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An option-based capacity control mechanism for code-sharing alliances

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ABSTRACT

This study addresses capacity control problems in code-sharing alliances, which deal with the determination of member airlines' booking limits. We propose an innovative option-based capacity control mechanism to overcome the drawback of inflexibility in blocked seat allotment for a two-airline code-sharing alliance. The mechanism incorporates the concept of a straddle, an advanced option strategy in finance, to allow member airlines the flexibility to tackle not only downward but also upward demand variations during the booking process. We design simulation experiments and use a case illustration to show scenarios when the code-sharing alliance can benefit from the proposed mechanism.

1. Introduction

Since the deregulation of the U.S. airline market in 1978, the civil aviation industry has seen a new era of liberalization. On the one hand, airlines gained the freedom to vary fares, develop network and schedule planning, and manage other key aspects of the airline business [1]. On the other hand, airlines worldwide started to engage in alliances and relied on foreign partners to expand and strengthen their global service networks [2].

Star Alliance, SkyTeam, and Oneworld are the three major passenger airline alliances nowadays. Due to their crucial role in defining the modern aviation industry, airline alliances have attracted increased attention in studying their economic and social impacts [3–8] as well as the decision-making dynamics involved in the collaborations [9–13]. Even though the aggregate market share of the three alliances dropped from 53.4 % in 2018 [14] to 47.7 % in 2020 [15], the three groups remain big influential players in the commercial aviation sector. In particular, the coronavirus pandemic (COVID-19) has rediscovered the value of airline alliances. Carriers restricted from operating specific routes due to mass flight suspensions, travel restrictions, and fleet groundings had relied on alliance partners to get passengers to their destinations. For example, as Oneworld member airlines, Qatar Airways and American Airlines restored their code sharing in May 2020 after a two-year suspension of their cooperation. The pandemic accelerated the partnership recovery because both airlines needed to maintain their global network, which would not have been viable for the airlines financially without the collaboration [16].

Adapted from [17], Fig. 1 shows a broad spectrum of cooperation among airline alliance partners, ranging from basic, limited arrangements to highly integrated joint ventures. In this study, we concentrate on airlines with a standard alliance relationship, primarily involving cooperation in frequent flyer programs, lounge access, and code sharing. Compared to carriers establishing a joint network or engaging in a merger-like integration, the code-sharing alliance partners exhibit the lowest degree of cooperation. They do not jointly make strategic decisions, such as setting prices or coordinating schedules, nor do they share revenue or profit.

The U.S. Department of Transportation defines code sharing as a marketing arrangement in which an airline places its designator code on a flight operated by another airline and sells tickets for that flight. This practice is a vital component of airline alliances, enabling allied airlines to broaden their market coverage and improve their competitiveness. Under a code-sharing agreement, an *operating carrier* is an airline operating the flight and providing the plane, the crew, and the ground handling services. An airline selling tickets for the same flight but not operating the flight is called a *ticketing carrier* or *marketing carrier*. [18] identifies two types of code sharing: parallel and complementary. A parallel alliance refers to collaborations between carriers competing on the same route. In contrast, a complementary alliance refers to the case where two carriers link their existing networks and build a new complementary network to provide improved service for connecting passengers. The proposed option-based capacity control mechanism fits better in the complementary alliance setting. In a parallel alliance, competing on the same route may add complexity to the

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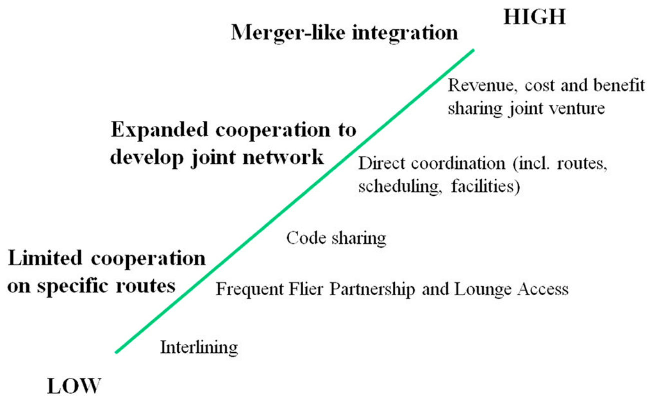

Fig. 1. Spectrum of Alliance Cooperation.

cooperation-based procedures when two airlines share the same market demand. In addition, there should be a positive demand correlation when the two carriers face similar customer groups. The simulation analysis will show that the more positive the demand correlation, the smaller the benefit of the proposed mechanism. Therefore, the proposed mechanism is more suitable for the complementary alliance setting where two airlines target different customer segments and do not compete directly.

As one of the key components of airline revenue management, capacity control (or seat inventory control) is a critical decision area which determines the booking limits of not only different customer segments but also the alliance members. As specified in [19] and [20], blocked seat allotment and free sale are two traditional approaches to allocating seats among the alliance members. These two methods, however, have the drawbacks of losing flexibility and missing higher-profit customers, respectively.

Blocked seat allotment is the method to partition the seats on an aircraft into blocks and assign each block to one carrier. Each alliance member will then individually control the seats they have been assigned. In contrast, free sale procedures follow a first-come-first-served (FCFS) rule. Using this method, the operating carrier provides real-time information about the seat availability to the ticketing carrier. The ticketing carrier will not be assigned any pre-specified number of seats. When any one of the carriers receives a customer reservation, the corresponding airline makes the accept/reject decisions based on the booking limits established by the operating carrier.

Normally, the free sale mechanism is preferred by large airlines due to the prevalence of instantaneous messaging software. The blocked seat allotment, however, is still a cost-effective approach for many regional or small-scale airlines. A revenue management system that allows in-time information exchange with other airlines is very expensive. Besides, the implementation and maintenance costs of such revenue management systems are both very high. In addition, the existence of antitrust law may prohibit the sharing of revenue management systems between alliance members [21]. As a result, in need of forming partnership, the blocked seat allotment method is still needed.

