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Fostering the connectivity on thin routes: Should regional airlines cooperate with network airlines or with local governments?

Yilin Chen [a], Hangjun Yang [b], Shiyuan Zheng [c], Kun Wang [d], Changmin Jiang [e,*]

[a] School of Economics, Qufu Normal University, Qufu, PR China
[b] School of International Trade and Economics, University of International Business and Economics, Beijing, PR China
[c] College of Transport and Communications, Shanghai Maritime University, Shanghai, PR China
[d] Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong, PR China
[e] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hong Kong, PR China

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ABSTRACT

This paper constructs two-stage Nash Bargaining models to examine two types of capacity purchase agreements (CPAs) for regional airlines: one with a local government and one with a network airline. The study compares the impacts of both CPAs on airline profits, consumer surplus, and social welfare. The results show that within a specific bargaining parameter range, both CPAs increase airline profits and net consumer surplus in small regional markets compared to the scenario without a CPA. However, these agreements may reduce consumer surplus in the trunk market. The social welfare levels under both CPAs are higher than in the case of no CPA. In comparison to the local government CPA, the network airline CPA results in lower profits for the network airline but higher profits for the regional airline. Additionally, the network airline CPA leads to lower consumer surplus in both the trunk and the regional markets, as well as reduced overall social welfare across the network. The model is further extended to incorporate flight frequency as a decision variable after CPAs are finalized. In this case, the network airline CPA can outperform the local government CPA in regional consumer surplus and network-wide social welfare when the regional airline faces high frequency-specific operational costs.

1. Introduction

Commercial airlines are the lifelines of passenger travel. Compared to the well-known full-service network airlines and low-cost airlines, regional airlines are a group of more obscure carriers that operate scheduled passenger air services with regional aircraft between communities lacking sufficient demand or infrastructure to attract mainline flights. These airlines have significantly contributed to the economic viability of remote communities by providing essential air connectivity. In the United States (US) and Europe, regional aviation has been promoted to support accessibility and eunsure equity among various regions (Wittman et al., 2016; Reynolds-Feighan, 2018). Regional airlines in the US mainly operate flights under a contractual relationship with network airlines through Capacity Purchase Agreements (CPAs) (Gillen et al., 2015).[1] Under such agreements, a regional airline operates flights on

* Corresponding author.
E-mail address: changmin.jiang@polyu.edu.hk (C. Jiang).

[1] For example, SkyWest Airlines, a leading regional airline in North America, maintains capacity purchase agreements with various U.S. network airlines. Notably, approximately 80% of SkyWest's revenue is derived from these agreements (SkyWest, 2022).

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behalf of a network airline, using its own aircraft and crew but adopting the branding and flight numbers of the network airline.[2] The network airline typically controls scheduling, pricing, reservations, and ticketing for these flights. In return, the regional airline receives a guaranteed payment from the network airline, ensuring financial stability. The network airline CPA offers substantial mutual benefits. For network airlines, it serves as a strategic initiative to reduce operational expenses and expand network coverage. Furthermore, this agreement adeptly addresses the limitations imposed by "grandfathering rights" at congested airports. These factors collectively make the CPA a cost-effective mechanism for network airlines to sustain an extensive hub-and-spoke network system (Forbes and Lederman, 2007, 2009, 2010). For regional airlines, the CPA reduces transaction costs and minimizes operational risks, supported by a more predictable revenue stream from the guaranteed business provided by network airlines.

On the other hand, China has become the world's second-largest aviation market, with its potential still largely untapped. However, the development of Chinese regional airlines is still in its early stage (e.g., Wang et al., 2014; Fu et al., 2015). According to the China Academy of Civil Aviation Science and Technology, the average penetration rate[3] of regional aviation is only 7.8 % in markets within 800 kilometers (i.e., short-haul markets) in China, and this number even drops to below 2 % for markets between 800 and 2000 kilometers (i.e., medium-to-long-haul markets). In comparison, the penetration rates are 36.6 % and 15.1 % in the US, respectively. Recently, Chinese regional airlines have adopted CPAs with local governments to enhance regional air accessibility, stimulate business and tourism, and boost local economies. Compared to network airlines, local governments have different incentives for engaging in CPAs with regional airlines. Governments are primarily concerned with local welfare (i.e., local consumer surplus), while network airlines collaborate with regional airlines to feed their trunk routes. Therefore, a natural research question arises: What are the different impacts of these two types of CPAs on market outcomes in the airline network and their social welfare implications? Such a comparison is not only academically intriguing but also has significant policy implications. It clarifies the rationale for adopting different CPAs and provides practical recommendations for stakeholders—local governments, network airlines, and regional airlines—to transition between CPA types.

To address this question, this paper establishes a two-stage Nash Bargaining model to analyze the interactions between a regional airline and its CPA partner, which could be either a network airline or a local government. We consider a simple hub-and-spoke network to account for the role of the regional airline in feeding traffic into hub airports and to explore the different effects of CPAs on large cities and small communities. The theoretical model also allows us to examine the impacts of each party's bargaining power. Specifically, we compare equilibrium ticket prices, traffic volumes, company profits, consumer surplus and social welfare under a benchmark scenario with no CPA and scenarios with the two different CPAs. It is important to note that, to accurately reflect real-world scenarios, our model assumes that the network airline takes a passive role (i.e., no active decision-making) in the local government CPA, and conversely, the local government takes a passive role in the network airline CPA.[4] However, the network airline's lack of active participation in the local government CPA does not imply that such a CPA has no impact on its profit. The same applies to the relationship between the local government and the network airline CPA. This fact underscores the significance of comparing the two types of CPAs, as we will demonstrate that under certain conditions, a local government CPA may be more beneficial to the network airline than a network airline CPA, and vice versa, leading to important policy implications.

The contributions of this paper are multi-fold. Methodologically, it is the first analytical study to specifically examine the two types of CPAs in the aviation industry. A Nash Bargaining model is applied to reflect the cooperative game nature of these agreements. This framework has not been widely utilized in the transportation literature, except by a few studies (see the literature review section for more discussion). Practically, our analysis yields clear policy implications. These conclusions can be useful for various regulators. For example, some may argue that the Chinese regional airline sector is still evolving, and that local government CPAs are only a temporary measure. As the sector matures, network airline CPAs may eventually prevail, as they have in the US. However, this argument may or may not hold true. Without rigorous comparison, we cannot conclusively determine which CPA is better. Our analysis will help regulators in China, the US, or any other country decide which CPA to support under their specific circumstances.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the economic model under different cases. Section 4 presents the comparative results of the two policies. The model extension and the additional analytical results are presented in Section 5. Section 6 concludes this study.

[2] For network airlines, CPAs offer a strategic opportunity to enhance profitability by outsourcing regional operations to specialized regional carriers. These smaller airlines excel on feeder routes, achieving superior cost-efficiency compared to network airlines due to several critical factors. These factors include the utilization of smaller aircraft, which are more economical for lower passenger volumes, reduced operating costs stemming from a leaner operational structure, and specialization in specific routes, leading to enhanced efficiency.

[3] The average penetration rate is defined as the average percentage of passengers served by regional airlines out of the total potential population, which includes all individuals who could potentially use these airline services within a specific region.

[4] In China, CPAs are typically signed between local governments and regional airlines. For instance, the Yunnan provincial government has agreements with regional carriers like Lucky Air and Tibet Airlines to ensure air connectivity for remote cities in Yunnan. Major airlines, such as Air China, China Eastern Airlines, and China Southern Airlines, do not participate in such agreements because they do not operate domestic connecting flights. In the United States, CPAs are usually signed between major airlines and regional carriers. For example, American Airlines has a CPA with its regional subsidiary, Piedmont Airlines, which primarily operates short- and medium-haul flights on behalf of American Airlines, connecting several smaller cities with American Airlines' hub airports. Local governments typically never intervene these agreements.

2. Literature review

Two streams of literature are relevant to this paper. The first stream focuses on airline alliances between network airlines (major airlines) and regional airlines, while the second stream examines government efforts to develop the regional market. For the first stream of literature, Forbes and Lederman (2009) investigate patterns of vertical integration within the US regional airline industry, which is characterized by incomplete contracts and frequent ex-post adaptations. Their findings suggest that network airlines are more likely to use their owned regional subsidiaries for city pairs prone to adverse weather conditions and those that are more deeply integrated into their network. Gillen et al. (2015) examine how network airlines can use the contractual relationships with regional airlines as an efficient tool to simultaneously drive out inefficient network airlines and accommodate other cost-efficient network airlines in any specific market. They find that market size, cost differences between network airlines, as well as cost differences between network and regional airlines, are the chief determinants of the network airlines' decisions on whether to serve a market with their own fleet and how many regional airlines to contract with.

Many papers have been dedicated to studying the contractual relationship between network airlines, namely, airline alliances (e.g., Park et al., 2001; Bilotkach, 2007). To provide international services, international airlines coordinate their operations to form alliances (Brueckner, 2001; Brueckner and Pels, 2005). Park et al. (2001) build a theoretical model to investigate the effect of airline alliances (complementary and parallel alliances) on market outcomes for fairly general demand and cost specifications. The complementary alliance refers to the case where two firms link up their existing networks to feed traffic to each other, while the parallel alliance refers to the collaboration between two firms who, prior to their alliance, are competitors on some routes of their networks. They predict that a complementary alliance is likely to increase total output, whereas a parallel alliance is likely to decrease it. Bilotkach (2007) compares the price and welfare effects of two types of airline partnerships (semi-complementary vs. complementary alliance) between low-cost carriers and their domestic partners. The results show that semi-complementary partnerships (through code-sharing agreements) yield higher total welfare but not necessarily lower prices. Bilotkach and Hüschelrath (2019) empirically investigate the impact of the implementation of airline revenue-sharing joint ventures (JVs) and found that joint ventures lead to a 3 %−5 % increase in seat capacity. Brueckner and Flores-Fillol (2020) show that airline alliances improve service quality by increasing flight frequencies (reducing double marginalization), lowering trip prices, and boosting traffic when layover costs are absent. However, when layover times are costly, the alliances reduce flight frequency, which can potentially raise the full trip price and decrease traffic.

The other relevant stream of literature focuses on regional public decision agreements or subsidies to airlines. Calzada and Fageda (2012) found that routes with discounts for island residents have higher fares than other domestic routes. From this point of view, these discounts can be regarded as specific subsidies to airlines. Valido et al. (2014) demonstrated that air transport subsidies for resident passengers may produce inefficiencies in the market, damaging the welfare of non-resident passengers. In this sense, they find that if the proportion of residents is high enough, non-resident passengers may be expelled from the market. Núñez-Sánchez (2015) proposed a structural model to explain the motivation of regional public authorities to arrange marketing agreements for route and traffic development. Based on data from Spanish airports, they found that public budgets, airport attributes, or intermodal competition affect the demand for aircraft operations of regional public agencies. Wu et al. (2020) found that aviation subsidy programs (e.g., connecting smaller communities to main centers, enabling mobility to sustain health and education, and improving the living standards and social inclusion of smaller regions) in the US and EU have received significant attention and have been widely studied, but not those in other countries. The Essential Air Service (EAS) Program in the US has provided government-subsidized air service to many small and rural communities for several decades.[5] Fuellhart et al. (2021) assessed EAS during the height of the COVID-19 pandemic and found that EAS airports performed much better during the early pandemic than their non-subsidized counterparts in terms of the preservation of seats; better-performing EAS communities connecting to hubs had better service. Chen et al. (2023) considered government subsidy interventions in regional airline markets based on aircraft size. They found that compared with the tax exemption policy, the subsidy policy may result in both higher social welfare and fewer emissions.

