An Analysis of International Airline Alliances and Joint Ventures*

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Abstract

International airline alliance helps airline carriers to cooperate in codesharing, frequent flyer programs, marketing, and many other business activities except pricing. In this paper, we analyze airline carriers' pricing strategies when they are alliance members on a given network, and compare with the situation where alliance members get antitrust immunity from the government to form a joint venture so that they can coordinate in price setting. We show that depending on airline carriers' pricing strategies and consumers' practice of fare arbitrage, inter-hub competition can generate important externality on the pricing of interlining flights where both carriers are involved in providing the service. Therefore, joint ventures may not always lead to lower prices for interlining flights even though it helps to eliminate double marginalization. Current government regulation is oversimplified, and policymakers should not underestimate the importance of the inter-hub market when granting antitrust immunity.

Keywords: Airline industry, hub-spoke network, airline alliance, joint venture, pricing strategies.

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1 Introduction

Airline carriers in the U.S. got the freedom to design their own network structure and prices after the Airline Deregulation Act of 1978. After that, we saw many important changes in the industry: hub-spoke networks, failure of new entrants, complicated pricing system, and interlinging. More freedom to the airline market also stimulated international cooperation. The international airline alliance, which mainly started in the late 1990s, developed very fast in the past twenty years. In 2017, the three major alliances (Star, SkyTeam and Oneworld) accounted for 57 percent of total scheduled traffic in the world (IATA, 2018). In the meantime, members of the alliance also received increasingly more freedom in coordinating different operations. Joint ventures which are currently implemented within SkyTeam and Star Alliance are "operationally very close to mergers" (Bilotkach and Huschelrath, 2011; Bilotkach 2018). In this paper, we analyze the growing cooperation among airline carriers and discuss how policymakers can improve its decisions in granting antitrust immunity to build joint ventures.

1.1 International Airline Network

International airline carriers often form hub-spoke networks because of the economies of density (Brueckner 2001; Hendricks et al 1995). Hub spoke network can easily pool consumers from different origins to reduce marginal costs and save fixed investments on airplanes and ground equipment. Therefore, our analysis relies on the network structure illustrated in Figure (1), where two airline carriers operate on two hub spoke components with an overlapped spoke to connect six cities. Between any two cities, there are certain amount of consumers who need flight service. Also, edge of the network represents that direct flight service is offered by an airline carrier. This network structure is similar to the international airline network operated by Air China (denoted by CA) and United Airlines (denoted by UA). We can consider city 1 and 2 to be CA and UA's international gateway airports: Beijing and San Francisco. Based on Beijing, CA offers direct flights to and from local cities 3 and 4 (e.g. Dalian and Wuhan) and a global destination, San Francisco. Similarly, UA operates direct flights from San Francisco to local cities 5 and 6 (e.g. Seattle and Las Vegas) and a global destination, Beijing. Due to government regulations, international airline carriers often cannot offer local flight services. Therefore, in our network, CA and UA do not have any overlapped service in its local spoke markets.[1]

[1] Carriers may face competition from other local carriers in its spoke markets. Their effect is not the focus of our paper.

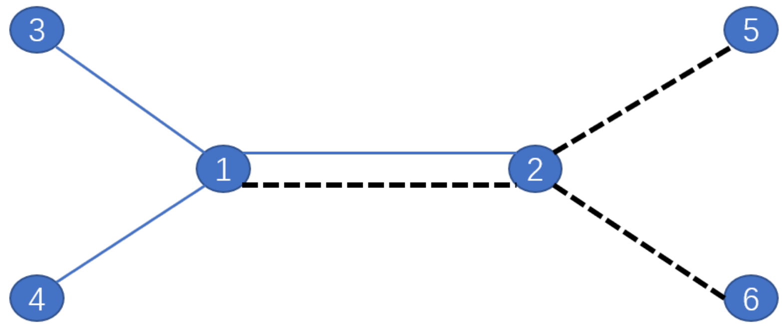

Figure 1: An airline network with six cities. Straight line edges represent carrier A (Air China) and dotted line edges represent carrier B (United Airlines)

1.2 Alliance Membership and Joint Venture

Alliance members are allowed to cooperate on many activities. For example, CA and UA, which are members of star alliance, focus on four major issues in their cooperation: expanding connecting flight opportunities, creating a more seamless experience when customers travel to Beijing and San Francisco, enhancing frequent flier program partnership, and coordinating joint marketing. As a result, alliance members often provide more and more similar quality of service. However, simple alliance membership does not allow members to coordinate in price setting due to government regulations (Bilotkach 2018). For any interlining market where both carriers are involved in providing the service (e.g. market between city 3 and 5), each carrier will noncooperatively set price for its segment of the interlining trip. The sum of the resulting fares determines the total price of the interlining trip.

To improve cooperation between alliance members, many members got approval from government and successfully formed joint ventures which allow them to coordinate in price setting. In 2016, 81% of the travelers who flew between America and Europe were on an airplane which was operated by a joint venture member carrier (Bilotkach 2018). With joint venture, each carrier can set prices for all city pair markets to maximize joint profit, and in our network, the two carriers are in fact merged to become a monopolist after forming a joint venture.

1.3 Current Government Regulation

In our network structure, flight services are complementary products for many city pair markets where direct flights are not available. As we discussed before, with simple alliance membership, each carrier will noncooperatively set prices for its segments and standard economic theory tells us that government should encourage airline carriers to form joint venture because it can eliminate the problem of double marginalization (IATA 2011). However, we also have direct competition in the inter-hub market where consumers can either go with CA or UA, and we can expect that price will increase after eliminating competition. Therefore, to determine whether carriers can be allowed to form joint venture, current government uses a simple rule: approving antitrust immunity unless carriers' networks overlap too much. In our simple network where we only have one overlapping inter-hub market, it is very likely the two carriers can gain antitrust immunity from the government. Since international airline carriers often have this kind of network structure, we are not so surprised that most of the flights between American and Europe are operated by joint ventures.

In this paper, we build a network flow model to analyze the price change after alliance members form a joint venture. We show that inter-hub competition can generate important externality on the pricing of local spoke markets due to carriers' different strategies and consumers' fare arbitrage. As a result, current government interventions may be too simplistic and joint venture may lead to higher prices for the interlining markets.

The rest of the paper proceeds as follows. In the second section, we will formally introduce the environment of our model and key assumptions. In the third section we will discuss consumers' fare arbitrage on network and characterize equilibrium prices under the two different cases: alliance membership and joint venture. Then we can show the price changes which depend on the properties of the demand function. We will also connect our results with different network structures and market sizes. In the fourth section, we will relate our results to the existing literature. Section 5 concludes. All proofs are in Appendix.

2 The Model

2.1 The Environment

In this economy, there are six cities and each city is represented by a node in the airline network. We use $N = \{1, 2, ..., 6\}$ to denote the set of cities. If two cities are connected by an edge, then some airline carrier provides direct flight service for customers to travel between these two cities. There are two airline carriers in this economy, and we denote them A and B. We assume that the network structure is exogenously determined with two hub-spoke components and an overlapping spoke. The Figure 1 illustrates this network structure. We can see that airline carrier A provides direct flights to connect hub city 1 to cities 2,3,4 while carrier B provides direct flights to connect hub city 2 to cities 1,5,6.

