Cost Pass-Through Mechanism in the Aviation Industry

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ABSTRACT OF THE
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Knowing the effect of cost changes for an airline on airfare is important for politicians and economists, as fuel taxing effects can be estimated more precisely. This thesis analyzes theoretical cost pass-through predictions within a contestable market and oligopoly markets. The following empirical part focuses on two questions: (1) what is the in-sample pass-through and (2) what are the main determinants of it? Lin and Gayle (2021) find that a 1% crude oil price increase is expected to cause a 0.065% decrease in ticket prices, mainly because of airline fuel hedging strategies and the market origin-destination distance. Shi et al. (2020) calculate that a 1% increase in fuel prices due to an airline's hedging strategy is associated with a 0.66% increase in ticket prices.

Keywords: microeconomics, cost pass-through, aviation industry

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Definitions and Examples

Cost pass-through

The rate at which product prices respond to production cost changes. Direct pass-through can be calculated whenever the cost changes happen for the same product and the units are the same. For example, a jeans reseller might experience a surge of jeans prices and pass them on directly to the customer, meaning that pass-through would be 1. On the other hand, with different units, it is required to use pass-through elasticity.

Cost pass-through elasticity

Pass-through elasticity is the percent change of prices caused by a percent change of costs. For example, if fuel prices decrease by 50% and ticket prices increase by 2.5%, pass-through elasticity would be -0.05.

Contestable market

Contestable markets are served by a small number of firms and there is no entry or exit cost to the market. Due to the entry threat of new firms, a contestable market finds itself in a competitive equilibrium. Some aviation markets have contestable characteristics.

1 Introduction

With airplane passenger numbers rising in-non crisis years since the beginning of commercial flights, the aviation industry commits significantly to global greenhouse emissions. Even in 2020, in the wake of the covid pandemic, the industry was responsible for 2% of global carbon dioxide emissions [1]. In order to regulate emissions, policy makers have the straight forward option of taxing fuel because a large portion of an airline's operating costs is spent on fuel. A fuel price increase means a direct cost increase for airlines. One would expect a positive correlation between petroleum and ticket prices, because airlines must cover their costs in case of a fuel price increase and must stay competitive in case of a fuel price decrease. However, ticket prices have stayed at more or less the same level in 2014-2015 [2], a period during which crude oil prices dropped from 100 $/barrel in June 2014 to 44 $/barrel in March 2015, a 54% decline [3]. History has shown that fuel costs and airfare don't always show a positive correlation, defying expectations. This thesis examines theoretical models and pre-pandemic empirical evidence about pass-through in the aviation industry and provides an explanation for previous phenomenon. I find that fuel hedging, competition intensity and flight distance are the key determinants of pass-through, and the mean pass-through rate in the U.S. aviation industry to be slightly negative, meaning that a cost decrease for the airlines results in ticket price increases and vice versa.

The rest of this paper is structured as follows: Section 2 starts off with implications about pass-through in a contestable market, which is close to a competitive one. Section 3 presents two oligopoly models, a Cournot and Bertrand model and evidence for high market concentration in the aviation industry. Section 4 discusses a study conducted by Gayle and Lin (2021), including a theoretical and empirical part. Despite some weaknesses, the model comes to precise predictions which are confirmed empirically. The role of an airline's hedging strategy is detailed in Section 5, where I review Shi et al. (2021)'s study about the connection between hedging and pricing. Results are summarized and discussed in Section 6. The final section concludes.

2 Contestable Markets

I begin by reviewing pass-through in competitive markets, which is 100%. Economics courses always start with a competitive equilibrium and some aviation markets might be contestable markets, which also yield a competitive equilibrium (Baumol, 1982).

After the U.S. deregulation of the aviation industry starting in the mid- 1970s (Borenstein and Rose, 2014), followed by deregulation in the EU soon after (Domanico, 2007), there weren't many entry obstacles left for new competitors. A contestable market is an oligopoly-type setting where few firms control the market but behave

[1] Air Transport Action Group, accessed 09.09.2021
[2] Washington Post, accessed 09.09.2021
[3] Tradingeconomics, accessed 09.09.2021

competitively due to weak barriers of entry. Unlike with traditional oligopolies, firms cannot enjoy profits due to market power because if they become overly profitable, a contestant can simply enter the market, copy the incumbent's business and output and undercut the prices, while still earning profits. Baumol (1982) stresses the importance of costless entry and exit, which still allows for investments and costs setting up the business. In this case, costless means that the entrant suffers no disadvantage regarding the production process or quality of the produced goods compared to the incumbent after entering the market. This wouldn't be the case with social networks, for example, because there are important network effects which weaken new firms in comparison to the already existing ones with a large userbase.

There are three major long-term welfare characteristics in perfectly contestable markets (Baumol, 1982). The first one requires firms to have zero profits, otherwise there is hit-and-run threat of new firms collecting profits by lowering prices, driving the incumbent out of business, and eventually leaving the market. Historically, the airline industry's operating margins have been relatively low, ranging from 4% to 15% in pre-covid years [4]. Second, there can be no production inefficiencies or price inefficiencies in perfectly contestable markets because such imperfections would constitute a source for profit and invite new firms to join the market. They could eliminate unnecessary costs and earn profits, eventually taking over market shares. Third, no product can be sold below its marginal cost. If this were the case, the cost for the product would exceed its revenue, and firms would try to reduce output until their marginal costs are covered by the price again. Let me ignore the strategy of producing below marginal costs simply for gaining market shares, as it is not a long-term sustainable strategy.

So whenever a market is contestable, it shows large similarities with a competitive one. I will proceed with the theoretical cost pass-through mechanism in such a setting, which depends on whether the cost shock is industry wide or happens on a firm level (Koopmans and Lieshout, 2016). If only one firm experiences a cost increase in a contestable market, it won't be able to pass them on because it most likely loses all of its customers to the competition. On the other hand, a lucky firm can enjoy profits above zero if costs decrease specifically for it and others still face the old costs. Potential entrants couldn't undercut current prices, so there is no reason for the lucky firm to lower them, meaning that the cost savings are not passed on to the customers. The other possibility is an industry wide cost shock, induced for example by a tax or normal oil price volatility. In that case, the pass-through rate will be 100%. Since the industry operates at zero profits, a cost increase must be passed on fully to the customers to maintain zero profitability, while also staying competitive. The hit-and-run threat applies to a sector wide cost decrease, where existing companies will lower their prices according to the cost decrease, otherwise there is an earnings opportunity for an entrant who can lower prices and still be profitable. Thus a perfectly contestable market gives clear predictions for the pass-through mechanism.

How far can the aviation industry be characterized as constestable? Likyanov et al. (2009) find that administrative barriers in the russian market make it restricted

[4] OliverWyman, accessed 09.09.2021

to competition. Pitelis and Schnell (2002) examine the EU market in a survey based study and conclude that the lack of time-attractive slots and retaliation measures by the incumbent[5] represent the largest perceived entry barriers. The European airline market hence isn't perfectly contestable and new entrants fail to pose the competitive threat which would yield a competitive equilibrium. Domanico (2007) lists even more existing barriers to entry but notes that the rise of low-cost carriers mitigates the effect of existing barriers as they are able to claim more market shares. Older U.S. studies identify hub-and-spoke systems resulting in one airline having a dominant position at their hub as a large entry barrier (Kahn, 1993; Saunders and Shepherd, 1993).

Signs in different locations indicate a non-perfect contestable market structure but I still believe that it's worth keeping this simple theory in mind because the predictions are straight-forward and some deregulated markets might come close to contestable.

3 Oligopoly

Another possible way to look at the aviation industry is through the oligopoly framework. I will discuss Cournot and Bertrand models because they are used in papers I cover in this thesis and because they produce clear predictions. For each model, I'll briefly explain its basics, and how firms set prices. From there, I can draw conclusions about the cost pass-through mechanism.