Existing studies related to the Nash Bargaining modeling approach in the transport literature include Song et al. (2017), which uses the bargaining-game model with complete information to investigate the compensation negotiation for the early termination of build-operate-transfer (BOT) highway projects. Different from our model, the parameters of both bargaining parties are simplified to the same parameter as 1, which weakens the role of bargaining parameters in the negotiation process. Talebian et al. (2018) use a game-theoretic bargaining approach to allocate rail line capacity in vertically integrated systems and characterize how passenger and freight sides bargain to determine train schedules and payment from the passenger rail agency to the host freight railroad. Blondiau et al. (2018) analyze air traffic control regulation using the Nash Bargaining model under a cooperative game framework, which is similar to Zheng et al. (2019). However, the former considers a one-on-one negotiation, while Zheng et al. (2019) address a one-to-many (one offset seller to many carriers) negotiation.

3. Base model setting

We begin with a base model designed to yield clear, analytically tractable results while addressing our core research question. To achieve this tractability, the simplified framework focuses solely on airlines' traffic decisions, excluding operational frequency as an

[5] It is worth noting that EAS is a federal initiative, which is different from the local government CPA we discuss in this paper.

explicit decision variable. In Section 5, we extend the model to incorporate frequency as a decision variable, employing numerical analysis to examine how results change under this expanded framework. The base model remains empirically relevant for many real-world routes, as frequency can often be a longer-term strategic consideration than CPAs. For instance, frequency decisions typically align with major airlines' network-wide priorities or local governments' strategic aviation service goals. In such cases, regional airlines operating under CPAs may lack discretion over frequency, which is institutionally predetermined. The base model provides a robust foundation for analyzing CPA dynamics—particularly for routes where frequency is predetermined.

Consider a three-point airline network depicted in Fig. 1. Points A and B are large cities, while point C is a small city. We assume there is no direct connection between A and C. In other words, there are two routes (i.e., route AB and route BC) and three markets (market AB, market BC, and city-pair market AC) in the network. It makes sense that there is no direct flight between A and C, as the potential airline passenger demand could be small due to the small size of point C and the potentially long flying distance. Residents of C thus need to first connect to B (the hub airport in this network) in order to travel to A. A network airline, denoted as M, serves the market AB with direct flights, while a regional airline, denoted as R, serves the market BC with direct flights (Brueckner and Flores-Fillol, 2020; Jiang, 2021). The airlines are assumed to make decisions on ticket prices, and the three markets are independent of each other.

We use q_{AB}, q_{BC} and q_{AC} to represent the air passenger traffic volumes of markets AB, BC and AC, respectively. We assume that the collective utility of passengers in this network adopts the classic quadratic form (e.g., Singh and Vives, 1984):

$$U = \alpha q_{AB} + q_{BC} + q_{AC} - \frac{1}{2}{q_{AB}}^2 - \frac{1}{2}{q_{BC}}^2 - \frac{1}{2}{q_{AC}}^2 \tag{1}$$

It is worth noting that Eq. (1) normalizes the market sizes of BC and AC to 1, and the market size of AB to α. Given that BC and AC are thinner regional markets, α is assumed to be significantly greater than 1, i.e., $\alpha > 1$.

3.1. The benchmark model

We first consider a benchmark case without CPA. We use p_{AB} and p_{BC} to represent the prices of airline tickets for markets AB and BC, respectively. In the absence of an interline agreement between the two airlines, the price for city-pair market AC can be expressed as $p_{AC} = p_{AB} + p_{BC}$, since passengers on this route need to purchase two separate tickets to complete their journey. From Eq. (1), we can derive the demand functions of markets AB, BC and AC as follows:

$$q_{AB} = \alpha - p_{AB} \tag{2}$$

$$q_{BC} = 1 - p_{BC} \tag{3}$$

$$q_{AC} = 1 - p_{AB} - p_{BC} \tag{4}$$

We then use π_1 and π_2 to denote the profits of the network airline (Airline 1) and the regional airline (Airline 2), respectively. The unit operating costs of the two airlines are represented by c_1 and c_2. Without loss of generality, we normalize c_1 to 0 in the following analysis. Given that network airlines benefit from larger economies of scale compared to regional airlines, their unit operating costs are assumed to be lower (i.e., $c_2 > 0$).[6] The profit functions of the network airline and the regional airline are

$$\pi_1 = p_{AB}(q_{AB} + q_{AC}) \tag{5}$$

$$\pi_2 = p_{BC}(q_{BC} + q_{AC}) - c_2(q_{BC} + q_{AC}) \tag{6}$$

The social welfare of the entire airline network under the benchmark case is

$$SW = U - p_{AB}q_{AB} - p_{BC}q_{BC} - (p_{AB} + p_{BC})q_{AC} + \pi_1 + \pi_2 \tag{7}$$

where $U = \alpha q_{AB} + q_{BC} + q_{AC} - \frac{1}{2}{q_{AB}}^2 - \frac{1}{2}{q_{BC}}^2 - \frac{1}{2}{q_{AC}}^2$ represent passengers in the entire airline network.

Given that the local government of City C is a key decision-maker within our analytical framework, we are also concerned with its objective function, which is assumed to maximize local social welfare. In most real-world scenarios, airlines operating in small regional cities are not registered there, meaning their profits do not contribute to local welfare. Consequently, we assume that the local welfare is equivalent to the local consumer surplus. This local consumer surplus covers all passengers departing from and arriving at City C (i.e., passengers in markets BC and AC). This local consumer surplus is:

$$\phi = U_1 - p_{BC}q_{BC} - (p_{AB} + p_{BC})q_{AC} \tag{8}$$

where $U_1 = q_{BC} + q_{AC} - \frac{1}{2}{q_{BC}}^2 - \frac{1}{2}{q_{AC}}^2$ represents the collective utility of passengers in markets BC and AC. And the consumer surplus in the trunk market AB is:

[6] For the major carriers, CPAs provide an opportunity to improve their bottom-line results by outsourcing their regional operations to smaller airlines, which operate at a lower cost. Regional airlines usually have lower operating costs on the routes they serve, which can lead to lower ticket prices for customers.

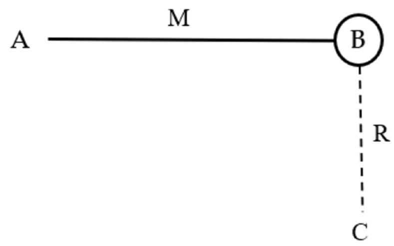

Fig. 1. Airline network.

$$\phi_{AB} = \alpha q_{AB} - \frac{1}{2}{q_{AB}}^2 - p_{AB}q_{AB} \tag{9}$$

3.2. Local government CPA

This subsection examines the case where the local government of City C signs a CPA with a regional airline. First, the local governments negotiates and signs agreements with the selected regional airline for the procurement of air transportation capacity. Then, with the CPA in place, the regional airline sells tickets to the public. In our model, we consider such CPA as the negotiation to determine a subsidy from the local government to the local passengers.[7] The parameter δ represents this subsidy for each passenger on route BC and city-pair market AC. The demand functions for the three markets remain the same as Eqs. (2)-(4).

There are two stages of decision making. In the first stage, Airline 2 and the local government jointly determine the subsidy value δ through a Nash Bargaining Game. In the second stage, given δ, Airline 1 and Airline 2 maximize their respective profits by determining p_{AB} and p_{BC}. The profit functions of the two airlines are

$$\pi_1 = p_{AB}(q_{AB} + q_{AC}) \tag{10}$$

$$\pi_2 = p_{BC}(q_{BC} + q_{AC}) + \delta(q_{BC} + q_{AC}) - c_2(q_{BC} + q_{AC}) \tag{11}$$

The consumer surplus functions are still

$$\phi_{AB} = \alpha q_{AB} - \frac{1}{2}{q_{AB}}^2 - p_{AB}q_{AB} \tag{12}$$

$$\phi = U_1 - p_{BC}q_{BC} - (p_{AB} + p_{BC})q_{AC} \tag{13}$$

Mathematically, in the first stage, the bargaining game between the local government and the regional airline can be formulated as follows:

$$\max_{\delta}\left(\phi - \delta(q_{BC} + q_{AC}) - \phi^B\right)^{\theta}\left(\pi_2 - \pi_2^B\right)^{1-\theta} \tag{14}$$

where ϕ^B and π_2^B are the equilibrium results of the two bargaining parties' objectives in the benchmark case, serving as reference points to ensure the success of the bargain.

The Nash Bargaining model functions as a cooperative game framework, aiming to maximize the combined objectives of the two bargaining parties (Wu et al., 2009; Wu, 2013). Once the total payoff for both parties is maximized, this payoff is divided based on their respective bargaining power. In the context of a local government CPA, the parameter θ indicates the bargaining power of the local government while $1-\theta$ denotes the bargaining power of the regional airline, with $\theta \in [0,1)$. Essentially, a proportion θ of the total benefit after the game will be allocated to the local government, with the regional airline taking the remaining $1-\theta$. Specifically, $\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right)$ represents the joint maximum payoff for the local government and the regional airline under a local government CPA, where the superscript L denotes the equilibrium results in this scenario. Therefore, $\theta\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right)$ denotes the net consumer surplus received by the local government, while $(1-\theta)\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right)$ represents the profit obtained by the regional airline if the bargaining is successful.

A key principle of the Nash Bargaining Game is that it must yield benefits for both parties involved. For cooperation to be successful, both the local government and the regional airline's objectives need to improve compared to the benchmark scenario. If either party

[7] The local government CPA can take on more complex forms in practice. For instance, a regional airline may agree to provide a certain capacity to the market in exchange for a guaranteed total revenue promised by the local government. Should the revenue from ticket sales fall short of the guaranteed amount, the local government compensates the difference. This arrangement allows regional airlines to employ lower fares to attract passengers, effectively functioning as a subsidy provided by the local government to its residents. Consequently, although the subsidy amount is typically determined unilaterally by the government in most cases, in our context, it resembles the outcome of a bargaining process between the local government and the regional airline.

ends up worse off, it will withdraw, causing the negotiations to collapse. Therefore, θ cannot be too small or too large. Otherwise, one party will fail to achieve its reservation benefit (disagreement point), which is its payoff in the benchmark case (Zheng et al., 2019). In particular, the conditions for successful bargaining are then $\theta(\phi^L - \hat{\delta}(q^L_{BC} + q^L_{AC}) + \pi^L_2) > \phi^B$ and $(1-\theta)(\phi^L - \hat{\delta}(q^L_{BC} + q^L_{AC}) + \pi^L_2) > \pi^B_2$.

The social welfare of the network under a local government CPA are

$$SW = U - p_{AB}q_{AB} - p_{BC}q_{BC} - (p_{AB} + p_{BC})q_{AC} + \pi_1 + \pi_2 - \delta(q_{BC} + q_{AC}) \tag{15}$$

3.3. Network airline CPA

Another mode of CPA involves a regional airline selling its capacity to a network airline. The purpose of such an agreement is to feed regional traffic to the network airline's hub, point B, thereby expanding its network services. Under this CPA, the network airline manages branding, sales, and customer service, while the regional airline operates flights and maintenance. This operation-management separation expands the network airline's coverage. In return, the network airline pays a fixed fee to the regional airline, which is jointly determined through negotiation. The demand functions for markets AB, BC and AC are as follows:

$$q_{AB} = \alpha - p_{AB} \tag{16}$$

$$q_{BC} = 1 - p_{BC} \tag{17}$$

$$q_{AC} = 1 - p_{AC} \tag{18}$$

There are also two stages of decision making. In the first stage, the two airlines jointly determine t, the fixed price charged by Airline 2 (regional airline) to Airline 1 (network airline), through negotiation (Nash Bargaining Game). In the second stage, Airline 1 maximizes its profit by determining p_{AB}, p_{BC} and p_{AC}. For the sake of comparison, we assume that the bargaining power of the network airline is the same as that of the local government in Section 3.2. Given t, the profit functions of the network airline and the regional airline in the second stage are

$$\pi_1 = p_{AB}q_{AB} + (p_{BC} - t)q_{BC} + (p_{AC} - t)q_{AC} \tag{19}$$

$$\pi_2 = (t - c_2)(q_{BC} + q_{AC}) \tag{20}$$

The bargaining problem between the network airline and the regional airline can be formulated as follows:

$$\max_t (\pi_1 - \pi^B_1)^\theta (\pi_2 - \pi^B_2)^{1-\theta} \tag{21}$$

where π^B_1 and π^B_2 are again the equilibrium results in the benchmark case, serving as reference points to ensure the success of the bargain.