2.2 Demand

We assume that there are consumers who want to travel between any two cities in the network. Also, we assume that consumers who need a round trip to travel from city g to h do not want to go anywhere else. Consumers only care about reaching their destinations at the lowest cost. This is a natural assumption in this network because we have only one shortest route (smallest amount of edges) between any two cities.[2] Formally, we assume that the flow from one city to another is determined by a given demand function, $D(p)$, which is the same for every city pair. This function reflects consumers' willingness to pay, and if p is the price of the cheapest return air ticket from city g to h, then the amount of $g - h$ consumers is $D(p)$. We assume that this demand function satisfies the standard assumptions: strictly positive, downward sloping and differentiable. In this economy, even though the demand function is the same for every city pair market, airline carriers can charge different prices so that the actual demand may be different in each city pair market.

2.3 Airline Alliance Agreements

We focus on two major airline cooperation agreements: alliance membership and joint venture. With simple alliance membership, each carrier will noncooperatively set prices for its segments and the sum of both carriers' prices determine the price of interlining trips where both carriers are involved in providing the services. If alliance members form a joint venture, carriers will set city pair market prices to maximize joint profits.

2.4 Important Assumptions

Based on Hendricks, Piccione and Tan (1997), we impose several assumptions on demand function and costs. We assume that carrier A and B have the same per traveler cost of a round trip on a direct flight (i.e. $c^A = c^B = c$).

Assumption 1 *$\epsilon(p) = -pD^{'}(p)/D(p)$ is nondecreasing in p. If $\epsilon(p)$ equals a constant α, then $\alpha > 1$. If $\epsilon(p)$ is an increasing function, then there exists a $\hat{p} > 0$ such that if $p > \hat{p}$, $\epsilon(p) > 1$.*

Assumption 2 *$D^{'}(p)/D(p)$ is strictly monotonic in p.*

Assumption 1 is sometimes called the Marshall's second law of demand (Nocke and Schutz, 2018). To understand the implications of these two assumptions, we consider a city pair market

[2] Some other networks may lead to the tradeoff between shorter distance with higher price versus longer distance with lower price.

composed of two direct flights. Each carrier operates one flight independently, and carrier i will choose price p, given the other carrier charges price s for its segment, in order to maximize the profit:

$$(p - c)D(p + s) \tag{1}$$

Let $\phi^i(s)$ denote the solution of the optimal p to maximize (1), and if $s = 0$, $\phi^i(0)$ is equal to the monopoly price of a city pair market with marginal cost c, which is also denoted by $p^M(c)$. We also use $\pi(c)$ to denote the corresponding monopoly profit with marginal cost c. With assumptions (1) and (2), we can derive some properties of the best reply function, $\phi^i(s)$.

Lemma 1 *(i) $\phi^i(s)$ is single valued. (ii) If $D'(p)/D(p)$ is strictly decreasing (increasing), then $\phi^i(s)$ is strictly decreasing (increasing) in s for $i = A, B$, which means that the flights of the two carriers are strategic substitutes (complements). (Hendricks, Piccione and Tan, 1997)*

The key thing of this lemma is that we can focus our analysis in two cases. In one case, the best reply functions are strategic substitutes (i.e. $\phi^i(s)$ is decreasing in s). It means that the best response to an increasing price by the other carrier is price decrease. In the other case, the best replies are increasing so that the pricing strategies are strategic complements. These two cases are critical in market competition as illustrated in Bulow, Geanakoplos, and Klemperer (1985). Simple analysis of assumption 2 will also show that whether the two carriers' pricing strategies in interlining are strategic substitutes or strategic complements depends on the concavity of the demand function. Specifically, prices are strategic substitutes if $D''(p)$ is less than $D'(p)^2/D(p)$. It means that if the demand function is concave then interlining prices are strategic substitutes. If the prices are strategic complement, then demand function must be strictly convex.

Rearranging first order condition of the profit in (1), we can get that:

$$\epsilon(p + s)\frac{p - c}{p + s} = 1 \tag{2}$$

Based on this equation, we can easily see that strategic substitute strategies require that $\epsilon(p)$ must be an strictly increasing function of p while for strategic complement strategies $\epsilon(p)$ can be a constant. As a result, iso-elastic demand function, $D(p) = p^{-b}$ where $b > 1$, leads to strategic complement pricing strategies. We can also verify that standard linear demand function, $D(p) = a - p$ where $a > c$, leads to strategic substitute pricing strategies.

3 Equilibrium Prices

In this section, we will introduce consumers' fare arbitrage into our model, characterize equilibrium prices and then analyze the price changes after forming joint venture. Since all alliance members can monopolize certain parts of their segment, we always start from discussing the joint venture and then extend to the alliance membership scenario.

3.1 Fare Arbitrage

One key feature of airline market is the complicated pricing system. Here we allow airline carriers to charge consumers different prices even though they may travel on the same flight. However, there are several pricing constraints to guarantee the effectiveness of discriminatory pricing and make consumers be willing to reveal their private information about their destinations.

In joint venture, the price for the market from city g to h (denoted by p^J_{gh}, where $g, h \in N$), which is composed of two or three direct flights, must satisfy the following condition:

$$p^J_{gj} + p^J_{jh} \geq p^J_{gh}, \quad if \quad h \neq g \neq j; \quad h, g, j \in N \tag{3}$$

It rules out the possibility that $g - h$ customers buy a $g - j$ ticket and a $j - h$ ticket instead of buying a $g - h$ ticket. Clearly, if this constraint is violated, the pricing on $g - h$ market is not effective. Note that if the $g - j$ market in the above condition contains two direct flights, then we can get:

$$p^J_{gk} + p^J_{kj} + p^J_{jh} \geq p^J_{gj} + p^J_{jh} \geq p^J_{gk}, \quad if \quad h \neq g \neq j \neq k; \quad h, g, j, k \in N$$

Now if airline carriers are only alliance members without joint venture, and we allow carriers to charge prices contingent on traveler's purchase of ticket from the other carrier, we need to impose additional constraints on prices. For example, if we look at the pricing for the $3 - 1$ edge, carrier A can potentially charge different prices for $3 - 1$ travelers, $3 - 2$ travelers, $3 - 5$ travelers, $3 - 6$ travelers and $3 - 4$ travelers who all need to use the $3 - 1$ flight for their trips. For travelers buying interlining flights in the $3 - 2$ market, we use s^A_{31} and s^B_{12} to denote the prices of buying tickets from the two carriers. Comparing with the travelers who just need to go from 3 to 1, interlining travelers in the $3 - 2$ market need to buy two tickets and they will only reveal that information if they can get lower prices. In other words, interlining travelers in the $3 - 2$ market can pretend to be $3 - 1$ travelers but $3 - 1$ travelers do not have the information to distinguish themselves. Therefore, interlining prices must satisfy this condition:

$$p^A_{31} \geq s^A_{31} \quad and \quad p^B_{12} \geq s^B_{12}$$

For the $3-5$ city pair market, consumers have to buy tickets from both carriers. We assume that $3-5$ consumers can always hide their private information and airline carriers cannot distinguish them from all the other travelers in the intermediate city pair markets (i.e. $3-1$, $3-2$, $1-5$, $2-5$, and $1-2$ markets which comprise $3-5$ market) unless $3-5$ travelers receive lower prices when they purchase any one of these intermediate tickets. We use w^A_{32} and v^A_{31} to denote prices charged on the $3-5$ consumers depending on whether carrier A chooses to monopolize the $3-2$ segment or share with carrier B for the $3-2$ segment. Therefore, we must have the following pricing constraints:

$$\begin{cases} p^A_{31} \geq s^A_{31} \geq v^A_{31}; \quad p^B_{12} \geq s^B_{12} \geq v^B_{12} & \text{if carrier } A \text{ shares with carrier } B \text{ for the 3-2 segment} \\ p^A_{31} + \min\{p^A_{12}, p^B_{12}\} \geq p^A_{32} \geq w^A_{32} & \text{if carrier } A \text{ monopolize the 3-2 segment} \end{cases}$$