For the case of two airlines forming a code-sharing alliance with a single flight leg, we propose an option-based capacity control mechanism to improve the blocked seat allotment method. The option here refers to the concept of a straddle, an advanced option strategy in finance. Specifically, a straddle is the purchase of a call and a put that have the same exercise price and expiration date. A call option is an option to buy an asset at a fixed price, i.e., exercise price, before the expiration date of the option. On the other hand, a put option is an option to sell an asset at the predetermined exercise price. A straddle is an appropriate strategy in the finance market when a trader suspects that the stock price will move substantially but does not know in which direction it will go. Similarly, if the demands of airlines are treated as stocks in financial market, carriers forming a code-sharing alliance can transfer seats between each another based on a capacity control mechanism involving purchasing and exercising call/put options on seats. In another word, an airline can maximize the revenue by minimizing its demand risks using straddles to request a flexible range in booking limits from its alliance partner. At the same time, the partner can also maximize its revenue by receiving profits earned from the option-based mechanism. The newly designed mechanism aims to combine the flexible options strategies with the traditional blocked seat allotment approach to improve the business processes at an acceptable cost.

Table 1
Code sharing between Japan Airlines and WestJet on the route from NRT to YEG.

Flight schedule provided by Japan Airlines		
JL018	NRT	YVR
(operated by Japan Airlines)	18:40	10:55
JL5802/WS168	YVR	YEG
(operated by WestJet)	14:00	16:30

An example is given here to demonstrate a code-sharing setting where the proposed mechanism can be applied. Table 1 shows the flight schedule of Japan Airlines on the route between Tokyo (Narita) (NRT) and Edmonton (YEG). This itinerary consists of two flights, with a stopover at Vancouver (YVR). The first flight JL018 is solely operated by Japan Airlines. For the second flight, Japan Airlines collaborates with WestJet, the second-largest Canadian airline, on the route between YVR and YEG. Though WestJet is the operating carrier for this flight, Japan Airlines can also sell seats on the same flight under its own brand. As a result, the second flight shares two codes as JL5802/WS168. This is a typical code-sharing arrangement where Japan Airlines can extend its network to the Canadian market without paying the actual operational costs. At the same time, WestJet can attract more demand from the Japanese market as Japan Airlines customers can enjoy a seamless connection experience onto a WestJet flight.

The alliance capacity control problem arises for flight JL5802/WS168 as WestJet needs to decide how to allocate the seats between Japan Airlines and itself. For situations like this example, we aim to propose and describe an option-based capacity control mechanism to add flexibility to the blocked seat allotment approach and improve the airlines' cooperation process. As long as the code sharing arrangement is involved, the problem of seat allocation for allied partners exists for every single flight. Moreover, we aim to model and simulate the proposed mechanism to show its effectiveness in increasing airlines' revenue.

We organize this paper as follows. Section 2 presents a literature review of capacity control in airline alliances and the application of options. We formulate the mechanism by narratives in Section 3 and build analytical models in Section 4. To show the effectiveness of the proposed mechanism, we design simulation experiments in Section 5 and discuss simulation results in Section 6. Specifically, we examine how different parameters such as demand correlation, demand variability, ticket price, option costs can impact the benefits brought by the mechanism. Lastly, Section 7 concludes the paper.

2. Literature review

2.1. Capacity control

In the airline industry, the fundamental problem of capacity control is about the decision to accept or deny a booking request for a particular fare during the booking period [22]. This is a topic that keeps attracting the interest of academics since 1972 when Littlewood's rule [23] first came out.

According to the review of the forty-year history of revenue management research in [24], the capacity control problem develops from Littlewood's rule for two fare classes, to expected marginal seat revenue control for multiple classes [25], to optimal booking limits for single-leg flights [26,27], and to segment and origin-destination control [26,28–32]. [33] presents another detailed review of the capacity control literature.

Although a lot of models and algorithms with increasing complexity are developed for capacity control in airline industry, most research treats the problem in an isolated environment without considering the impact of competition and collaboration [34]. In the context of airline alliances, capacity control problems deal with the determination of booking limits of not only different customer segments but also the alliance members. In this case, even the fundamental single-leg flight problem involves complications. By jointly marketing the seats on an aircraft, the alliance members need to know how to effectively synchronize revenue management decisions in general, and capacity control decisions in particular, across the alliance network.

[19] is the first one who discusses revenue management in the alliance scenario. In the paper, the author compares the centralized and decentralized revenue management systems for alliances and introduces two common capacity control methods, namely blocked seat allotment and free sale. The same two concepts are presented as hard blocks and soft blocks by [20], who also introduces the decision control mechanisms used by airline alliances in practice. In discussing the scenario of hard blocks, [20] mentions the use of an inventory release agreement between the allied airlines. By signing the agreement, the ticketing carrier can release some of the unused hard block space back to the operating carrier at a pre-determined time before departure. The existence of an inventory release agreement appears to be the earliest evidence that supports the idea of treating airline seats as tradable products so as to design a new mechanism that can overcome the drawback of blocked seat allotment.

The centralized and decentralized environments are also considered in [35], who provide a more formal analysis of alliance revenue management mechanism and examines the behavior of alliance members. In addition, issues of capacity control have been addressed together with other revenue management decisions. For example, [36] proposes a two-stage game-theoretic approach where the allied carriers negotiate the revenue sharing rates in stage one and implement the capacity control independently in stage two. [37] proposes a mechanism that allocates both alliance resources and profits for air cargo alliances.

Another stream of literature considers the capacity control problem for the multiple-flight cases. [38] studies the simultaneous capacity control of a set of parallel flights on the same route. Their work differs from previous literature because the authors examine the situation where customers select seats in the same fare class among those parallel flights, instead of selecting seats in different fare classes from a specific flight. Another work [22] investigates a two-flight case where there are three types of booking requests. The first and second types are for the first and the second flight only, respectively. The third type request is flexible, and customers are willing to take either flight. Though only single airline is involved, the above studies may shed light on future research of capacity control for airline alliances, especially for the parallel alliances.