Similarly, the consumer surplus of market AB, the consumer surplus of markets BC and AC, and the social welfare of the network under a network airline CPA are

$$\phi_{AB} = \alpha q_{AB} - \frac{1}{2}{q_{AB}}^2 - p_{AB}q_{AB} \tag{22}$$

Table 1
The equilibrium results in the benchmark case.

p^B_i	$p^B_{AB} = \frac{1}{15}(4\alpha + 2(1 - c_2))$
	$p^B_{BC} = \frac{1}{15}(-\alpha + 8c_2 + 7)$
	$p^B_{AC} = \frac{1}{5}(\alpha + 2c_2 + 3)$
q^B_i	$q^B_{AB} = \frac{1}{15}(11\alpha + 2(c_2 - 1))$
	$q^B_{BC} = \frac{1}{15}(\alpha + 8(1 - c_2))$
	$q^B_{AC} = \frac{1}{5}(-\alpha + 2(1 - c_2))$
π^B_k	$\pi^B_1 = \frac{8}{225}(2\alpha - c_2 + 1)^2$
	$\pi^B_2 = \frac{2}{225}(\alpha + 7(c_2 - 1))^2$
ϕ^B_{AB}	$\frac{121\alpha^2 - 44\alpha + 4(11\alpha - 2)c_2 + 4({c_2}^2 + 1)}{450}$
ϕ^B	$\frac{\alpha^2 - 2\alpha + 2(\alpha - 10)c_2 + 10({c_2}^2 + 1)}{45}$
SW^B	$\frac{199\alpha^2 - 56\alpha + 2(28\alpha - 316)c_2 + 316({c_2}^2 + 1)}{450}$

$$\phi = U_1 - p_{BC}q_{BC} - p_{AC}q_{AC} \tag{23}$$

$$SW = U - p_{AB}q_{AB} - p_{BC}q_{BC} - p_{AC}q_{AC} + \pi_1 + \pi_2 \tag{24}$$

where $U_1 = q_{BC} + q_{AC} - \frac{1}{2}q_{BC}{}^2 - \frac{1}{2}q_{AC}{}^2$ and $U = \alpha q_{AB} + q_{BC} + q_{AC} - \frac{1}{2}q_{AB}{}^2 - \frac{1}{2}q_{BC}{}^2 - \frac{1}{2}q_{AC}{}^2$ represent the collective utilities of passengers in markets BC and AC and passengers in the entire airline network under a network airline CPA, respectively.

Similar to the local government CPA, for a network airline CPA, θ also cannot be too small or too large. Only when θ is within a reasonable range, both the network airline and the regional airline will see an increase in profits compared to the benchmark scenario. Otherwise, the negotiation between the two party will fail.

4. Analytical results and discussions

In this section, we first obtain the equilibrium outcomes under the three cases, including airline profits, consumer surplus, and the overall social welfare of the entire network. The detailed notations used in our models are summarized in Table 1A (see Appendix). The detailed mathematical derivations are also collated in the Appendix. We then compare the market equilibrium outcomes. The equilibrium and the comparison results under different cases are summarized in Tables 1–4. It should be noted that certain normalizing conditions must be satisfied to ensure that prices and traffic levels remain non-negative across different scenarios. These conditions are $1 < \alpha < 2(1 - c_2)$ and $0 < c_2 < 1/2$. As shown in Table 1, if α is too large, the non-negativity condition for the connecting market traffic q_{AC}^B cannot be satisfied. This scenario lies beyond the scope of our research question. To maintain the relevance of our discussion, we assume these conditions hold in the following analysis.

Lemma 1. *Compared to the benchmark case of no agreement, a local government CPA decreases prices and increases traffic in markets BC and AC (*i.e., $p_{BC}^L < p_{BC}^B$, $p_{AC}^L < p_{AC}^B$, $q_{BC}^L > q_{BC}^B$, $q_{AC}^L > q_{AC}^B$*). Conversely, it raises price and reduces traffic in market AB (*i.e., $p_{AB}^L > p_{AB}^B$, $q_{AB}^L < q_{AB}^B$*). The total demand for both the network airline and the regional airline is higher under a local government CPA than under no CPA (*i.e., $q_{AB}^L + q_{AC}^L > q_{AB}^B + q_{AC}^B$, $q_{BC}^L + q_{AC}^L > q_{BC}^B + q_{AC}^B$*).*

The proofs of Lemma 1, as well as the subsequent lemmas and propositions, can be found in the Appendix. Under a local government CPA, the local government of City C subsidizes passengers of the regional airline, thereby lowering ticket prices of the regional markets. This subsidy increases the demand in markets BC and AC, resulting in more passengers for the regional airline under a local government CPA. The higher demand on Route BC also affects the network airline, which serves Route AB. The network airline increases the fare on Route AB to capture more profit from the higher demand in city-pair market AC. The ticket price in city-pair market AC consists of two parts: the fare for Route AB set by the network airline, and the fare for Route BC set by the regional airline. While the subsidy reduces the fare for Route BC, the network airline's pricing strategy increases the fare for Route AB. However, the reduction on Route BC fares is greater than the increase on Route AB fares, leading to higher overall demand in the AC market. This is because the subsidy directly affects Route BC, whereas its impact on Route AB is indirect and weaker. The increased demand on Route BC outweighs the decreased demand on Route AB, resulting in more passengers for the network airline. Overall, compared to the benchmark case, a local government CPA increases total traffic in the network.

Table 2
The equilibrium results under the local government CPA

p_i^L	$p_{AB}^L = \frac{8}{31}(\alpha + 1 - c_2)$
	$p_{BC}^L = \frac{1}{31}(-\alpha + 28c_2 + 3)$
	$p_{AC}^L = \frac{1}{31}(7(\alpha + 3c_2) + 10)$
q_i^L	$q_{AB}^L = \frac{1}{31}(23\alpha - 7(1 - c_2))$
	$q_{BC}^L = \frac{1}{31}(\alpha + 28(1 - c_2))$
	$q_{AC}^L = \frac{1}{31}(-7\alpha + 27(1 - c_2))$
$\hat{\delta}$	$\frac{1}{62}(-4\alpha + 43(1 - c_2))$
π_1^L	$\frac{2}{961}(8\alpha + 7(1 - c_2))^2$
$(1-\theta)(\phi^L - \hat{\delta}*(q_{AC}^L + q_{BC}^L) + \pi_2^L)$	$\frac{1}{62}(1-\theta)(2\alpha^2 - 12(1 - c_2)\alpha + 49(1 - c_2)^2)$
ϕ_{AB}^L	$\frac{1}{1922}(529\alpha^2 - 322\alpha - 98c_2 + 322\alpha c_2 + 49c_2{}^2 + 49)$
$\theta(\phi^L - \hat{\delta}*(q_{AC}^L + q_{BC}^L) + \pi_2^L)$	$\frac{\theta}{62}(2\alpha^2 - 12(1 - c_2)\alpha + 49(1 - c_2)^2)$
SW^L	$\frac{1}{1922}(847\alpha^2 - 246\alpha - 3528c_2 + 246\alpha c_2 + 1764c_2{}^2 + 1764)$

Table 3
The equilibrium results under the major airline CPA.

p_i^M	$p_{AB}^M = \frac{\alpha}{2}$ $p_{BC}^M = \frac{1+c_2}{2}$ $p_{AC}^M = \frac{1+c_2}{2}$
q_i^M	$q_{AB}^M = \frac{\alpha}{2}$ $q_{BC}^M = \frac{1-c_2}{2}$ $q_{AC}^M = \frac{1-c_2}{2}$
$\widehat{t}$	c_2
$\theta(\pi_1^M + \pi_2^M)$	$\theta\left(\frac{\alpha^2 + 2(1-c_2)^2}{4}\right)$
$(1-\theta)(\pi_1^M + \pi_2^M)$	$(1-\theta)\left(\frac{\alpha^2 + 2(1-c_2)^2}{4}\right)$
ϕ_{AB}^M	$\frac{\alpha^2}{8}$
ϕ^M	$\frac{1}{4} - \frac{c_2}{2} + \frac{c_2{}^2}{4}$
SW^M	$\frac{3}{8}\alpha^2 + \frac{3}{4}c_2{}^2 - \frac{3}{2}c_2 + \frac{3}{4}$

Table 4
Equilibrium Results Comparison.

	Local government CPA vs. the benchmark		Network airline CPA vs. the benchmark		Network airline CPA vs. Local government CPA	
	Network Airline	Regional Airline	Network Airline	Regional Airline	Network Airline	Regional Airline
Δq	>0	>0	>0	>0	>0	<0
$\Delta\pi$	>0	>0	>0	>0	<0	>0
$\Delta\phi_{AB}$	<0		<0		<0	
$\Delta\phi$	>0		>0		<0	
ΔSW	>0		>0		<0	

Note: Δq represents the difference in total traffic volumes for the network (regional) airline under different scenarios.

Proposition 1. *Under a local government CPA, when the bargaining parameter θ is within a certain range (*i.e., $\frac{62(\alpha^2+2\alpha c_2+10c_2{}^2-2\alpha-20c_2+10)}{45(2\alpha^2+12\alpha c_2+49c_2{}^2-12\alpha-98c_2+49)} < \theta < \frac{326\alpha^2+964\alpha c_2+4949c_2{}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49c_2{}^2-12\alpha-98c_2+49)}$*), the profit of the network airline is higher, but the consumer surplus in market AB is lower compared to the benchmark case (*i.e., $\pi_1^L > \pi_1^B$, $\phi_{AB}^L < \phi_{AB}^B$*). The local government CPA can lead to higher profit for the regional airline, and higher regional net consumer surplus in markets BC and AC (*i.e., $\theta(\phi^L - \widehat{\delta}(q_{BC}^L + q_{AC}^L) + \pi_2^L) > \phi^B$, $(1-\theta)(\phi^L - \widehat{\delta}(q_{BC}^L + q_{AC}^L) + \pi_2^L) > \pi_2^B$*). Moreover, the local government CPA also leads to higher overall social welfare (*i.e., $SW^L > SW^B$*).*

The bargaining framework requires that a local government CPA should enhance both the consumer surplus of the small city and the profit of the regional airline compared to the benchmark case of no agreement. Proposition 1 demonstrates that the success of the local government CPA hinges on the bargaining parameter θ falling within a specific range. When this condition is met, it facilitates a cooperative agreement between the local government and the regional airline, yielding mutual benefits. Conversely, if this condition is not satisfied, both parties will revert to their respective payoffs under the benchmark scenario. As a result, the local government CPA not only enhances consumer welfare in the small city but also increases the regional airline's profitability. The subsidy reduces ticket prices and increases net consumer utility in those markets. Additionally, network airlines can benefit from a local government CPA by raising fares and acquiring higher profits. Compared to the benchmark, the local government CPA increases ticket prices and decreases traffic in the AB market, resulting in lower consumer surplus in that market.

The subsidy also increases overall demand in the network, thereby enhancing total social welfare. This has significant policy implications for local governments aiming to support their regional airlines and consumers. However, it is important to note that such an agreement incurs its own costs (i.e., the shadow price of the subsidy), which are not considered in our analytical model. Real-life policy decisions should account for the cost of the subsidy.