If carrier A decides to share with B in the $3-2$ segment, it only chooses a price of the $3-1$ segment and let $3-2$ and $3-5$ consumers use the other carrier for the $1-2$ segment. The above inequality ensures that $3-5$ consumers can only be charged lower (or same) price for using the $3-1$ flight. If carrier A wants to monopolize the $3-2$ segment, then the monopoly price of the $3-2$ segment must be lower than buying two components (i.e. $3-1$ and $1-2$) separately, and $3-5$ travelers should be able to get cheaper price than the $3-2$ consumers. In summary, we can generalize previous examples and impose these pricing conditions for alliance members ($i = A, B$):

$$\begin{cases} p^i_{gh} \geq s^i_{gh} \geq v^i_{gh} & \text{if} \quad g, h \in N, g \neq h, \text{and g-h market contains one edge} \\ p^i_{gh} \geq w^i_{gh} & \text{if} \quad g, h \in N, g \neq h, \text{and g-h market contains two edges} \end{cases} \tag{4}$$

As we discussed before, we use v^i and w^i to denote the prices for customers who use interlining service to travel between two rim cities (e.g. $3-5$ and $3-6$). s^i is the price for the interlining trips between one rim city and one hub city (i.e. $j-2$ and $g-1$, where $j \in \{3,4\}$ and $g \in \{5,6\}$). For p^i_{gh} where $g-h$ market contains two edges, constraints from (3) also need to be satisfied so that p^i_{gh} is effective. Also, we add superscripts to identify city pair markets which use same flight but can be distinguished from each other. $s^{i_\beta}_{12}$ where $\beta \in \{3,4,5,6\}$ are used to distinguish interlining prices charged on $3-2$, $4-2$, $1-5$ and $1-6$ travelers. Similarly, $v^{A_\gamma}_{j1}$, $w^{A_\gamma}_{j2}$ (where $j \in \{3,4\}$, $\gamma \in \{5,6\}$) and $v^{B_\theta}_{g2}$, $w^{B_\theta}_{g1}$ (where $g \in \{5,6\}$, $\theta \in \{3,4\}$) are used to denote different prices for interlining tickets between rim cities.[3]

3.2 Joint Venture Pricing

If the two alliance members A and B form a joint venture, the joint venture chooses prices for all city pair markets to maximize total profit, and the total profit is:

$$\begin{aligned}\Pi^J = \;& 2\sum_{j=2}^{4}(p^J_{j1}-c)D(p^J_{j1}) + 2\sum_{g=5}^{6}(p^J_{g2}-c)D(p^J_{g2}) \\ & + 2\sum_{j=3}^{4}(p^J_{j2}-2c)D(p^J_{j2}) + 2\sum_{g=5}^{6}(p^J_{g1}-2c)D(p^J_{g1}) + 2(p^J_{34}-2c)D(p^J_{34}) + 2(p^J_{56}-2c)D(p^J_{56}) \\ & + 2\sum_{j=3}^{4}\sum_{g=5}^{6}(p^J_{gj}-3c)D(p^J_{gj})\end{aligned} \quad (5)$$

Therefore, the joint venture will choose prices p^J_{gh} $(g \neq h; g, h \in N)$ to maximize (5) subject to constraints (3). With assumption 1 we can characterize joint venture pricing in the following lemma:

Lemma 2 *Suppose the two airline carriers form a joint venture. The equilibrium prices are that* $p^J_{gh} = p^M(kc)$ *where* k *is the number of edges in the* $g-h$ *market, and* $p^M(2c) \leq 2p^M(c)$, $p^M(3c) \leq 3p^M(c)$, $p^M(3c) \leq p^M(2c) + p^M(c)$. *Therefore, the joint venture's total profit is:*

$$\Pi^J = 10\pi(c) + 12\pi(2c) + 8\pi(3c). \quad (6)$$

This lemma shows that under joint venture, airline carriers choose monopoly prices to maximize total profit and fare arbitrage constraints are not binding. This result is not affected by assumption 2 so both strategic complement and strategic substitute strategies have same result.

3.3 Alliance Membership Pricing

When the two carriers are alliance members without joint venture, each of them chooses prices for its city pair markets to maximize its own profits. For the inter-hub market $1-2$, the two carriers engage in Bertrand type of competition which means that the carrier offers lower price wins the entire market. Each airline carrier is also able to monopolize some part of the economy. For example,

[3]Consumers in the intermediate markets can potentially choose to buy longer distance tickets and give up part of their trip if the price is lower. This practice is often not possible in airline industry since consumers will not be able to take the return flight. Airline carriers often require consumers to board their return flights at the city designated on the ticket. Also, we can easily show that in equilibrium prices are higher for longer distance flights.

customers in the $3-4$ market can only travel with carrier A. For city pair markets $j-2$ ($j \in \{3,4\}$) or $g-1$ ($g \in \{5,6\}$) which involve one rim city and one oversea hub city, carriers can choose between monopolize the market and share them with the other carrier depending on whether p^A_{j2}(p^B_{g1}) is lower or higher than $s^A_{j1}+s^B_{12}$($s^B_{g2}+s^A_{12}$). Similarly, for markets between cities g and j, each carrier can also choose to monopolize or share the $j-2$ and $g-1$ components. We first define a function $\delta(x,y)$:

$$\delta(x,y) = \begin{cases} 1 & \text{if x < y} \\ \frac{1}{2} & \text{if x=y} \\ 0 & \text{if x>y} \end{cases} \tag{7}$$

We assume that when two carrier's prices are the same, then the market is equally shared between the two carriers. The airline carrier A's total profit is:

$$\begin{aligned} \Pi^A = \; & 2\delta(p^A_{12}, p^B_{12})(p^A_{12}-c)D(p^A_{12}) + 2\sum_{j=3}^{4}\delta(s^A_{j1}+s^{B_j}_{12}, p^A_{j2})(s^A_{j1}-c)D(s^A_{j1}+s^{B_j}_{12}) \\ & + 2\sum_{j=3}^{4}(1-\delta(s^A_{j1}+s^{B_j}_{12}, p^A_{j2}))(p^A_{j2}-2c)D(p^A_{j2}) + 2\sum_{g=5}^{6}\delta(s^B_{2g}+s^{A_g}_{12}, p^B_{1g})(s^{A_g}_{12}-c)D(s^{A_g}_{12}+s^B_{2g}) \\ & + 2\sum_{g=5}^{6}\sum_{j=3}^{4}\delta(v^{A_g}_{j1}+w^{B_j}_{1g}, w^{A_g}_{j2}+v^{B_j}_{2g})(v^{A_g}_{j1}-c)D(v^{A_g}_{j1}+w^{B_j}_{1g}) \\ & + 2\sum_{g=5}^{6}\sum_{j=3}^{4}(1-\delta(v^{A_g}_{j1}+w^{B_j}_{1g}, w^{A_g}_{j2}+v^{B_j}_{2g}))(w^{A_g}_{j2}-2c)D(w^{A_g}_{j2}+v^{B_j}_{2g}) \\ & + 2\sum_{j=3}^{4}(p^A_{j1}-c)D(p^A_{j1}) + 2(p^A_{34}-2c)D(p^A_{34}) \end{aligned} \tag{8}$$

Carrier A chooses its prices to maximize equation (8) subject to constraints (3) and (4) depending on whether carrier A chooses to monopolize the market or not. Here carrier B's profit maximization problem is symmetric to carrier A.

We can analyze carriers' profit maximization problem and show that both airline carriers will compete intensively on the inter-hub market and they will focus on choosing prices of its local spokes contingent on different destinations of the consumers.