In the limited literature of capacity control in airline alliances, existing work is almost silent about possible application of real options. To the best of our knowledge, the only option-related work is [39], which incorporates the concept of call options in a model that helps with the determination of booking limits for two alliance partners. In their proposed mechanism, the operating carrier provides seats in an aircraft and the ticketing carrier can access the seats of the operating carrier by buying call options for the seats. For the seats reserved under the call options, the ticketing carrier can then exercise the call options by paying the exercise price to the operating carrier in order to obtain the actual control right of the corresponding seats. Considering the above mechanism is similar to the traditional blocked seat allotment approach, the authors also discuss a re-optimization procedure in which the operating carrier has the right to buy back options from the ticketing carrier during the booking process. In the paper, it is mentioned that a buy-back will add more complication to the problem since penalty may need to be considered. Notably [40] extends [39] as a follow-up study where the optimal transfer prices are determined by a negotiation process rather than pre-determined.

The capacity control mechanism developed in this paper differs from [39] in three ways. First, the proposed mechanism tackles not only downward but also upward demand variations of the ticketing carrier. Second, the option buy-back by the operating carrier is not needed, involving no additional complications. Third, the initial setting in [39] allocates all the seats to the operating carrier, and each seat obtained by the ticketing carrier is through the purchase of a call option. In contrast, the initial setting of the newly-designed mechanism is exactly the traditional blocked seat allotment where each carrier will be assigned certain number of seats. Thus, the analyses of the proposed mechanism can directly help those airlines using blocked seat allotment improve their revenue management systems.

2.2. Application of options

Referring to the book written by [41], an option is a contract between two parties – a buyer and a seller – that gives the buyer a right, but not an obligation, to purchase or sell something on a future day at a price agreed upon today. Options are valuable when there are uncertainties. The option buyer pays the seller a sum of money, called the option price or premium, to obtain the corresponding right.

Specifically, a call option is an option to buy an asset at a fixed price, namely the exercise price, before the expiration date of the option. On the other hand, a put option is an option to sell an asset at the predetermined exercise price. As an advanced options strategy, a straddle is the purchase of a call and a put that have the same exercise price and expiration date.

Fig. 2 on the next page shows the payoff of a straddle. In the stock market, the option prices of a call and a put are c and p, respectively. Their exercise prices are both x, and their expiration dates are the same. By paying $c + p$, traders holding both a call and a put can capitalize on stock price movements in either direction, for example when the stock price is below S_3 or higher than S_4. In other words, a straddle allows the options holder to profit based on how much the price of the underlying security moves, regardless of the direction of price movement.

If the underlying asset of an option is a real (non-financial) asset, the option is a real option. [42] points out that moving from financial options to real options requires a way of thinking, one that brings the discipline of the financial markets to internal strategic investment decisions. Their book demonstrates in detail how the "real options thinking" adds value to businesses by showing applications of real options in various industries, such as telecommunications and production

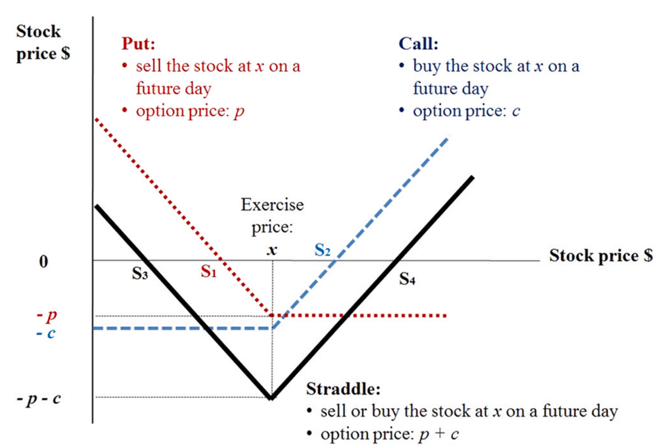

Fig. 2. Option Payoff Diagram for a Straddle.

industry. In addition to the comprehensive introduction in [42], prior work discusses real options application in specific industries. [43] presents a real options approach to revenue management that is tailored for the car rental industry. Their model can produce pricing and inventory release recommendations for the concerned business. Another example is [44], which focuses on real options application in air cargo revenue management. In the work, the author analyzes the pricing of capacity through option contracts and evaluates the financial impacts of such contracts as compared to traditional fixed-commitment contracts. More related studies include [45] and [46], who incorporate the concept of options in the study of production systems.

Built on related extant literature, this paper develops an innovative capacity control mechanism that overcomes the drawback of blocked seat allotment for strategic airline alliances. It extends the previous literature by tackling not only downward but also upward demand variations of the ticketing carrier. Besides, the initial setting of the newly designed mechanism is exactly the traditional blocked seat allotment where each carrier will be assigned certain number of seats. Thus, this work can provide practical guidance for those airlines using blocked seat allotment. Lastly, this work enriches cross-disciplinary research as it expands the literature in revenue management and finance.

3. Mechanism formulation

We consider a code-sharing alliance formed by two airlines. The operating carrier (OC) provides the seats on an aircraft, i.e., flight *i*, while the seats can be marketed by both OC and the other carrier – the ticketing carrier (TC).

In the first place, the allied carriers adopt blocked seat allotment in allocating the seats on flight *i*. It is assumed that the information needed for this blocked seat allotment procedure is available. The seats are partitioned into two blocks based on the forecasted demand of the two carriers.

Before the booking process, each seat representing one booking request can be seen as the underlying asset of a real option. A straddle in this scenario is thus the purchase of a call option and a put option that are for the same seat and have the same exercise price and expiration date.

TC can purchase a straddle from OC by paying the *option price* before the booking process to own the right but not the obligation of buying (selling) one seat from (to) OC at the predetermined exercise price on a future day. As sometimes the direction of demand fluctuation is unknown, straddle-approach allows TC the flexibility to adjust booking limits upon the preliminary seat allotment result. If TC observes higher-than-expected demand during the booking process, it can exercise the call side to buy one seat from OC and thus be able to satisfy one more booking request. In contrast, if the actual demand appears to be lower than expected, TC can exercise the put side to sell one seat back to OC and receive the exercise price payment from OC as a remedy to the loss stemming from a seat vacancy.