Lemma 2. *Compared with the benchmark case of no agreement, a network airline CPA increases the prices and decreases the traffic in markets AB and BC (*i.e., $p_{AB}^M > p_{AB}^B$, $p_{BC}^M > p_{AB}^B$, $q_{AB}^M < q_{AB}^B$, $q_{BC}^M < q_{BC}^B$*). It also reduces the price and raises the traffic of market AC (*i.e., $p_{AC}^M < p_{AC}^B$, $q_{AC}^M > q_{AC}^B$*). The total traffic of both the network airline and the regional airline is higher under a network airline CPA than under no CPA (*i.e., $q_{AB}^M + q_{AC}^M > q_{AB}^B + q_{AC}^B$, $q_{BC}^M + q_{AC}^M > q_{BC}^B + q_{AC}^B$*).*

Lemma 2 demonstrates that a network airline CPA increases the total demand for both airlines, but it also alters the demand and prices of each route. The demand in markets AB and BC decreases because the network airline raises prices in these markets to cover the commission costs paid to the regional airline. Conversely, the demand on the city-pair market AC increases as the network airline lowers prices on this route to attract more passengers. The reduced price on the city-pair market AC also benefits the regional airline, which receives higher commissions from the network airline. The increased demand on the city-pair market AC creates a positive network effect, meaning that more passengers in this market will boost demand for other markets (i.e., markets AB and BC) within the network. Therefore, the network airline CPA is advantageous for both airlines, as it increases their total demand and revenue in their respective service markets.

The observed reduction in prices is attributed to the elimination of double marginalization. With the CPA in place, the major airline assumes control over pricing decisions, effectively streamlining the process and reducing the cumulative markup that would otherwise result from independent pricing strategies of two separate entities. This unified pricing approach under the major airline's control tends to lower prices, which can stimulate demand and enhance overall market efficiency.

Proposition 2. *Under a network airline CPA, when the bargaining parameter θ is within a certain range (*i.e., $\frac{32(1-c_2+2\alpha)^2}{225(\alpha^2+2c_2{}^2-4c_2+2)} < \theta < \frac{217\alpha^2-112\alpha c_2+58c_2{}^2+112\alpha-116c_2+58}{225(\alpha^2-4c_2+2c_2{}^2+2)}$*), the profits of both airlines are higher compared to the benchmark case (*i.e., $\theta(\pi_1^M+\pi_2^M) > \pi_1^B$, $(1-\theta)(\pi_1^M+\pi_2^M) > \pi_2^B$*). Such a CPA also increases consumer surplus in markets BC and AC (*i.e., $\phi^M > \phi^B$*), while it decreases consumer surplus in market AB (*i.e., $\phi_{AB}^M < \phi_{AB}^B$*). Moreover, the network airline CPA improves overall social welfare (*i.e., $SW^M > SW^B$*).*

The bargaining framework requires that a network airline CPA increases the profits of both airlines compared to the benchmark case. Therefore, as indicated by Proposition 2, the bargaining parameter should be within a reasonable range to ensure increased profits for both airlines (similarly, to ensure the feasibility of a network airline CPA within this specified range). The network airline has the power to set prices in each market after the negotiation process and can increase its profit by charging different prices for different markets. In the AB market, where the market size is large, the network airline can raise the fare to earn more profit. In the smaller AC market, it can lower the fare to attract more demand and revenue. This strategy, while beneficial to the network airline, may adversely affect the regional airline, which sees a decrease in earnings per passenger on the AC route. However, the network airline can compensate the regional airline for its loss with part of its increased profit, depending on their respective bargaining power. This compensatory mechanism is integral to maintaining the equilibrium of the bargaining framework.

The network airline CPA also benefits the consumers in the small city C, as they have lower fares and higher net utility on city-pair market AC. The network airline CPA also benefits consumers in the small city C, as they enjoy lower fares and higher net utility in the city-pair market AC. Similar to Proposition 1, the ticket price is higher and the traffic volume is lower in the AB market under the network airline CPA, resulting in lower consumer surplus in that market. However, the network airline CPA still enhances overall social welfare within the network. This improvement is due to the vertical integration of airlines, which eliminates the double marginalization in providing transportation services, thereby increasing social welfare.

Proposition 2 has important policy implications. Similar to the local government CPA, a network airline CPA can also increase airline profits, improve local consumer surplus, and enhance social welfare across the entire network. However, it is not clear which of the two policies is better for market outcomes and welfare. To answer this question, we compare the local government CPA and the network airline CPA in Lemma 3 as well as Propositions 3 and 4. It is important to note that for the comparison between the two CPAs to be meaningful, the bargaining parameter θ must ensure that both agreements are valid. In other words, the following results are based on the intersection of the feasible ranges of θ as specified in Proposition 1 and Proposition 2. This range is given by $\frac{32(1-c_2+2\alpha)^2}{225(\alpha^2+2c_2{}^2-4c_2+2)} < \theta < \frac{326\alpha^2+964\alpha c_2+4949c_2{}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49c_2{}^2-12\alpha-98c_2+49)}$. The proof for the existence of this feasible range can be found in the Appendix. All conclusions below are discussed within this range of θ.

Lemma 3. *Compared to a local government CPA, the network airline CPA' price is higher and traffic is lower in markets AB and BC (*i.e., $p_{AB}^M > p_{AB}^L$, $p_{BC}^M > p_{BC}^L$, $q_{AB}^M < q_{AB}^L$, $q_{BC}^M < q_{BC}^L$*). Besides, the price is lower and the traffic is higher in market AC (*i.e., $p_{AC}^M < p_{AC}^L$, $q_{AC}^M > q_{AC}^L$*). The total traffic of the network airline is higher, but the total traffic of the regional airline is lower under a network airline CPA than under a local government CPA (*i.e., $q_{AB}^M + q_{AC}^M > q_{AB}^L + q_{AC}^L$, $q_{BC}^M + q_{AC}^M < q_{BC}^L + q_{AC}^L$*).*

From Lemmas 1 and 2, we can see that $p_{BC}^L < p_{BC}$ and $p_{BC}^M > p_{BC}$, suggesting $p_{BC}^M > p_{BC}^L$. The same logic applies to the traffic in this market. In the AB market, under a local government CPA, the network airline benefits indirectly from the subsidy provided by the local government. This benefit is not available under a network airline CPA, which forces the network airline to charge a higher price and have a lower traffic volume in this market. In the AC market, a network airline CPA eliminates the double marginalization present in other cases, effectively lowering the price and increasing the traffic volume for this interlining market. Moreover, compared to the local government CPA, the network airline has higher traffic under a network airline CPA, because the increase in traffic volume in the AC market can compensate for the decrease in the AB market. However, for the regional airline, under a network airline CPA, the total demand is lower than under a local government CPA, because the decrease in traffic volume in the BC market is greater than the increase in the AC market.

Proposition 3. *Compared to a local government CPA, the profit of the network airline is lower under a network airline CPA (*i.e., $\theta(\pi_1^M+\pi_2^M) < \pi_1^L$*) but the regional airline's profit is higher under a network airline CPA than under a local government CPA (*i.e., $(1-\theta)(\pi_1^M+\pi_2^M) > (1-\theta)(\phi^L - \widehat{\delta}(q_{BC}^L+q_{AC}^L)+\pi_2^L)$*).*

Proposition 3 is somewhat surprising and suggests that the profit of the regional airline is higher under a network airline CPA. The regional airline cannot acquire the full benefit of the subsidy under a local government CPA because the government subsidizes the regional airline to improve passenger demand in markets BC and AC, and the regional airline must share part of the benefit from the increased traffic with passengers. On the other hand, the network airline directly negotiates a fixed price t with the regional airline to purchase all the capacity in markets BC and AC, resulting in higher profits for the regional airline under a network airline CPA.

When comparing the network airline's profits under the two forms of CPA, it is important to note that the bargaining power of the regional airline is assumed to be the same for both comparisons. According to Propositions 1 and 2, the profit of the network airline is higher under both CPAs compared to the benchmark case. However, the mechanisms driving these outcomes differ. Under the local government CPA, the network airline benefits as a "free rider," generating profits without incurring additional fees, which leads to higher profitability. In contrast, under the network airline CPA, although vertical integration can enhance traffic volumes and improve overall profits, the network airline must pay higher commissions to regional airlines. As a result, the profit sharing for the network airline is lower under the network airline CPA compared to the local government CPA. Consequently, the network airline's profit is higher under the local government CPA than under the network airline CPA.

Next, we will analyze the consumer surplus and the social welfare under different forms of CPA.

Proposition 4. *Compared to a local government CPA, a network airline CPA leads to lower consumer surplus in market AB, lower net consumer surplus in markets BC and AC, and lower overall social welfare for the entire network (*i.e., $\phi_{AB}^M < \phi_{AB}^L$, $\phi^M < \theta\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right)$, $SW^M < SW^L$*).*

Proposition 4 indicates that the total social welfare of the entire network is always lower under a network airline CPA than under a local government CPA. This can be understood from the traffic comparison in Lemma 3. The higher traffic levels under a local government CPA are the primary reason for its higher total social welfare. From Lemma 3, we observe that the total traffic level in regional markets AC and BC is higher under a local government CPA than under a network airline CPA, leading to a higher gross local consumer surplus. Additionally, fare reductions and significant traffic increases result in an increase in consumer surplus that can offset the subsidy incurred under a local government CPA, leading to higher net consumer surplus in the small city C. For the AB market, Lemma 3 shows that compared to a local government CPA, a network airline CPA further increases ticket prices in the AB market, resulting in lower consumer surplus in that market.

Proposition 4 has significant policy implications. When small cities are underdeveloped and the local government aims to attract traffic volumes and improve local consumer welfare, the local government CPA is more favorable than the network airline CPA. In such situations, the local government CPA should be implemented if the subsidy is not overly burdensome for the local government. However, if these conditions are not met, policymakers need to be more cautious. Although our analysis indicates that a network airline CPA is less conducive to consumer surplus in small cities and overall social welfare, it can still increase both without additional subsidy costs compared to the benchmark case of no CPA. Therefore, local governments should encourage partnerships between network airlines and regional airlines. While a network airline CPA can be a more mature form of capacity contract, it is important to note that due to the low market demand in small cities, a subsidy policy may initially be necessary to attract regional airlines. For example, in the US regional market, regional airlines primarily sign CPAs with network airlines. Additionally, the government subsidizes regional airlines (e.g., through the EAS program) to support services for small and remote cities. Conversely, the central government may seek to increase traffic flows and consumer surplus in small cities through financial allocations to local governments, while also considering the social welfare of the entire network. Regulators must choose policies based on the government's budget and expected goals.

5. Extension

A central element of our model is the relationship between the regional airline and the network airline within a hub-and-spoke network, as depicted in Fig. 1. This network structure is foundational to our analysis. However, to maintain analytical tractability, the base model simplifies the framework by excluding network effects. Specifically, it does not account for demand-side network effects (e.g., flight frequency impacts on passenger choice) or supply-side network effects (e.g., economies of traffic density), instead assuming constant returns to scale. To address these limitations, we extend the base model by specifically considering flight frequency. This approach achieves multiple objectives. First, it captures airline network effects from both the demand and the supply sides. Second, it explicitly models the critical aspect of capacity decision-making, as frequency planning serves as a proxy for capacity planning under certain assumptions (i.e., exogenously given aircraft size and load factor). As discussed in Section 3, the base model effectively captures the dynamics of routes where flight frequency is predetermined prior to CPA negotiations. However, it may be less suited to predicting outcomes for routes where frequency remains adjustable after CPAs are finalized.

Due to the increased complexity, we are unable to derive closed-form solutions. Instead, we rely on numerical analysis to see how results differ when formalizing frequency as a decision variable. It is important to note that the feasibility conditions may differ across the settings. The quadratic utility function remains the same as in Eq (1). Following Flores-Fillol (2009) and D'Alfonso et al. (2015), we introduce flight frequencies additively in the full price functions, assuming that the frequency of flights offered by the airline delivers higher value to passengers and, therefore, determines service quality as a measure of flight flexibility. The full price P_i can be expressed as $P_i = p_i - f_i$, and the demand functions can be obtained as $q_{AB} = \alpha - p_{AB} + f_{AB}$, $q_{BC} = 1 - p_{BC} + f_{BC}$ and $q_{AC} = 1 - (p_{AB} + p_{BC}) + f_{AC}$ under the benchmark case and the local government CPA. The demand functions for the AB and BC markets remain unchanged under the network airline CPA, while the AC market demand function is $q_{AC} = 1 - p_{AC} + f_{AC}$. The minimum flight frequency on routes AB and

Table 5
Local government CPA vs. the benchmark.

