malina et. al. (2012), find U.S. airlines may not pass through to airfare the full cost of emission charge since the imperfectly competitive market

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[4] Considered as an increase in "effective fuel price". A carbon-tax scheme or carbon emission permits charge is effectively viewed as equivalent to an increase in jet fuel prices paid by airlines. Many studies adopt this idea, see Brueckner and Zhang (2010), Toru (2011), Malena et. al. (2012), Brueckner and Abreu (2016).

structure facilitates airlines with market power to absorb part of the cost increase. Koopmans and Lieshout (2016) compute the concentration level for each aviation market and suggest that most aviation markets in the world can be characterized as an oligopoly with differentiated products.[5] Based on the pass-through rates in differentiated products oligopolies computed by Zimmerman and Carlson (2010), Koopmans and Lieshout (2016) further suggested 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) uses reduced-form regression analysis and find an industry-wide fuel pass-through rate of 0.08 during periods of constant capacity, and 0.89 during periods of changing capacity. Toru (2011) adopt a structural econometric model and find the average estimated pass-through rates in the European airline market fall into the range of 0.985 to 0.989 when the corresponding effective jet fuel prices increase by 50% to 500%.

Our paper is different from the above studies in the following ways. First, unlike previous studies, we consider both demand-side and supply-side market channels through which changes in crude oil price pass-through to airfare. For example, on the air travel demand side, changes in crude oil price, through the pressure placed on gasoline price, trigger changes in consumer substitution between air travel and private automobile travel in shorter distance markets. It is indeed important to note that the demand-driven price transmission channel considered in our analysis has not been considered in the aforementioned literature.[6] Neglecting the demand-side pass-on effects can result in substantial bias in measuring the crude oil price-airfare pass-through relationship.

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. Focusing on this supply-side pass-on effect is likely to result in an inaccurate perception that there ought to be a direct

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[5] Bulow and Pfleiderer (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) 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. 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.

[6] 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 U.S. air travel market.

positively correlated pass-on effect from jet fuel price to airfares, a prediction made by many business analysts. Our research therefore emphasizes the importance of jointly considering both demand side and supply side market channels when examining the crude oil price-airfare pass-through relationship.

Second, unlike previous studies, our theoretical and empirical models allow market-specific and airline-specific factors to affect airfare levels as well as the rate of crude oil price-airfare pass-through. The previous literature has uniquely focused on how cost shocks impact firms' pricing strategies, profitability, and other firm-level and market-level performance measures.[7] There is a notable lack of discussion on the driving forces and impacting factors that directly or indirectly influence the magnitude of the cost-price pass-through in the aviation sector.[8]

This research makes clear that a key airline-specific factor that influences the sign and strength of the crude oil price-airfare pass-through relationship is the extent to which an airline engages in jet fuel hedging.[9] Extent of fuel hedging here means the proportion of an airline's estimated fuel consumption (in volume) covered by fuel hedging contracts. [10] Our analysis also reveals that an airline's hedging strategy influences the marginal impact of other market-specific factors on the pass-through rate. To best of our knowledge, our paper is the first to provide a formal theoretical and empirical analysis on how airlines' fuel hedging strategies influence the size of crude oil price-airfare pass-through.

Our paper also contributes to the literature on financial risk management in aviation. Several studies have examined the impact of airline jet fuel hedging programs on the firms' market value, fuel price risk exposure, and operating cost. For example, Carter, Rogers,

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[7] See Forsyth (2008), Brueckner and Zhang (2010), and Toru (2011), etc.

[8] There is a broad range of literature on other industries that studies the underlying driving forces and influencing factors that may lead to different estimates of cost-price pass-through. Hellerstein and Villas-Boas (2010) is one example that focuses on the auto manufacturing sector. They look at the influence of vertical structure of auto production on the pass-through rate estimates driven by changing exchange rates. Another example, Verboven and Dijk (2009) propose a theoretical framework and introduce a "discount" variable to capture the pass-on effect due to a shock in a cartel input market, and the size of discount is determined by intensity of market competition in the downstream industry.

[9] Airlines utilize over-the-counter fuel derivative instruments to hedge a portion of its expected future jet fuel requirements to address not only fuel price increases, but also fuel price volatility.

[10] Financial instruments often used individually or collectively in airline fuel hedging programs include, but are not limited to the following: forward contracts, futures contracts, options, swaps, and collars [Morrell and Swan (2006)]. The percentage of estimated fuel consumption covered by fuel hedging programs is reported in airlines' annual reports.

and Simkins (2006) investigated whether jet fuel hedging behavior of airlines is a source of their market value, and find that an airline's jet fuel hedging is indeed positively related to its market value. Treanor et.al. (2014) examined the effects of both financial and operational hedging on jet fuel exposure in the U.S. airline industry and find both types of hedging are important tools in reducing airline exposure to jet fuel price risk. Lim and Hong (2014) studied the role of fuel hedging in reducing airlines' operating costs, and therefore its role in generating cost efficiency gains for airlines. We, instead, examine both theoretically and empirically, the role of jet fuel hedging programs as an influencing factor of airline pricing and of the crude oil price-airfare pass-through relationship.

Key results from the analysis are as follows. First, our theoretical model predicts that the crude oil price-airfare pass-through relationship, also referred to as "price transmission" relationship, [11] can be either positive or negative; and this pass-through varies by some firm-specific and market-specific characteristics. To the best of our knowledge, a formal theoretical prediction with systematic supporting empirical evidence of a negative crude oil price-airfare pass-through relationship is new to the literature. Note that firm-specific and market-specific situations that yield a negative crude oil price-airfare pass-through relationship further imply that falling crude oil price results in a higher, rather than lower, airfare. Such countercyclical movement of crude oil price with many airfares has been perplexing to market analysts, and frustrating for many consumers of air travel.

A key firm-specific characteristic is airlines' jet fuel hedging ratios, i.e. the percentage of airlines' jet fuel consumption (in volume) covered by their hedging contracts. The theory predicts that the crude oil price-airfare pass-through rate declines with higher airlines' fuel hedging ratios. Specifically, on the one hand, a greater percentage of fuel hedging has a weakening effect on a positive pass-through, reducing the direct pass-on effect from crude oil price changes to airfare. On the other hand, a greater percentage of fuel hedging magnifies a negative pass-through, causing a greater increase (decrease) in airfare as crude oil price decreases (increases).[12] Consistent with what the theory predicts,

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[11] This term "price transmission" has been used interchangeably with "cost pass-through" in many empirical works that study the cost-price pass-through relationship in a variety of markets, such as Aguiar and Santana (2002), Leibtag et. al. (2007), Bonnet and Villas-Boas (2016) and many others.

[12] Graphically, our theory suggests that a curve depicting the relationship between crude oil-airfare pass-through rate and an airline's fuel hedging ratio is negatively sloped.

our empirical results suggest a negative relationship between crude oil price-airfare pass-through rates and airlines' fuel hedging ratios.

One market-specific characteristic that influences the pass-through rate is the intensity of market competition. Our theory model predicts that this effect can be positive or negative, depending on airlines' jet fuel hedging ratios. Our empirical results suggest an average positive effect of market competition on the crude oil price–airfare pass-through rate when competition intensity is measured by the number of non-stop products offered in the market. The competition effect on pass-through rate from number of non-stop products is particularly stronger than the effects when market competition is measured by number of competing one-intermediate stop products, and number of competing products with two or more intermediate stops.

Another market-specific characteristic that has substantial influence on the crude oil-airfare pass-through rate is the direct distance between the origin and destination. Our theory predicts the influence of market distance on the pass-through rate depends on both the range of distance and airlines' adoption of jet fuel hedging programs. The empirical results suggest that the value of crude oil price-airfare pass-through elasticity is negatively influenced by market distance.

Given our finding that the pass-through relationship is positive in some market and airline specific cases, but negative in other cases, this research reveals why it can be misleading to focus on the relationship between industry average airfare and crude oil price changes. An industry average airfare masks the countervailing negative and positive responses of various market and airline specific airfares to changes in crude oil price. Furthermore, even when the pass-through relationship is positive, suggesting that a portion of airlines' fuel cost savings is passed on to consumers via lower airfares, this research reveals the market and airline specific factors that limit the size of these savings passed on to consumers via lower airfares.

The paper proceeds as follows. In the next section, we specify and analyze a theoretical model of air travel demand and supply in an origin-destination market. Section 3 provides the empirical analysis, which starts by describing the data, then specifying and estimating the empirical model, and discussing the empirical results. Concluding remarks are gathered in section 4.

2. Theoretical Model

The purpose of this section is to provide a 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 pass-through rate. The theoretical model comprises both demand and supply sides of the market for air travel.[13]

To construct the consumer demand function, we consider consumers' willingness to substitute between the mode of mass transit by air travel and alternate modes of transportation. In particular, the alternate mode of transport that our analysis focuses on is private automobile travel. Conditional on the two modes of transport being technically feasible between the origin and destination, we posit that consumers' willingness to substitute between the two modes of transport depends on the market distance between origin and destination.[14] 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.[15] Following this argument, air travel as well as other modes of mass transit, become relatively cheaper compared with private automobile travel when there is an increase in gasoline price. Therefore, we introduce gasoline price into the air travel demand equation.

On the supply side, airline fuel cost is a major component of airline operating costs. During year 2014 the aviation fuel expense of the aforementioned four major U.S. airlines accounts for approximately 32% of their respective total operating expenses, the largest component of airline operating costs, followed by their operating expenses on labor.[16] Airlines' aviation fuel costs are directly affected by the jet fuel price level. Both gasoline

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[13] We focus the crude oil-airfare pass-through analysis in the short-run, and therefore, both consumer and firm behavior reflect their responses to changing energy prices during a time horizon sufficiently short such that there are little or no changes in production technology in response to energy price changes.

[14] According to the Bureau of Transportation Statistics, among all the long-distance (greater than 50 miles) travel modes in the U.S., 89.5% of annual trips are taken by personal automobiles, 7.4% are taken by air travels, 2.1% are taken by buses, only 0.8% are taken by train. See the following source link: https://www.bts.gov/archive/publications/america_on_the_go/long_distance_transportation_patterns/entire

[15] 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.

[16] Labor cost represents 21% to 40% of total operating expenses for the four major airlines during the sample period. Readers may refer to airlines' annual reports for detailed information of their operating expenses.

and jet fuel are petroleum products that are refined from crude oil, therefore, changes in crude oil price result in changes in jet fuel and gasoline prices.

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.[17]

2.1 Demand

We consider 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 the destination. As such, a given origin-destination market may have several competing products that are differentiated by their routing. Following the framework of Shubik-Levitan (1980) demand system, the demand of an air travel product $i = 1,2,\dots,n$ among n differentiated air travel products in a market can be represented by:

$$q_i = H_i - \beta P_i + \tilde{\beta} \sum_{j \neq i}^{n-1} P_j \quad \text{for all } i = 1,2,\dots,n \tag{1}$$

where q_i represents the demand level for air travel product i, and P_i is the associated price level for product i. All other products are considered substitute goods to product i, placing an equal cross-price impact on product i's demand, which is measured by the parameter $\tilde{\beta} > 0$. We make a standard assumption when specifying a system of demand equations, which is that the demand impact of an own price change is greater than cross-price demand impacts, i.e. $\beta > \tilde{\beta}$.

Motivated by analyses in Gillen et. al. (2003), to account for the different elasticity of air travel demand in markets of differing distances, we argue 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 a more realistic alternative for relative shorter distance travel. We capture this effect by specifying β to be a decreasing function of market distance based on an exponential functional form, i.e.:

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[17] U.S. Energy Information Administration website provides daily spot prices for crude oil and its refinery products, which include gasoline and jet fuel. It clearly shows strong positive relationships among these prices. Readers may refer to the source link: https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm

$$\beta = e^{-\beta_0 Mkt\_Dist} \tag{2}$$

where $\beta_0 > 0$, and Mkt_Dist is a metric of market distance, measured by the non-stop flying distance between the origin and the destination of the market. Rearranging equation (1) to express it in inverse demand function form,[18] and considering the relationship between β and market distance specified in equation (2), it is evident that β gets smaller as market distance increases, and smaller β corresponds to a steeper inverse demand curve, suggesting a less elastic air travel demand in longer distance markets.