Lemma 3 *Suppose two airline carriers only form an alliance without joint venture. Then* $p^i_{12} = s^i_{12} = c$, *where* $i = A, B$, *and without loss of generality, we can assume that carrier A monopolizes all the* $j-2$ *segments while carrier B shares in all the* $1-g$ *segments where* $j \in \{3,4\}$ *and* $g \in \{5,6\}$, *then each carrier's optimal prices are as follow:*

$$(p^A_{j1}, p^A_{j2}, w^{A_5}_{j2}, w^{A_6}_{j2}) = (p, s + c, v_1 + c, v_2 + c)$$
$$(p^B_{2g}, s^B_{2g}, v^{B_3}_{2g}, v^{B_4}_{2g}) = (p, s, v_1, v_2),$$

where

$$(p, s, v_1, v_2) = \arg\max_{p,s,v_1,v_2} \{(p - c)D(p) + (s - c)D(s + c) + (v_1 - c)D(v_1 + c + v'_1) + (v_2 - c)D(v_2 + c + v'_2)\}$$

$$\text{subject to} \quad p \geq s \geq v_1 \qquad p \geq s \geq v_2 \tag{9}$$

Here we use v'_1 and v'_2 to denote the price charged by the other carrier for its component in the interlining trips between rim cities.

Intensive competition makes the inter-hub market unprofitable. This result shows that each carrier will instead try to charge different prices on its local spoke edges contingent on consumers' destinations in order to maximize profits since the local spoke edges are essential complements for many city pair markets. With alliance membership, both carriers in fact divest its inter-hub services into independent divisions which compete against each other. We can also easily show that each carrier does not have the incentive to completely quit the inter-hub market. If carrier A completely quits the inter-hub market, carrier B will charge higher prices for the inter-hub edge and the total profits of carrier A will be reduced. This analysis is very similar to the findings of Tan and Yuan (2003) which shows that a firm which produces several complements can obtain higher profits through divesting complementary products when these products have substitutes produced by another company. They conclude that the more severe the competition between these two firms, the higher the incentives to divest. Our lemma 3 shows a similar result when we have Bertrand type of competition in the inter-hub airline market.

3.4 Price Comparison

We now compare the equilibrium prices between alliance membership and joint venture. We will show that the results are different depending on whether the pricing strategies are strategic substitutes or strategic complements. In the former case, all constraints in lemma 3 are not binding because the best reply functions are downward sloping. In the latter case, all constraints (9) in lemma 3 are binding because of the upward sloping best reply functions. As a result, competition in the inter-hub market generates externalities on other spoke markets. Carrier A (B) in fact has to charge same price for $j-1$ ($2-g$), $j-2$ ($1-g$) and $j-g$ ($j-g$) travelers who use the same $j-1$ ($2-g$) flight service.

3.4.1 Strategic Substitute Strategies

Our first proposition indicates that if we have strategic substitute strategies, equilibrium prices with only alliance membership are higher than joint venture for all interlining markets between any rim cities. We denote the equilibrium prices under alliance membership for interlining market between rim cities j and g to be p^*_{jg}, and clearly we have $p^*_{jg} = w^{A_g}_{j2} + v^{B_j}_{2g}$.

Proposition 1 *With strategic substitute pricing strategies, $p^*_{jg} > p^M(3c)$ for any $j \in \{3,4\}$ and $g \in \{5,6\}$. For the inter-hub market, $p^*_{12} < p^M(c)$. All other markets have same prices in alliance membership and joint venture.*

Note that this result is not affected by the number of spokes in the network. Following this result, we can see that joint venture can reduce the prices of all interlining markets between rim cities and increase the price of the inter-hub market. Therefore, customers in the interlining markets will benefit from the joint venture while customers in the inter-hub market will be worse off in joint venture. This finding is similar to the results of Brueckner (2001) and we can draw the same policy recommendation that government should allow airline carriers to form joint venture because we normally have much more interlining markets between rim cities than inter-hub markets.[4] As long as we have sufficiently large amount of spokes, then the benefits of joint venture dominate its costs.

The reason for this result is also consistent with our traditional understanding of double marginalization. For any interlining market between two rim citites, both carriers' flight services are perfect complements under alliance membership. The unbinding constraints (9) in lemma 3 due to strategic substitute strategies mean that each carrier can freely charge prices for its segments of the interlining trips without considering its negative externalities on other carrier's profits. Therefore, both carriers overcharge prices for its segments under alliance membership and as a result, joint venture can eliminate double marginalization problem and reduce prices because it is in fact a merger of the producers of complementary goods.

[4] If the number of spokes in each hub spoke segment is m, then the interlining markets between rim cities will be $(m-1)^2$.

3.4.2 Strategic Complement Strategies

Now we move to the case of strategic complement strategies. For any interlining market between rim cities, each carrier still tries to charge optimal prices to maximize its profits without considering potential negative externalities on other carrier. However, due to travelers' fare arbitrage conditions, each carrier needs to consider both the pricing of local spoke markets and its impact on other related markets. Therefore, unlike in the previous case, we are uncertain about the price changes if we allow alliance members to form joint venture. In this section, we will derive several sufficient conditions under which we can determine whether joint venture can lead to lower or higher prices for interlining markets between rim cities.

Proposition 2 *When $\epsilon(p)$ is constant a ($a > 2$), then there exists an $\hat{a}$ such that when $a > \hat{a}$, $p^*_{jg} < p^M(3c)$ for any $j \in \{3,4\}$ and $g \in \{5,6\}$.*[5] *Also, $p^*_{j2} = p^*_{1g} < p^M(2c)$ when $a > \hat{a}$. For the inter-hub market, $p^*_{12} < p^M(c)$. For the spoke market prices, $p^*_{j1} = p^*_{2g} > p^M(c)$. All other markets have same prices in alliance membership and joint venture.*

In this proposition, we attempt to understand the connection between elasticity of demand and the price change after forming joint venture. Due to strategic complement strategies, each carrier's pricing of any spoke market $j-1$ or $2-g$ is no longer independent of other markets. They may want to increase the price, p^A_{j1} (p^B_{2g}), so that they can charge higher prices on $j-2$ ($1-g$) and $j-g$ ($j-g$) travelers. The following graphs illustrate carrier's optimal choice of spoke market price. Comparing Figure (2) and (3), we can see that when elasticity is small, an increase of price in the spoke market will lead to much higher profits from the other two markets (e.g. $j-2$ and $j-g$) than the profit reduction in the spoke market. As a result, the equilibrium price under simple alliance membership will be much further away from the optimal price of the spoke market when fare arbitrage constraints are not binding. Also, the equilibrium price is higher than $p = \frac{ac+\frac{c}{2}}{a-1}$ which means that the interlining market between rim cities will be: $p^*_{jg} > p^M(3c) = \frac{3ac}{a-1}$. As elasticity gets higher, we can see from Figure (3) that the spoke market, which has the highest profit level, becomes much more sensitive to price changes, and the equilibrium price moves closer to spoke market's optimal price without fare arbitrage constraints and this price makes p^*_{jg} less than $p^M(3c)$.

[5] Assuming $a > 2$ can guarantee that interlining market between rim cities has a positive maximum point in the unconstrained problem. Gayle (2013) shows that own-price elasticity of demand is 4.72 in the U.S.