3.1 Cournot Model

As Koopmans and Lieshout (2016) write, airlines choose their flight schedules first, and adapt the prices according to demand. We have all looked at ticket prices to our favourite destination and wondered one week afterwards why airfare changed. For this reason, a model where firms choose their quantity first and adjust their prices afterwards seems like a fitting model to begin with. In the following section, I will explore the classic Cournot model with its basic assumptions, after which I will make advanced predictions about the pass-through in a more detailed Cournot model.

In the Cournot model, each firm has expectations about other firm's output and decides its own quantity supplied (Varian, 2014). Basic assumptions include linear demand, and varying marginal costs across N firms but constant within a firm.
Inverse demand curve: $p = a - bq$
Costs function of firm i: $C_i(q_i) = c_i q_i \quad , i = 1, \dots, N$
From there, one can show (Appendix A.1) that the equilibrium price in a Cournot oligopoly is

$$p^e = \frac{a + \sum_{i=1}^{N} c_i}{N+1}, \tag{1}$$

[5] e.g. expanding flight schedule or lowering fares

where p^e stands for equilibrium price. Kate and Niels (2005) use Equation (1) to explain the pass-through mechanism of costs. If a single firm experiences a cost change Δc, the equilibrium price changes to $p^e + \frac{\Delta c}{N+1}$, meaning that only a ratio of $\frac{1}{N+1}$ of cost change is passed on to the consumer. Whenever the cost change affects the whole industry, all companies are affected. In that case, the equilibrium price becomes $p^e + \frac{\Delta c N}{N+1}$. A fraction of $\frac{N}{N+1}$ of the cost change for the whole industry is passed on to price. Both pass-through rates are entirely independent of any model parameters other than the number of firms. Whenever the number of firms gets large, an industry wide cost shock is passed on with near 100%, which is exactly as expected in a competitive market.

However, the assumptions of this model might be too strict to fit to the aviation market. Demand could be non-linear and the cost functions of airlines are probably more complex than assumed. Also, Kate and Niels (2005) don't take into account that the products in the aviation market might be differentiable and firm market shares vary (Koopmans and Lieshout, 2016). Zimmerman and Carlson (2010) explore a more complex model, which corrects some oversimplifications. The firms in their model are allowed to have differing marginal costs, and the products in the market can be differentiable. They begin with a linear inverse demand curve and state the profit maximizing optimization problem each firm faces:

$$\max_{q_i} \pi_i = (p_i(q) - c_i)q_i. \tag{2}$$

Taking the partial derivative with respect to q_i and setting to 0 yields the reaction function for firm i, where q_i is expressed in terms of other variables. I won't go over the details of finding the Nash equilibrium for the system of equations in which each firm maximizes profits and each firm's expectations about other firms production supplies hold [6]. Wang and Zhao (2007) calculate the equilibrium price, which can be differentiated with regards to firm specific costs to get to the cost pass-through.

In Zimmerman and Carlson (2010)'s model, the equilibrium price is the same as in Wang and Zhao (2007)'s paper (see Equation (3)). To allow for product differentiation, they use a substitutability parameter ϕ, which is 0 whenever outputs of firms are unrelated. Increasing ϕ means that outputs can be substituted more and more because they become increasingly equal.

$$p_i^e = \frac{(N+\phi)a_i}{2N+(N+1)\phi} + \frac{N\phi(N+\phi)\overline{c}}{(2N+\phi)(2N+(n+1)\phi)} + \frac{Nc_i}{2N+\phi}, \tag{3}$$

where $\overline{c}$ is the average cost of the industry, and a_i is the individual firm's inverse demand curve constant. It follows from the equilibrium price that the pass-through of a change in a firm's marginal cost to its own price depends on the number of firms n, and on ϕ.

$$\frac{\partial p_i^e}{\partial c_i} = \frac{2N^2 + N(N+2)\phi + \phi^2}{(2N+\phi)(2N+(N+1)\phi)} \tag{4}$$

[6] An example equilibrium calculation can be found in section 4, I didn't want to overload this section with math.

If ϕ is 0, outputs of firms can't be seen as substitutes. In that case, which is identical to monopolistic competition, Zimmerman and Carlson (2010)'s model yields a pass-through rate of $\frac{1}{2}$. Varian (2014), p.462 finds the same pass-through number in a monopoly setting with constant marginal costs and linear demand curves. If ϕ tends to infinity, firms produce homogenous products and the pass-through rate is expected to be $\frac{1}{N+1}$, confirming the results from Kate and Niels (2005). See the Appendix (A.2) for a detailed calculation.

Zimmerman and Carlson (2010) plot the firm specific cost pass-through, dependent on the number of firms and holding the parameter ϕ constant. I took the liberty of plotting Equation (4) myself.

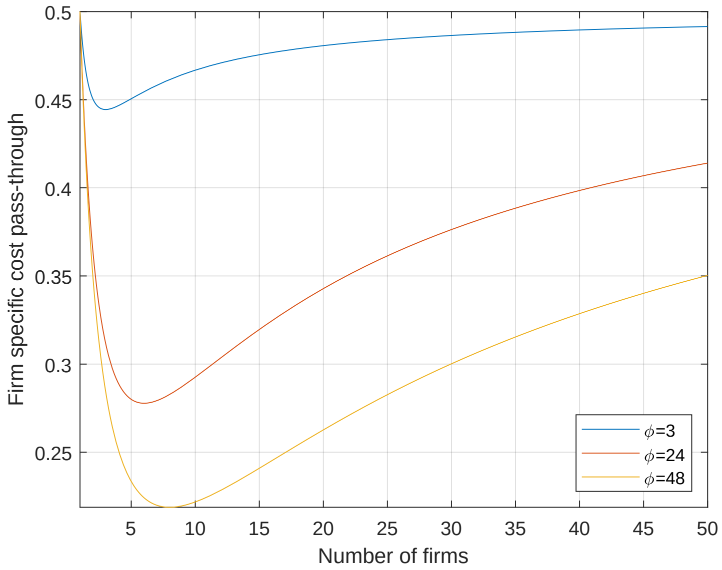

Figure 1: Cournot model with asymmetric firms and differentiated products.

When $\phi = 48, N = 8$, the cost pass-through is about 22%, and when $\phi = 3, N = 50$, the cost pass-through gets close to 50%. Higher substitutability-values (ϕ) are associated with lower pass-through rates. There exist two main effects which drive the function in opposite directions. Each firm passes on increasing parts of cost changes for higher levels of n, which can be explained by higher competition. On the other hand, product differentiation flattens the pass-through function. Less product differentiation implies that firms act more like a price taker than a monopolist and the number of firms has a negative effect on the pass-through rates at first. After a tipping point n^*, the two effects cancel each other out and the pass-through rates increase in the number of firms.

The same model allows for observations about price changes whenever the whole industry experiences a cost change but requires defining an average Nash-Cournot market equilibrium price. Remember, each firm faces their own demand curve due to product differentiation. Zimmerman and Carlson (2010) define a simple market equilibrium price as

$$\begin{aligned}
\overline{p^e} &= \frac{1}{N}\sum_{i=1}^{N} p_i^e \\
&= \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(N+\phi)a_i}{2N+(N+1)\phi} + \frac{N\phi(N+\phi)\overline{c}}{(2N+\phi)(2N+(N+1)\phi)} + \frac{Nc_i}{2N+\phi}\right) \\
&= \frac{(N+\phi)\overline{a}}{2N+(N+1)\phi} + \frac{N\phi(N+\phi)\overline{c}}{(2N+\phi)(2N+(N+1)\phi)} + \frac{N\overline{c}}{2N+\phi,}
\end{aligned} \tag{5}$$

where $\overline{a}$ is the arithmetic mean from the individual a_i's. Partially differentiating the average market price with respect to the average cost yields the market pass-through rate. Zimmerman and Carlson (2010) only calculate the pass-through rate of firm specific costs to the market price, so I'm happy to contribute a small part to the literature here. The partial derivative simplifies to

$$\frac{\partial \overline{p^e}}{\partial \overline{c}} = \frac{N(\phi+1)}{\phi(N+1)+2N}, \tag{6}$$

which I also plot for some values ϕ.