We now augment the specification of the demand function for air travel product i to capture the fact that a product's level of demand depends on several product-specific and market-specific factors. In particular, let the H_i component of product $i's$ demand be determined by the following functional specification:

$$H_i = h_0 + h_1 X_1 + h_2 X_{2i} + h_3 \sum_{j \neq i}^{n-1} X_{2j} + \gamma D_i P_g \tag{3}$$

where X_1 is a vector of demand-shifting factors that are not product-specific and influence the level of demand for all air travel products, while h_1 is a vector of parameters that caputre the marginal demand impact of each of the variables in X_1, respectively. X_{2i} and X_{2j} are vectors of product-specific non-price characteristics that influence the level of demand for product i, while h_2 is a vector of parameters that capture the marginal demand impact of each of the product-specific variables in X_{2i}. The demand-shifting factors in X_{2j} marginally impact product i's demand according to parameter vector h_3. Including X_{2i} and X_{2j} in equation (3) recognizes that the demand for product i is not only influenced by its own non-price characteristics, but also influenced by the non-price characteristics of substitute products, a demand feature we often see in discrete choice models of demand [Gayle and Xie (2018 and 2019)].

Equation (3) recognizes that air travel product $i's$ demand level is influenced by gasoline price, P_g, but its marginal impact on air travel demand depends on γ and D_i. γ is a function of market distance, Mkt_Dist, and D_i identifies the intermediate stop(s) feature of product i, i.e., D_i identifies whether product i is non-stop, has one intermediate stop, or

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[18] $P_i = \frac{H_i}{\beta} - \frac{1}{\beta} q_i + \frac{\tilde{\beta}}{\beta}\left(\sum_{j \neq i}^{n-1} P_j\right)$, for all $i = 1,2, \dots n$

has two or more intermediate stops. First, we discuss why market distance does matter for the marginal impact of gasoline price on air travel demand.

A consumer's travel cost on a trip can be broken down into implicit and explicit costs. The explicit travel costs are the actual cash payments the consumer makes to obtain transportation services for the trip, e.g. purchase of airline ticket for air travel services, or purchase of gasoline in the case of automobile travel. The implicit cost of travel a consumer bears is the opportunity cost of the consumer's time used up in getting from the origin to destination. As such, the implicit travel cost suggests a consumer's travel cost is positively correlated with the time it takes to complete the journey from origin to destination.

It is expected that consumers' choice between private automobile travel and air travel depends on the relative cost that the consumer faces between the two modes of transportation, which is driven by the implicit component of a consumer's travel cost previously discussed, i.e., the relative cost is influenced by the relative travel times associated with the two modes of transportation. As previously mentioned, we use non-stop flying miles between the market's endpoints as an index of the market distance. Even though this metric of market distance is not an approximation of the actual driving distance, the assumption is that it is positively correlated with driving distance, i.e., the further away the destination is from the origin as measured by non-stop flying miles, the greater will be the driving distance between these endpoints.

First, when consumers travel from an origin to a destination, total traveling time increases as the two endpoints become farther away, regardless of the chosen mode of transportation. In other words, the associated total time cost of each transportation mode to consumers is expected to be a monotonic increasing function of the market distance. However, one difference between driving with personal vehicles and flying with airplanes is a lumpsum/fixed component of travel time associated with air travel, which includes time required in getting to the airport, going through security checkpoint(s), and waiting to board the aircraft; whereas auto travelers can simply "jump" into the car and begin the journey towards their destination. For the air transport mode in a given market, if a consumer is traveling with indirect flights, there will be some layover time for each connecting flight, adding extra time cost to the total time cost compared to those who fly with a direct flight.

Second, we assume that the cost to the consumer of driving, which includes the opportunity cost of time, increases faster with market distance compared to the cost to the consumer of air travel. In particular, due to the substantially faster pace in which air transport technology covers a mile towards the destination compared to automobile transport technology, the incremental time cost to the consumer associated with using ground transport to cover an extra mile toward the destination is expected to be greater than the incremental time cost associated with using air transport to cover the extra mile.

Figure 1: Diagram illustrating consumer travel cost curves for the two distinct modes of transportation

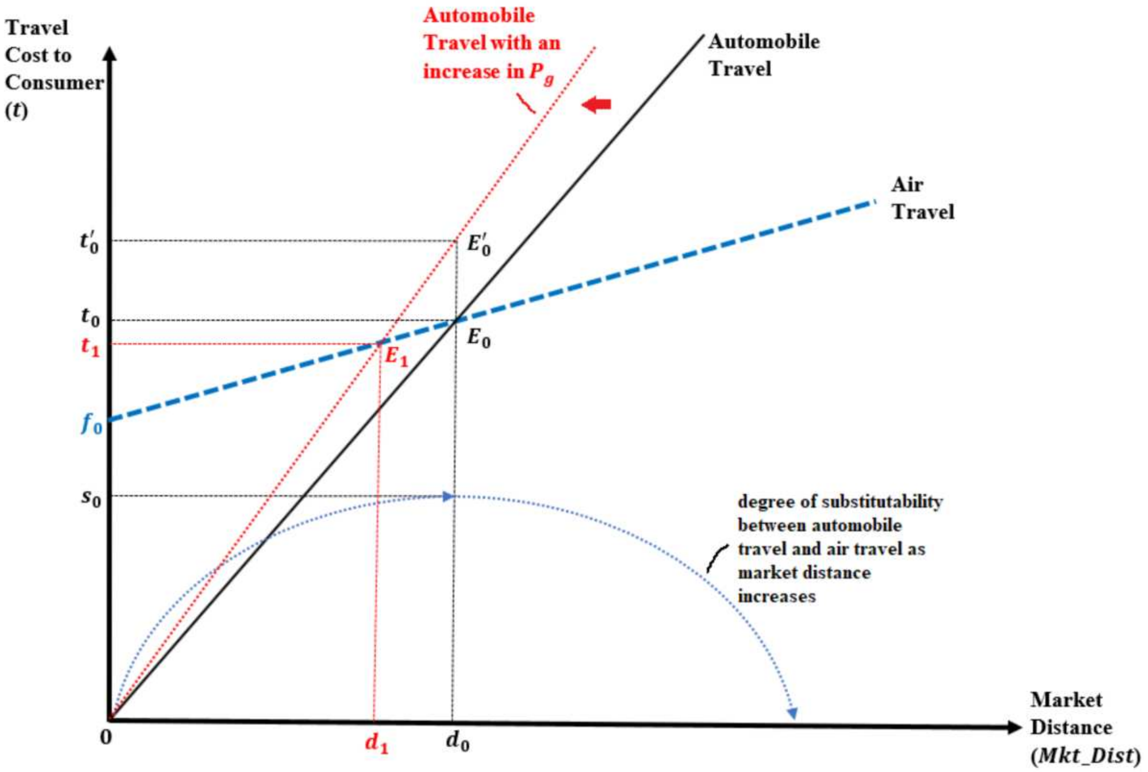

Figure 1 depicts the relationship between travel cost (the aggregate of explicit and implicit components of travel costs) a consumer faces with each transporation mode and market distance at given gaosline and airline ticket price levels. The travel cost curves depicted in the figure have distinctive features, which are consistent with discussions above. Key distincitve features of the travel cost curves are: (*i*) upward sloping, which is owing to consumers' implicit cost component of travel cost increasing with travel time as the two endpoints become farther away from each other;[19] (*ii*) the automobile travel cost curve is

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[19] We use upward sloping straight lines for illustrative purpose. The actual total traveling time cost associated with each transportation mode does not necessarily follow constant rate of change with market distance.

the steeper among the two, reflecting the fact that the incremental time cost to the consumer associated with using ground transport to cover one extra mile towards the destination is greater than the incremental time cost associated with using air transport to cover the extra mile; (*iii*) owing to a lumpsum/fixed component of travel time cost associated with air travel, the air travel cost curve has a positive vertical intercept; and (*iv*) the vertical intercept for the automobile travel cost curve is located approximately close to the origin of the diagram, indicating nearly zero lumpsum/fixed time cost associated with private automobile travel.

In Figure 1, the automobile travel cost curve intersects the air travel cost curve at E_0, which identifies the market distance d_0 at which consumers' travel cost from using air transport is equal to their travel cost from using automobile transport. As such, in a market with distance d_0, the two transportation options are perceived by consumers to be perfect substitutes. Starting at market distance d_0, as market distance decreases, the perceived substitutability between the two modes of transportation also decreases, with automobile travel being the prefered mode of transport due to this mode having lower travel cost to the consumer at these shorter market distances. Again starting at market distance d_0, but now moving towards longer market distances, the perceived substitutability between the two modes of transportation again decreases, with air travel being the prefered mode of transport due to this mode having lower travel cost to the consumer at these longer market distances. In other words, the consumers' perceived substitutability between the two modes of transportation has an inverted U-shaped relationship with market distance, with the highest perceived substitutability occuring at market distance d_0. Assuming consumers' perceived substitutability is also measured on the vertical axis of Figure 1, we use a thin dashed arc with arrows to represent the degree of substitutability between the two modes of tansportation across market distances.

Using the consumer travel cost framework depicted in Figure 1 as a starting point, to develop the demand model further, it's useful to consider comparative statics resulting from a change in gasoline price. An increase in gasoline price will result in a leftward shift and rotation of the automobile cost curve reflecting the fact that the explicit cost component of automobile travel cost is now higher for each market distance. With this change in the automobile cost curve, consumers in markets with distance d_0 will no longer be indifferent between driving versus flying, but will prefer flying causing an increase in air travel demand in such markets. Furthermore, it is straightforward to use the model to argue that the largest impacts on air travel demand resulting from changes in gasoline price will be in markets with distances in the neighborhood of d_0, with demand impacts attenuating at market distances further away from d_0.

Therefore, the marginal impacts on air travel demand resulting from changes in gasoline price should reflect the inverted U-shaped relationship between consumers' perceived substitutability between the two modes of transportation and market distances. To capture such nonlinear marginal impact on air travel demand resulting from changes in gasoline price, we specify that γ in equation (3) depends on market distance given by:

$$\gamma = \gamma_1 Mkt\_Dist \ + \gamma_2 Mkt\_Dist^2 \tag{4}$$

where $\gamma_1 > 0$, $\gamma_2 < 0$, $Mkt\_Dist \in (0, -\frac{\gamma_1}{\gamma_2}]$ and $\gamma_1 Mkt\_Dist + \gamma_2 Mkt\_Dist^2 > 0$; and the maximum value of γ occurs when $Mkt\_Dist = -\frac{\gamma_1}{2\gamma_2}$, corresponding to the idea captured by d_0 in Figure 2.[20] We now discuss why the intermediate stop(s) feature of an air travel product, captured by D_i in equation (3), also influences the marginal impact on demand resulting from changes in gasoline price.

For a given origin-destination market (thus for a given market distance), a consumer is more likely to prefer an air travel product with shorter total travel time (flying time plus layover time for connecting flights), *ceteris paribus*. Therefore, the demand of a non-stop air travel product is likely more strongly affected by changes in gasoline price than a product with one intermediate stop, which has greater total travel time relative to non-stop products. Similarly, in a given origin-destination market, the demand of an air travel product that has one intermediate stop is likely more heavily affected by changes in gasoline price than a product with two or more intermediate stops. Consequently, when gasoline price increases, the level of air travel product i's demand is expected to have a greater increase if product i is a non-stop flight than if it is a one-stop flight; and the demand increase is greater if it is a one-stop flight than if it is a two-or-more-stop flight.