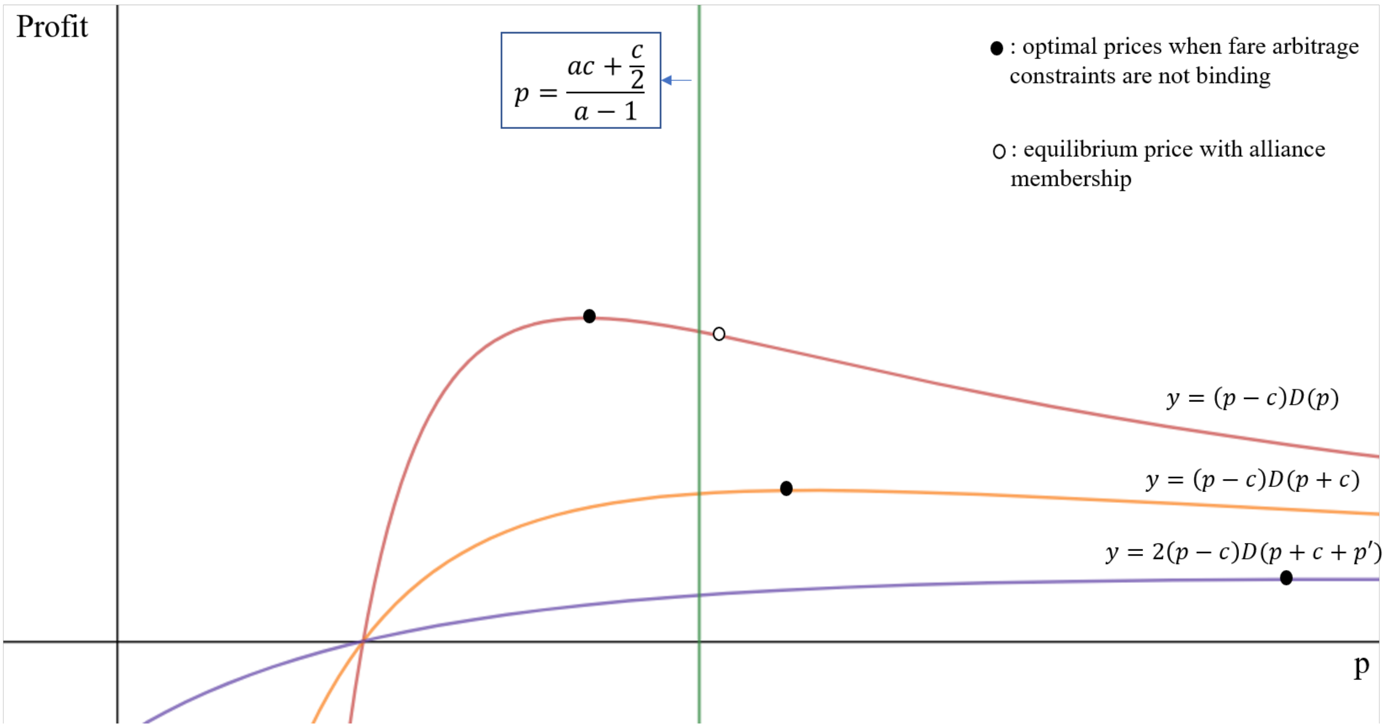

Figure 2: Optimal Prices when $a = 2.1$ and $c = 4$

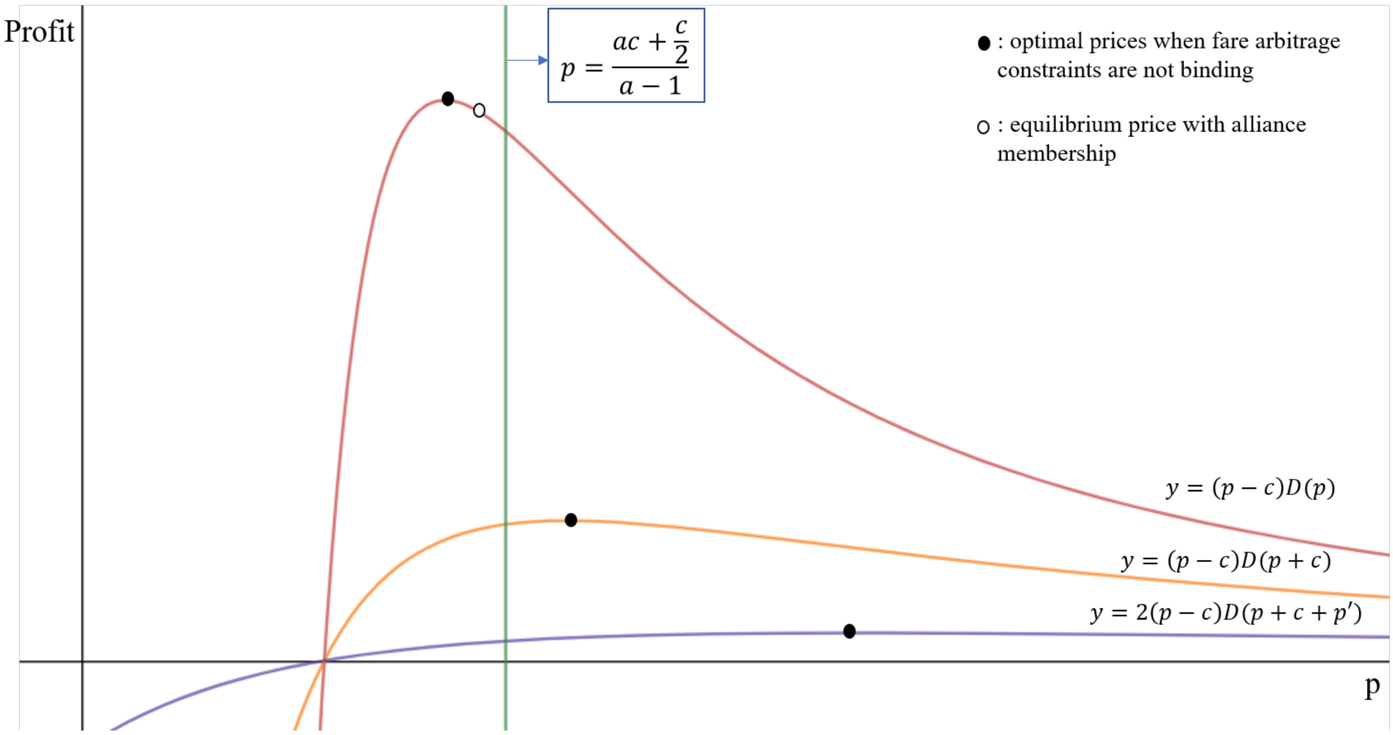

Figure 3: Optimal Prices when $a = 3$ and $c = 4$

Figure 4: Network Structure when $m = 2$

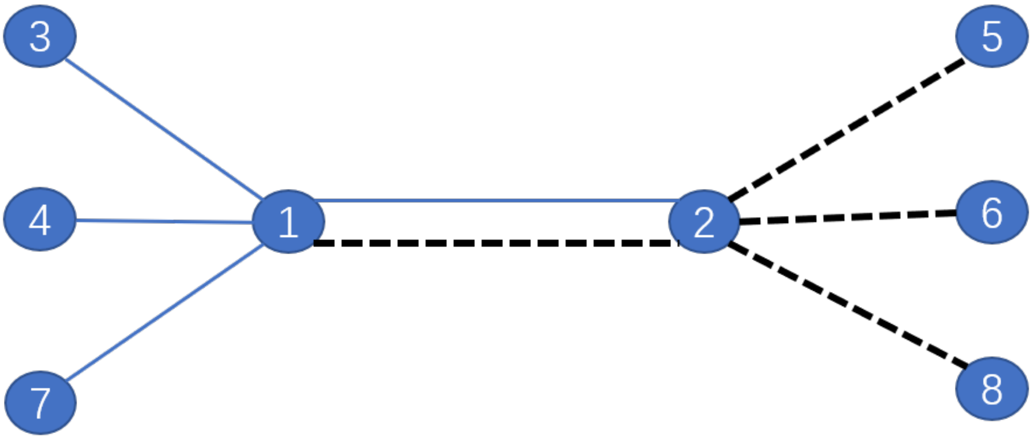

Figure 5: Network Structure when $m = 4$

3.4.3 Network Structure and Market Size

So far we focused on the exogenously given network structure as defined in Figure (1). In airline market, each hub city may connect to much more local cities. Under strategic substitute pricing strategies, the previous results still hold. However, if more spokes are added to each carrier, then under strategic complement strategies, alliance members will have higher incentives to raise its spoke market price because it can lead to higher prices and profits in the interlining trips between rim cities and equilibrium price may become higher than the price under joint venture. Another factor we did not consider in the previous section is that city pair market between rim city and hub city often has much bigger size than the city pair market between rim cities. There may be a large number of city pair markets between rim cities but they may not have a big impact on the whole economy due to their small sizes.