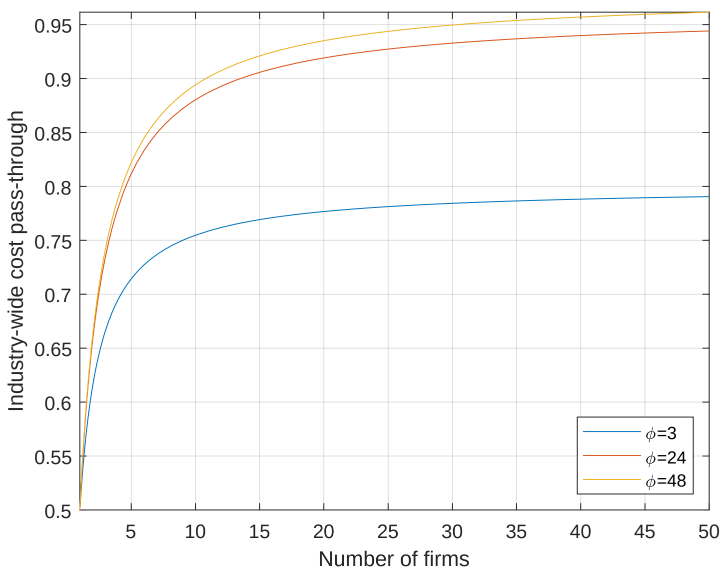

Figure 2: Industry wide cost cost pass-through in Cournot model.

Figure 2 shows the pass-through rates for different ϕ-values. If the substitutability parameter is small and the consumer can differentiate between the products, pass-through is in general lower for any number of firms. Increasing the number of firms in the market results in higher pass-through rates for all values of ϕ and the pass-through rate doesn't exceed 1. The model is well in line with expectations.

Unfortunately, Zimmerman and Carlson (2010) also assume linear demand functions, restricting the external validity of the model in the aviation industry case. However, I still believe that the model has good potential of capturing reality because it allows for differentiated products and varying market shares. In Equation (5), I calculated the arithmetic mean for the market price, but this formula can be expanded to include varying market shares of the firms. Zimmerman and Carlson (2010) calculate the weighted average but I decided that including another complication wouldn't significantly help understanding the model.

3.2 Bertrand Model

The most detailed empirical paper on cost pass-through mechanism in the aviation market I'm aware of by Gayle and Lin (2021) uses the Bertrand model. They introduced me to the topic and I want to explore the Bertrand oligopoly setting separately so that the theoretical parts are clear as soon as I start going over Gayle and Lin (2021)'s contents in section 4. In this section, I'll again start with the basic model with perfect Bertrand competition, followed by some empirical evidence about firm concentration in the aviation market.

In a Bertrand competition, firms set their prices and let the customer choose the demanded quantities. The equilibrium consists of prices where each price is a profit-maximizing choice and expectations from firms regarding other firms hold (Varian, 2014). Usually one assumes (1) identical firms and (2) homogenous products which yield an equilibrium where all firms set the price equal to their marginal costs. If marginal costs are not symmetric, no pure strategy Nash equilibrium exists. In that case, which still assumes homogenous goods, the market stabilizes in a mixed strategy equilibrium (Demuynck et al., 2019).

This has implications for pass-through. If costs change for the whole market, prices will be passed on to full extend as both initial assumptions still hold. The new equilibrium price will be at the new marginal cost faced by all firms. On the other hand, a cost shock experienced by a single firm implies that assumption (1) doesn't hold. There will be a new mixed strategy equilibrium. Going over pass-through in such a scenario would involve a deeper mathematical discussion of Demuynck et al. (2019)'s paper and is out of the scope of this thesis.

I will now have a look at real world data, which sheds some light on the prevailing market structure in aviation markets. Basically, a pair of airports is considered a market in which different airlines compete. Koopmans and Lieshout (2016) compute the market shares of the competitors and the Herfindahl-Hirschman Index (HHI) for each market from 2010 passenger data. The HHI captures market concentration neatly in one number:

$$\text{HHI}_{a,x,y} = \sum_{a} \textit{Market share}^2_{a,x,y}, \tag{7}$$

where the HHI is the index for one market between hub x and y. For example, on the route New York to London, all airports in these cities are factored into the same HHI (Koopmans and Lieshout, 2016). The market shares of different airlines (non-stop or indirect flights) a get summed up and squared. In a monopoly, the HHI would be $100^2 = 10,000$, and a lower index indicates a more competitive market. In general, an HHI of < 1000 can be interpreted as a competitive market, an HHI between 1000 and 1800 is moderately concentrated, and HHI values above 1800 indicate a highly concentrated market. Koopmans and Lieshout (2016) note that the index is prone to measurement errors because the market share values and the respective errors get squared. They summarize their results in a table which demonstrates that 99% of markets have an HHI of over 1800, including 98% of all customers. 0% of markets have an HHI below 1000, which also means that no customers experience competitive aviation markets. The overall average HHI is 4600. The authors also count the number of competitors in each case to get more insight into the market concentration, this time leaving out companies with less than 5% market share. Long-haul markets characteristically consist of many direct and indirect flight alternatives, where the indirect flights become attractive for the customer whenever her longer travel time is compensated for with significantly lower airfares. Since indirect flights are in nature less popular, they make up only a small percentage of the market and can be ignored by setting the threshold market share to 5%, the authors argue. The numbers show that half of the markets are monopolies, and 10% of passengers travel in these markets. 75% of all passengers travel in oligopoly markets with 2-4 competitors.

I believe it is fair to say that Koopmans and Lieshout (2016) provide empirical evidence for the oligopoly view in the aviation industry. Although they make some design choices like setting the number for a highly concentrated market to HHI ≥ 1800 and not counting in competitors with less than 5% market share, the numbers are still clear enough to be fairly convincing. I would like to see some statistics with a higher HHI threshold to be safe. Also, when counting the competitors, I'd be interested in directly ignoring all indirect flights or adjusting the 5% market share to higher and lower numbers. Since the basic models are now dealt with and I presented evidence for high market concentration in the aviation market, I will look more closely into a Bertrand model and review some empirical studies about pass-through.

4 Crude Oil Pass-Through and Determinants

I now analyze the theoretical model and empirical work by Gayle and Lin (2021). In their paper, they examine the pass-through mechanisms which might influence airfare. Their model includes a demand and supply side for the aviation market and allows for some specific predictions about the pass-through. After that, I will go over their empirical analysis which confirms key theoretical predictions.

4.1 Demand Side

Calculating a Nash equilibrium requires some kind of profit function for each firm, which can be maximized by a firm's action. It is therefore helpful to analyze the demand side of the market to get to a demand function $q(p) = \ldots$ which can later be used in equilibrium calculations.

An air travel market is defined as a specific origin-destination pair, and a product in this market is a route between those two locations, direct or indirect. Product differentiation is allowed because routes have differing travel times and prices, which might sort customers according to their preferences. Gayle and Lin (2021) construct the following demand framework for N air travel products:

$$q_i = H_i - \beta p_i + \tilde{\beta} \sum_{j \neq i}^{N} p_j \quad , i = 1, \ldots, N \tag{8}$$

where q_i is the demand level for product i,
H_i is the constant part of the demand function and is determined by a formula itself.

$$H_i = h_0 + h_1 X_1 + h_2 X_{2i} + h_3 \sum_{j \neq i}^{N} X_{2j} + \gamma D_i P_g \tag{9}$$

Let me explain the determinants of H_i first before coming back to the initial demand function. The H_i-function is split up into a non-product specific part X_1, a product specific part X_2 and another part which depends on market distance, number of stops and gasoline price. X_1 is a vector capturing all demand shifting factors for the whole industry, like for example a seasonal variable and h_1 is a parameter vector which represents the impact of the X_1-variables on H_i.