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[20] A simple quadratic function is sufficient to capture the changing substitutability between automobile travel and air travel as market distance varies. Other polynomial functions that capture the same idea are also applicable but not considered here for computational simplicity.

To introduce the above discussed effects into the demand equations, we formally characterize D_i using the following equation:

$$D_i = h_4 d_{i0} + h_5 d_{i1} + h_6 d_{i2} \tag{5}$$

In equation (5), d_{i0}, d_{i1} and d_{i2} are each zero-one indicator variables: d_{i0} takes the value 1 if product i is a non-stop product; d_{i1} takes the value 1 if product i has only one intermediate stop; and d_{i2} takes the value 1 if product i has two or more intermediate stops. Therefore, air travel product i can only fall into one of three intermedaite stop(s) product categories, $d_{i0} = 1$, $d_{i1} = 1$ or $d_{i2} = 1$. Parameters h_4, h_5 and h_6 capture the respective intermedaite stop(s) specifc marginal impact of gasoline price on product $i's$ demand, and based on our previous discussion, they have the following relationship: $h_4 > h_5 > h_6 \geq 0$.

Last, we specify that gasoline price, P_g, is influenced by crude oil price, P_c, via a simple equation given by: $P_g = \delta_0 + \delta_1 P_c$. Through the 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.

2.2 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:

$$\pi_i = (P_i - c_i) q_i \qquad \text{for all } i = 1,2,\dots,n \tag{6}$$

where $c_1, c_2, \dots, c_n$ are the marginal costs that firms incur to provide products $1,2,\dots,n$, respectively. We assume that airlines simultaneously and non-cooperatively choose prices, in Bertrand-Nash fashion, to maximize profit. Assuming strictly positive prices, $P_i > 0$, and production levels, $q_i > 0$, the following closed-form expression for Nash equilibrium airfares can be obtained:[21]

$$P_i = \frac{2\beta-(n-2)\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} H_i + \frac{\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} \left(\sum_{j\neq i}^{n-1} H_j\right) + \frac{\beta[2\beta-(n-2)\tilde{\beta}]}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} c_i + \frac{\beta\tilde{\beta}}{(2\beta+\tilde{\beta})[2\beta-(n-1)\tilde{\beta}]} \left(\sum_{j\neq i}^{n-1} c_j\right) \quad \text{for all } i = 1,2,\dots,n \tag{7}$$

We further specify airline i's marginal cost function as:

$$c_i = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_{2i} + \alpha_{3i} P_f + D_i^c P_f + \alpha_7 ItineraryDist_i P_f \tag{8}$$

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[21] The reader is referred to the appendix in Gayle and Lin (2020) for detailed calculations.

where

$$D_i^c = \alpha_4 d_{i0} + \alpha_5 d_{i1} + \alpha_6 d_{i2} \tag{9}$$

$$\alpha_{3i} = a_0 + a_1 Hedge_i \tag{10}$$

$$P_f = \phi_0 + \phi_1 P_c \tag{11}$$

In the equations above, c_i represents the marginal cost incurred by the relevant airline to provide air travel product $i = 1,2, \dots, n$; Z_1 is a vector of non-product-specific cost-shifting variables that affect an airline's marginal cost; Z_{2i} is a vector of product-specific cost-shifting variables; while α_1 and α_2 are vectors of parameters that capture the influence of the respective cost-shifting variables on the level of marginal cost for product i. P_f represents jet fuel spot price. Equation (8) reveals that jet fuel spot price, P_f, influences the marginal cost of air travel product i through three distinct sources: (*i*) through the interaction of P_f with α_{3i}; (*ii*) through the interaction of P_f with D_i^c; and (*iii*) through the interaction of P_f with $ItineraryDist_i$. We now discuss each of these sources in turn.

The parameter α_{3i} captures a portion of the marginal effect of jet fuel spot price on airline i's marginal cost of providing product i. The way in which α_{3i} captures a partial impact of jet fuel spot price on airline i's marginal cost is specified in equation (10), where variable $Hedge_i$ measures the proportion of airline i's estimated fuel consumption (in volume) covered by fuel hedging contracts.[22] Airlines utilize over-the-counter fuel derivative instruments that have petroleum products as underlying assets, such as crude oil, heating oil, and gasoline, which are highly correlated with jet fuel, to hedge a portion of its expected future jet fuel requirements to address not only fuel price increases, but also fuel price volatility, hedge costs, and hedge collateral requirements (Southwest 2013).[23] The definition of the hedging ratio implies $Hedge_i \in [0,1]$, and $Hedge_i = 0$ when airline i

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[22] Note that we model equation (10) as a linear function; however, with a willingness to handle additional computational challenges, the hedging ratio may enter α_{3i} non-linearly. In addition, fuel hedging ratio, $Hedge_i$, is based on the description in airlines' annual reports. It represents the average percent of estimated fuel consumption requirements in terms of gallons covered by fuel derivative contracts at varying underlying commodities price levels (for example, see Southwest 2013, p59; Alaska 2013, p132).

[23] For example, airlines may use a collar (combination of a call and a put option) to "lock in" price that will be paid for fuel between two agreed price levels ("strike price"), in order to mitigate the impact of spot market fuel price volatility [Morrell and Swan (2006)]. Specifically, the call option gives airlines the right to purchase the fuel (or other commodities) at a future date for a price agreed today; while the put option gives airlines the right to sell it at a future date for a price agreed today. These financial instruments do not necessarily require the delivery of the hedging assets. We use Southwest Airlines as an example for illustrative purpose, as it is a relatively experienced hedger in the industry [Lim and Turner (2016)].

does not engage in any fuel hedging, leading to a complete exposure of the product i's marginal cost, c_i, to jet fuel and crude oil market fluctuations. In the event that an airline does not have any hedging programs, then we would expect a positive correlation between the spot price of fuel and product i's marginal cost. Therefore, the constant term in equation (10) is expected to be positive, i.e., $a_0 > 0$, capturing the positive marginal effect of jet fuel spot price on the marginal cost for air travel products when airlines do not hedge.

In most cases, airlines utilize a mixture of financial derivative instruments as a form of insurance against the potential for significant increase in fuel prices. When an airline hedges directly in jet fuel, the use of fuel hedging programs is beneficial during subsequent periods of rising spot fuel price since the airline is able to procure the hedged portion of fuel requirements at a cheaper "locked-in" price level; whereas, when an airline hedges in other jet fuel proxies, such as crude oil, heating oil or gasoil, the airline is able to receive financial gains upon execution of these hedging contracts [Lim and Turner (2016)]. Assuming other determinants of marginal cost are equal across airlines, airlines with relatively higher jet fuel hedging ratio benefit in terms of having relatively lower marginal cost during periods of rising fuel spot price. On the other hand, an airline's fuel hedging program is disadvantaged during subsequent periods of falling fuel spot price since the airline is obligated to obtain the hedged portion of its fuel at a more expensive "locked-in" price in cases when the airline hedges directly in jet fuel, or incur financial loss in cases when the airline hedges in other commodities. Therefore, airlines with relatively greater fuel hedging ratios are disadvantaged in terms of having relatively higher marginal cost during periods of falling fuel spot price. These arguments imply a negative correlation between fuel spot price and the marginal cost of airlines with a sufficiently large hedging ratio, which in turn imply that $a_1 < 0$.[24]

Given that $a_0 > 0$ and $a_1 < 0$, equation (10) reveals that the entire hedging parameter, α_{3i}, can be either positive or negative, determined by airline i's hedging

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[24] We did not model the so called "locked-in" fuel/fuel proxies' price in this equation for two reasons. First, airlines tend to use a portfolio of hedging contracts that vary by financial derivatives (futures, forwards, swaps, etc. and what are the underlying assets), durations, purchase volume, and so on. The detailed information of these contracts, including the contracted fuel/fuel proxies' prices, are normally not observable to researchers. Second, these "locked-in" prices influence costs indirectly only when airlines execute their fuel hedging contracts, achieving a lump sum dollar amount of financial gain or loss at the end of the relevant time period. Airlines, in essence, pay the spot market fuel price for their daily operations.

strategy. In particular, $\alpha_{3i} > 0$ when airline i has a fuel hedging ratio, $Hedge_i \in \left[0, -\frac{a_0}{a_1}\right)$, indicating that a rising (declining) spot fuel price results in a higher (lower) marginal cost of air travel product i and this positive marginal cost effect attenuates with higher hedging ratio/proportion. Conversely, $\alpha_{3i} < 0$ when airline i has a fuel hedging ratio/proportion, $Hedge_i \in \left(-\frac{a_0}{a_1}, 1\right]$, indicating that a rising (declining) spot fuel price results in a lower (higher) marginal cost of air travel product i and this negative marginal cost effect intensifies with higher hedging ratio/proportion.[25]

It is commonly known that aircraft landings and take-offs use fuel more intensively compared to aircraft cruising.[26] Air travel products with more intermediate stops add more landings and take-offs within a given itinerary; and thus, for a given itinerary flying distance, products with fewer intermediate stops use less fuel. As such, it is expected that products with fewer intermediate stops will experience a smaller impact on fuel cost at the margin when jet fuel price changes. In the marginal cost function, D_i^c captures how the marginal cost impact of jet fuel price is associated with product i's intermediate stop feature. The zero-one indicator variables d_{i0}, d_{i1}, d_{i2} for intermediate stop feature of product i are the same as previously defined. α_4, α_5 and α_6 are the parameters that measure the respective marginal effect of jet fuel price on marginal cost associated with each of these intermediate stop dummy variables. Consistent with the discussions above regarding differing fuel-intensive usage across products with different numbers of intermediate stops, these parameters have the following relationship: $\alpha_6 > \alpha_5 > \alpha_4 > 0$.

We allow jet fuel price to influence an air travel product's marginal cost according to the product's actual flying miles, $ItineraryDist_i$, simply because longer flying routes consume more aviation fuel. Therefore, a fuel-intensive air travel product's marginal cost is likely to be influenced more by jet fuel price fluctuations. The parameter, α_7, measures the marginal cost effect of jet fuel price associated with an air travel product's itinerary distance, and it is expected to be positive, i.e., $\alpha_7 > 0$.

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[25] When $\alpha_{3i} > 0$, $\alpha_{3i} \to 0$ as $Hedge_i \to -\frac{a_0}{a_1}$. When $\alpha_{3i} < 0$, α_{3i} decreases away from 0 and becomes more negative as $Hedge_i \to 1$. This specification with respect to the hedging ratio also implies that $|a_0| < |a_1|$.

[26] See http://www.co2offsetresearch.org/aviation/Distance.html

Last, equation (11) specifies that jet fuel price, P_f, is influenced by crude oil price, P_c. Through the assumption that parameter $\phi_1 > 0$, the effect of fuel price on marginal cost translates into the indirect marginal effect of crude oil price on airline's marginal cost.

Substituting equations (3) and (8) through (11) into the Nash equilibrium solution price equation (7) yields a reduced-form equation for Nash equilibrium price for product i:

$$\boldsymbol{P_i^*} = \boldsymbol{f}(\boldsymbol{\theta}; P_c, Hedge_i, Mkt\_Dist, ItineraryDist_i, D_i, D_i^c, n, n_0, n_1, n_2, X_1, X_{2i}, X_{-2i}, Z_1, Z_{2i}) \tag{12}$$

Where

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

n is the total number of air travel products in the relevant origin-destination market; n_0 is the total number of air travel products that are non-stop in the relevant origin-destination market; n_1 is the total number of air travel products that have one intermediate stop in the relevant origin-destination market; and n_2 is the total number of air travel products that have two or more intermediate stops in the relevant origin-destination market. The actual reduced-form expression for the right-hand-side of equation (12) is reported in the appendix of Gayle and Lin (2020).