To see how these two factors will affect our previous results, we first assume that the amount of spokes that each carrier has is m, and $m \geq 1$. Let n be the total amount of cities in the network and we must have $m = \frac{n}{2}$. Figure (4) and (5) illustrate the cases when we have $m = 2$ and $m = 4$. We also revise our previous assumption on demand between any two cities. If j and g are two rim cities, then $D_{jg}(p) = D(p)$, while if j or g is a hub city, then $D_{jg}(p) = lD(p)$ where l is a constant greater than 1. We can easily extend our previous model to incorporate these two factors:

Proposition 3 *When $\epsilon(p)$ is constant a ($a > 2$), there exists $\delta > 0$, such that for any rim cities j and g which belong to carrier A and B respectively, $p^*_{jg} < p^M(3c)$ if and only if $\frac{m-1}{l} < \delta$. If $\frac{m-1}{l} < \delta$, we also have $p^*_{j2} = p^*_{1g} < p^M(2c)$. Other markets have same result in Proposition 2.*

This proposition shows that despite the airline network is large with lots of spokes we cannot easily draw the conclusion that forming joint venture can reduce the price of interlining tickets between two rim cities. It is possible that markets between rim city and hub city are so large that airline carriers are unwilling to increase spoke markets prices to increase the profits from interlining trips between rim cities.

4 Related Literature

4.1 Hub Spoke Network

The theoretical foundation of hub spoke network structure comes from the seminal papers by Ken Hendricks, Michele Piccione and Guofu Tan. Hendricks, Piccione and Tan (1995) first studies the network formation in a monopoly environment and show that monopolist will choose to build hub-spoke network when there exists economies of density. Hendricks, Piccione and Tan (1999) focuses on the competition between two large airline carriers which are allowed to form different airline networks. They show the conditions under which airline carriers choose to form hub-spoke networks. Our network with two hub spoke segments may seem to contradict with their conclusion that when carriers compete intensively for customers, there is no equilibrium in which both carriers choose hub-spoke networks. However, our paper in fact is very different from the assumptions in Hendricks, Piccione and Tan (1999) where airline carriers can connect any two cities they want. As we discussed before, international airline market has the feature that carriers are not allowed to enter a different country's market. Therefore, our network structure is more like Hendricks, Piccione and Tan (1995) where each carrier is a monopoly of its local cities, and they build one connection with international markets to increase market coverage. Therefore, our exogenous network structure does not contradict with the existing literature and it is in fact a common practice in the current airline industry.

4.2 Impacts of Airline Alliance

Our finding is mostly related to Brueckner (2001) which considers airline competition and alliance in a same network structure shown in Figure (1). It analyzes the price difference before and after forming codesharing alliance between the two competing airline carriers. Their pre-alliance agreement is similar to our alliance membership agreement and their modeling of alliance is actually equivalent to our joint venture. It concludes that airline alliance can reduce the price of interlining flights between two rim cities due to the elimination of double marginalization, while in inter-hub market where carriers provide competing services, market price increases because alliance reduces competition. Therefore, this result leads to the conclusion that airline alliance is often beneficial to consumers as a whole because we often just have a few inter-hub markets between countries but the interlining markets are much bigger.

However, their results underestimate the impact of inter-hub competition due to some of their assumptions. They assume that inter-hub competition has a Cournot type of competition and they impose the assumption that each carrier is a monopolist in its own hub-spoke segment so that consumers travel on its home airline as much as possible (this simplifying assumption is also used in Brueckner and Proost 2010; Bilotkach 2005).[6] As a result, carriers cannot charge lower inter-hub ticket price to attract customers from other carrier's rim cities. Inter-hub market is in fact separated from the rest of the markets in their settings. Therefore, each carrier can easily monopolize its component, and noncooperative pricing leads to the standard problem of double marginalization. In contrast, our model shows that once carriers compete more intensively in the inter-hub market, monopoly (or joint venture) may not always lead to lower prices in the interlining markets.

Many theoretical papers in this problem heavily rely on the assumption of linear demand and they often notice that fare arbitrage constraints are not binding and as a result, different markets are independent of each other (Brueckner 2001; Brueckner and Proost 2010; Lin 2008). Our model provides a more general result on this issue and shows that theoretical airline market model needs to focus on the two critical cases: strategic substitute and strategic complement strategies.

Lastly, we notice that more and more papers show that airline cooperation may not always benefit consumers. For example, Chen and Gayle (2006) shows that when one carrier offers competing services for a city pair market (one direct flight and one indirect flight), then more cooperation between carriers (codesharing with price coordination) can lead to higher prices. Lin (2008) shows that airline alliance can be used as a credible threat to deter entrants which do not have significant cost

[6]It may be a reasonable assumption for the modeling of pre-alliance competition.

advantages. Many empirical papers find that airline cooperation leads to price reductions, but recent trends also show that the positive effect on pricing is less and less significant (Brueckner and Whalen, 2000; Bilotkach 2018). Combining with our results, we believe government needs to be much more careful in granting antitrust immunity to airline carriers and more empirical research about carriers' competition strategies is very useful.

5 Conclusion

In this paper, we build a network flow model to analyze international airline alliance and joint venture. We rely on a critical distinction: strategic complement strategies and strategic substitute strategies. We show that intensive competitions in the inter-hub market can generate externalities to local markets due to consumers' fare arbitrage and carriers' strategic complement strategies. As a result, joint venture may not always lead to lower interlining prices comparing with simple alliance membership. Traditional viewpoint that overlapping market is separated from the rest of the markets is only a result of strategic substitute strategies. More empirical works should focus on this distinction so that government interventions on airline market can be improved.

Appendices

A Proof of Lemma 2

In the unconstrained problem, the first order condition shows that:

$$(p_{31}^M - c)D^{'}(p_{31}^M) + D(p_{31}^M) = 0$$
$$(p_{34}^M - 2c)D^{'}(p_{34}^M) + D(p_{34}^M) = 0$$
$$(p_{35}^M - 2c)D^{'}(p_{35}^M) + D(p_{35}^M) = 0$$

Then we can rearrange these equations to get:

$$p_{31}^M(1 - \frac{1}{\epsilon(p_{31}^M)}) = c$$
$$p_{34}^M(1 - \frac{1}{\epsilon(p_{34}^M)}) = 2c$$
$$p_{35}^M(1 - \frac{1}{\epsilon(p_{35}^M)}) = 3c$$

we clearly have: $p_{31}^M = p_{41}^M = p_{52}^M = p_{62}^M = p_{12}^M = p^M(c)$, $p_{34}^M = p_{56}^M = p_{32}^M = p_{42}^M = p_{51}^M = p_{61}^M = p^M(2c)$ and $p_{35}^M = p_{36}^M = p_{45}^M = p_{46}^M = p^M(3c)$.