A natural question is whether OC is willing to join such a mechanism. When TC purchases a straddle and exercises the call side to buy one seat, OC's revenue can be increased only if the sum of option price and exercise price paid by TC is greater than or equal to the revenue OC would have otherwise earned from selling the ticket to an external customer. Similarly, when TC exercises the put side to sell one seat, OC is better off only if this extra ticket can be sold to a customer and the revenue of selling ticket together with the option price received earlier is greater than the exercise price paid to TC. Interestingly, there could be a third situation where OC can benefit from the options mechanism. It is when TC buys the straddle but will never exercise it. In this case, while other things remain unchanged, OC's revenue is increased by receiving the option price of the straddles. From the above analyses, the option-based mechanism does create a win-win situation for OC and TC under some realistic scenarios.

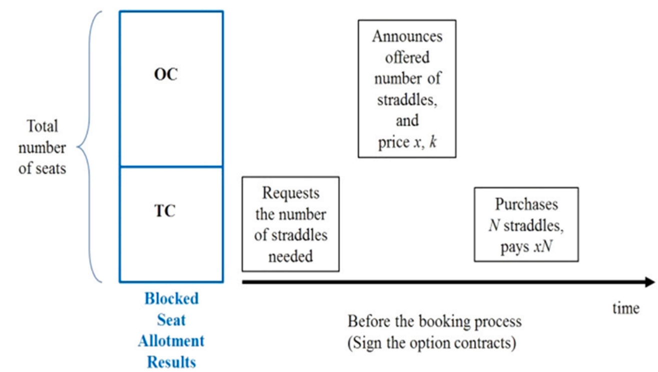

Fig. 3. Decision-making Interaction between OC and TC – Before the Booking Process.

Fig. 3 and Fig. 4 depict the decision-making interaction between OC and TC before and during the booking process, respectively.

On top of the blocked seat allotment results, TC first requests the number of straddles needed based on its demand forecast. After receiving the requests from TC, OC decides the number of straddles it can offer and the associated option price x and exercise price k. TC, in turn, informs OC of the number of straddles it accepts (N) and, at the same time, pays the corresponding option payments xN to OC. The two carriers can reach such an agreement by signing a contract containing all the details before the booking process commences.

Once the booking process begins, airlines' demand patterns may differ from the forecasts to different degrees. Before the cut-off time

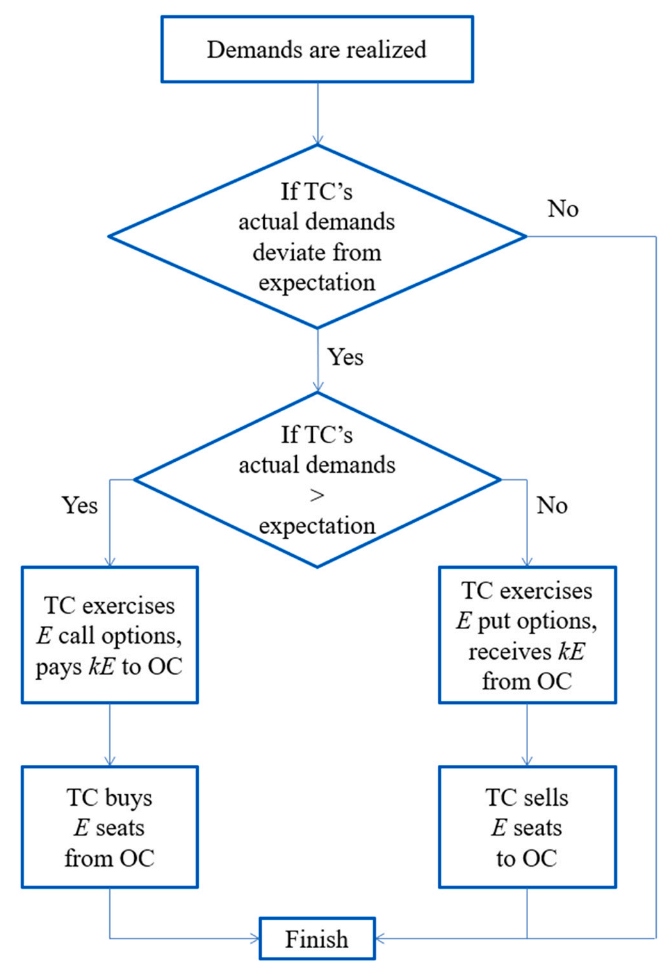

Fig. 4. Decision-making Interaction between OC and TC – During the Booking Process.

Table 2
Variable definitions.

Variables	Definitions
N	Number of straddles purchased by TC
E	Number of options exercised by TC
n	Total number of seats on the flight
n_{TC}	Number of seats assigned to TC in the blocked seat allotment
R_{TC}	TC's revenue without adopting the option-based mechanism
R_{TC}^{S}	TC's revenue when adopting the option-based mechanism
R_{OC}^{S}	OC's revenue when adopting the option-based mechanism
D_{TC}	Total number of booking requests of TC (actual demand of TC)
D_{OC}	Total number of booking requests of OC (actual demand of OC)
B_{TCm}	The benefit obtained by TC when D_{TC} is in demand range m.
B_{OCm}	The benefit obtained by OC when D_{TC} is in demand range m.
m = P1, P2, C2, C1	Demand range Put 1, Put 2, Call 2, Call 1, respectively
P_{TC}	Ticket price of TC
P_{OC}	Ticket price of OC
x	Option price
k	Exercise price

defined in the agreement, TC decides whether to exercise the straddle and on which side (call or put). If TC's total number of booking requests exceeds its expectation, TC can exercise E call options, pays kE to OC, and purchase E seats from OC. Specifically, if the number of seats assigned to TC is n_{TC} and the total number of booking requests TC receives is D_{TC}, E is the minimum of the number of straddles N and the difference between D_{TC} and n_{TC}. In contrast, by exercising E put options, TC can sell E seats back to OC and receive kE from OC.

The above option-based procedures provide the two carriers with a seat-transference mechanism. Thus, flexibility is added to the preliminary blocked seat allotment result.