2.3 Theoretical Analysis

2.3.1 The impact of crude oil price on airfare: Pass-through Rate

The marginal effect of crude oil price on a typical air travel product's price level determines the pass-through relationship, which is derived from our theoretical model based on the following partial derivative:[27]

$$\frac{\boldsymbol{\partial P_i^*}}{\boldsymbol{\partial P_c}} = \underbrace{\frac{\tilde{\beta}(h_4 n_0 + h_5 n_1 + h_6 n_2) + [2\beta - (n-1)\tilde{\beta}]D_i}{(2\beta + \tilde{\beta})[2\beta - (n-1)\tilde{\beta}]}\gamma\delta_1}_{\boldsymbol{Demand\ Effect}\ (+)} + \underbrace{\frac{[2\beta - (n-2)\tilde{\beta}]\big((a_0 + a_1 Hedge_i) + D_i^c + \alpha_7 ItineraryDist_i\big)}{(2\beta + \tilde{\beta})[2\beta - (n-1)\tilde{\beta}]}\beta\phi_1}_{\boldsymbol{Direct\ Cost\ Effect}\ (+/-)} +$$

$$\underbrace{\frac{\tilde{\beta}\sum_{j \neq i}^{n-1}\big((a_0 + a_1 Hedge_j) + D_j^c + \alpha_7 ItineraryDist_j\big)}{(2\beta + \tilde{\beta})[2\beta - (n-1)\tilde{\beta}]}\beta\phi_1}_{\boldsymbol{Strategic\ Cost\ Effect}\ (+/-)} \tag{13}$$

where $h_4 n_0 + h_5 n_1 + h_6 n_2 = \sum_{i=1}^{n} D_i$; $\sum_{j \neq i}^{n-1} \alpha_{3j} = \alpha_{-3i}$. The above equation suggests that changes in crude oil price are translated into changes in airfare through two market

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[27] We use the similar definition of cost-price pass-through used in Kim and Cotterill (2008) in page 39.

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

The demand effect captures how crude oil price changes affect air travel demand. The component in equation (13) that captures this effect is positive, and therefore consistent with our previous discussion. An increase (decrease) in crude oil price pushes up (down) gasoline price, leading to higher (lower) air travel demand as driving becomes relatively more (less) costly. The higher (lower) demand for air travel causes airfare to rise (fall). Note that the size of the demand effect depends on the intermediate stop(s) feature of the relevant product captured by D_i. Based on our definition of D_i, the demand effect is particularly stronger the fewer the number of intermediate stops required by the air travel product. This demand-side prediction is consistent with our previous discussion.

Last, it is evident that the demand effect not only depends on the total number of competing products in the relevant market, n, but also how these competing products break down into numbers of non-stop, one intermediate stop, and two or more intermediate stops products in the market, i.e., n_0, n_1 and n_2, respectively. Later, we discuss further the pass-through rate impacts associated with number of competing products.

Direct cost effect

The 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 effect may be positive or negative, depending on the airline's hedging strategy, i.e. the airline's hedging ratio/proportion. A sufficiently small hedging ratio/proportion will yield a positive direct cost effect;[28] however, with sufficiently large hedging ratio/proportion, α_{3i} is negative and can be sufficiently large in magnitude to cause a negative direct cost effect. In fact, equation (13) can be used to show that an airline can adopt a sufficiently high hedging ratio such that most or even all its fuel usage is hedged, resulting in a negative direct cost effect that is sufficiently large to further result in a negative pass-through effect from crude oil price changes to its optimal airfare.

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[28] In this case, α_{3i} could either be positive or negative, but not sufficiently large in magnitude to cause a negative direct cost effect.

The size of the direct cost effect in equation (13) also depends on the intermediate stop(s) feature of the relevant product captured by D_i^c, as well as the itinerary flying distance of the relevant product captured by $ItineraryDist_i$. Conditional on the itinerary flying distance, a positive (negative) direct cost effect becomes weaker (stronger) the fewer the number of intermediate stops required by the air travel product. Furthermore, conditional on the number of intermediate stop(s) feature of the product, a positive (negative) direct cost effect is stronger (weaker) the longer is the itinerary flying distance of the air travel product. Last, it is evident that the direct cost effect depends on the total number of competing products in the relevant market, n.

Strategic cost effect

The strategic cost effect captures the extent to which 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. Similar arguments from the analysis of direct cost effect apply to the analysis of the strategic cost effect. This effect could be positive or negative, depending on the rival firms' hedging strategies. Due to the strategic interdependence across competing oligopolistic airlines, it is important to note that the strategic effect facilitates a positive (negative) correlation between an airline's price level and crude oil price, when the strategic cost effect is positive (negative), even in an extreme situation in which the airline's own marginal cost is insensitive to crude oil price changes. The size of the strategic cost effect also depends on the intermediate stop(s) feature and the itinerary flying distance of rival carrier products, as well as the total number of competing products in the relevant market.

In summary, the demand effect constitutes the demand-side market channel that allows changes in crude oil price to be reflected in airfare. The derived pass-through rate in equation (13) suggests that it is important to recognize the demand-side market channel when modeling the pass-through channels of changes in crude oil price to airfare; and neglecting the demand-side channel is tantamount to neglecting a positively related impact of crude oil price changes on airfares. Previous literature has focused on the supply-side pass-through from jet fuel price changes to airfare, but neglected the key role of airline fuel hedging on the pass-through rate. [29] Our theory suggests that it is essential to consider the jet fuel hedging effect when specifying the cost function. According to the derived pass-through rate in equation (13), a change in crude oil price can positively or negatively transmit to the equilibrium airfare, depending on the airline's and rival airlines' hedging strategies. The fuel hedging effect plays a determining role in influencing the sign of supply-side effect and further the sign of the crude oil-airfare pass-through relationship. [30]

2.3.2 Model Predictions

Table 1 provides some predictions from our theoretical model. Formal derivations of each prediction are presented in the appendix of Gayle and Lin (2020). We now provide brief discussions of each theoretical prediction listed in Table 1, respectively.

In an extreme case, suppose airline i has 100% of its fuel consumption covered by hedging contracts and suppose it hedges directly in jet fuel, i.e., all its fuel procurements in the relevant future periods can be done at previously agreed upon "locked-in" fuel prices. Consequently, if spot crude oil and fuel prices increase, airline i has a cost advantage relative to airlines with no or little hedged fuel by being able to procure fuel at previously agreed upon "locked-in" fuel price that is lower than spot fuel price. It is reasonable to predict airline i has an incentive to lower its airfare when the profit margins of its rival airlines are shrinking, perhaps to steal market share from rival airlines. In the scenario just discussed, the highly fuel-hedged airline i decreased its airfare in response to increases in spot crude oil and fuel prices, which is consistent with a negative crude oil-airfare pass-through rate possibility suggested in **Prediction 1**. On the contrary, in the event that the spot crude oil and fuel prices decrease, airline i has a cost disadvantage relative to its rival airlines; and therefore, it has an incentive to pass along the relative higher cost to passengers by raising its airfare. Note that the highly fuel-hedged airline i increased its airfare in response to decreases in spot crude oil and fuel prices, again a result consistent with a negative crude oil-airfare pass-through rate possibility suggested in **Prediction 1**.

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[29] There are a considerable number of studies that focus on how airline fuel hedging strategies affect airlines in terms of firms' market value and risk management [see Carter, Rogers and Simkins (2006a, 2006b), Morrell and Swan (2006), and Treanor et. al. (2014)].

[30] Previously mentioned airline pass-through literature has uniquely found a positive supply-side pass-through from jet fuel price to airfare; whereas, our theory suggests the supply-side pass-through could be positive or negative, depending on airlines' hedging strategy.

Now consider the opposite extreme case in which airline i does not use any fuel hedging contracts. In this extreme case, airline $i's$ marginal cost fluctuates positively with spot crude oil and fuel prices since none of its fuel is hedged against the spot fuel price level. Given that a profit-maximizing airline is likely to set airfare in manner that causes its airfare to be positively correlated with its own marginal cost, the positive correlation between spot crude oil and fuel prices and the airline's marginal cost in turn results in a positive correlation between crude oil price and its airfare, a result consistent with a positive crude oil-airfare pass-through rate possibility suggested in **Prediction 1**.

Table 1: Some Predictions from our Theoretical Model

Prediction #	**Description of Prediction**
Prediction 1	The pass-through from changes in crude oil price to an air travel product's equilibrium airfare can be either positive or negative, depending on the airline's and its rival airlines' fuel hedging strategies.
Prediction 2	The magnitude of the pass-through rate from changes in crude oil price to an air travel product's optimal airfare is a decreasing function of the airline's jet fuel hedging ratio, i.e. $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial Hedge_i} < 0 \; \forall i$.
Prediction 3	The magnitude of the pass-through rate from changes in crude oil price to an air travel product's optimal airfare is an increasing function of the product's itinerary flying distance, i.e. $\frac{\partial\left\{\frac{\partial P_i^*}{\partial P_c}\right\}}{\partial ItineraryDist_i} > 0 \; \forall i$.
Prediction 4	The magnitude of the pass-through rate from changes in crude oil price to an air travel product's equilibrium airfare can be positively or negatively influenced by the intensity of market competition, depending on the airline's and its rival airlines' fuel hedging strategies; and the effect on the pass-through rate is non-linear with respect to competition intensity.

Prediction 2 describes a negative relationship between the hedging ratio and the magnitude of the pass-through rate. However, depending on whether the pass-through rate is negative or positive, this negative relationship means different things for changes in the magnitude of the pass-through rate as a firm increases its fuel hedging. Specifically, if an airline has a negative crude oil-airfare pass-through rate, then this negative pass-through rate is predicted to increase in magnitude as the airline increases the extent of its fuel hedging. On the other hand, if an airline has a positive crude oil-airfare pass-through rate, then this positive pass-through rate is predicted to decrease in magnitude as the airline increases the extent of its fuel hedging.

Prediction 3 implies that in a given origin-destination market, the greater an air travel product's actual flying distance: (i) the smaller the marginal effect of changing crude oil price on the optimal airfare level when the pass-through rate is negative; and (*ii*) the greater the marginal effect of changing crude oil price on the optimal airfare level when the pass-through rate is positive. The underlying intuition follows from the fact that products with longer flying routes use jet fuel more intensively. For airlines with no or little fuel hedging, and consequently a positive crude oil-airfare pass-through rate, a rising (falling) crude oil price induces greater increase (decrease) in marginal cost of products with longer flying routes, and thus a greater direct positive pass-on effect on the price level of these products. For airlines with a sufficiently large hedging ratio and consequently a negative crude oil-airfare pass-through rate, on the one hand, during time periods when crude oil price increases, the relative cost advantage of highly fuel-hedged airlines is lessened due to the extra fuel needed on longer flying routes, inducing a smaller reduction in airfare on longer itinerary routes. On the other hand, during time periods when crude oil price drops, the relative cost disadvantage of highly fuel-hedged airlines is again lessened due to the extra fuel needed on longer routes, inducing a smaller increase in airfare on longer itinerary routes.

Prediction 4 tells us that the magnitude of the crude oil-airfare pass-through rate is influenced by the level of market competition, where the level of market competition is measured in our theoretical model from the following three perspectives: (*i*) the total number of air travel products in the relevant market that use non-stop itinerary, n_0; (*ii*) the total number of air travel products in the relevant market that have one intermediate stop, n_1; and (*iii*) the total number of air travel products in the relevant market that have two or more intermediate stops, n_2. We believe it is reasonable to use the above three measures, as products within each of the three classifications are considered to be closer substitutes with each other; and therefore, this disaggregated method of measuring competition should be more informative compared to using total number of products in a market without regard for the intermediate stop features of the products.