Since in assumption 1 we assume that $\epsilon(p)$ is nondecreasing, then we must have $p^M(c) \leq p^M(2c) \leq p^M(3c)$. Also, we can get from the previous equations that:

$$2p_{31}^M(1 - \frac{1}{\epsilon(p_{31}^M)}) = p_{34}^M(1 - \frac{1}{\epsilon(p_{34}^M)})$$

It implies that $p^M(2c) \leq 2p^M(c)$ with assumption 1.

Similarly, we can obtain:

$$3p_{31}^M(1 - \frac{1}{\epsilon(p_{31}^M)}) = p_{35}^M(1 - \frac{1}{\epsilon(p_{35}^M)})$$

It shows that $p^M(3c) \leq 3p^M(c)$ with assumption 1.

Lastly, we can obtain:

$$3p_{34}^M(1 - \frac{1}{\epsilon(p_{34}^M)}) = 2p_{35}^M(1 - \frac{1}{\epsilon(p_{35}^M)})$$

It implies that: $2p^M(3c) \leq 3p^M(2c)$ with assumption 1. Therefore, we can also get:

$$p^M(3c) = \frac{1}{3}p^M(3c) + \frac{2}{3}p^M(3c) \leq p^M(c) + p^M(2c). \qquad Q.E.D.$$

B Proof of Lemma 3

We first show that for any market $j-g$, where $j \in \{3,4\}$ and $g \in \{5,6\}$, one of the carriers will choose to share in the $j-2$ or $g-1$ segments. Suppose both carriers monopolize the $j-2$ and $g-1$ segments for any $j-g$ market, travelers can go from city j to 2 with carrier A and from 2 to g with carrier B (denoted by trip A) or they can go from j to 1 with carrier A and from 1 to g with carrier B (denoted by trip B). Then consumers choose trip A if and only if $u^A_{j2} + v^B_{2g}$ is less than or equal to $v^A_{j1} + u^B_{1g}$. Since both carriers want to monopolize the $j-2$ and $1-g$ segments, price competition will lead to set $u^A_{j2} = u^B_{1g} = 2c$ and $v^A_{j1} = v^B_{2g} = \infty$ and it means that both carriers earn zero profit for any $j-g$ market. Similarly, we can conclude that it is impossible to have both carriers share in the $j-2$ and $g-1$ segments for any $j-g$ market. Therefore, we can assume without loss of generality that carrier A monopolizes all the $j-2$ segments while carrier B shares in all the $1-g$ segments since both carriers can earn positive profits.

In the $1-2$ market, two airline carriers offer competing direct flights. Suppose we have $p^B_{12} = c$, then we show that carrier A's best reply is $p^A_{12} = c$. If carrier A raises the price, then it will lose the $1-2$ market since consumers will shift to carrier B, and other markets will not be affected. If carrer A reduces this price, then it generates negative profit in the $1-2$ market, and profits in other markets will not be higher since constraints (3) and (4) get tighter. Similarly, it is easy to see that $s^i_{12} = c$ for $i = A, B$ since it cannot be higher than c and carriers will earn negative profits if $s^i_{12} < c$.

In all other connecting markets, carrier A chooses p^A_{j1}, p^A_{j2}, $w^{A_5}_{j2}$ and $w^{A_6}_{j2}$ for any $j \in \{3,4\}$ to maximize:

$$(p^A_{j1} - c)D(p^A_{j1}) + (p^A_{j2} - 2c)D(p^A_{j2}) + (w^{A_5}_{j2} - 2c)D(w^{A_5}_{j2} + v^{B_j}_{25}) + (w^{A_6}_{j2} - 2c)D(w^{A_6}_{j2} + v^{B_j}_{26})$$

subject to:

$$p^A_{j1} + c \geq p^A_{j2} \geq w^{A_5}_{j2}$$

$$p^A_{j1} + c \geq p^A_{j2} \geq w^{A_6}_{j2}$$

. If we define $p^A_{j2} - c$ to be s^A_{j2} and define $w^{A_g}_{j2} - c$ to be $v^{A_g}_{j2}$, then we can equivalently transfer carrier A's profit maximization problem to be:

$$(p^A_{j1} - c)D(p^A_{j1}) + (s^A_{j2} - c)D(s^A_{j2} + c) + (v^{A_5}_{j2} - c)D(v^{A_5}_{j2} + c + v^{B_j}_{25}) + (v^{A_6}_{j2} - c)D(v^{A_6}_{j2} + c + v^{B_j}_{26}) \quad (10)$$

subject to:

$$p^A_{j1} \geq s^A_{j2} \geq v^{A_5}_{j2}$$

$$p^A_{j1} \geq s^A_{j2} \geq v^{A_6}_{j2}$$

Despite that carrier A monopolizes all the $j - 2$ segments, its optimal pricing is similar to sharing in the $j - 2$ segments due to the Bertrand competition in the inter-hub market. Equivalently, carrier A only focuses on the pricing of the $j - 1$ segments contingent on consumers' destinations.

From carrier B's perspective, it chooses p^B_{2g}, s^B_{2g}, $v^{B_3}_{2g}$ and $v^{B_4}_{2g}$ for any $g \in \{5, 6\}$ to maximize:

$$(p^B_{2g} - c)D(p^B_{2g}) + (s^B_{2g} - c)D(s^B_{2g} + c) + (v^{B_3}_{2g} - c)D(v^{B_3}_{2g} + w^{A_g}_{32}) + (v^{B_4}_{2g} - c)D(v^{B_4}_{2g} + w^{A_g}_{42})$$

subject to:

$$p^B_{2g} \geq s^B_{2g} \geq v^{B_3}_{2g}$$

$$p^B_{2g} \geq s^B_{2g} \geq v^{B_4}_{2g}$$

As we have redefined $w^{A_g}_{32}$ and $w^{A_g}_{42}$ in carrier A's problem, we can easily rewrite carrier B's problem to be:

$$(p^B_{2g} - c)D(p^B_{2g}) + (s^B_{2g} - c)D(s^B_{2g} + c) + (v^{B_3}_{2g} - c)D(v^{B_3}_{2g} + c + v^{A_g}_{32}) + (v^{B_4}_{2g} - c)D(v^{B_4}_{2g} + c + v^{A_g}_{42}) \quad (11)$$

subject to:

$$p^B_{2g} \geq s^B_{2g} \geq v^{B_3}_{2g}$$

$$p^B_{2g} \geq s^B_{2g} \geq v^{B_4}_{2g}$$

Therefore, based on (10) and (11) we get the results in lemma 3. Clearly, for city pair markets like $3 - 4$ or $5 - 6$, each carrier is an monopoly of the market and its pricing is not constrained by fare arbitrage conditions as we illustrated in lemma 3 and price competition can only increase spoke market prices.[7] *Q.E.D.*

[7] We can easily verify this result in proposition 1 and 2.

C Proof of Proposition 1

With strategic substitute strategies, we can easily see that all constraints in Lemma 4 (9) are not binding by using Lemma 1.

First order conditions of the unconstrained problem shows that:

$$(v_1 - c)(-\frac{D'(v_1 + c + v_1')}{D(v_1 + c + v_1')}) = 1$$

Due to symmetric assumption, $v_1 = v_1'$. We define $p^* = 2v_1 + c$. Then we can rewrite above equation to be:

$$(p^* - 3c)(-\frac{D'(p^*)}{D(p^*)}) = 2 \tag{12}$$

Here p^* is the equilibrium price for interlining trips between rim cities.