	Flight frequency	Ticket price	Traffic volume
AB	> 0	> 0	< 0
BC	> 0	> 0	> 0
AC	> 0	> 0	< 0

Table 6
Network airline CPA vs. the benchmark.

	Flight frequency	Ticket price	Traffic volume
AB	>0	>0	<0
BC	>0	>0	>0 or <0
AC	>0	>0	>0

BC is used to measure the service frequency of the connecting route AC, namely $f_{AC} = min\,(f_{AB}, f_{BC})$. As discussed in Lin (2012) and Wang and Wang (2019), this modeling specification is grounded in the practical realities of air travel and passenger decision-making. For a connecting flight, the overall travel experience is constrained by the less frequent of the two flight legs, as passengers must align their schedules with the departure and arrival times of both segments. If one leg operates less frequently, it becomes the bottleneck, limiting the flexibility and convenience of the entire journey. By using the minimum frequency, we capture this critical constraint, reflecting how passengers perceive the availability and reliability of connecting flights.

According to Brueckner (2004) and Flores-Fillol (2009), the operating cost per flight can be expressed as $\varphi_i f_i$. The parameter φ_i reflects the level of frequency-specific costs, which include maintenance, fuel or energy consumption, and other non-passenger-specific expenses. We assume that the marginal cost of serving a passenger of airlines is c_i and $c_1 \leq c_2$. Assuming passengers are evenly distributed on each flight, the number of passengers carried on each flight is q_i/f_i. Therefore, the cost per flight is expressed as $\varphi_i f_i + c_i(q_i/f_i)$. The total cost of airlines can thus be calculated as $f_i[\varphi_i f_i + c_i(q_i/f_i)] = \varphi_i f_i^2 + c_i q_i$. The profit functions of the network airline and the regional airline in the benchmark case are $\pi_1 = p_{AB}(q_{AB}+q_{AC}) - \left[\varphi_1 (f_{AB})^2 + c_1(q_{AB}+q_{AC})\right]$ and $\pi_2 = p_{BC}(q_{BC}+q_{AC}) - \left[\varphi_2 (f_{BC})^2 + c_2(q_{BC}+q_{AC})\right]$, respectively. As clarified by Flores-Fillol (2009), this setting demonstrates that the cost per seat decreases with increasing aircraft size, effectively capturing the economies of traffic density (i.e., the cost advantages of operating larger aircraft) that are well-established in the airline industry.

In the local government CPA, there are two stages of decision making. Given δ, the profit functions of the two airlines are

$$\max_{p_{AB}, f_{AB}} \pi_1 = p_{AB}(q_{AB}+q_{AC}) - \left[\varphi_1 (f_{AB})^2 + c_1(q_{AB}+q_{AC})\right] \tag{25}$$

$$\max_{p_{BC}, f_{BC}} \pi_2 = p_{BC}(q_{BC}+q_{AC}) + \delta f_{BC} - \left[\varphi_2 (f_{BC})^2 + c_2(q_{BC}+q_{AC})\right] \tag{26}$$

In the first stage, Airline 2 and the local government determine the subsidy value δ together through a Nash Bargaining Game. In the second stage, Airline 1 and Airline 2 maximize their profits by determining p_{AB}, f_{AB}, p_{BC} and f_{BC}. The bargaining game between the local government and the regional airline can be formulated as follows:

$$\max_{\delta} \left(\phi - \delta f_{BC} - \phi^{BF}\right)^{\theta} \left(\pi_2 - \pi_2^{BF}\right)^{1-\theta} \tag{27}$$

where ϕ^{BF} represents the consumer surplus on routes BC and AC and π_2^{BF} represents the profit of the regional airline after considering flight frequency, both under the benchmark case. At this stage, we can obtain the equilibrium subsidy, which is expressed as $\widehat{\delta}^F$.

In the network airline CPA, there are also two stages of decision making. In the first stage, the two airlines determine *t*, the fixed capacity price charged by Airline 2 to Airline 1, together by negotiation (Nash Bargaining Game). In the second stage, Airline 1 maximizes its profit by determining p_{AB}, p_{BC}, p_{AC}, f_{AB}, and f_{BC}. Given t, the profit functions of the two airlines are

$$\max_{p_{AB}, p_{BC}, p_{AC}, f_{AB}, f_{BC}} \pi_1 = p_{AB}q_{AB} + p_{BC}q_{BC} + p_{AC}q_{AC} - tf_{BC} - \left[\varphi_1 (f_{AB})^2 + c_1(q_{AB}+q_{AC})\right] \tag{28}$$

Table 7
Network airline CPA vs. Local government CPA.

	Flight frequency	Ticket price	Traffic volume
AB	>0 or <0	>0 or <0	>0
BC	<0	>0 or <0	<0
AC	<0	<0	>0 or $0<$

Table 8
Equilibrium Comparison Results Under Flight Frequency.

	Local government CPA vs. the benchmark		Network airline CPA vs. the benchmark		Network airline CPA vs. Local government CPA	
	Network Airline	Regional Airline	Network Airline	Regional Airline	Network Airline	Regional Airline
Δq	>0	>0	>0	>0	>0 or <0	>0
$\Delta \pi$	>0	>0	>0	>0	<0	>0 or <0
$\Delta \phi_{AB}$	<0		<0		>0 or <0	
$\Delta \phi$	>0		>0		>0 or <0	
ΔSW	>0		>0		>0 or <0	

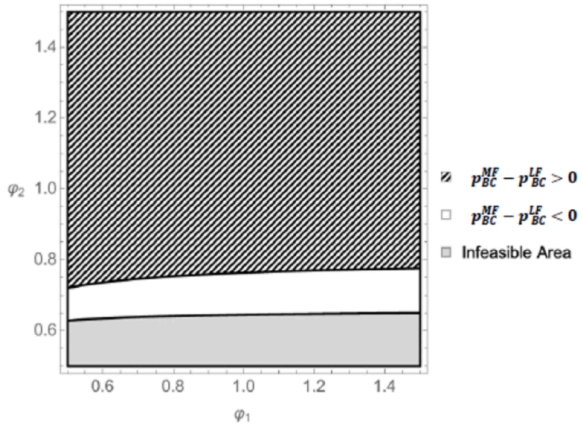

Fig. 2. The comparison results between the price of market BC under the network airline CPA and the local government CPA.

$$\pi_2 = tf_{BC} - \left[\varphi_2 (f_{BC})^2 + c_2(q_{BC} + q_{AC})\right] \tag{29}$$

In the first stage, the bargaining game between the local government and the regional airline can be formulated as follows:

$$\max_t \left(\pi_1 - \pi_1^{BF}\right)^\theta \left(\pi_2 - \pi_2^{BF}\right)^{1-\theta} \tag{30}$$

At this stage, we can obtain the equilibrium subsidy, which is expressed as $\hat{t}^F$. The social welfare functions and the bargaining game models remain unchanged.

Given the large number of parameters in the model and the complexity of the analysis, obtaining closed-form analytical solutions is challenging. Therefore, we conduct numerical experiments to identify parameter sets that satisfy all constraints. As mentioned at the beginning of the section, the base and the extension models represent different scenarios, so it is important to understand how the additional parameters in the extension model, φ_1 and φ_2, affect the analytical results. Therefore, we fix the other parameters and let φ_1 and φ_2 to vary within their feasible ranges. To ensure that the function is concave, we assume that $\varphi_1 > 0$, $\varphi_2 > 0.5$ and $3 - 42\varphi_1 + 148\varphi_1^2 - (2 - 15\varphi_1)^2\varphi_2 < 0$. We have tested various parameter values within these sets, and the qualitative results are consistent and robust. It is important to note that, while we have explored many parameter constellations in our numerical analysis, the results presented in this section cannot be guaranteed to hold for all untested parameter values. This limitation is inherent to numerical analyses and underscores why we refrain from claiming that our conclusions are general or universal. To reflect this cautious approach, we present the findings as observations rather than propositions. We summarize the comparison results of the different cases in Tables 5–8. Furthermore, we present the non-unidirectional results in Figs. 2–8. For consistency, we have set $\alpha = 1.638$, $c_1 = 0.1$, $c_2 = 0.15$ and $\theta = 0.7$ for these figures.[8] We illustrate the results within the ranges $0.5 < \varphi_1 < 1.5$, $0.5 < \varphi_2 < 1.5$, which effectively highlights the key insights while maintaining a clear and visually concise representation. It is important to note, however, that the feasible parameter space is not strictly confined to these ranges. The only conditions that need to be satisfied are the concavity conditions mentioned above. To ensure clarity in our presentation, the figures have been designed with hatched areas that represent the parameter spaces where the results align with the base model when applicable.

From Table 5 and the first column "Local government CPA vs. Benchmark" in Table 8, we can confirm that the results for traffic in Lemma 1 remain valid. Incorporating flight frequencies into the model shows that subsidies, compared to the benchmark case, result in increased flight frequency on each route. This higher flight frequency enhances passenger utility, leading to increased demand, but also raises costs for airlines. Contrary to Lemma 1, both factors contribute to higher fares in the BC market. However, the increase in flight

[8] It is important to note that in the base model, we assume $c_1 = 0$. To maintain consistency, we have also conducted numerical analyses under this assumption while keeping all other parameters unchanged. The results remain qualitatively identical.

frequency is more pronounced, resulting in higher traffic volumes in the BC market. Since the AC market is jointly served by the two airlines, the increase in flight frequency on route BC leads to higher flight frequencies on route AB, which subsequently elevates flight frequencies for AC passengers. In the AC market, the higher flight service frequency directly drives an increase in passenger traffic. Consequently, fares in both the AB and the AC markets also increase. The total demand for both airlines remains consistent with Lemma 1.

Similarly, we numerically verify that the major findings in Proposition 1 hold with the linear schedule delay cost specification. The profits of the network airline and the consumer surplus in market AB, as well as the net consumer surplus in markets BC and AC, remain unchanged after the introduction of flight frequency. Consistent with Proposition 1, the social welfare level is also higher than the benchmark case when considering flight frequency. This indicates that the flight frequency subsidy in the current domestic situation not only promotes the development of regional aviation but also improves social welfare across the entire network.

Table 6 and the second column "Network airline CPA vs. Benchmark" in Table 8 confirm that the major findings of Lemma 2 and Proposition 2 remain valid after introducing flight frequency. Compared to the benchmark case, the results for the BC and AC markets differ from those in Lemma 2. For the airlines, higher frequencies are advantageous for attracting passenger traffic. However, providing higher flight frequency leads to increased operating costs, especially with higher frequency-specific cost parameters. As a result, BC and AC passengers experience higher flight frequencies and fares, but the overall effect is an increase in traffic volumes. In the AB market, ticket prices and traffic volumes remain unchanged, as does the consumer surplus in the AB and the BC markets. Moreover, both airlines' profits are still higher than in the benchmark case. As the cost of introducing flight frequencies increases, the network airline CPA leads to higher social welfare, consistent with Proposition 2. This further demonstrates that, in the long term, when accounting for flight frequency, the network airline CPA, compared with the local government CPA, effectively improves local consumer welfare and airline profits without additional government expenditure.

Table 7 and the third column "Network airline CPA vs. Local government CPA" in Table 8 confirm that when the frequency-specific cost parameter of the regional airline is large, the major findings of Lemma 3 still hold. After introducing flight frequency, the comparison results for prices in each market and traffic volumes in markets BC and AC remain valid when the frequency-specific cost parameter of regional airlines is large. From Fig. 2, when the frequency-specific cost parameter of the regional airline is large, government capacity subsidies, compared to the network airline CPA, directly reduce operating costs, resulting in lower market prices for BC under the government CPA. This situation is consistent with Lemma 3. However, considering the influence of flight frequency, when the frequency-specific cost parameter of the regional airline is large, the flight frequency and market price for route AB are higher (see Figs. 3 and 4). Although the traffic volume in the AB market is lower, the increase in traffic volume in the AC market is higher, resulting in a higher total demand for the network airline. This is consistent with Lemma 3.