Vector X_{2i} includes product i's specific demand shifting factors, influencing H_i according to the parameters in h_2. Since Vector X_{2j} captures all demand-shifting variables in other flights, Equation (9) recognizes that product i is both influenced by its own characteristics and other flights acting as substitutes. The last determinant of H_i is $\gamma D_i P_g$, where $\gamma = \gamma_1 \text{Mkt\_Dist} + \gamma_2 \text{Mkt\_Dist}^2$ is a function of market distance, and D_i contains information about whether the flight is non-stop, has one stop, or two or more intermediate stops. P_g is a variable for the gasoline price. The last three variables are put together because γ and D_i influence the effect of a gasoline price change on product i's demand level.

In the following, I'll illustrate how γ is put together. The prediction is that parameter γ_1 is positive and γ_2 is negative, resulting in a downward opened parabola. Assume that the distance between two markets were really small. Consumers prefer using their cars to travel between the points and air travel isn't really a substitute. The parabola is still at a low level, which means that a change in gasoline price will not effect the demand level for this market as much because flying isn't really an alternative. The γ function rises in market distance until a maximum point is reached, which is whenever consumers are indifferent between the two modes of travel. Gasoline price changes have the largest impact on demand. If the distance becomes even larger, flights are preferred due to time savings and comfort and the price change effect decreases.

Let me also explain another interaction between the variables, namely the number of intermediate stops and the gasoline price. As already mentioned, when gasoline prices increase, cars become much more expensive and consumers will opt for an alternative, preferably a non-stop flight. The demand for a non-stop air travel product is thus expected to be influenced more by gasoline price increases than the demand for a flight with one intermediate stop. The discussed effects are considered in the definition of D_i:

$$D_i = h_4 d_{i0} + h_5 d_{i1} + h_6 d_{i2}, \tag{10}$$

where d_{i0} is a dummy which is 1 if the flight is non-stop, and 0 otherwise. d_{i1} is defined similarly and d_{i2} is 1 whenever the flight has two or more stops, and 0 otherwise. Following the previous discussion, h_4 is expected to have a larger value than h_5 because a gasoline price increase has a larger positive effect on the demand of product i if it is non-stop. The same argument holds for the other parameters, which will result in the inequalities $h_4 > h_5 > h_6 \geq 0$. The last detail to consider is the specification of the gasoline price: $P_g = \delta_0 + \delta_1 P_c$, which includes the crude oil price P_c in the gasoline price. Since Gayle and Lin (2021) are ultimately looking for the pass-through mechanism of crude oil price changes to ticket prices, it makes sense to include the variable P_c.

Coming back to the initial demand curve in Equation (8), product i's price influences demand through the parameter β. Similarly to H_i, where the product itself and substitutes were allowed to impact the demand level, Equation (8) considers the competition's prices. It's easy to imagine how product i's demand increases if the competition drastically raises prices, hence the sign for $\tilde{\beta}$ is positive. Its absolute value is probably smaller than β because the direct effect from changing product i's prices on route i's demand is simply more relevant.

4.2 Supply Side

After getting a detailed view on the demand side of the model, it's now time to look at the supply side. Gayle and Lin (2021) choose a Bertrand competition to model firm behaviour and I'll go over their calculations deriving a formula for the cost pass-through from crude oil price changes to ticket sales.

As often in microeconomics, firms will maximize their profit function with the model's respective actions. In this case the model manages with several assumptions: firms are assumed to set prices and let demand be determined later, and each (differentiated) product in the market is offered by a different airline. From there, every airline will noncooperatively maximize their profit function

$$\max_{p_i} \pi_i = (p_i - c_i)q_i, \tag{11}$$

where q_i can be substituted with Equation (8). Inserting the demand function and taking the derivative with respect to p_i yields the following:

$$\begin{aligned} \pi_i &= (p_i - c_i)\left(H_i - \beta p_i + \tilde{\beta}\sum_{j\neq i} p_j\right) \\ \frac{\partial \pi_i}{\partial p_i} &= H_i - 2p_i\beta + \tilde{\beta}\sum_{j\neq i} p_j + c_i\beta = 0, \end{aligned} \tag{12}$$

which holds for all $i = 1 \dots N$. Since airlines try to maximize their profits, the derivative is set to zero in the end. This system of equations can be summarized in matrix form, known as the first order condition for the Nash equilibrium:

$$\begin{pmatrix} -2\beta & \tilde{\beta} & \dots & \tilde{\beta} \\ \tilde{\beta} & -2\beta & \dots & \tilde{\beta} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\beta} & \tilde{\beta} & \dots & -2\beta \end{pmatrix} \begin{pmatrix} p_1 \\ p_1 \\ \vdots \\ p_N \end{pmatrix} + \begin{pmatrix} H_1 + c_1\beta \\ H_2 + c_2\beta \\ \vdots \\ H_N + c_N\beta \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix} \tag{13}$$

The goal is to isolate the price vector on one side of Equation (13), therefore the inverse of the matrix on the very left, hereby denoted by B, is required. I guess it is computationally easier to find the inverse after multiplying Equation (13) with -1, at least that's what Gayle and Lin (2020) do in their mathematical appendix, following Wang and Zhao (2007). For such a matrix, lemma 2 from Howe and Zhao (2004)'s paper can be applied to find the inverse. Previously referenced lemma 2 gives an explicit formula for B^{-1}:

$$
\begin{aligned}
B^{-1} &= \begin{pmatrix} x_1 & x_2 & \dots & x_2 \\ x_2 & x_1 & \dots & x_2 \\ \vdots & \vdots & \ddots & \vdots \\ x_2 & x_2 & \dots & x_1 \end{pmatrix} \\
x_1 &= \frac{2\beta + 2\tilde{\beta} - \tilde{\beta}N}{\left(2\beta + \tilde{\beta}\right)\left(2\beta + \tilde{\beta} - \tilde{\beta}N\right)} \\
x_2 &= \frac{\tilde{\beta}}{\left(2\beta + \tilde{\beta}\right)\left(2\beta + \tilde{\beta} - \tilde{\beta}N\right)},
\end{aligned} \tag{14}
$$

thus arriving at the solution for optimal airfare pricing in matrix form. A few steps and insertions later the Nash equilibrium price expression is obtained.

$$
\begin{aligned}
\begin{pmatrix} p_1 \\ p_1 \\ \vdots \\ p_N \end{pmatrix} &= B^{-1} + \begin{pmatrix} H_1 + c_1\beta \\ H_2 + c_2\beta \\ \vdots \\ H_N + c_N\beta \end{pmatrix} \\
p_i &= \frac{2\beta - (N-2)\tilde{\beta}}{(2\beta + \tilde{\beta})\left(2\beta - (N-1)\tilde{\beta}\right)} H_i \\
&+ \frac{\tilde{\beta}}{(2\beta + \tilde{\beta})\left(2\beta - (N-1)\tilde{\beta}\right)} \sum_{j \neq i}^{N} H_j \\
&+ \frac{\beta\left(2\beta - (N-2)\tilde{\beta}\right)}{(2\beta + \tilde{\beta})\left(2\beta - (N-1)\tilde{\beta}\right)} c_i \\
&+ \frac{\beta\tilde{\beta}}{(2\beta + \tilde{\beta})\left(2\beta - (N-1)\tilde{\beta}\right)} \sum_{j \neq i}^{N} c_j
\end{aligned} \tag{15}
$$

Note how product differentiation enables a pure Nash-equilibrium in a scenario with asymmetric costs. The last step needed before taking the partial derivative with respect to crude oil prices involves substituting H_i and c_i. H_i is known from the previous chapter and the demand side discussion, and c_i is defined as:

$$
\begin{aligned}
c_i &= \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_{2i} + \alpha_{3i} P_f + D_i^c P_f + \alpha_7 ItinerayDist_i P_f \\
P_f &= \phi_0 + \phi_1 P_c \\
\alpha_{3i} &= a_0 + a_1 Hedge_i \\
D_i^c &= \alpha_4 d_{i0} + \alpha_5 d_{i1} + \alpha_6 d_{i2}
\end{aligned} \tag{16}
$$

Let me go over the details of an airline's marginal cost function c_i. Z_1 is a vector of variables which influence the marginal cost of product i, but are not product specific, like wind direction and strength. Vector Z_{2i} captures product specific variables affecting the marginal cost, for example the passenger number on a specific flight. P_f stands for the jet fuel spot price, which depends on the crude oil price P_c, and is involved in the last three summands of the cost Equation (16). The definition of α_{3i} recognizes that an airline's level of fuel hedging $Hedge_i$, combined with the fuel spot price, affects the marginal costs of product i. Specifically, $Hedge_i$ measures the proportion of airline i's fuel hedging contracts covering fuel consumption (in volume).