Prediction 4 suggests that increased market competition can either encourage or discourage an airline's pass-through behavior depending on airlines' fuel hedging strategies; and this effect is non-linear with respect to the competition intensity. Specifically, our theory predicts that when airline i is "heavily hedged" yielding a negative pass-through rate, increases in market competition intensifies the negative pass-through rate, i.e. pushing the negative pass-through rate further away from zero. However, if airline i is "moderately hedged" and has a negative pass-through rate, increases in market competition attenuates the negative pass-through rate, i.e. pushing the negative pass-through rate closer to zero.

Last, for airlines with no or little fuel hedging and a positive pass-through rate, increases in market competition intensifies the positive pass-through rate, i.e. pushing the positive pass-through rate further away from zero. Intuitively, an airline that is exposed to crude oil cost shocks (positive or negative) would quickly adjust its optimal price, 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 as these airlines' profit margins shrink when markets become 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 little room for airlines to absorb costs without passing through cost changes to prices. [31]

The impact of market competition on the magnitude of the pass-through rate is determined by two distinct sources: demand-side and supply-side. On the demand side, an air travel product with fewer intermediate stops is associated with shorter overall flying time, and thus, is viewed as a closer substitute to driving, *ceteris paribus*. When crude oil price increases (decreases), causing an increase (decrease) in ground transport cost for driving, the demand for air travel products with fewer intermediate stops experiences a greater increase (decrease). This larger demand effect for products with fewer intermediate stops occur because $h_4 > h_5 > h_6 \geq 0$. Therefore, the demand-side positive effect of market competition on the pass-through rate is expected to be the greatest when market competition is measured by n_0, and the smallest when market competition is measured by n_2.

On the supply side, an air travel product with fewer intermediate stops is associated with fewer numbers of landings and take-offs; and these two stages of a flight have the highest fuel-burn rates. For airlines that are not completely hedged, when crude oil price increases (decreases), which results in higher (lower) jet fuel expenses associated with

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[31] Neither of the two papers considers the potential effect of jet fuel hedging strategy on airlines' pass-through from jet fuel price changes to airfare.

those unhedged fuel usage, the marginal cost of products that have more intermediate stops experiences a greater increase (decrease) compared to products that have fewer intermediate stops. This effect is captured by the previously posited parameter ranking: $\alpha_6 > \alpha_5 > \alpha_4 > 0$. Therefore, for an airline travel product i, we may expect the supply-side effect is the greatest when market competition is measured by n_2, and the smallest when market competition is measured by n_0. Therefore, the ranking of the supply-side effects across products with different numbers of intermediate stops is the reverse of the ranking of the demand-side effects.

The impact of market distance on the pass-through rate

Our theory suggests that consumer preference between air travel and private automobile travel depends on the relative transport cost that the consumer faces between the two modes of transportation, and the relative transport cost is influenced by the distance between the origin and destination. The overall effect of market distance on the crude oil-airfare pass-through rate can be split into two effects: "*level effect*" and "*elasticity effect*".

The "*Level Effect*"

The "*level effect*" measures the extent to which market distance affects airlines' optimal adjustment of their airfares in response to changing crude oil price, where the optimal adjustment is driven by the likelihood of consumers switching between air travel and private automobile travel. In a market where the two endpoints are relatively close to each other within a certain threshold distance, automobile travel is a preferred transportation mode to air travel. When crude oil price (and gasoline price) increases, switching from automobile to air travel in this case becomes more likely as market distance increases, resulting in a greater increase in air travel demand. The increase in air travel demand, and thus airfare, get larger as market distance increases, suggesting a positive "*level effect*". When the two endpoints become even further apart beyond a certain threshold distance, air travel is a more ideal option as automobile is no longer realistic in very long distance markets, making switching modes of transport increasingly less likely with rising crude oil price. The increase in air travel demand and thus airfare get smaller as market distance increases beyond the threshold distance, suggesting a negative "*level effect*".

The size of the "*level effect*" depends on the intermediate stop(s) feature of the relevant product. In particular, the absolute magnitude of the "*level effect*" is larger the fewer the number of intermediate stops required by the air travel product. This demand-side prediction is consistent with our previous discussion.

The "*Elasticity Effect*"

The "*elasticity effect*" measures the extent to which market distance affects an airline's optimal airfare response to crude oil price changes based on consumers' sensitivities to changes 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 expect airlines that are significantly exposed to jet fuel price fluctuations, i.e. airlines with little or no fuel hedging, to pass along a crude oil induced cost shock to airfare more heavily to long-distance air travelers given their less elastic air travel demand compared to short-distance travelers. However, for airlines that are engaged in some jet fuel hedging plans, the pass-on effect can be positively or negatively correlated with market distance. The sign of the "*elasticity effect*" is determined by airlines' jet fuel hedging strategy along with airlines' incentive to pass-on any cost changes due to a potential growing price insensitivity of passengers; and the size of this effect exhibits a non-linear pattern with market distance.

Table 2 summarizes predictions from our theoretical model regarding the overall effect of market distance on the crude oil-airfare pass-through rate. The table shows that for scenarios (*i*), (*v*) and (*vi*), the overall effect of market distance on the pass-through rate depends on the relative countervailing strengths of the "*level effect*" and the "*elasticity effect*". However, our theoretical model yields unambiguous predictions under scenarios (*ii*), (*iii*) and (*iv*). For scenario (*ii*), the negative pass-through rate increases toward 0 (i.e. decreases in magnitude) as market distance increases. For scenario (*iii*), the positive pass-through rate increases away from 0 (i.e. increases in magnitude) as market distance increases. For scenario (*iv*), the negative pass-through rate decreases away from 0 (i.e. increases in magnitude) as market distance increases.

Table 2: Predicted Impacts of Market Distance on the Crude Oil-Airfare Pass-through Rate

Market Distance	**Scenario**	**Airline $i's$ Hedging Ratio**	**Pass-through Rate**	**Level Effect**	**Elasticity Effect**	**Overall Effect of Market Distance on Pass-through rate**
Relatively Short	(*i*)	Relatively Large	Negative	Positive	Negative	Depends on relative strengths of level & elasticity effects.
	(*ii*)	Moderate	Negative	Positive	Positive	**Positive**: The negative pass-through rate increases toward 0 (i.e. decreases in magnitude) as market distance increases.
	(*iii*)	Relatively Low	Positive	Positive	Positive	**Positive**: The positive pass-through rate increases away from 0 (i.e. increases in magnitude) as market distance increases.
Relatively Long	(*iv*)	Relatively Large	Negative	Negative	Negative	**Negative**: The negative pass-through rate decreases away from 0 (i.e. increases in magnitude) as market distance increases.
	(*v*)	Moderate	Negative	Negative	Positive	Depends on relative strengths of level & elasticity effects.
	(*vi*)	Relatively Low	Positive	Negative	Positive	Depends on relative strengths of level & elasticity effects.

Notes: Formal parameter restrictions from our theory that define the hedging ratios categories of "Relatively Large", "Moderate" and "Relative Low", as well as parameter restrictions from our theory that define the market distance categories of "Relatively Short" and "Relatively Long" can be found in Gayle and Lin (2020).

3. Empirical Analysis

We now analyze whether these theoretical predictions are supported by systematic patterns across a sample of U.S. domestic origin-destination air travel markets. We start by describing the data sample and then describe the empirical models used for analyzing the data, followed by a discussion of results from the empirical models.

3.1 Data and Sample Selection

Our empirical analysis focuses on U.S. domestic coach-class airline tickets over the period 2013Q3 to 2015Q4.[32] This time period spans relatively substantial fluctuations in

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[32] Before this sample period, American Airlines (AA) and US Airways (US) announced plans to merge in February 2013, but the proposed merger was challenged by the Department of Justice in August 2013, and settled in November 2013. We assume that the price effects of the merger was realized when it was announced in the beginning of 2013. As such, our analysis of airfares during our sample period, which begins in the third quarter of 2013, avoids the potential undue influence of this merger. The argument here 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."

crude oil price; these fluctuations are important for empirical identification of the relationships between changes in crude oil price and airfares, which is key to achieve the primary objectives of the analysis. The sample is constructed in the similar manner as in Gayle and Thomas (2015, 2016) and Gayle and Yimga (2018). Airline ticket information data represent 10% of all domestic tickets issued by airlines and are obtained from the DB1B database.[33]

A *market* is defined as a directional pair of an origin and a destination airport. For example, air travel for which the origin is Atlanta and the destination is Boston is in a different market than air travel for which the origin is Boston and the destination is Atlanta. This definition allows for the characteristics of the origin city to affect consumers' air travel demand.

A *product* is defined as a unique combination of itinerary and operating carrier. For example, one product in the Atlanta to Boston market is a non-stop flight from Atlanta to Boston operated by American Airlines. We focus on products that use a single operating carrier[34] for all segments of a given itinerary, i.e. pure online products. Product *price* and *quantity* sold are obtained by averaging the market fare and aggregating the number of passengers, respectively, according to our definition of product. Thus, in the collapsed data, a product is a unique observation during a given time period.

Table 3 reports summary statistics. There are 603,745 observations across 147,073 markets. The variable, *Hedge*, measures the proportion of an airline's aviation fuel consumption protected by hedging contracts relative to the airline's total projected annual aviation fuel usage, reported in airlines' 10-K annual reports.[35] Across all airlines over the

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[33] The DB1B data do 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, etc. Following Brueckner and Spiller (1994) and Berry, Carnall, and Spiller (2006), we keep only round-trip itineraries within the continental U.S. with at most four segments (i.e. no more than three intermediate stops). We eliminate all itineraries with market fares less than $50 or greater than $2,000. We relax this rule when creating the entry threat variables (denoted by *EntryThreat*) used in the regression analysis in order to accurately calculate the level of potential competition.

[34] There are 21 relevant carriers in our sample, including American, Alaska, JetBlue, Delta, ExpressJet, Frontier, AirTran, Allegiant, GoJet, Hawaiian, Spirit, SkyWest, Chautauqua, Shuttle America, Sun Country, United, US Airways, Virgin, Southwest, Mesa, and MidWest. These air carriers include those that provide air travel services in the data sample, as well as those that place an entry threat to market incumbent carriers without actually serving the relevant market.

[35] For example, Southwest Airlines' 10-K annual report in 2012 (filed on 12/31/2012) projected its average percent of estimated fuel consumption covered by fuel derivative contracts at varying WTI/Brent crude oil-equivalent price levels was about 15% for 2013, 50% for 2014, and 30% for 2015. However, the actual

sample period, the value of *Hedge* varies from 0% to 50%, with an average of 15.3%. The variable, $\overline{Hedge^c}$, represents the average jet fuel hedging ratio of an airline's competitors in an origin-destination market. Therefore, in principle and practice, variable $\overline{Hedge^c}$ varies across airlines in a given origin-destination market since each airline has its own unique set of rivals in the market. The average rival fuel-hedging ratio in the data is 13.4%. The information regarding itinerary's actual flying miles is represented by *ItineraryDist*, while *Mkt_Dist* represents the market non-stop flight distance.

Table 3: Summary Statistics

Variables	**Mean**	**Std. Dev.**	**Min**	**Max**
Airfare* (dollars)	267.926	108.127	49.737	1,974.787
Crude Oil Price* (dollars/barrel)	81.479	27.134	43.321	112.004
Jet Fuel Price* (cents/gallon)	233.415	64.656	136.877	302.898
Gasoline Price* (cents/gallon)	307.058	53.233	225.211	374.604
Quantity (number of passengers per product)	79.753	375.325	1	10,294
Hedge** (%)	15.271	9.957	0	50
$\overline{\text{Hedge}^{\text{C}}}$ (%)	13.368	8.974	0	50
ItineraryDist: Itinerary flying distance (miles)	1,688.516	709.15	70	5,382
Mkt_Dist: Non-stop flight distance (miles)	1,414.865	636.442	70	2,783
N_nonstop	1.371	1.357	0	7
N_onestop	9.45	8.379	0	47
N_twostop	2.381	4.202	0	39
EntryThreat	1.36	1.185	0	11
Interstop	1.01	0.503	0	3
Inconvenience	1.244	0.308	1	3.732
Origin_Presence	28.701	25.745	0	128
Dest_Presence	26.908	24.997	0	126
Population	1,436,077	1,740,341	5,292.955	9,449,256
Number of Observations	603,745			
Number of Markets	147,073			

* Inflation-adjusted in 2014 dollar. Energy prices are obtained from EIA. ** We are not able to find the hedging information for the following five airlines: F9, EV, OO, SY, and YV. Therefore, we exclude those observations that have missing hedging ratio, leading to a total of 603,745 observations.