For the regional airline, the total demand is always higher under the network airline CPA than under the local government CPA, which is inconsistent with Lemma 3. The main reason is that when the frequency-specific cost parameter of regional airlines is large, the network airline CPA stimulates higher traffic volumes to the small city C by reducing ticket prices in market AC and increasing flight frequencies for the served route. Not only is the network airline's total demand higher, but the traffic volume of the entire network under the network airline CPA is higher than under the local government CPA. On the other hand, when the frequency-specific cost parameter of the regional airline is small, local government capacity subsidies directly increase flight frequency on all routes, boosting the traffic volume of regional airlines. However, this leads to higher prices in the regional airline service markets. Compared to the network airline CPA, the network carrier, under the local government CPA, raises ticket prices in market AB through a free-rider effect while reducing service frequency, resulting in lower traffic volumes in the AB market and even a lower total traffic volume for the whole network. This situation is inconsistent with Lemma 3.

We also numerically verify that the results in Proposition 3 and Proposition 4 regarding airline profits and consumer surplus in the AB market remain valid when the frequency-specific cost parameter for the regional airline is large (see Figs. 5 and 6). However, after incorporating flight frequency into the model, the results for consumer surplus in markets BC and AC, as well as the overall social

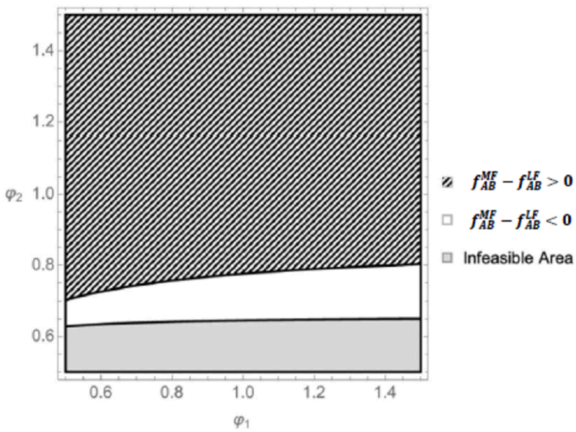

Fig. 3. The comparison results between the frequency of route AB under the network airline CPA and the local government CPA.

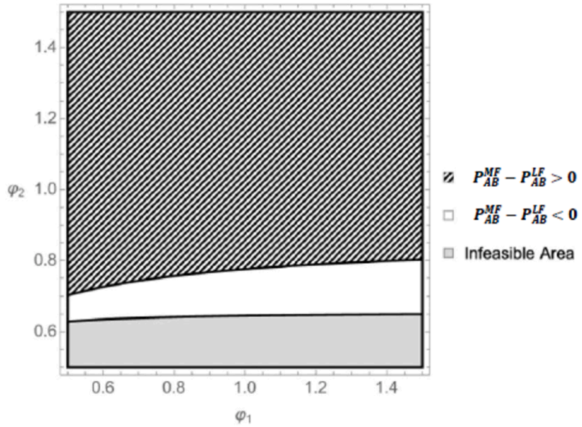

Fig. 4. The comparison results between the price of market AB under the network airline CPA and the local government CPA.

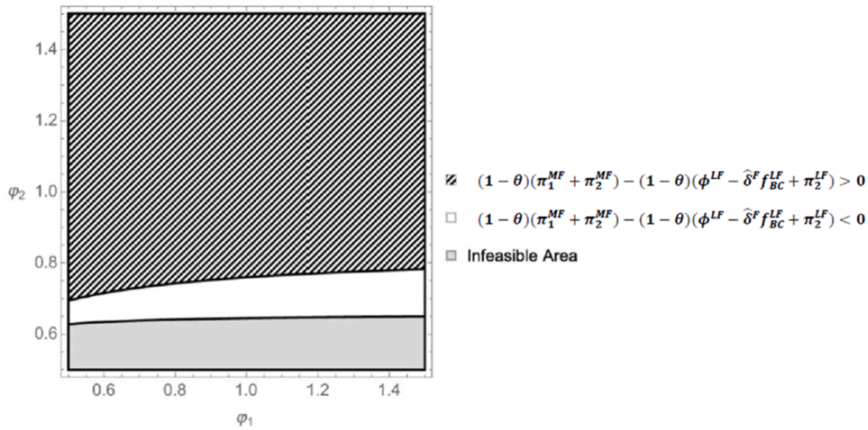

Fig. 5. The comparison results between the regional airline's profit under the network airline CPA and the local government CPA.

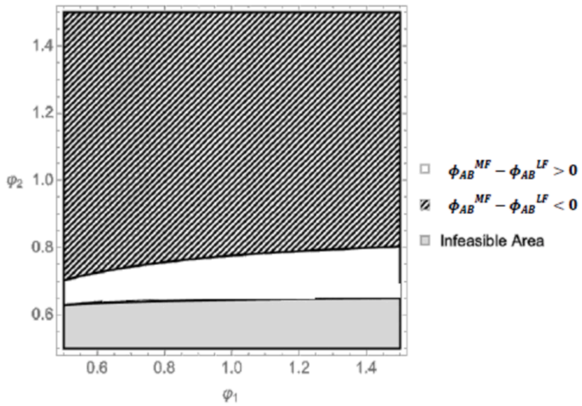

Fig. 6. The comparison results between the consumer surplus in market AB under the network airline CPA and the local government CPA.

welfare of the network, are reversed between the two types of CPAs. These findings are summarized in Observation 5.

Observation 5. *Compared to a local government CPA, when the frequency-specific cost parameter of the regional airline is relatively large, a network airline CPA results in a higher net consumer surplus in markets BC and AC, as well as a greater social welfare for the entire network (*i.e., $\phi^{MF} > \theta\left(\phi^{LF} - \hat{\delta}^{F} f_{BC}^{LF} + \pi_2^{LF}\right)$, $SW^{MF} > SW^{LF}$*).*

Observation 5 indicates that the net consumer surplus in markets BC and AC is higher under a network airline CPA than under a local government CPA when the frequency-specific cost parameter of regional airlines is sufficiently large (see From Figs. 7 and 8). This can be easily understood from the comparison results in Tables 5–7. Compared to the local government CPA, it shows that the total traffic level in the regional market is higher under a network airline CPA than under a local government CPA, leading to a higher net consumer surplus in markets BC and AC. Moreover, when the frequency-specific cost parameter of regional airlines is large, the total traffic volume of the whole network is higher, lead to higher social welfare. It is important to note that the conclusion from Observation 5 differs from that of Proposition 4. This discrepancy arises from the distinct model settings of the base model and the extension model. However, this does not imply that Observation 5 and Proposition 4 contradict each other. As highlighted at the beginning of the section, the two models represent different scenarios: the base model assumes flight frequency is predetermined prior to CPA negotiations, while the extension model allows frequency to remain adjustable after CPAs are finalized. Since both scenarios are plausible in reality, it is not surprising that some conclusions differ. In fact, these differences enrich the analysis by providing a broader range of policy implications.

Observation 5 has significant policy implications. As highlighted in the discussion of Proposition 4, the social welfare comparison between the two types of CPAs necessitates careful interpretation. The assertion that one type of CPA consistently outperforms the other likely arises from the omission of key real-world factors. Observation 5 reinforces this caution by illustrating how the consideration of frequency as a decision variable influences outcomes. In particular, when frequency remains adjustable after CPAs are signed, if the frequency-specific cost parameter of regional airlines is high, the network airline CPA may be more advantageous than the local government CPA. Specifically, the network airline CPA not only benefits the consumer surplus of passengers arriving in the small city without requiring financial assistance but also enhances the social welfare of the entire network. Therefore, when the frequency-specific cost parameter of regional airlines is high, the network airline CPA should be implemented. However, if this condition is not met, policymakers need to exercise caution. In such cases, compared to the local government CPA, the network airline CPA may be detrimental to the welfare of passengers arriving in the small city and the overall network. It is important to note that due to the low market demand in small cities, a subsidy policy may initially be necessary to attract regional airlines. For example, in the US regional market, regional airlines primarily sign CPAs with network airlines. Additionally, the federal government subsidizes regional airlines (e.g., EAS) to support services for underdeveloped and remote small cities. On the other hand, the central/federal government may aim to increase traffic flows and consumer surplus in small cities through financial allocations to local governments, while also considering the social welfare of the entire network. Our analysis suggests that a network airline CPA may be conducive to overall social welfare when the frequency-specific cost parameter of regional airlines is higher than that of network airlines.

6. Conclusions

Transport connectivity, facilitated by regional aviation, is crucial for the economic development of small cities. The regional airline sector is well-established in major economies such as the US and Europe, thanks to their mature CPA models that enable regional airlines to partner with major network airlines. Meanwhile, the regional airline sector is also experiencing rapid growth in emerging markets, particularly in China. In China, CPAs are regarded as a vital business model to enhance regional aviation. However, unlike the US and Europe, local governments in China are more actively involved in signing CPAs with regional airlines. Therefore, it is worthwhile to examine the potential differences between the impacts of local government CPAs and network airline CPAs on the regional airline sector.

This paper develops a Nash Bargaining model to analyze two types of CPAs for regional airlines: partnerships with local governments versus network airlines. The results show that both CPAs improve airline profits, regional consumer surplus, and overall social welfare compared to no agreement, but with distinct trade-offs. A local government CPA prioritizes lowering regional ticket prices, increasing demand in small cities, and maximizing local welfare, though it reduces consumer surplus in trunk markets (e.g., major hub routes). Conversely, a network airline CPA vertically integrates regional and trunk operations, eliminating double marginalization and

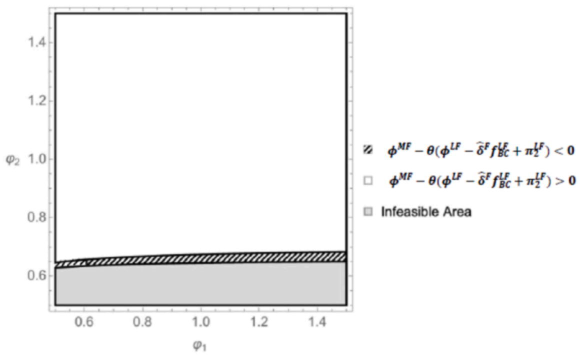

Fig. 7. The comparison results between consumer surplus in the BC and AC markets under the network airline CPA and the local government CPA.

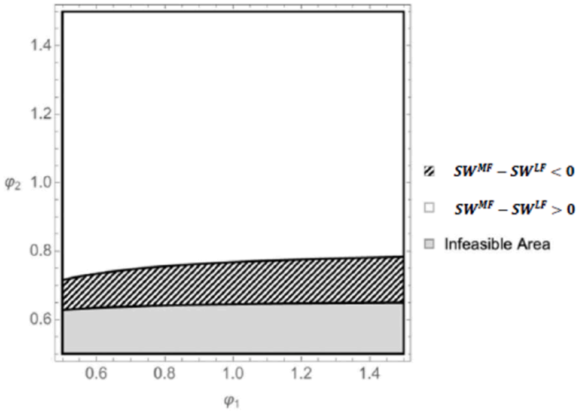

Fig. 8. The comparison results between social welfare under the network airline CPA and the local government CPA.

lowering prices for connecting routes, but it reduces profits for the network airline and may harm trunk-market consumers. Consequently, when flight frequency is predetermined before the CPAs are signed, local government CPAs are more socially favorable than network airline CPAs.