Fuel hedging in the aviation industry is an own topic and the second large paper by Shi et al. (2021) in this thesis dives deeper into it. For now, it is sufficient for the reader to know that hedging is a measure taken by airlines to protect themselves against fuel price volatility. They basically buy financial instruments which act as an insurance and provide predictability and fuel price stability. If airline i does not engage in fuel hedging at all, variable $Hedge_i$ is equal to zero, and a fuel price increase implies a marginal cost increase for airline i. If flight i's fuel is completely covered by hedging contracts, $Hedge_i$ is one. In periods of rising fuel prices, the airline benefits from a fuel hedging strategy because it can purchase fuel at a cheaper, locked in price level. On the other hand, if prices fall and the airline is highly involved in hedging, it will miss out on price savings because it has fixed hedging contracts. Therefore, it is expected that parameter $a_0 > 0$ and $a_1 < 0$, meaning that the hedging parameter α_{3i} can be positive or negative. Previous explanation is challenged by Shi et al. (2021), who argue that hedging gains or losses occur as a lump sum and as such have no impact on marginal costs. I will come back to this concern more specifically in section 5.

P_f also interacts with D_i^c, a variable capturing the intermediate stops through the dummies d_{ij}, similar to D_i's previous definition. Since aircraft must accelerate for takeoff, they burn more fuel when the route includes intermediate stops. Marginal costs for a route thus depend on the intermediate stops and the fuel price. If the flight has two or more intermediate stops, a fuel price increase will influence the marginal cost more than it would with only one or zero stops, the parameters are expected to be of magnitude $\alpha_6 > \alpha_5 > \alpha_4 > 0$.

The model allows the flight distance *ItineraryDist* to influence marginal costs because longer flights consume more fuel. The marginal costs of long-distance flight will be affected more by a fuel price increase than a shorter flight and α_7 should be positive. Since both demand and supply sides are explained and work together to form a Nash equilibrium price expression, I'm ready for the next step.

A quick pause gives me the possibility to look back and critically evaluate the model. I was at first unsure about the meaning of a unit increase in output. Does it mean adding another flight or does it mean adding length to an existing flight? Looking at the functional definition of c_i and keeping the first assumption in mind, I come to the conclusion that marginal costs refer to cost changes arising from increments within one specific flight operated by one specific airline. I also want to clarify the meaning of the separate functions for fuel price: $P_g = \delta_0 + \delta_1 P_c$ on the demand side models the gasoline price consumers face when using cars and $P_f = \phi_0 + \phi_1 P_c$ on the supply side stands for the fuel spot price paid by airlines. In my opinion, the model's main flaws are its choice of Bertrand oligopoly and the inclusion of fuel hedging in the marginal cost function. Maybe the authors chose Bertrand competition for computational reasons and better results, but intuitively it makes much more sense to model an air travel product's pricing with a Cournot model (Koopmans and Lieshout, 2016). Since marginal costs don't actually depend on an airline's hedging strategy, the model makes a false assumption and any predictions should be examined skeptically.

4.3 Model Predictions

I will skip substituting the expressions in Equation (15) for spacing reasons and instead focus on the partial derivative and the model's pass-through predictions. Like with simpler models, one takes the partial derivative of the equilibrium price with respect to costs or in this case, crude oil price. The partial derivative in a system with N firms now takes the form

$$\begin{aligned}\frac{\partial p_i}{\partial P_c} &= \frac{\left(2\beta-(N-1)\right)\tilde{\beta}+\tilde{\beta}(h_4 n_0+h_5 n_1+h_6 n_2)}{(2\beta+\tilde{\beta})\left(2\beta-(N-1)\tilde{\beta}\right)}\gamma\delta_1 \\ &+ \frac{\left(2\beta-(N-2)\right)\tilde{\beta}\left((a_0+a_1 Hedge_i)+D_i^c+\alpha_7 ItineraryDist_i\right)}{(2\beta+\tilde{\beta})\left(2\beta-(N-1)\tilde{\beta}\right)}\beta\phi_1 \\ &+ \frac{\tilde{\beta}\sum_{j\neq i}^{N}\left((a_0+a_1 Hedge_j)+D_j^c+\alpha_7 ItineraryDist_j\right)}{(2\beta+\tilde{\beta})\left(2\beta-(N-1)\tilde{\beta}\right)}\beta\phi_1.\end{aligned} \quad (17)$$

n_0 is the sum of nonstop flights on the relevant route i, n_1 is the sum of flights with one intermediate stops, and so on. Gayle and Lin (2021) split Equation (17) into three parts, determined by the coefficients in each summand. The first line includes $\gamma\delta_1$, which is the substitution parameter between car and airplane and the gasoline price parameter, so it's fair to call line 1 the *demand effect.* Variables in the second line have subscript i and the parameters $\beta\phi_1$ are connected to price i and fuel spot price, respectively. Therefore, the second line is the direct pass-through mechanism induced by the airline itself, or *direct cost effect.* The third line recognizes the influence of other airline's strategies and hence is called *strategic cost effect.* Next, I will summarize the intuitive explanations behind the three effects and go over the model predictions.

For the *demand effect*, a crude oil price increase makes gasoline more expensive via δ_1, which will make cars less attractive in comparison to air planes. Customers will demand more flight tickets, increasing their price. The same logic applies to crude oil price decreases, making pass-through positive, that is, changes in crude oil prices result in ticket price changes with the same sign. The demand pass-through mechanism depends on the number of stops of the specific route, as it becomes weaker with more intermediate stops on the route (customers prefer non-stop flights) and it also depends on the itinerary distance, which is part of γ. I already discussed how a specific distance, where consumers are indifferent between the two modes of travel, comes with the highest impact of gasoline price changes to ticket demand. This also translates to ticket prices.

The optimal price reaction to a marginal cost change for airline i is captured in the *direct cost effect*. The magnitude of the direct cost effect depends on airline i's hedging strategy. If the percentage of fuel covered by hedging contracts is sufficiently large, the fraction in front of $\beta\phi_1$, and with it pass-through, can become negative. Other factors influencing the direct cost effects are the intermediate stops and the itinerary distance of flight i. More intermediate stops strengthen pass-through because more fuel is burnt during takeoffs. An increase in crude oil price will increase fuel spot price via ϕ_1, and if everything else stays equal but the route increases its stops, it needs more fuel. This makes the route more expensive, and the costs will be passed on to customers. A longer flight distance makes fuel price changes more noticeable, and increases pass-through.

The *strategic cost effect* captures airline i's optimal response to marginal cost changes experienced by the competition. Firms are interdependent in a Bertrand Nash game, and therefore rival firms influence firm i' pass-through as well. The indirect pass-through depends on the same variables and parameters as before, and the argumentation remains similar. If for example rival firms all have a high hedging ratio, they might have a negative pass-through rate of costs, which influences firm i's own strategy. It should also be noted that all effects depend on the number of firms N in the market and on the price parameters β and $\tilde{\beta}$, which determine how much a price change influences demand.