4. Analytical model

In this section, we develop an analytical model to calculate the revenue obtained by the code-sharing airlines from the optioned-based capacity control mechanism. Variable definitions are in Table 2.

Eqs. (1) and (3) show the respective revenue earned by TC and OC without adopting the option-based mechanism. The number of tickets sold by an airline equals the minimum of its total number of booking requests and the number of seats assigned to the airline.

$$R_{TC} = \min(D_{TC}, n_{TC}) \times P_{TC} \tag{1}$$

$$R_{TC}^{S} = \min(D_{TC}, n_{TC}) \times P_{TC} - x \times N \pm k \times E + [\min(D_{TC} - n_{TC}, E)]^{+} \times P_{TC} \tag{2}$$

$$R_{OC} = \min(D_{OC}, n - n_{TC}) \times P_{OC} \tag{3}$$

$$R_{OC}^{S} = \min(D_{OC}, n - n_{TC}) \times P_{OC} + x \times N \mp k \times E \pm \text{Extra/Lost revenue} \tag{4}$$

Eqs. (2) and (4) show the respective revenue earned by TC and OC when adopting the option-based mechanism, where $[x]+$ represents $\max(x, 0)$ and $E = \min(N, |D_{TC} - n_{TC}|)$. The prepayment of the option price xN is the expense of TC while is the revenue of OC. When TC exercises E put options, TC's revenue will be increased by kE and OC will pay kE to buy back E seats. There is a chance for OC to sell more seats than assigned and receive extra revenue from customers. In contrast, when TC exercises E call options, TC will have an expense of kE and OC's revenue is increased by kE. By purchasing E seats from OC, TC gets a chance to sell more seats to customers and receive extra revenue, while OC has a risk of sacrificing potential revenue from its own customers.

Whether OC can earn extra revenue or lose potential revenue from its own customers highly depends on the relationship among the number of seats assigned to OC, $n - n_{TC}$; the number of options exercised by TC, E; and OC's total number of booking requests, D_{OC}.

When TC exercises E put options, OC's potential extra revenue is given by:

$$[\min(D_{OC}, n - n_{TC} + E) - (n - n_{TC})]^{+} \times P_{OC}$$

When TC exercises E call options, the magnitude of OC's potential lost revenue is given by:

$$[\min(D_{OC}, n - n_{TC}) - (n - n_{TC} - E)]^{+} \times P_{OC}$$

By subtracting Eq. (1) from Eq. (2), and subtracting Eq. (3) from Eq. (4), the benefit obtained by TC and OC from the option-based mechanism, B_{TC} and B_{OC}, can be calculated. For clarity, "benefit" here refers to the increase in an airline's revenue.

As TC makes different decisions in exercising options depending on the relationship between its expected and actual demands, the possible values of TC's total number of booking requests are divided into four ranges corresponding to four option exercise behaviors. Fig. 5 shows TC's actual demand classification, and Table 3 provides detailed descriptions of the corresponding option exercise behaviors. For modeling purposes, TC's expected demand is assumed to equal n_{TC}, the number of seats assigned to it in the blocked seat allotment.

When TC receives a total number of booking requests that is smaller than the difference between its expected demand and the number of straddles purchased, TC will exercise all the put options to minimize the loss brought by the seat vacancies. The corresponding range is denoted by Put 1. When TC's actual demand is greater than the difference above but smaller than expected, TC will exercise part – $(n_{TC} - D_{TC})$ to be specific – of the put options to maximize revenue. This range is called Put 2. Similarly, on the call side, the two ranges are named Call 1 and Call 2. TC will exercise all or part of the call options to buy more seats to satisfy more booking requests.

The benefit obtained by TC is calculated in different ways when its actual demand, D_{TC}, falls in different ranges, as is shown in (5a) to (5d):

$$B_{TC_{P1}} = -x \times N + k \times N \tag{5a}$$

$$B_{TC_{P2}} = -x \times N + k \times (n_{TC} - D_{TC}) \tag{5b}$$

$$B_{TC_{C2}} = -x \times N + (P_{TC} - k) \times (D_{TC} - n_{TC}) \tag{5c}$$

$$B_{TC_{C1}} = (P_{TC} - x - k) \times N \tag{5d}$$

For example, in the range of Put 2, TC exercises $(n_{TC} - D_{TC})$ put

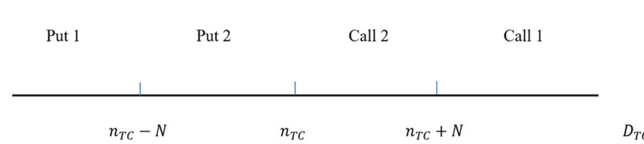

Fig. 5. Demand Ranges Corresponding to Four Option Exercise Behaviors.

Table 3
Descriptions of TC's option exercise behaviors.

Name	Range of demand	TC's corresponding option exercise behavior
Put 1	$0 \le D_{TC} \le n_{TC} - N$	Exercise all the put options, $E = N$
Put 2	$n_{TC} - N < D_{TC} < n_{TC}$	Exercise part of the put options, $0 < E = n_{TC} - D_{TC} < N$
Call 2	$n_{TC} < D_{TC} < n_{TC} + N$	Exercise part of the call options, $0 < E = D_{TC} - n_{TC} < N$
Call 1	$D_{TC} \ge n_{TC} + N$	Exercise all the call options, $E = N$

options and sells $(n_{TC} - D_{TC})$ seats back to OC at the exercise price k. The benefit TC can obtain from exercising options is thus the total exercise price received from OC, subtracting the initial payment of N straddles. Similarly, in the range of Call 2, TC exercises $(D_{TC} - n_{TC})$ call options and buys $(D_{TC} - n_{TC})$ seats at the price of k. Because TC can then sell the seats to its customers, the benefit TC can obtain is the incremental revenue of exercising call options, subtracting the initial payment of N straddles.