If two carriers form a joint venture, first order condition shows that the price of interlining trip between rim cities, $p = p^M(3c)$, must satisfy the equation:

$$(p - 3c)(-\frac{D'(p)}{D(p)}) = 1 \tag{13}$$

Suppose $p \geq p^*$, then if $\frac{D'(p)}{D(p)}$ is strictly decreasing in p, we must have:

$$(p^* - 3c)(-\frac{D'(p^*)}{D(p^*)}) \leq (p - 3c)(-\frac{D'(p)}{D(p)})$$

Then it contradicts with equation (12) and (13). Therefore, $p < p^*$. Joint venture leads to lower price for interlining tickets between rim cities than alliance membership alone. For inter-hub market, we can easily see that $p_{12}^* < p^M(c)$ because Bertrand competition leads to have $p_{12}^* = c$ while $p^M(c) > c$. City pair markets like $3 - 4$ and $5 - 6$ are still monopolized by carrier A and B and prices will be the same in joint venture and alliance membership.

Lastly, since constraints in lemma 3 are not binding, markets between city j and 2 or between city 1 and g have same prices under alliance membership or joint venture. We can easily see that the profit maximization problem under alliance membership is:

$$\max_s \quad (s - c)D(s + c)$$

We can denote $s + c$ to be p and rewrite above maximization problem:

$$\max_{p} \quad (p-2c)D(p)$$

This is equivalent to the profit maximization problem under joint venture for markets between j and 2 and between 1 and g. *Q.E.D.*

D Proof of Proposition 2

First, under joint venture, the price of interlining trip between rim cities can be determined from the profit maximization problem:

$$\max_{p} \quad (p-3c)D(p)$$

Due to constant elasticity of demand, we can derive that $p^M(3c) = \frac{3ac}{a-1}$. Therefore, to show $p^*_{jg} < p^M(3c)$, we just need to prove that $v_1 = v_2 < \hat{p} = \frac{ac+\frac{c}{2}}{a-1}$.

We assume $a > 2$ so that the interlining market between rim cities has a meaningful equilibrium price.[8] Also, with constant elasticity, carriers' pricing strategies are strategic complement and we can see that constraints (9) are binding in equilibrium:

Let p^*, s^* and v^* be optimal prices to maximize the unconstrained functions: $g_1(p) = (p-c)D(p)$, $g_2(s) = (s-c)D(s+c)$ and $g_3(v) = (v-c)D(v+c+v')$ respectively. With strategic complement strategies, $p^* < s^* < v^*$ and all these functions only have one unique global maximum.[9] To maximize the sum of $g_1(p)$, $g_2(s)$ and $g_3(v)$ subject to the constraint that $v \leq s \leq p$ from lemma 3, clearly we must have $p^* \leq p \leq v^*$. If $p^* \leq p \leq s^*$, then carrier will choose $s = v = p$ as $g_2(s)$ and $g_3(v)$ are increasing function when $s < s^*$ and $v < v^*$. If $s^* < p \leq v^*$ and constraint is unbinding, we must have $v = s$ and $s < p$ since $g_3(v)$ increases when $v < v^*$. Then this case cannot be optimal and carrier will reduce p to s since $g_1(p)$ decreases when $p* < p$. Therefore, the constraint should be binding when $s^* < p \leq v^*$. In equilibrium, we must have $p = s = v$.

Since we have $\epsilon(p) = \frac{-pD'(p)}{D(p)} = a$, we can derive the general form of demand function to be:

$$D(p) = Kp^{(-a)} \tag{14}$$

Where K is a positive constant.

[8]This guarantees that interlining market has a positive maximum point in the unconstrained problem. Otherwise, its optimal p goes to infinity

[9]Our assumption that $a > 2$ ensures that all these functions are increasing if price is below optimum point and decreasing if price is higer than optimum point.

Therefore, the profit maximization problem in lemma 3 under alliance membership becomes:

$$\max_{p} \quad f(p) = K(p-c)p^{(-a)} + K(p-c)(p+c)^{(-a)} + 2K(p-c)(p+c+p')^{(-a)} \tag{15}$$

Noting that in symmetric equilibrium $p = p'$, the derivative of the objective function, $f'(p)$, is:

$$\begin{aligned} f'(p) &= -aK(p^{-(a+1)})(p(1-\frac{1}{a})-c) - aK(p+c)^{-(a+1)}((p+c)(1-\frac{1}{a})-2c) \\ &\quad - 2aK(2p+c)^{-(a+1)}((2p+c)(1-\frac{1}{a})-(p+2c)) \end{aligned} \tag{16}$$

When $p > \frac{c(1+\frac{1}{a})}{1-\frac{2}{a}}$, then $f'(p) < 0$; when $p = c$, then $f'(p) > 0$. Therefore, by intermediate value theorem, there must exist a p^* ($c < p^* < \frac{c(1+\frac{1}{a})}{1-\frac{2}{a}}$) such that $f'(p^*) = 0$. We can also easily verify that for any $p < p^*$, then $f'(p) > 0$, and for any $p > p^*$, $f'(p) < 0$. Therefore, there exists a unique global maximum of (15) at p^*.

For $\hat{p} = \frac{ac+\frac{c}{2}}{a-1}$, we plug it into the function $f'(p)$ and we can get:

$$f'(\hat{p}) = -aK(p^{-(a+1)})\frac{c}{2a} + aK(p+c)^{-(a+1)}(\frac{c}{2a}) + 2aK(2p+c)^{-(a+1)}(\frac{\frac{3}{2}c}{a-1})$$

The sufficient and necessary condition for $\hat{p} > p^*$ is that $f'(\hat{p}) < 0$ which is equivalent to have:

$$(\frac{1}{3}+\frac{1}{6a})^{-(a+1)} - (\frac{2}{3}-\frac{1}{6a})^{-(a+1)} > 6\frac{a}{a-1}$$

The left hand side of the above inequality is an increasing function of $a > 0$ and approaches infinity as a increases. The right hand side of the above inequality approaches 6 as a increases. As a result, there must exist an $\hat{a} > 0$ such that when $a > \hat{a}$ the above inequality is satisfied, and thus, $p^*_{jg} = 2p^* + c < 2\hat{p} + c = \frac{3ac}{a-1} = p^M(3c)$.

For city pair markets $j-2$ and $1-g$, if under joint venture, the price is simply $p^M(2c) = \frac{2ac}{a-1}$ with constant elasticity. Since we showed that when a is big enough, we have $p^* < \hat{p} = \frac{ac+\frac{c}{2}}{a-1}$, and we can conclude that $p^*_{j2} = p^*_{1g} = p^* + c < \hat{p} + c < p^M(2c)$. The inter-hub market has a Bertrand competition under alliance membership and like before we always have $p^*_{12} < p^M(c)$. All other markets are not changed after alliance members form joint venture [10]. *Q.E.D.*

[10]Strategic complement pricing can only make spoke market prices increase and monopoly prices for all other markets are still not constrained by fare arbitrage conditions.

E Proof of Proposition 3

We can follow the proof of Proposition 3 and show that the sufficient and necessary condition for $\hat{p} > p^*$ is that:

$$((\frac{1}{3}+\frac{1}{6a})^{-(a+1)}-(\frac{2}{3}-\frac{1}{6a})^{-(a+1)})\frac{a-1}{3a} > \frac{m-1}{l} \tag{17}$$

For any given $a > 2$, we can get that:

$$\delta = ((\frac{1}{3}+\frac{1}{6a})^{-(a+1)}-(\frac{2}{3}-\frac{1}{6a})^{-(a+1)})\frac{a-1}{3a} \tag{18}$$

If $\frac{m-1}{l} < \delta$, then $\hat{p} > p^*$ which means that $p^*_{jg} = 2p^* + c < 2\hat{p} + c = \frac{3ac}{a-1} = p^M(3c)$. All other results can be proved in the same way in Proposition 2.

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