Gayle and Lin (2021) work out four key predictions from their model, which they check later in their empirical analysis. First off, the pass-through rate of a crude oil price change to airfare can be negative or positive, depending on airline i's and its rival's fuel hedging strategies. The second point predicts pass-through to be negatively correlated with an airline's hedging ratio, which comes from the fact that a_1 is negative. Third, the itinerary distance has a positive effect on pass-through, meaning a longer route distance is predicted to be associated with a larger pass-through magnitude. The last prediction implies that the number of competitors in the market influences pass-through. Since N appears in different places in Equation (17), it is not intuitive whether the number of firms strengthens or weakens the incentive to pass on cost changes. In order to get to the effect of competition intensity, one needs to take the partial derivative of Equation (17) with respect to n_0, n_1 and n_2, separately. In their mathematical appendix, Gayle and Lin (2021), pp.10-15 go through this procedure to find out that pass-through can be positively or negatively influenced by the number of competitors dependent on airline i's hedging strategy. At high hedging levels, pass-through will be negative and more intense competition will strengthen negative pass-through, that is, drive it further away from zero. If airline i exercises a moderate hedging strategy and has a negative pass-through rate, theory predicts that increased competition will push the pass-through rate closer to zero. At very low hedging levels and positive pass-through rates, more competition is predicted to increase pass-through. To summarize the predictions, airline i's pass-through

1. depends on hedging strategies of all airlines,

2. is negatively correlated with airline i's hedging ratio,

3. is positively correlated with flight distance,

4. depends on the number of competitors and their fuel hedging ratio.

4.4 Empirical Analysis

Are the previous predictions supported by real world data? In the following part, I will go over Gayle and Lin (2021)'s empirical work included in the same paper as before.

The setting in their paper is domestic flights in the United States over the period 2013Q3 to 2015Q4. The time period spans over the interval of interest, when oil prices fluctuated significantly but airfare stayed relatively stable. Since the U.S. domestic air travel market had the most passengers before covid and is one of the largest in the world, it allows for a sufficiently large data sample. Getting detailed data in the aviation market poses a challenge to researchers, as there aren't many sophisticated, public flight level data sets available. Gayle and Lin (2021) use the DB1B database, which is a 10% random sample of U.S. airline ticket data published by Bureau of Transportation Statistics on quarterly basis.

Information in the DB1B database allows the researcher to analyze ticket prices in different origin-destination markets with differing operating carriers. A market is defined as a pair of airports and an observation is a combination of a market and operating carrier at a specific time. After taking out outliers following the literature, the sample includes 603,745 observations, 147,073 markets, and some ticket and market specific data like the itinerary distance, number of passengers, and airfare. The data set is structured in a way which allows for a differentiation between a non-stop flight and a flight with intermediate stops. The authors refer to airline's 10-K annual reports for their hedging information, but are not able to find hedging information for 5 airlines, which are excluded from the sample. Energy prices like the jet fuel price and gasoline price are obtained from the U.S. Energy Information Administration.

There are three steps required to examine the impact of different variables on cost pass-through. First, airfare has to be modeled by some exogenous variables in OLS fashion. In the second step, one takes the derivative of price with respect to crude oil price to get to the general pass-through mechanism, which will depend on some variables. Taking another partial derivative of pass-through with respect to the variable in interest, say itinerary distance, reveals the impact of a change in itinerary distance on cost pass-through. I will now take a closer look at each of the three steps.

Regressing airfare is done in a comprehensive equation with 35 summands. Air product price in logs is a linear function of the variables

$$
\begin{aligned}
log(P) = f(&p_c, Hedge, \overline{Hedge^c}, ItineraryDist, N\_nonstop, N\_onestop, \\
&N\_twostop, EntryThreat, Mkt\_Dist, Origin\_Presence, Dest\_Presence, Interstop, \\
&Inconvenience, Population, fixed\ effects)
\end{aligned} \tag{18}
$$

and many interactions of them, like $log(p_c) \times Hedge$. In this example, a variable interaction allows the effect of a percent change in crude oil price (p_c) to depend on *Hedge*, and all other variable interactions can be interpreted in the same fashion.

Hedge describes the hedging ratio of an airline, $\overline{Hedge^c}$ measures the average hedging ratio of the competition in a specific market. *ItineraryDist* and *Mkt_Dist* are two separate variables because of the possibility of intermediate stops. *Mkt_Dist* is the nonstop flight distance, whereas *ItineraryDist* represents the sum of miles including intermediate stops.

N_nonstop counts the number of nonstop flights offered in a specific market, and *N_onestop*, *N_twostop* are defined similarly. The variable *EntryThreat* counts the number of distinct carriers present at both endpoints in the market who don't offer a route yet, therefore posing a potential competition threat. Note that *EntryThreat* influences prices but there is also a possibility of simultaneous causality. High prices attract more (potential) competitors (Gerardi and Shapiro, 2009), hence there could be an endogeneity issue.

Origin_Presence and *Dest_Presence* capture the size of an airline presence at an airport as in Berry (1990). There is no exact definition of both origin and destination presence, but my best guess is that whenever an airline is more present at an airport, that is, offers flights to more destinations from one airport, one of the *_Presence* variables becomes larger. The number of intermediate stops in one itinerary are included in variable *Interstop*.

Flights in the same market with the same number of intermediate stops might still exhibit different utilities because of differing stop locations. Thus, *Inconvenience* takes into account the location of intermediate stops. The mean origin and destination population are merged into *Population*, controlling for the possibility that larger markets have larger demands and higher prices. Lastly, Equation (18) includes some time, air carrier, and location fixed effects. Estimating Equation (18) yields the relevant coefficients, which are useful for any marginal effect calculations. Out of the 35 summands and their coefficients, only five are not significant at the 1%-level and the regression reaches a r^2 of 0.402.

The second step requires differentiating airfare with respect to crude oil price, giving a functional expression of the general pass-through. Since both airfare and crude oil prices are measured in logarithms, $\frac{\partial log(P)}{\partial log(p_c)} := PTE$ can be interpreted as pass-through elasticity: what is the percent change in airfare if crude oil prices change by one percent?

The final, maybe most interesting step, looks at the marginal effect of a specific variable on pass-through. I believe it is helpful to examine one such example and explain other marginal effects afterwards. Since it is unlikely that all variables are jointly zero, they are set to their sample mean, similar to calculating at means marginal effects after a logit or probit regression. In the next equation, sample means are indicated by a line over the variable. The marginal effect of jet fuel hedging is

$$\begin{aligned}\frac{\partial PTR}{\partial Hedge}|_{samplemean} &= -0.00691 + 0.000059\overline{N\_nonstop} + 0.0000128\overline{N\_onestop} \\ &- 0.00000828\overline{N\_twostop} - 0.0000452\overline{EntryThreat} \\ &+ 0.0003log\overline{Mkt\_Dist} = -0.005,\end{aligned} \tag{19}$$

meaning that a 1% increase in the airline's fuel hedging ratio is associated with a 0.005 decrease in pass-through elasticity if all other variables are set to their respective mean. This is in line with the second model prediction from section 4.3, although I would have wished for a statistical significance measure for the marginal effects. P-values or standard errors for at means marginal effects are not included in the paper or math appendix of the paper, reducing the relevance of these crucial numbers.

However, the whole point of this empirical analysis is to get to the marginal effects, so I will continue. It turns out that the partial derivative of pass-through with respect to itinerary distance is just a coefficient estimated in the initial OLS regression with a p-value of less than 0.01. PTE will increase by 0.0384 with each percent increase in itinerary distance, confirming prediction number 3. The authors find that an additional nonstop, one-stop and two-or-more stop flight offered in the market changes cost pass-through elasticity by 0.012, -0.00034, 0.0017, respectively, if the hedging variables are set to their means. Theory predicted pass-through to increase and get closer to zero at moderate hedging levels, which is qualitatively confirmed by the numbers for nonstop and two-or-more stop flights.

The entry of a one-stop competitor in the market however slightly decreases pass-through at moderate hedging levels. It would again be helpful to see a p-value for this number, as it might be insignificant. To demonstrate the importance of fuel hedging and market distance on pass-through, the authors compute pass-through elasticities from step two for all airlines and report summary statistics. The mean elasticity rate is -0.065, with a standard error of 0.00007, and 86.7% of products exhibit negative rates. After that, they artificially set hedging variables to zero, which means that they look at pass-through in a counterfactual world where fuel hedging doesn't exist. Mean pass-through becomes positive, its rate is 0.0045 at high significance. 50.7% of products have negative pass-through. The authors repeat this step for market distance, setting its variable to zero, increasing the mean pass-through to 0.66 at a significance level of $p < 0.01$. Now, with the influence of fuel hedging and market distance shut down, 0% of products have a negative cost pass-through rate.