With the same rationale, there are different ways to calculate the benefit obtained by OC when TC makes different decisions in exercising options. Eqs. (6a) to (6d) show the calculation:

$$B_{OC_{P1}} = (x - k) \times N + [\min(D_{OC}, n - n_{TC} + N) - (n - n_{TC})]^{+} \times P_{OC} \tag{6a}$$

$$B_{OC_{P2}} = x \times N - k \times (n_{TC} - D_{TC}) + [\min(D_{OC}, n - D_{TC}) - (n - n_{TC})]^{+} \times P_{OC} \tag{6b}$$

$$B_{OC_{C2}} = x \times N + k \times (D_{TC} - n_{TC}) - [\min(D_{OC}, n - n_{TC}) - (n - D_{TC})]^{+} \times P_{OC} \tag{6c}$$

$$B_{OC_{C1}} = (x + k) \times N - [\min(D_{OC}, n - n_{TC}) - (n - n_{TC} - N)]^{+} \times P_{OC} \tag{6d}$$

With revenue management, airlines dynamically adjust their ticket prices throughout the booking process to better match demand with supply. For example, when actual bookings exceed expectations, airlines may increase ticket prices to discourage further bookings [47]. Conversely, ticket prices may be lower when flights are not fully booked. Essentially, airlines adjust ticket prices based on the level of demand and how close they are to their capacity limit.

In the proposed model, P_{TC} and P_{OC} are assumed to be the highest possible prices TC and OC set when their capacity approaches the limit for the following reasons.

When TC exercises put option(s), $B_{TC_{C2}}$ and $B_{TC_{C1}}$ in Eqs. (5a) and (5b) has no relation with P_{TC}. $B_{TC_{C2}}$ and $B_{TC_{C1}}$ only relate to the option price, x, the exercise price, k, and the number of options exercised.

Correspondingly, in Put 1 and Put 2, there are two possibilities for OC.

If OC's demand, D_{OC}, is greater than $n - n_{TC}$, the number of seats assigned to it, OC's demand already reaches its capacity limit, and it needs more seat(s). Under this circumstance, P_{OC} in Eqs. (6a) and (6b) (which calculate the benefit obtained by OC) should both be the highest possible price OC sets when its capacity is already at the limit.

If OC's demand, D_{OC}, is smaller than or equal to $n - n_{TC}$, the number of seats assigned to it, OC does not want more seat(s). In this case, there is no revenue gain related to P_{OC}. Depending on the number of options exercised by TC, E, ranging from 0 to N, OC needs to pay kE to TC as a contractual obligation. In other words, P_{OC} is irrelevant to $B_{OC_{P1}}$ and $B_{OC_{P2}}$ in Eqs. (6a) and (6b).

When TC exercises call option(s), it implies that TC's demand already reaches the limit of n_{TC}, the number of seats assigned to it. In this case, P_{TC} in Eqs. (5c) and (5d) (which calculate the benefit obtained by TC) should both be the highest possible price TC sets when its capacity is already at the limit.

Correspondingly, in Call 1 and Call 2, there are two possibilities for OC.

In the first situation, OC does not need to sacrifice its demand. In this case, there is no revenue loss related to P_{OC}. OC's total revenue will be topped up by the exercise price TC pays. In other words, P_{OC} is irrelevant to $B_{OC_{C2}}$ and $B_{OC_{C1}}$ in Eqs. (6c) and (6d).

In the second situation, OC fulfills the contractual obligation to provide seats to TC at the expense of sacrificing its demand and, therefore, revenue. The number of sacrificed seats could be smaller than or equal to E, the number of options exercised by TC. Given the small scale of E, this scenario should be where OC's demand nearly reaches its capacity limit. As a result, P_{OC} in Eqs. (6c) and (6d) (which calculate the benefit obtained by OC) should fall in a price range OC sets when its capacity is nearly at the limit. When OC sacrifices more than one demand, each sacrificed seat may correspond to a different ticket price because airlines dynamically adjust the price during the booking process and typically raise prices when demand approaches the capacity limit. By modeling P_{OC} as the highest possible price in the high price range, $B_{OC_{C2}}$ and $B_{OC_{C1}}$ in Eqs. (6c) and (6d) capture the smallest possible benefit OC can obtain.

Table 4 summarizes the analysis for P_{TC} and P_{OC} being modeled as the highest possible prices TC and OC set when their demand approaches the capacity limit.

5. Simulation procedures

As the demand of both airlines involves a lot of uncertainties, we design simulation experiments to study the effectiveness of the proposed option-based capacity control mechanism. Detailed procedures are as follows:

(1) Input the values of n, n_{TC}, P_{TC}, P_{OC}, x, and k for a codeshare flight.
(2) Generate the total number of booking requests, i.e., the actual demand, for TC and OC, where $D_{TC} \sim N(n_{TC}, \sigma_{TC}^2)$, $D_{OC} \sim N(n_{OC}, \sigma_{OC}^2)$ and the correlation between D_{TC} and D_{OC} equals ρ.
(3) Calculate the number of seats sold on the flight, S_0, if the option-based capacity control mechanism is not adopted. $S_0 = \min(D_{TC}, n_{TC}) + \min(D_{OC}, n - n_{TC})$.

Table 4
Scenario analysis of ticket prices for airlines' benefit calculation.

	When calculating benefit obtained by TC	When calculating benefit obtained by OC	
When TC exercises put option(s)	P_{TC} is irrelevant.	If $D_{OC} > n - n_{TC}$	P_{OC} should be the highest possible price OC sets when its capacity already reaches the limit.
		If $D_{OC} \le n - n_{TC}$	P_{OC} is irrelevant.
When TC exercises call option(s)	P_{TC} should be the highest possible price TC sets when its capacity already reaches the limit.	If OC does not need to sacrifice its demand	P_{OC} is irrelevant.
		If OC needs to sacrifice its demand	By modeling P_{OC} as the highest possible price OC sets when its capacity approaches the limit, the benefit calculation reflects the smallest possible benefit OC can obtain.

Table 5
Parameter specifications.