However, when flight frequency is incorporated, the analysis reveals nuanced outcomes: network airline CPAs outperform local government CPAs in regional consumer surplus and network-wide social welfare only when regional airlines face high frequency-specific operational costs. Under these conditions, the network airline's centralized pricing and frequency decisions mitigate inefficiencies, boosting demand and welfare. However, if frequency costs are low, the local government CPA remains more beneficial for small cities. These findings underscore that policymakers must weigh regional priorities against network efficiency gains when designing CPAs, particularly in markets with varying cost structures.

This paper has some limitations, which offer opportunities for future research. First, to simplify the modeling derivations, we have assumed that the network airline has zero cost. While the cost of the network airline may also affect airline profits and social welfare, the main results based on the current model setting should not change significantly by considering this factor explicitly. Second, the signing of a CPA in reality is a complex process. Network airlines may face difficulties in signing agreements with regional airlines due to low demand in the regional market. Therefore, the network airline CPA may also require government support in the form of subsidies to develop the market. In other words, the two forms of CPAs considered in this paper may not be mutually exclusive. It would be interesting to explore the combined effects of the two in future research. Finally, our model assumes that route BC is provided solely by the regional airline. In reality, it is possible that after the regional airline cultivates the market, the network airline may enter the market to compete, making the interactions between airlines more complex. This is beyond the scope of the current study but can be investigated in future research.

CRediT authorship contribution statement

Yilin Chen: Writing – review & editing, Writing – original draft, Formal analysis. **Hangjun Yang:** Supervision, Project administration. **Shiyuan Zheng:** Writing – original draft, Validation, Supervision, Methodology. **Kun Wang:** Writing – original draft, Supervision, Project administration. **Changmin Jiang:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

None.

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Appendix A

Table A1
Summary of notations.

Notation	Definitions
α	Potential market size of market AB
p_i^B	Ticket price of market i under the benchmark case*
p_i^j	Ticket price of market i under CPA type j**
q_i^B	Traffic volume of market i under the benchmark case
q_i^j	Traffic volume of market i under CPA type j
π_k^B	The profit of airline k under the benchmark case***
π_k^j	The profit of airline k under CPA type j
θ	The bargaining power of the small city government or the network airline
t	The fixed price charged by the regional airline to the network airline
$\widehat{\delta}$	Per-passenger equilibrium subsidy offered to the regional airline
$\widehat{\delta}^F$	Per-flight equilibrium subsidy offered to the regional airline
ϕ_{AB}^B	The consumer surplus in market AB under the benchmark case
ϕ_{AB}^j	The consumer surplus in market AB under CPA type j
ϕ^B	The consumer surplus in markets BC and AC under the benchmark case
ϕ^j	The consumer surplus in markets BC and AC under CPA type j
U^B	The collective utility of the entire network under the benchmark case
U^j	The collective utility of the entire network under CPA type j
U_1^B	The collective utility of markets BC and AC under the benchmark case
U_1^j	The collective utility of markets BC and AC under CPA type j
SW^B	The social welfare of the entire network under the benchmark case
SW^j	The social welfare of the entire network under CPA type j
ϕ^{BF}	The consumer surplus in markets BC and AC under the benchmark case after considering flight frequency
ϕ^{jF}	The consumer surplus in markets BC and AC under CPA type j after considering flight frequency**
π_k^{BF}	The profit of airline k under the benchmark case after considering flight frequency ***
π_k^{jF}	The profit of airline k under CPA type j after considering flight frequency

* $i = AB$, BC or AC.
** $j = L$ or M.
*** $k = 1$ or 2.

Under different cases, the conditions are $1 < \alpha < 2(1 - c_2)$ and $0 < c_2 < \frac{1}{2}$. And $p_{AB}^M + p_{BC}^M > p_{AC}^M$. We assume that these conditions hold in the following analysis.

The process of backward induction under the two CPAs:

For the local government CPA, through backward induction, we first solve for the equilibrium prices of the two airlines in the second stage given the optimal subsidy value (Equations (11) and (12)),

$$\frac{\partial \pi_1}{\partial p_{AB}} = 0 \tag{A1}$$

$$\frac{\partial \pi_2}{\partial p_{BC}} = 0 \tag{A2}$$

From the two equations above, we can obtain the results as:

$$p_{AB} = \frac{4\alpha}{15} + \frac{2}{15} - \frac{2c_2}{15} + \frac{2\delta}{15} \tag{A3}$$

$$p_{BC} = -\frac{\alpha}{15} + \frac{7}{15} + \frac{8c_2}{15} - \frac{8\delta}{15} \tag{A4}$$

Next, we substitute Eqs. (A3) and (A4) into the bargaining model to derive the equilibrium subsidy in the first stage (Eq. (10)). The bargaining model is equivalent to maximizing the integrated gains of the two players, which are subsequently divided between the two parties based on their respective bargaining power parameters (Wu et al., 2009; Wu, 2013). This process is subject to the condition that both parties benefit from the bargain. Mathematically, this derivation can be expressed as solving the following:

$$\max_{\delta}\left(\phi - \delta(q_{BC} + q_{AC}) - \phi^B + \pi_2 - \pi_2^B\right) \tag{A5}$$

From which we obtain

$$\widehat{\delta} = \frac{43}{62} - \frac{2\alpha}{31} - \frac{43c_2}{62} \tag{A6}$$

After substituting Eq. (A6) back to Eqs. (A3) and (A4), we can obtain the equilibrium results in Table 2.

Similarly, for the network airline CPA, we can obtain the equilibrium price and traffic volume in the second stage (Equations (20) and (21)),

$$\frac{\partial \pi_1}{\partial p_{AB}} = 0 \tag{A7}$$

$$\frac{\partial \pi_1}{\partial p_{BC}} = 0 \tag{A8}$$

$$\frac{\partial \pi_1}{\partial p_{AC}} = 0 \tag{A9}$$

We can obtain:

$$p_{AB} = \frac{\alpha}{2} \tag{A10}$$

$$p_{BC} = \frac{1}{2} + \frac{t}{2} \tag{A11}$$

$$p_{AC} = \frac{1}{2} + \frac{t}{2} \tag{A12}$$

Next, we substitute Eqs. (A10) - (A12) into the bargaining model to derive the equilibrium subsidy in the first stage (Eq. (19)). Again, the bargaining model is equivalent to

$$\max_{t}\left(\pi_1 - \pi_1^B + \pi_2 - \pi_2^B\right) \tag{A13}$$

From Eq. (A13) we obtain.

$$\widehat{t} = c_2, \tag{A14}$$

After substituting Eq. (A14) back to Eqs. (A10) - (A12), we can obtain the equilibrium results in Table 3.

Proof of Lemma 1.

The difference between the local government CPA and the benchmark case:

$$q_{AB}^L - q_{AB}^B = \frac{4\alpha}{465} - \frac{43}{465} + \frac{43c_2}{465} < 0$$

$$q_{BC}^L - q_{BC}^B = -\frac{16\alpha}{465} + \frac{172}{465} - \frac{172c_2}{465} > 0$$

$$q_{AC}^L - q_{AC}^B = -\frac{4\alpha}{155} + \frac{43}{155} - \frac{43c_2}{155} > 0$$

$$\left(q_{AB}^L + q_{AC}^L\right) - \left(q_{AB}^B + q_{AC}^B\right) = -\frac{8\alpha}{465} + \frac{86}{465} - \frac{86c_2}{465} > 0$$

$$\left(q_{BC}^L + q_{AC}^L\right) - \left(q_{BC}^B + q_{AC}^B\right) = -\frac{28\alpha}{465} + \frac{301}{465} - \frac{301c_2}{465} > 0$$

$$p_{AB}^L - p_{AB}^B = -\frac{4\alpha}{465} + \frac{43}{465} - \frac{43c_2}{465} > 0$$

$$p_{BC}^L - p_{BC}^B = \frac{16\alpha}{465} - \frac{172}{465} + \frac{172c_2}{465} < 0$$

$$\left(p_{AB}^L+p_{BC}^L\right)-\left(p_{AB}^B+p_{BC}^B\right)=\frac{4\alpha}{155}-\frac{43}{155}+\frac{43c_2}{155}<0$$

Proof of Proposition 1.

$$\pi_1^L-\pi_1^B=-\frac{2(4\alpha+43c_2-43)(244\alpha-167c_2+167)}{216225}>0$$

$$\phi_{AB}^L-\phi_{AB}^B=\frac{1}{432450}\left(30166\alpha c_2-14362c_2-30166\alpha+2744\alpha^2+7181{c_2}^2+7181\right)<0$$

The convex function of α has two positive solutions, when $\alpha\epsilon\left[\frac{167}{686}(1-c_2),\frac{43}{4}(1-c_2)\right]$, we have $\phi_{AB}^L-\phi_{AB}^B<0$, but in order to satisfy $p_i,q_i>0$, then the condition that market size of AB market is $1<\alpha<2(1-c_2)$ and $0<c_2<\frac{1}{2}$. We have $\phi_{AB}^L<\phi_{AB}^B$.

$$\begin{aligned}\theta\left(\phi^L-\widehat{\delta}\left(q_{BC}^L+q_{AC}^L\right)+\pi_2^L\right)-\phi^B&=\frac{(90\theta-62)\alpha^2}{2790}+\frac{(-540\theta+124)\alpha}{2790}+\frac{(2205\theta-620){c_2}^2}{2790}+\frac{((540\theta-124)\alpha-4410\theta+1240)c_2}{2790}\\&\quad+\frac{49\theta}{62}-\frac{2}{9}\\&>0\end{aligned}$$

$$\begin{aligned}(1-\theta)\left(\phi^L-\widehat{\delta}\left(q_{BC}^L+q_{AC}^L\right)+\pi_2^L\right)-\pi_2^B&=\frac{(-450\theta+326)\alpha^2}{13950}+\frac{(2700\theta-964)\alpha}{13950}+\frac{(-11025\theta+4949){c_2}^2}{13950}\\&\quad+\frac{((-2700\theta+964)\alpha+22050\theta-9898)c_2}{13950}-\frac{49\theta}{62}+\frac{4949}{13950}\\&>0\end{aligned}$$

In order for the local government and the regional airline to cooperate, these equations need to be met. Then, the conditions can be summarized as,

$$\frac{62(\alpha^2+2\alpha c_2+10{c_2}^2-2\alpha-20c_2+10)}{45(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}<\theta<\frac{326\alpha^2+964\alpha c_2+4949{c_2}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}$$

$$SW^L-SW^B=-\frac{(4\alpha+43c_2-43)(83\alpha-1084c_2+1084)}{216225}>0$$

Proof of Lemma 2.