What is the intuitive meaning of a negative pass-through rate? Why would an airline decrease ticket prices if their fuel price costs increase? In general, if an airline is heavily hedged and fuel prices decrease, it will have higher reported fuel costs because of the hedging contract costs. The airline will suffer larger losses compared to competitors with a smaller hedging ratio, giving it an incentive to raise prices. On the other hand, if fuel prices rise, the effect is the opposite. Hedging results in a relative cost advantage, and airfare can be lowered.

The other large discovery is the influence of itinerary distance on pass-through. Intuitively, this can be explained by the fact that long-distance flights are more fuel extensive. The longest flights are exposed to the largest fuel cost changes, increasing pass-through.

To conclude this section, I would say that the previously discussed paper makes a contribution in understanding the pass-through mechanism in the aviation industry. In the empirical part, I don't see a problem with the data itself, as it comes from trustworthy sources, and the DB1B ticket data is a large enough random sample. Since pass-through is heavily influenced by market distance, findings from the United States might not be applicable to smaller countries, which most likely also have a smaller number of competitors. The numerous variable interactions, use of logs and different units (fuel costs in \$/barrel and ticket price in \$/ticket) make coefficient interpretation difficult, especially after two partial derivatives. A detailed but flawed theoretical model takes in airline-specific and demand-specific factors and comes to precise predictions, which are confirmed empirically. Problems in the theoretical model include using a Bertrand model instead of a Cournot model and associating marginal costs with fuel hedging gains/losses. The next section deals with the latter problem.

5 Influence of Hedging on Pricing

The part of Shi et al. (2021) paper which I will analyse in the following clarifies the role of fuel hedging in airline pricing decisions. I felt like my thesis required a more thorough analysis on the topic, especially since it has lead to academic disagreement. The authors reflect on their empirical model, providing me with an opportunity to standardize my empirical research criticism.

5.1 Hedging in the Aviation Industry

First off, a simple example illustrates a fuel hedging strategy by an airline which wants to reduce uncertainty in their cash flows due to fuel price volatility. Assume that fuel costs 5\$/gallon. I'll go over two ways of insuring against price changes on the financial market, buying a call or selling a put option. Suppose the strike price of the call option is 5.6\$/gallon with an expiration date sometime in the future, and airline i has the right to purchase x gallons of fuel at that price before the expiration date. The call option comes of course with a cost C_c, also known as a premium. If fuel market price p rises above 5.6\$/gallon, then airline i makes a profit of $(5.6 - p)x - C_c$ from executing its call options. On the other hand, the airline will lose the premium paid if p never rises above the spot price, because it is not obligated to buy fuel with a call option. Since these premiums can be quite high with larger contracts, the airline might reduce costs via put options, which give the buyer the right to sell the underlying asset at some strike price. It sells put options at strike price 3.8\$/gallon for a premium. If prices stay above that level, airline i can keep the premium. In the unlikely case of a large price decrease below 3.8$/gallon, airline i makes significant loss: she must pay the buyer of the put option and she loses the premium from the call option.

In any case, fuel never changes hands between the buyers and sellers of derivatives, only money does. Also note that any payment is made as a lump sum, which doesn't depend on the amount of fuel consumed by the airline. Airlines buy fuel at market price, and therefore it is false to assume that hedging influences the purchase cost of fuel. However, the authors find an empirical connection between hedging outcomes and ticket prices, for which they offer several explanations.

If firms choose their hedging extent with regards to their expected fuel consumption, hedging outcomes are connected to variable costs. It is deemed unlikely that large companies with their own pricing divisions are susceptible to behaviour bias and irrational pricing decisions. McAfee et al. (2010) point out that it can be rational for agents to condition behaviour on sunk costs. Airlines might follow a full cost pricing strategy, which takes into account fixed and variable costs. Firms often employ full cost pricing when separating fixed and variable costs is too complicated. Since airlines have straight forward variable costs, this explanation can be ruled out.

In some situations, hedging can directly influence ticket pricing: if an airline experiences a significant hedging gain, it might sacrifice current profits by lowering ticket prices for a larger market share, which will increase future profits. Conversely, if the firm suffers severe hedging losses, prices might have to be raised to generate enough cash flow for normal operations (binding budget constrain). Adam et al. (2007), pp. 2450 show that in general, hedging reduces expected production costs, leading to lower output prices. Pinning down the driving forces behind the aforementioned connection proves to be difficult and should be subject of future research.

5.2 Empirical Analysis

Shi et al. (2021) find empirical evidence for the impact of hedging outcomes on ticket pricing, which I will analyze next. They model airfare in a reduced form equation:

$$ln(fare_{ijt}) = \alpha + \beta ln(afc_{ijt}) + (\gamma X_{ijt} + \lambda Y_{jt} + \tau Z_{it}) + \theta_{ij} + \sigma_t + \epsilon_{ijt}. \quad (20)$$

The dependent variable measures average airfare for carrier i on route j in year-quarter t, documented in the DB1B dataset. afc_{ijt} stands for the reported fuel cost of an airline, which includes hedging gains or losses. The actual fuel purchase price across airlines differs only slightly, and airlines include their hedging profits in their reported fuel cost for accounting reasons. The average fuel cost thus includes cost variations across airlines and it is the main concern of Equation (20) to isolate hedging differences inside the afc_{ijt} variable. If this is done successfully, β captures the effect of a change in costs on airfare due to hedging. In order to isolate hedging and avoid omitted variable bias, Equation (20) must include all variables which are correlated with the average reported fuel costs, and a determinant of airfare at the same time. The authors introduce several control variables X, Y, Z, θ, σ but remain vague about their explicit definitions.

First, a substantial share of an airline's cost comes from labor, thus average salary is included. Second, market concentration might be correlated with the average reported fuel cost and is definitely a determinant of ticket prices, hence it makes sense to control for it. Instead of including the HHI known from section 3.2 as a direct measure, the authors recognize that HHI might be endogenous because high prices will probably attract more competitors. Causality would run in both directions, resulting in an inconsistent HHI estimator. They instrument competitive intensity with the distance of a route and an indicator of an airlines' average loading share at the departure and destination airport. Mian et al. (2014) and Gerardi and Shapiro (2009) use different instruments (population averages at endpoints and total passengers enplaned on a route), but their research focuses on price dispersion. I am not entirely convinced that the instruments used by Shi et al. (2021) are valid because they might be correlated with the error term, as shown by Gerardi and Shapiro (2009). However, I am interested in a correct β estimate and an inconsistency for the market concentration measure can be accepted. The third controlling variable in Equation (20) is the share of round trip tickets. Finally, the authors include merger and bankruptcy dummies.

The result of the instrumental variable regression with several control variables demonstrates a link between the financial market and the product market. A 10% increase in average fuel costs due to hedging is associated with a 2.21% increase in airfare ($p < 0.01$). Although this model doesn't go into detail, it shows that hedging and pricing are connected, which is in line with findings from Gayle and Lin (2021). To make sure that the fixed effects properly control for other factors in their model, Shi et al. (2021) use cases with large reported fuel price differences between carriers due to hedging strategies. Their check confirms assumptions: carriers with a significantly lower (higher) fuel price due to hedging also offered significantly lower (higher) ticket prices.

6 Discussion

A large part of a bachelor thesis is outlining the reasons why results from studies differ and analyzing drawbacks. This section summarizes findings, provides explanations for any differences and lists general criticisms applicable to the explored studies. The following table presents results from different models, sorted by the type of cost change: is only one firm affected or do cost changes influence the whole market?