Variables	Definitions
n	100
n_{TC}	40
D_{TC}	$N(40, 2^2)$
D_{OC}	$N(60, 3^2)$
P_{TC}	\$130
P_{OC}	\$125
x	\$10
k	\$110

(4) Calculate B_{TC} and B_{OC} according to Eqs. (5a) – (5d) and (6a) – (6d).
(5) Calculate the number of seats sold on the flight, S, after adopting the option-based capacity control mechanism.
(6) For each $N \in [1, 3\sigma_{TC} + 2]$, repeat Steps (2) – (5) for 1000 times which represent 1000 flight departures. As 99.7 % of D_{TC} are within $\pm 3\sigma_{TC}$ of the mean, the upper limit of N aims to include nearly all the deviations of D_{TC}.
(7) For each N, calculate the values of $E[B_{TC}]$, $E[B_{OC}]$ and $E[B_{Alliance}]$ for the 1000 flights, where the expected value of the benefit obtained by the alliance as a whole, $E[B_{Alliance}]$, equals $E[B_{TC}] + E[B_{OC}]$.
(8) Compare the proportions of flights that have full load factor with and without the proposed mechanism adopted.

6. Simulation results

We use the following case to demonstrate scenarios where the proposed capacity control mechanism brings higher revenue for the two airlines and the code-sharing alliance. We also examine how different parameters such as demand correlation, ticket price, demand variability, option price, and exercise price can impact the expected benefit that the airlines can obtain. We conduct the simulation using the parameters outlined in Table 5.

6.1. Impact of demand correlation

6.1.1. Cases when the mechanism brings benefits

In each simulation run, we model 1000 code-sharing flights and vary the correlation coefficient ρ from -1 to 1 in increments of 0.25. It allows us to create nine different scenarios reflecting varying degrees of correlation between the demand of the two airlines, including negative, independent, and positive correlation. Table 6 lists the number of flights corresponding to five possible cases that can occur for different values of ρ.

The first two cases, where both airlines need options, represent win-win situations. In other words, under those circumstances, when TC exercises put (call) options, OC has extra demands (seat vacancies). Therefore, TC can return (buy) at least one seat to (from) OC, and OC will benefit from fulfilling extra demands (selling empty seats) at the same time.

In the third and fourth cases, only TC can benefit from exercising options. When TC exercises put (call) option, OC does not have any extra demand (seat vacancy), so OC simply fulfills contract obligations and bears the costs of holding more empty seats (sacrificing its demands).

In the last case, TC does not need to exercise any options because it has booking requests equal to the number of seats assigned to it.

As shown in Table 6, TC does not need options for about 20 % of the flights. This proportion is not affected by the demand correlation, and the variation in its value is attributable to the randomized simulation process. For the remaining 80 % of the flights, the distribution of flight counts is split between the win-win situations and cases where only TC benefits from exercising options.

When the two airlines' demands are more negatively correlated, i.e., when one airline's demand increases (decreases), the other airline's demand will decrease (increase) on a more similar scale, more win-win situations will occur. When the two airlines have a perfect negative demand correlation, both airlines will benefit from the option-based mechanism if TC exercises options. Likewise, no win-win situation will exist when the two airlines' demands have a perfect positive correlation. Fig. 6 depicts the number of win-win situations out of 1000 flights for different ρ values. It is worth noting that the win-win situations are the sole means of generating mutual benefits to the code-sharing airlines. Therefore, the proposed mechanism is most effective when the airlines' demands are weakly positively correlated, independent, or negatively correlated.

As discussed in Section 1, the proposed option-based capacity control mechanism is better suited for a complementary alliance setting. In contrast to a parallel alliance where both carriers encounter comparable market demands, airlines in a complementary alliance receive booking requests from different customer segments. For instance, in the code sharing arrangement between Japan Airlines and WestJet, the two carriers face demands from the Asian and North American markets, respectively. Since the booking requests originate from diverse geographic locations and during distinct holiday schedules, the demands of the two airlines for the same flight are typically independent or, at most, weakly positively correlated. The simulation analysis of demand correlation supports the notion that the proposed mechanism is more advantageous for the complementary alliance setting where the two airlines do not compete directly.

6.1.2. Expected benefit and optimal number of straddles

The above analysis does not identify the optimal number of options for each win-win situation. For the case where the two airlines' demands are independent of each other, Table 7 looks deeper into the win-win situation count in the shaded cells in Table 6 and summarizes

Table 6
Number of flights requiring options vs. not requiring options by demand correlation (out of 1000 flights).

	Correlation (ρ)								
Number of flights where	**-1**	**-0.75**	**-0.5**	**-0.25**	**0**	**0.25**	**0.5**	**0.75**	**1**
both airlines need put options	392	297	250	207	178	122	83	44	0
both airlines need call options	410	291	253	212	177	150	106	43	0
only TC needs put options	0	93	157	193	243	278	301	346	410
only TC needs call options	0	94	150	195	242	264	308	350	392
TC does not need options	198	225	190	193	160	186	202	217	198

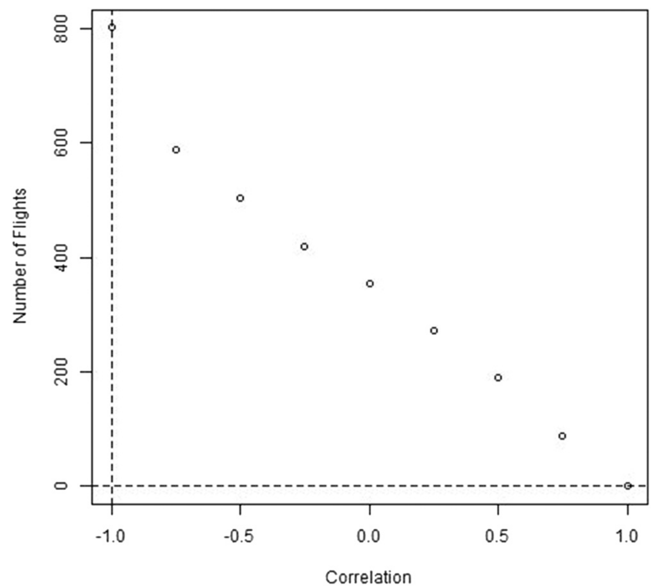

Fig. 6. Number of Flights Where Options Benefit Both Airlines by Demand Correlation (out of 1000 flights).

the optimal number of put/call options needed for the alliance and the corresponding number of flights. In 17.8 % (17.7 %) of the cases, when TC needs to exercise $E(E \in [1, 8])$ put (call) options, OC just gets E additional booking requests (seat vacancies). In other words, 35.5 % of the flights are cases when both airlines' needs are perfectly aligned. Among the 355 flights, both airlines need one to three straddles more than 96 % of the time.