Guided by our theory, *N_nonstop* counts the number of all competing non-stop products offered in a market; *N_onestop* counts the number of all competing one-stop products offered in a market; and *N_twostop* counts the number of all competing two-or-more-stops products offered in a market. Following Goolsbee and Syverson (2008) and Gayle and Wu (2013), variable *EntryThreat* captures the extent of potential competition incumbent carriers of a relevant market faces. The variable counts the number of all distinct

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percentage of hedged fuel consumption was adjusted to be 20% for 2014 based on 2013's 10-K (filed on 12/31/2013) and 0% for 2015 based on 2014's 10-K (filed on 12/31/2014).

carriers that are present at both endpoints of a market without actually offering an air travel product between the two endpoint cities. These variables are jointly used to control for the impact of market structure factors on equilibrium airfares, as well as their impact on the size of crude oil-airfare pass-through.

Carriers may offer both non-stop and connecting service in a market. Consumers likely value the two types of products differently. Variable *Interstop* is used as one measure of travel inconvenience of an itinerary, as it counts the number of intermediate stops of the itinerary. We also use variable *Inconvenience* as an additional measure of an itinerary's travel inconvenience resulting from the location(s) of the intermediate stops.[36] The argument is that there may be products that have the same number of intermediate stops in an origin-destination market; but because the location(s) of the intermediate stop airport(s) are different for the products, their associated itinerary flying distance will differ and thus exhibit different relative routing qualities.

We use two different measures of the size of airlines' airport presence, *Origin_Presence* and *Dest_Presence,* similar to the airport presence variables in Berry (1990).[37] To control for the likelihood that larger markets have greater demand for air travel service, we use as a measure of market size the geometric mean of the population estimates, *Population*, in 2014, following Berry, Carnall, and Spiller (2006).

3.2 Reduced-form Regression Analysis

According to our theory, we argue that there exists a positive or negative pass-through relationship from changes in crude oil price to airline market fare, and the sign and size of this pass-through is influenced by some airline-specific and market-specific characteristics. To empirically analyze the relevant relationships suggested by our theory,

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[36] Variable *Inconvenience* is computed by dividing the itinerary miles flown from the origin to the destination by the market non-stop radian distance. This variable is similar in spirit to the "Cost" variable used by Ciliberto and Tamer (2009), in which the authors divide the difference between the itinerary flying miles and the non-stop distance by the non-stop distance between a market's endpoints. See also Chen and Gayle (2019), Gayle and Wu (2015), and Gayle and Le (2015).

[37] Refer to Berry (1990) for detailed discussion on this topic.

and consistent with many empirical analyses of pass-through, we use the following log-linear reduced-form regression model: [38]

$$
\begin{aligned}
log(P_{imt}) = {} & \theta_0 + \theta_1\, log\left(P_{c,t}\right) + \theta_2 Hedge_{at} + \theta_3 \overline{Hedge_{at}^{C}} \\
& + \theta_4\, log\left(P_{c,t}\right) \times Hedge_{at} + \theta_5\, log\left(P_{c,t}\right) \times \overline{Hedge_{at}^{C}} \\
& + \theta_6\, log(ItineraryDist_{im}) + \theta_7\, log\left(P_{c,t}\right) \times log(ItineraryDist_{im}) \\
& + \theta_8 N\_nonstop_{imt} + \theta_9\, log\left(P_{c,t}\right) \times N\_nonstop_{imt} \\
& + \theta_{10}\, log\left(P_{c,t}\right) \times N\_nonstop_{imt} \times Hedge_{at} + \theta_{11}\, log\left(P_{c,t}\right) \times N\_nonstop_{imt} \times \overline{Hedge_{at}^{C}} \\
& + \theta_{12} N\_onestop_{imt} + \theta_{13}\, log\left(P_{c,t}\right) \times N\_onestop_{imt} \\
& + \theta_{14}\, log\left(P_{c,t}\right) \times N\_onestop_{imt} \times Hedge_{at} + \theta_{15}\, log\left(P_{c,t}\right) \times N\_onestop_{imt} \times \overline{Hedge_{at}^{C}} \\
& + \theta_{16} N\_twostop_{imt} + \theta_{17}\, log\left(P_{c,t}\right) \times N\_twostop_{imt} \\
& + \theta_{18}\, log\left(P_{c,t}\right) \times N\_twostop_{imt} \times Hedge_{at} + \theta_{19}\, log\left(P_{c,t}\right) \times N\_twostop_{imt} \times \overline{Hedge_{at}^{C}} \\
& + \theta_{20} EntryThreat_{mt} + \theta_{21} \log\left(P_{c,t}\right) \times EntryThreat_{mt} \\
& + \theta_{22} \log\left(P_{c,t}\right) \times EntryThreat_{mt} \times Hedge_{at} + \theta_{23} \log\left(P_{c,t}\right) \times EntryThreat_{mt} \times \overline{Hedge_{at}^{C}} \\
& + \theta_{24}\, log(Mkt\_Dist_m) + \theta_{25}\, log\left(P_{c,t}\right) \times log(Mkt\_Dist_m) \\
& + \theta_{26}\, log\left(P_{c,t}\right) \times log(Mkt\_Dist_m) \times Hedge_{at} + \theta_{27}\, log\left(P_{c,t}\right) \times log(Mkt\_Dist_m) \times \overline{Hedge_{at}^{C}} \\
& + \theta_{28} Origin\_Presence_{amt} + \theta_{29}\, log\left(P_{c,t}\right) \times Origin\_Presence_{amt} \\
& + \theta_{30} Dest\_Presence_{amt} + \theta_{31}\, log\left(P_{c,t}\right) \times Dest\_Presence_{amt} \\
& + \theta_{32} Interstop_{imt} + \theta_{33} Inconvenience_{imt} + \theta_{34}\, log(Population_{mt}) \\
& + \eta_y + \eta_q + \eta_a + Origin_m + Dest_m + \varepsilon_{imt} \qquad (14)
\end{aligned}
$$

The dependent variable is the air travel product price level in logs. The model includes year and quarter fixed effects (η_y, η_q), air carrier fixed effects (η_a), origin airport fixed effects ($Origin_m$), and destination airport fixed effects ($Dest_m$). In the log-log linear reduced-form regression specification, the coefficient associated with the logarithm of crude oil price (θ_1) is a measure of the pass-through elasticity, i.e. the percent change in airfare due to a percent change in crude oil price. Coefficients associated with the interactions between the logarithm of crude oil price with other market-level and firm-level variables capture the extent to which the pass-through elasticity is influenced by the

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[38] See similar log-log linear reduced-form specifications used in Hellerstein and Villas-Boas (2010) on page 175, Kim and Cotterill (2008) on page 45, Goldberg and Knetter (1996) on page 6. In addition, we believe a reduced-form regression analysis in this particular study is sufficient to address our research questions. In future research we plan to consider a structural approach to deepen the analysis.

relevant market-level or firm-level characteristic. According to equation (14), the crude oil-airfare pass-through rate (denoted by PTR) is derived as follows:

$$\begin{aligned}
&PTR_{imt} = \frac{\partial \log(P_{imt})}{\partial \log(P_{ct})} = \theta_1 + \theta_4 Hedge_{at} + \theta_5 \overline{Hedge_{at}^{C}} + \theta_7\, log(ItineraryDist_{im}) + \theta_9 N\_nonstop_{imt} + \\
&\theta_{10} N\_nonstop_{imt} \times Hedge_{at} + \theta_{11} N\_nonstop_{imt} \times \overline{Hedge_{at}^{C}} + \theta_{13} N\_onestop_{imt} + \theta_{14} N\_onestop_{imt} \times \\
&Hedge_{at} + \theta_{15} N\_onestop_{imt} \times \overline{Hedge_{at}^{C}} + \theta_{17} N\_twostop_{imt} + \theta_{18} N\_twostop_{imt} \times Hedge_{at} + \\
&\theta_{19} N\_twostop_{imt} \times \overline{Hedge_{at}^{C}} + \theta_{21} EntryThreat_{mt} + \theta_{22} EntryThreat_{mt} \times Hedge_{at} + \\
&\theta_{23} EntryThreat_{mt} \times \overline{Hedge_{at}^{C}} + \theta_{25}\, log(Mkt\_Dist_m) + \theta_{26}\, log(Mkt\_Dist_m) \times Hedge_{at} + \\
&\theta_{27}\, log(Mkt\_Dist_m) \times \overline{Hedge_{at}^{C}} + \theta_{29} Origin\_Presence_{amt} + \theta_{31} Dest\_Presence_{amt} \qquad (15)
\end{aligned}$$

Table 4 presents the results for the reduced-form regression estimated by ordinary least squares.[39] The top panel of the table presents the key pass-through parameter estimates in equation (15), while the coefficient estimates of other control variables are reported in the bottom panel. Except the coefficient estimates for *N_onestop* and *logPopulation*, the coefficient estimates for all other control variables in the bottom panel of the table have expected signs, and are statistically significant at conventional levels of statistical significance.[40] The pass-through parameter estimates reported in the top panel of the table are all statistically significant at conventional levels of statistical significance. Consistent with the primary objectives of this research, the subsequent discussion focuses on interpreting the key coefficient estimates in the top panel.

Guided by equation (15), the coefficient estimate, $\widehat{\theta_1}$, reveals that the crude oil-airfare pass-through elasticity is 0.37 if all other explanatory variables are set to be zero. However, note that it is unlikely that all explanatory variables are simultaneously zero. As

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[39] The variables that measure the number of products offered in the market, *N_nonstop*, *N_onestop*, and *N_twostop*, are likely endogenous. We mitigate this endogeneity concern by including in the regression airline-specific fixed effects as well as time, origin airport, destination airport fixed effects. Consistent with discussions in Nevo (2000), brand-specific (here, airline-specific) dummy variables capture the characteristics that do not vary by market, as well as the mean product-specific unobserved components, which serve to mitigate correlation between the error term in the reduced-form regression with *N_nonstop*, *N_onestop*, and *N_twostop*. We acknowledge that using strong instruments are ideal for fully addressing the endogeneity concern. Unfortunately, strong instruments are difficult to find in our empirical setting. As such, our second best is to rely on the above-listed fixed effects to mitigate the endogeneity problem.

[40] Many of these coefficient estimates are consistent with results from the use of similar control variables in previous studies. For example, our coefficient estimates for *Mkt_Dist* yield qualitatively similar results found in Brueckner, Dyer and Spiller (1992) and Brueckner and Spiller (1994); similarly for coefficient estimates on "airport presence" variables used in our study and in Berry (1990), Borenstein (1989), and Morrison and Winston (1989).

such, one way to proceed with interpreting the empirical results is to compute the marginal effect of each explanatory variable on the pass-through elasticity assuming the other explanatory variables are set equal to their sample means, respectively.

We find that the mean marginal effect of jet fuel hedging on the crude-oil airfare pass-through rate is -0.005 when relevant explanatory variables are set equal to their sample means.[41] The interpretation of the negative mean marginal effect is twofold according to our theory. On the one hand, if the typical air travel product initially has a positive pass-through rate, the crude oil-airfare pass-through elasticity is expected to decline by 0.005 in magnitude for every 1% increase in the relevant airline's jet fuel hedging ratio. On the other hand, if the typical air travel product initially has a negative pass-through rate, the negative crude oil-airfare pass-through elasticity is expected to increase in magnitude (i.e. move further away from zero) by 0.005 for every 1% increase in the relevant airline's jet fuel hedging ratio. The negative relationship between the pass-through rate and jet fuel hedging validates our theoretical predictions described in **Prediction 2** in Table 1.