The difference between the network airline CPA and the benchmark case:

$$q_{AB}^M-q_{AB}^B=-\frac{7\alpha}{30}+\frac{2}{15}-\frac{2c_2}{15}<0$$

$$q_{BC}^M-q_{BC}^B=-\frac{\alpha}{15}-\frac{1}{30}+\frac{c_2}{30}<0$$

$$q_{AC}^M-q_{AC}^B=\frac{\alpha}{5}-\frac{c_2}{10}+\frac{1}{10}>0$$

$$\left(q_{AB}^M+q_{AC}^M\right)-\left(q_{AB}^B+q_{AC}^B\right)=-\frac{\alpha}{30}+\frac{7}{30}-\frac{7c_2}{30}>0$$

$$\left(q_{BC}^M+q_{AC}^M\right)-\left(q_{BC}^B+q_{AC}^B\right)=\frac{1}{15}-\frac{c_2}{15}+\frac{2\alpha}{15}>0$$

$$p_{AB}^M-p_{AB}^B=\frac{7\alpha}{30}-\frac{2}{15}+\frac{2c_2}{15}>0$$

$$p_{BC}^M-p_{BC}^B=\frac{\alpha}{15}+\frac{1}{30}-\frac{c_2}{30}>0$$

$$p_{AC}^M-p_{AC}^B=\frac{c_2}{10}-\frac{\alpha}{5}-\frac{1}{10}<0$$

Proof of Proposition 2.

$$\theta\left(\pi_1^M+\pi_2^M\right)-\pi_1^B==\frac{(225\theta-128)\alpha^2}{900}+\frac{(128\alpha-900\theta+64)c_2}{900}+\frac{(450\theta-32){c_2}^2}{900}-\frac{32\alpha}{225}+\frac{\theta}{2}-\frac{8}{225}>0$$

$$(1-\theta)\left(\pi_1^M+\pi_2^M\right)-\pi_2^B=\frac{(-225\theta+217)\alpha^2}{900}+\frac{(-112\alpha+900\theta-116)c_2}{900}+\frac{(-450\theta+58){c_2}^2}{900}+\frac{28\alpha}{225}-\frac{\theta}{2}+\frac{29}{450}>0$$

Similarly, in order for the network airline and the regional airline to cooperate, these equations need to be met. Then, the conditions can be summarized as,

$$\frac{32(1-c_2+2\alpha)^2}{225(\alpha^2+2{c_2}^2-4c_2+2)}<\theta<\frac{217\alpha^2-112\alpha c_2+58{c_2}^2+112\alpha-116c_2+58}{225(\alpha^2-4c_2+2{c_2}^2+2)}$$

$$\phi_{AB}^M-\phi_{AB}^B=\frac{1}{1800}\left(-176\alpha c_2+32c_2+176\alpha-259\alpha^2-16{c_2}^2-16\right)<0$$

$$\phi^M-\phi^B=\frac{(1-c_2+2\alpha)(5-5c_2-2\alpha)}{180}>0$$

$$SW^M-SW^B=\frac{-121\alpha^2}{1800}+\frac{28\alpha(1-c_2)}{225}+\frac{43(1-c_2)^2}{900}>0$$

Proof of the bargaining parameter's intersection range

The two conditions that need to be satisfy are $\frac{62\left(\alpha^2+2\alpha c_2+10{c_2}^2-2\alpha-20c_2+10\right)}{45(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}<\theta<\frac{326\alpha^2+964\alpha c_2+4949{c_2}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}$ and $\frac{32(1-c_2+2\alpha)^2}{225(\alpha^2+2{c_2}^2-4c_2+2)}<\theta<\frac{217\alpha^2-112\alpha c_2+58{c_2}^2+112\alpha-116c_2+58}{225(\alpha^2-4c_2+2{c_2}^2+2)}$. It is straightforward to show that $\frac{62\left(\alpha^2+2\alpha c_2+10{c_2}^2-2\alpha-20c_2+10\right)}{45(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}<\frac{32(1-c_2+2\alpha)^2}{225(\alpha^2+2{c_2}^2-4c_2+2)}$ and $\frac{326\alpha^2+964\alpha c_2+4949{c_2}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}<\frac{217\alpha^2-112\alpha c_2+58{c_2}^2+112\alpha-116c_2+58}{225(\alpha^2-4c_2+2{c_2}^2+2)}$ always hold. Therefore, for the intersection of the two conditions to exist, we only need $\frac{32(1-c_2+2\alpha)^2}{225(\alpha^2+2{c_2}^2-4c_2+2)}<\frac{326\alpha^2+964\alpha c_2+4949{c_2}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49{c_2}^2-12\alpha-98c_2+49)}$, which can be shown to be true when both α and c_2 are not too large (as indicated by the hatched area in the following graph).

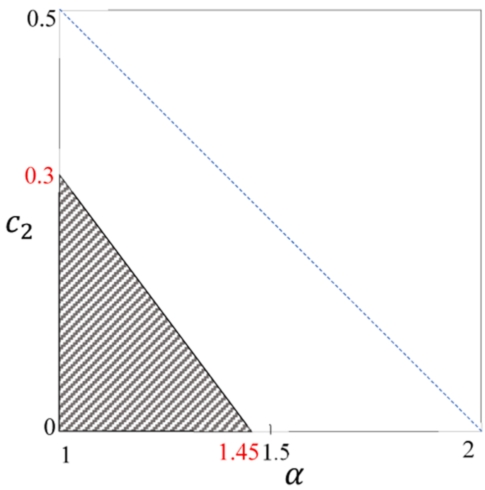

Fig. A1. Intersection Range of the Bargaining Parameter θ.

Proof of Lemma 3.

The difference between the network airline CPA and the local government CPA:

$$q_{AB}^M-q_{AB}^L=\frac{7}{31}-\frac{7c_2}{31}-\frac{15\alpha}{62}<0$$

$$q_{BC}^M - q_{BC}^L = -\frac{25}{62} + \frac{25c_2}{62} - \frac{\alpha}{31} < 0$$

$$q_{AC}^M - q_{AC}^L = \frac{7\alpha}{31} - \frac{11}{62} + \frac{11c_2}{62} > 0$$

$$\left(q_{AB}^M + q_{AC}^M\right) - \left(q_{AB}^L + q_{AC}^L\right) = -\frac{\alpha}{62} + \frac{3}{62} - \frac{3c_2}{62} > 0$$

$$\left(q_{BC}^M + q_{AC}^M\right) - \left(q_{BC}^L + q_{AC}^L\right) = -\frac{18}{31} + \frac{18c_2}{31} + \frac{6\alpha}{31} < 0$$

$$p_{AB}^M - p_{AB}^L = \frac{15\alpha}{62} + \frac{7c_2}{31} - \frac{7}{31} > 0$$

$$p_{BC}^M - p_{BC}^L = \frac{\alpha}{31} + \frac{25}{62} - \frac{25c_2}{62} > 0$$

$$p_{AC}^M - \left(p_{AB}^L + p_{BC}^L\right) = \frac{11}{62} - \frac{11c_2}{62} - \frac{7\alpha}{31} < 0$$

Proof of Proposition 3.

In order to ensure the realization of the two CPAs, the bargaining parameter condition is $\frac{32(1+c_2+2\alpha)^2}{225(\alpha^2+2c_2{}^2-4c_2+2)} < \theta < \frac{326\alpha^2+964\alpha c_2+4949c_2{}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49c_2{}^2-12\alpha-98c_2+49)}$.

The profit difference between the network airline CPA and the local government CPA:

$$\pi_1^L - \theta\left(\pi_1^M + \pi_2^M\right) = \theta\left(-\frac{\alpha^2}{4} - \frac{1}{2} + c_2 - \frac{c_2{}^2}{2}\right) + \frac{128\alpha^2}{961} - \frac{224\alpha c_2}{961} + \frac{224\alpha}{961} + \frac{98c_2{}^2}{961} - \frac{196c_2}{961} + \frac{98}{961}$$

The function is a linear function with respect to θ, which monotonically decreases and the solution is $\theta_1 = \frac{8\left(64\alpha^2+112(1-c_2)\alpha+49(c_2-1)^2\right)}{961\left(\alpha^2+2(c_2-1)^2\right)}$. We compared θ_1 and the upper bound of θ, we have $\frac{326\alpha^2+964\alpha c_2+4949c_2{}^2-964\alpha-9898c_2+4949}{225(2\alpha^2+12\alpha c_2+49c_2{}^2-12\alpha-98c_2+49)} - \frac{8\left(64\alpha^2+112(1-c_2)\alpha+49(c_2-1)^2\right)}{961\left(\alpha^2+2(c_2-1)^2\right)} < 0$. So, the result is $\pi_1^L - \theta\left(\pi_1^M + \pi_2^M\right) > 0$

$$(1-\theta)\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right) - (1-\theta)\left(\pi_1^M + \pi_2^M\right) = \theta\left(\frac{27\alpha^2}{124} + \frac{6\alpha}{31} - \frac{6\alpha c_2}{31} + \frac{18}{31}c_2 - \frac{9c_2{}^2}{31} - \frac{9}{31}\right) - \frac{27\alpha^2}{124} + \frac{6\alpha c_2}{31} - \frac{6\alpha}{31} + \frac{9c_2{}^2}{31} - \frac{18c_2}{31} + \frac{9}{31}$$

This function is a linear function with respect to θ, which monotonically increases and the solution is $\theta_2 = 1$. So, we have $(1-\theta)\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right) - (1-\theta)\left(\pi_1^M + \pi_2^M\right) < 0$.

Proof of Proposition 4.

$$\theta\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right) - \phi^M = \theta\left(\frac{\alpha^2}{31} - \frac{6\alpha}{31} + \frac{6\alpha c_2}{31} - \frac{49}{31}c_2 + \frac{49c_2{}^2}{62} + \frac{49}{62}\right) - \frac{1}{4} + \frac{c_2}{2} - \frac{c_2{}^2}{4}$$

The solution is $\theta_3 = \frac{31(c_2-1)^2}{2\left(2\alpha^2+12(c_2-1)\alpha+49(c_2-1)^2\right)}$. We compared θ_3 and the lower bound of θ, we have $\frac{32(1+c_2+2\alpha)^2}{225(\alpha^2+2c_2{}^2-4c_2+2)} - \frac{31(c_2-1)^2}{2\left(2\alpha^2+12(c_2-1)\alpha+49(c_2-1)^2\right)} > 0$. So, the result is $\theta\left(\phi^L - \widehat{\delta}\left(q_{BC}^L + q_{AC}^L\right) + \pi_2^L\right) - \phi^M > 0$.

$$SW^M - SW^L = -\frac{505\alpha^2}{7688} + \frac{123\alpha(1-c_2)}{961} - \frac{645(1-c_2)^2}{3844} < 0$$

Equilibrium solutions after introducing flight frequencies

After introducing flight frequency, the equilibrium results under the benchmark case with no policy and the two CPAs are as follows. As closed-form analytical results cannot be obtained, we rely on numerical simulations to obtain the equilibrium solutions. The following parameter values are chosen as $\alpha = 1.638$, $\varphi_1 = 0.815$, $\varphi_2 = 0.846$, $c_1 = 0.1$, $c_2 = 0.15$, $\theta = 0.707$.

Numerical Simulations Results Under Flight Frequency.

p_{AB}^{BF}	0.805
p_{BC}^{BF}	0.697
p_{AC}^{BF}	1.502
q_{AB}^{BF}	1.266
q_{BC}^{BF}	0.950
q_{AC}^{BF}	0.146
f_{AB}^{BF}	0.433
f_{BC}^{BF}	0.647
f_{AC}^{BF}	0.647
π_1^{BF}	0.842
π_2^{BF}	0.245
ϕ^{BF}	0.461
ϕ_{AB}^{BF}	0.801
SW^{BF}	2.349
$\widehat{\delta}^F$	0.907
p_{AB}^{LF}	0.992
p_{BC}^{LF}	1.238
p_{AC}^{LF}	2.230
q_{AB}^{LF}	1.193
q_{BC}^{LF}	1.584
q_{AC}^{LF}	0.592
f_{AB}^{LF}	0.547
f_{BC}^{LF}	1.822
f_{AC}^{LF}	1.822
π_1^{LF}	1.348
$(1-\theta)\left(\phi^{LF}-\widehat{\delta}^F f_{BC}^{LF}+\pi_2^{LF}\right)$	0.290
$\theta\left(\phi^{LF}-\widehat{\delta}^F f_{BC}^{LF}+\pi_2^{LF}\right)$	0.699
ϕ_{AB}^{LF}	0.712
SW^{LF}	3.048
$\widehat{t}^F$	2.886
p_{AB}^{MF}	1.209
p_{BC}^{MF}	1.628
p_{AC}^{MF}	1.359
q_{AB}^{MF}	1.109
q_{BC}^{MF}	0.990
q_{AC}^{MF}	1.259
f_{AB}^{MF}	0.681
f_{BC}^{MF}	1.617
f_{AC}^{MF}	1.617
ϕ^{MF}	1.282
ϕ_{AB}^{MF}	0.615
SW^{MF}	3.395
$\theta\left(\pi_1^{MF}+\pi_2^{MF}\right)$	1.059
$(1-\theta)\left(\pi_1^{MF}+\pi_2^{MF}\right)$	0.439

Data availability

No data was used for the research described in the article.

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