Model	firm specific cost change	market cost change
contestable	0 or 1	1
Cournot simple	$\frac{1}{N+1}$	$\frac{N}{N+1}$
Cournot differentiated	$\frac{2N^2+N(N+2)\phi+\phi^2}{(2N+\phi)(2N+(N+1)\phi)}$	$\frac{N(\phi+1)}{\phi(N+1)+2N}$
Bertrand simple		1
Gayle and Lin		-0.065
Shi et al.	0.221 due to hedging	

Table 1: Pass-through from different models.

For the top part of the table, differences in pass-through come from the model choice and its assumptions. The numbers reported for Gayle and Lin (2021) and Shi et al. (2021) are pass-through elasticities. Empirical examples make it evident why computing direct pass-through rates in the aviation industry causes problems: the units are not the same. Gayle and Lin compute the effect of a percent change in crude oil prices on airfare, and they get a negative number. A 10% increase in crude oil prices results in a mean 0.65% decrease in ticket prices. Interestingly, negative pass-through levels are not in the scope of the traditional models in the top part of the table. Shi et al. concentrate on the pass-through elasticity due to hedging strategies of airlines, finding that a 10% cost increase due to hedging will lead to a 2.21% increase in airfare on average.

The estimates from Gayle and Lin (2021) and Shi et al. (2021) are not easy to compare because they examine cost changes from different sources and their research poses separate questions. Both studies agree on hedging strategies having a significant effect on pricing and pass-through, however. In general, studies about pass-through should keep in mind the following details (Walter, 2014):

As common units are sometimes not feasible, empirical studies calculate pass-through elasticities. With absolute rates and pass-through elasticities, one encounters the problem of linearity. Computed numbers assume linearity whereas it is probable that pass-through depends on the magnitude of the cost shock. For example, pass-through might look very different in a case where prices increase by 80% when compared to a moderate 5% price increase.

A straight forward way of calculating pass-through empirically is by reduced form regression, as seen in both presented studies. Price is a function of marginal costs and other variables. 2-fold variable interactions can be interpreted as the impact of one variable depending on the other variable, but this relationship becomes more complex with 3-fold interactions. When studies use them, they should justify their use and provide interpretation of the regression parameters, some of which is missing in Gayle and Lin (2021)'s case. I would guess that they wanted their model to include plenty of interactions as to not miss any significant relationships and they were left with more variables after two partial derivatives. This might have made marginal effect estimates more precise.

In oligopoly settings, firms react to actions of their competitors. Firm interactions are likely correlated with marginal cost changes and they determine prices in the market. Leaving out firm linkage in the regression equation would lead to omitted variable bias and inconsistent estimators, an issue disregarded by Shi et al. (2021) in Equation (20). Another cause of trouble in regression equations is the choice of control variables. Studies should explain the fixed effects they considered and controlled for. If done correctly, parameters can be interpreted directly because they are consistent and don't include correlated effects from other variables.

With pass-through, one should also keep in mind time lags. Especially in cases with longer supply chains, cost changes might take a while to effect consumer prices and studies might not find correct results if they examine the situation in high frequency. Since both presented studies use quarterly DB1B data, I don't think that time lags pose a problem.

7 Conclusion

This thesis reviews theoretical and empirical frameworks modeling pass-through in the aviation industry. I begin with standard economic models which predict absolute pass-through rates between zero and one, depending on the assumptions and details of the models. I argue that there is sufficient evidence for airline markets to be seen as oligopolies, following an analysis by Koopmans and Lieshout (2016). Although a Cournot model represents airline pricing more accurately, Gayle and Lin (2021) use a Bertrand model to get to equilibrium prices. In addition to that, I find that their theoretical model misplaces hedging into variable costs. A company buys fuel at market price, regardless of her hedging strategy and gains or losses realize as a lump sum. Their model includes airline specific and market specific features, which allow for a detailed analysis about the sign and size of pass-through as well as its determinants. Hedging, flight distance and competitiveness in the market are predicted to be the key determinants of pass-through. The following empirical part verifies predictions but doesn't account for an endogeneity issue between prices and *EntryThreat*. The marginal effects of hedging and flight distance on pass-through are -0.005 and 0.038, respectively. An additional nonstop, one-stop and two-or-more stop flight changes pass-through by 0.012, -0.00034, 0.0017, respectively. In general, 86.7% of flights in the sample have negative pass-through, with a mean elasticity of -0.065. After artificially eliminating the hedging and market distance effect, 0% of products have negative pass-through, and their mean elasticity is 0.66. The next considered study by Shi et al. (2021) also demonstrates a link between hedging and pricing, but they aren't interested in the determinants of pass-through, complicating the comparison of both studies. They compute a pass-through elasticity of 0.221 in the case where an airline reports a deviant average fuel cost due to fuel hedging. In a separate discussion part, I present general criticism for empirical studies, some of which applies to the aforementioned papers.

Coming back to the relevance statement of this thesis, the findings have important policy implications. Taxing crude oil with the intent to reduce ticket sales might have unexpected consequences because of a slightly negative pass-through. If ticket prices follow the empirical prediction and decline as a response to a crude oil price increase, passengers will (in the short term) probably buy more tickets and the policy will have failed. Greenhouse gas emissions from the industry would have to be tackled in a different way.

The fundamental weakness of this thesis is the lack of comparable empirical results and the time scope of results. It would be useful to compare different studies with the same objective, as this could give more credibility to findings or highlight potential shortcomings. I believe that more research should be conducted to be certain, and new research could use different approaches, for example a diff-in-diff estimator. Long term pass-through examinations are in my opinion not yet very present in current research on the aviation market. It would be especially interesting for policy makers to know the long term pass-through. I suspect that in the long run, a lasting fuel price increase would result in rising ticket prices, regardless of hedging strategies.

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A Mathematical Appendix

A.1 Classical Cournot equilibrium with n firms

$$\begin{aligned}
\max_{q_1} \pi_1 &= (p(q) - c_1)q_1 \\
&= (a - b(q_1 + \cdots + q_N) - c_1)q_1 \\
\frac{\partial \pi_1}{\partial q_1} &= 0 \\
\Leftrightarrow 0 &= a - b(q_1 + \cdots + q_N) - c_1 - bq_1 \\
\Leftrightarrow q_1 &= \frac{a - b(q_2 + \cdots + q_N) - c_1}{2b}
\end{aligned}$$

Symmetric firms such that $q_1 = \cdots = q_N := q_i$

$$\begin{aligned}
q_i &= \frac{a - b(N-1)q_i - c_i}{2b} \\
\Leftrightarrow q_i &= \frac{a - c_i}{b(N+1)}.
\end{aligned}$$

Getting to the equilibrium price: industry output is

$$\sum_i q_i = \frac{Na - \sum_i c_i}{b(N+1)},$$

with $\sum_i q_i = Q$, equilibrium price is

$$p = a - bQ = a - \frac{Na - \sum_i c_i}{(N+1)} = \frac{a + \sum_i c_i}{(N+1)}.$$

A.2 Pass-through when $\phi \to \infty$

$$\begin{aligned}
\lim_{\phi\to\infty} \frac{\partial p_i^e}{\partial c_i} &= \lim_{\phi\to\infty} \frac{2N^2 + N(N+2)\phi + \phi^2}{(2N+\phi)(2N+(n+1)\phi)} \\
&= \lim_{\phi\to\infty} \frac{\phi^2\left(\frac{2N^2}{\phi^2} + \frac{N(N+2)}{\phi} + 1\right)}{\phi\left(\frac{2N}{\phi} + 1\right)\phi\left(\frac{2N}{\phi} + N + 1\right)} \\
&= \lim_{\phi\to\infty} \frac{\frac{2N^2}{\phi^2} + \frac{N(N+2)}{\phi} + 1}{\left(\frac{2N}{\phi} + 1\right)\left(\frac{2N}{\phi} + N + 1\right)} \\
&= \frac{\lim_{\phi\to\infty} \frac{2N^2}{\phi^2} + \frac{N(N+2)}{\phi} + 1}{\lim_{\phi\to\infty}\left(\frac{2N}{\phi} + 1\right)\left(\frac{2N}{\phi} + N + 1\right)} \\
&= \frac{1}{N+1}.
\end{aligned}$$