The coefficient estimate for the interaction of logarithm crude oil price with logarithm air travel product itinerary distance is positive. If the typical air travel product initially has positive pass-through rate/elasticity, the marginal effect estimate suggests that the positive pass-through elasticity will further increase by a mean 0.0384 with each 1% increase in the product's itinerary flying distance. However, if the typical air travel product initially has negative pass-through rate/elasticity, the marginal effect estimate suggests that the negative pass-through elasticity will decrease (i.e. move toward zero) by a mean 0.0384 with each 1% increase in the product's itinerary flying distance. This empirically estimated positive relationship between a product's pass-through rate and its itinerary flying distance is indeed consistent with the theoretical predictions described in **Prediction 3** in Table 1.

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[41] $\frac{\partial PTR_i}{\partial Hedge}|_{sample\ mean} = -0.00691 + 0.000059\overline{N\_nonstop} + 0.0000128\overline{N\_onestop} - 0.00000828\overline{N\_twostop} - 0.0000452\overline{EntryThreat} + 0.0003\, log(\overline{Mkt\_Dist}) = -0.005$

Table 4: Reduced-form Airfare Regression Model Estimated by Ordinary Least Squares

	Dependent Variable: $logP$	
	Coefficient Estimates	Standard Errors of Coefficient Estimates
$logPc$ ($\widehat{\theta_1}$)	0.37***	(0.0251)
$logPc \times Hedge$ ($\widehat{\theta_4}$)	-0.00691***	(0.000234)
$logPc \times \overline{Hedge^C}$ ($\widehat{\theta_5}$)	-0.00389***	(0.000213)
$logPc \times logItineraryDist$ ($\widehat{\theta_7}$)	0.0384***	(0.00506)
$logPc \times N\_nonstop$ ($\widehat{\theta_9}$)	0.0122***	(0.00168)
$logPc \times N\_nonstop \times Hedge$ ($\widehat{\theta_{10}}$)	0.000059***	(0.0000104)
$logPc \times N\_nonstop \times \overline{Hedge^C}$ ($\widehat{\theta_{11}}$)	-0.0000531***	(0.0000164)
$logPc \times N\_onestop$ ($\widehat{\theta_{13}}$)	-0.000639*	(0.000347)
$logPc \times N\_onestop \times Hedge$ ($\widehat{\theta_{14}}$)	0.0000128***	(0.00000207)
$logPc \times N\_onestop \times \overline{Hedge^C}$ ($\widehat{\theta_{15}}$)	0.0000077**	(0.00000334)
$logPc \times N\_twostop$ ($\widehat{\theta_{17}}$)	0.0015***	(0.000522)
$logPc \times N\_twostop \times Hedge$ ($\widehat{\theta_{18}}$)	-0.00000828***	(0.00000314)
$logPc \times N\_twostop \times \overline{Hedge^C}$ ($\widehat{\theta_{19}}$)	0.0000228***	(0.00000502)
$logPc \times EntryThreat$ ($\widehat{\theta_{21}}$)	0.012***	(0.00124)
$logPc \times EntryThreat \times Hedge$ ($\widehat{\theta_{22}}$)	-0.0000452***	(0.00000915)
$logPc \times EntryThreat \times \overline{Hedge^C}$ ($\widehat{\theta_{23}}$)	-0.0000572***	(0.00000912)
$logPc \times logMkt\_Dist$ ($\widehat{\theta_{25}}$)	-0.0921***	(0.00528)
$logPc \times logMkt\_Dist \times Hedge$ ($\widehat{\theta_{26}}$)	0.0003***	(0.0000251)
$logPc \times logMkt\_Dist \times \overline{Hedge^C}$ ($\widehat{\theta_{27}}$)	0.000562***	(0.0000220)
$logPc \times Origin\_Presence$ ($\widehat{\theta_{29}}$)	-0.000371***	(0.0000494)
$logPc \times Dest\_Presence$ ($\widehat{\theta_{31}}$)	-0.000375***	(0.0000504)
$Hedge$ ($\widehat{\theta_2}$)	0.019***	(0.000632)
$\overline{Hedge^C}$ ($\widehat{\theta_3}$)	-0.00123*	(0.000651)
$logItineraryDist$ ($\widehat{\theta_6}$)	-0.306***	(0.0257)
$logMkt\_Dist$ ($\widehat{\theta_{24}}$)	0.814***	(0.0257)
$N\_nonstop$ ($\widehat{\theta_8}$)	-0.0658***	(0.00622)
$N\_onestop$ ($\widehat{\theta_{12}}$)	0.00164	(0.00127)
$N\_twostop$ ($\widehat{\theta_{16}}$)	-0.00985***	(0.00189)
$EntryThreat$ ($\widehat{\theta_{20}}$)	-0.0393***	(0.00485)
$Origin\_Presence$ ($\widehat{\theta_{28}}$)	0.00532***	(0.000216)
$Dest\_Presence$ ($\widehat{\theta_{30}}$)	0.00534***	(0.000221)
$Interstop$ ($\widehat{\theta_{32}}$)	0.0497***	(0.000873)
$Inconvenience$ ($\widehat{\theta_{33}}$)	0.339***	(0.00898)
$logPopulation$ ($\widehat{\theta_{34}}$)	0.000269	(0.00135)
$Constant$ ($\widehat{\theta_0}$)	1.399***	(0.106)
N	603,745	
R^2	0.402	
F	673.5	

Standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01. Regression includes year, quarter, airline, origin airport, destination airport fixed effects.

Guided by our theory model, we include two-way interaction variables between the logarithm of crude oil price and each of the four competition measures, as well as three-way interaction variables created by interacting the two-way interaction variables with fuel hedging ratio variables. Setting hedging variables equal to their respective sample means, we obtain the marginal effects of each competition variable on the crude oil-airfare pass-through rate. With hedging ratio variables set equal to their respective sample means, we find that additional market entry of non-stop, one-intermediate-stop, and two-or-more intermediate stop products marginally affects the crude oil-airfare pass-through elasticity by a mean 0.012, -0.00034, and 0.0017, respectively, while an additional entry threat marginally affects the crude oil-airfare pass-through elasticity by a mean 0.0105.[42]

The empirical results suggest that an additional non-stop product offered in the market raises the pass-through elasticity by a mean 0.012. According to our previous discussions of **Prediction 4** from our theory, this positive marginal effect of competition on the pass-through rate is predicted to occur when airline jet fuel hedging is at a moderate or low level. At moderate jet fuel hedging levels and a negative pass-through elasticity, the negative pass-through elasticity is pushed closer to 0 by 0.012 with each additional non-stop product offered in the market. However, at sufficiently low jet fuel hedging levels and a positive pass-through elasticity, the positive pass-through elasticity is pushed further way from 0 by 0.012 with each additional non-stop product offered in the market. Consistent with our theory, similar qualitative empirical results hold for the market entry of products with two or more intermediate stops, but with weaker marginal effects since 0.0017 < 0.012.

The estimated negative mean marginal effect (-0.00034) on the pass-through elasticity associated with the market entry of an additional one-stop product suggests that the increasingly intense market competition measured by the number of one-stop air travel products encourages those airlines with heavily hedged fuel plans to lower (raise) their airfares in response to increasing (declining) crude oil price as their relative cost advantage increases (decreases).

Guided by our theory model, we include a two-way interaction between the logarithm of crude oil price and market distance, as well as a three-way interaction of the

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[42] $\frac{\partial PTR}{\partial N\_nonstop}|_{\overline{Hedge},\overline{Hedge^c}} = 0.012$; $\frac{\partial PTR}{\partial N\_onestop}|_{\overline{Hedge},\ \overline{Hedge^c}} = -0.00034$; $\frac{\partial PTR}{\partial N_{twostop}}|_{\overline{Hedge},\ \overline{Hedge^c}} = 0.0017$; $\frac{\partial PTR}{\partial EntryThreat}|_{\overline{Hedge},\ \overline{Hedge^c}} = 0.0105$.

two-way interaction with fuel hedging ratios. The mean marginal effect is -0.08 with fuel hedging ratio variables set equal to their respective sample means.[43] This finding suggests a negative correlation between the market distance and the crude oil-airfare pass-through rate. According to Table 2, the negative relationship between the pass-through rate and market distance suggests two things. First, when market distance is relatively short, the "*level effect*" is positive, and therefore the negative relationship only occurs when the "*elasticity effect*" is negative, which at short market distances requires airlines that are heavily fuel hedged as characterized by scenario (*i*) in Table 2, and dominates the "*level effect*". Second, when market distance is relatively long, the "*level effect*" is negative, and therefore a negative relationship can occur at any level of jet fuel hedging, i.e. fuel hedging ratios can lie in any of the three ranges characterized by scenarios (*iv*), (*v*), and (*vi*) in Table 2. However, the negative "*level effect*" needs to dominate a positive "*elasticity effect*" in the case of moderate and low levels of fuel hedging, i.e. hedging ratios satisfying scenarios (*v*) or (*vi*) in Table 2.

By interacting the size of airlines' airport presence with logarithm crude oil price, we allow the sizes of airlines' origin and destination airport presence to influence the crude oil-airfare pass-through differently. The coefficient estimates for the two interaction terms, $\widehat{\theta_{29}}$ and $\widehat{\theta_{31}}$, suggest the size of airlines' airport presence have a similar negative and statistically significant effect on the pass-through elasticity. If a typical product initially has a positive pass-through, greater airport presence tends to reduce the positive pass-through elasticity; if a typical product initially has a negative pass-through, greater airport presence tends to increase the magnitude of the negative pass-through elasticity.

A closer look at the product-level pass-through rate

According to equation (15), we further compute the estimated crude oil-airfare pass-through rate/elasticity for each product using the information in Table 4, and report the summary statistics in Table 5. In column (1), we summarize the estimated product-level pass-through rate assuming all determinants of the pass-through rate, including the effect of hedging, are taken into account. The summary statistics in this column reveal a negative mean crude oil-airfare pass-through rate/elasticity of -0.065, suggesting that a 1% decline

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[43] $\frac{\partial PTR}{\partial \log(Mkt\_Dist)}\Big|_{\overline{Hedge},\overline{Hedge^{c}}} = -0.08.$

in the crude oil price results in a mean 0.065 percent increase in airfares. While not all products in the sample have negative estimated crude oil-airfare pass-through rates, the vast majority (approximately 86.7%) do.

Table 5: Summary Statistics of Estimated Product-level Crude oil-Airfare Pass-through Rate

	Estimated Product-level Pass-through Rate (1)	Estimated Product-level Pass-through Rate when we counterfactually shut down the influence of airline fuel hedging (2)	Estimated Product-level Pass-through Rate when we counterfactually shut down the influences of airline fuel hedging and market distance (3)
Mean	-0.065 (0.00007)	0.0045 (0.000054)	0.66 (0.000039)
Median	-0.0725	-0.00075	0.661
10th percentile	-0.128	-0.0446	0.623
25th percentile	-0.106	-0.0265	0.640
75th percentile	-0.028	0.0305	0.682
95th percentile	0.033	0.0803	0.712
Std. Dev.	0.054	0.042	0.030
Percentage of Products with Negative Estimated Pass-through Rate	86.7%	50.7%	0%

Notes: Standard errors of the means are in parentheses for the mean pass-through rates.

The regression results do reveal that a negative crude oil-airfare pass-through rate is associated with sufficiently strong airline fuel hedging, having large airport presence, and servicing long distance markets. Among these determinants of a negative crude oil-airfare pass-through rate, the empirical estimates suggest that airline hedging and long-distance markets are the strongest. However, if we counterfactually set to zero the influence of airline hedging on the crude oil-airfare pass-through rate, then the mean pass-through rate/elasticity across products in our sample is positive and equal to 0.0045, suggesting that a 10% decline in the crude-oil price would have resulted in a mean 0.045% decrease in airfares. Counterfactually shutting down the influence of airline hedging yields a positive crude oil-airfare pass-through rate among nearly half (49.3%) of the products in our sample, as shown in column (2). If in addition, we counterfactually set to zero the influence of market distance on the crude oil-airfare pass-through rate, then the mean predicted pass-through rate is 0.66, with 100% of the products in our sample having a positive crude oil-airfare pass-through rate, as shown in column (3).

The results and discussion above do reveal airline fuel hedging is a strong contributor to negative crude oil-airfare pass-through rates. Why might this make economic sense? Airlines engage in fuel price hedging by the use of financial instruments to "lock in" fuel prices over a certain period. While this practice is beneficial to airlines as a source of falling relative fuel cost during periods of rising fuel spot price, it becomes a source of increasing relative fuel cost during periods of falling fuel spot price. In other words, the increasing relative fuel cost of airlines that are more extensively locked into fuel hedging contracts during periods of falling fuel spot price, and these airlines decreasing relative fuel cost during periods of rising fuel spot price, can result in optimal airfares for these airlines moving counter to changes in fuel spot price, which would yield a negative crude oil-airfare pass-through rate. Our empirical analysis suggests that airfares moving counter to changes in fuel spot price is a systematic occurrence in the data, and the occurrences are most strongly associated with airlines' fuel price hedging and relatively long-distance markets.

Figure 2: Relationships between estimated Product-level Pass-through Rate and Fuel Hedging Ratios

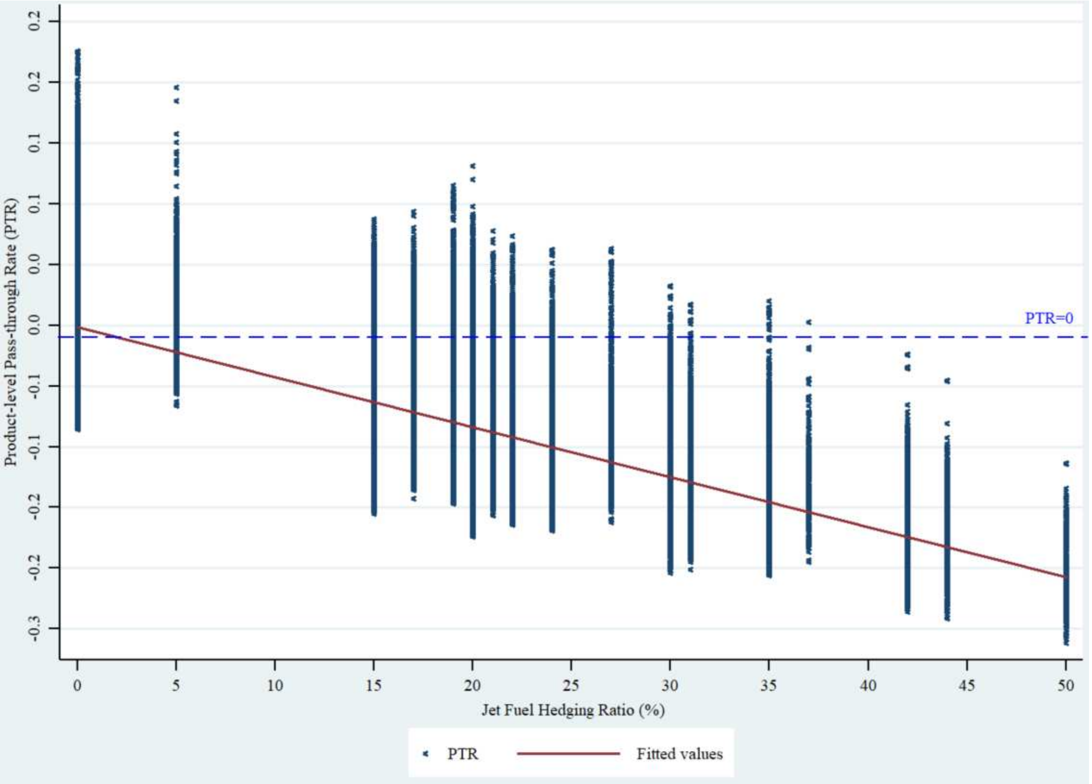
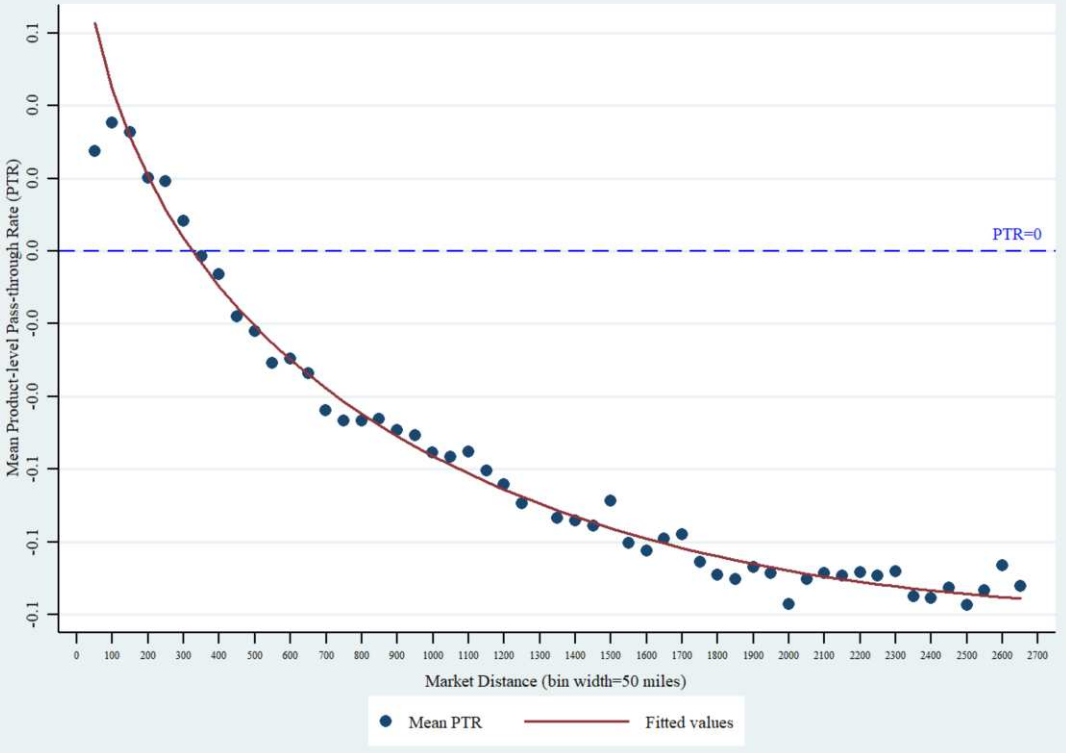


Figure 2 plots the relationship between estimated product-level pass-through rate (measured on the vertical axis) and airlines' hedging ratios (measured on the horizontal axis). The downward sloping solid line in the plot represents the best-fit linear regression line between the variables measured on the axes of the graph; while the horizontal dashed line delineates zero pass-through rate on the diagram. This plot empirically confirms the negative relationship between crude oil-airfare pass-through rate and the jet fuel hedging ratio, suggested by **Prediction 2** in Table 1; and it also shows most air travel products in the data sample have a negative pass-through rate.

To further investigate the empirical relationship between pass-through rate estimates and market distance, we compute mean model-predicted product-level pass-through rates by market distance groups with the bin width of 50 miles. In Figure 3, we plot the empirical relationship between the two with mean model-predicted pass-through rates on the vertical axis and market distance bands on the horizontal axis. The downward sloping solid curve in the plot represents the best-fit polynomial regression line between the variables measured on the axes of the graph. First, Figure 3 reveals that the computed average pass-through rates over the market distance bands are mostly negative, especially for market distances beyond 350 miles. Second, the plot confirms a negative relationship between the mean pass-through rate and market distance. These observations suggest that as market distance increases up to approximately 350 miles, the positive pass-through rate declines toward the zero pass-through line; however, as market distance further increases, the negative pass-through rate increases in magnitude by moving further away from the zero pass-through rate line.

Figure 3: Relationships between estimated Mean Product-level Pass-through Rate and Market Distance



4. Conclusion

The primary objective of this paper is to examine the market mechanisms through which crude oil price may influence airfare, which facilitates identifying the possible market and airline-specific characteristics that may influence the extent to which crude oil price changes affect airfare. We first use a theoretical model of air travel demand and Nash equilibrium price-setting behavior of airlines to derive clear theoretical predictions that guide proper specification of a reduced-form regression model, and help with interpreting empirical results from the regression model. According to our theoretical model, the pass-through from crude oil price changes to changes in airfare is facilitated by demand-side, supply-side, and competitiveness features of origin-destination air travel markets. A key demand-side feature is consumers' willingness to substitute between driving and flying, a key supply-side feature is the extent to which an airline's marginal cost is influenced by changes in jet fuel price, while a key competitiveness feature is the number of competing products in the origin-destination market.

Our empirical estimates reveal a mean product-level crude oil-airfare pass-through rate/elasticity of -0.065, suggesting that a 1% decline in the crude oil price results in a mean 0.065 percent increase in airfares. While not all products in the sample have negative estimated crude oil-airfare pass-through rates, the vast majority (approximately 86.7%) do.

Consistent with predictions from our theoretical model, we find evidence that the sign and size of the pass-through of crude oil price changes to airfare depends on several market and airline-specific factors, with airline fuel hedging and relatively long distance travel markets being the strongest determinants of a crude oil-airfare pass-through rate being negative. First, we find that airlines' adoption of jet fuel hedging contracts has a significant impact on airline pricing as well as the pass-through elasticity of airfare with respect to crude oil price changes. On average, the value of crude oil-airfare pass-through elasticity declines by 0.005 for each percentage increase in the proportion of airlines' jet fuel consumption covered by hedging contracts. Furthermore, counterfactually shutting down the influence of airline fuel hedging yields a positive crude oil-airfare pass-through rate among nearly half (49.3%) of the products in our sample, with the mean counterfactual pass-through elasticity being 0.0045 instead of the mean factual pass-through elasticity of -0.065.

Second, we find that the crude oil-airfare pass-through elasticity is negatively correlated with origin-destination market distance, and the level of this effect also varies by airlines' fuel hedging ratios. In fact, if in addition to counterfactually shutting down the influence of airline fuel hedging, we counterfactually shut down the influence of market distance on the crude oil-airfare pass-through elasticity, then the mean predicted pass-through elasticity is 0.66, with 100% of the products in our sample having a positive crude oil-airfare pass-through elasticity.

Third, we find that the intensity of air travel market competition measured by the number of non-stop or two-or-more stop products has an average positive effect on the value of crude oil-airfare pass-through rate, and the level of this effect varies by airlines' fuel hedging ratios. However, market competition measured by the number of one-stop products has a negligible negative effect on the pass-through rate. Market competition measured by the number of non-stop air travel products has a particularly stronger influence on the size of crude oil-airfare pass-through rate compared to other competition measures. The value of pass-through rate also increases when there are more airlines credibly threatening to enter the relevant market.

A 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 U.S. domestic air travel market fares, which has not been well studied in the 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 and onto consumers. In the theory model, we consider both airline-specific and market-specific characteristics in determining the sign as well as the size of the pass-through. To the best of our knowledge, such an analysis has not been done in the cost-price pass-through literature. Relying on a reduced-form regression analysis, however, we are unable to empirically disentangle various demand side and supply side effects on the size of pass-through. As such, future research may want to consider using a structural econometric model designed to empirically unpack the reduced-form evidence provided in this paper.

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