One straddle may not be enough if TC gets more than one excessive passenger or seat vacancy. In contrast, too many straddles may be redundant since TC pays the option costs but has no need to exercise all the put/call options. Thus, there is a trade-off in determining the optimal number of straddles. Fig. 7, Fig. 8, and Fig. 9 depict the expected benefits TC, OC, and the alliance can obtain when TC purchases one to eight straddles. The three charts show the results when the two airlines' demands are negatively correlated, independent, and positively correlated, respectively.

Consistent with the result shown in Fig. 6, the code-sharing alliance obtains greater expected benefit when the demand correlation is more negative. Notably, the expected benefit for TC does not vary with different correlations because TC is the one who determines whether to exercise an option and how many options it desires. For the same randomly generated 1000 flights, demand correlation will not affect the option exercise behavior of TC. In contrast, demand correlation directly affects OC's profitability. When the correlation is more positive, the synchronized demands mean that there are fewer extra demands (seat vacancies) available for OC when TC exercises put (call) options.

Table 7
Optimal number of put/call options needed and corresponding flight counts when demand correlation = 0 (out of 1000 flights).

Optimal number of put options needed	Number of flights	Optimal number of call options needed	Number of flights
1	112	1	100
2	49	2	50
3	11	3	20
4	4	4	6
5	1	5	0
6	1	6	1
7	0	7	0
8	0	8	0
Total Flight Counts	178		177

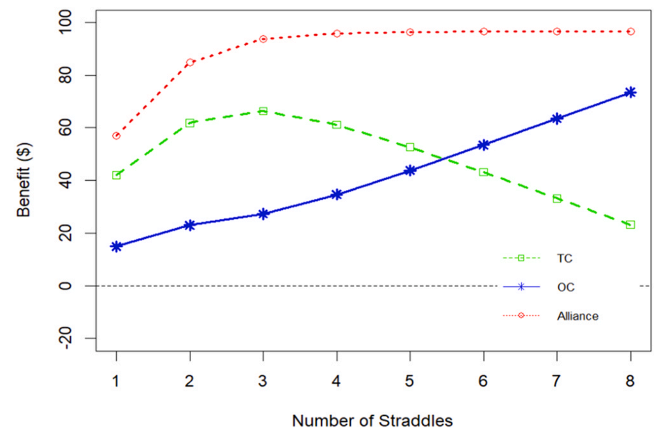

Fig. 7. Expected Benefit ($\rho = -0.25$).

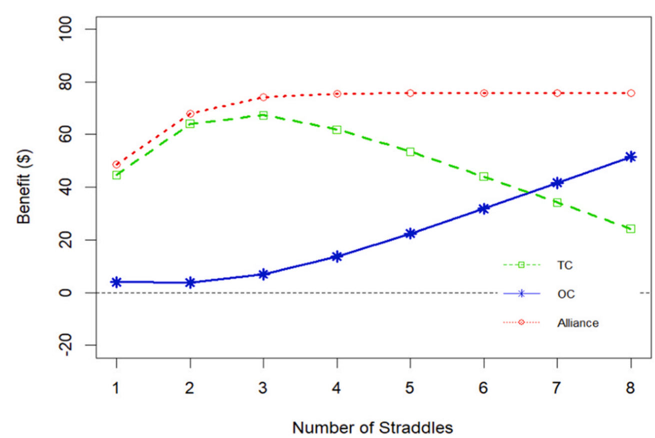

Fig. 8. Expected Benefit ($\rho = 0$).

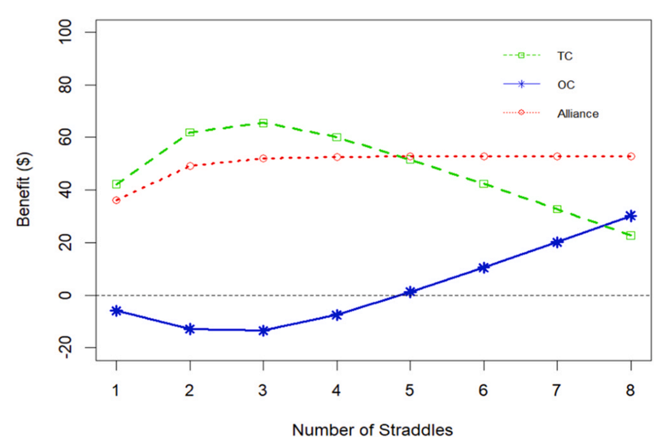

Fig. 9. Expected Benefit ($\rho = 0.25$).

Therefore, a more positive demand correlation reduces the expected benefit OC can obtain, dragging down the expected benefit for the alliance.

As for the optimal number of straddles, it depends on the individual case. For example, in this case illustration, the alliance's expected benefit is highest when three to eight straddles are purchased. However, within this range, the more straddles TC purchases, the higher (lower) the expected benefit TC (OC) can obtain. Ultimately, the two carriers' bargaining power

Table 8
Proportions of flights having 100 % load factor corresponding to different number of straddles (demand correlation = 0).

N	Percentage of Flights with 100 % Load Factor
0	33.6 %
1	46.6 %
2	52.5 %
3	55.1 %
4	55.6 %
5	55.8 %
6	55.8 %
7	55.8 %
8	55.8 %

Table 9
Three scenarios of airlines' demand variability.

Scenario	Coefficient of Variation	σ_{TC}	σ_{OC}	Relevant Range for N
1	0.05	2	3	1 ~ 8
2	0.10	4	6	1 ~ 14
3	0.20	8	12	1 ~ 26

and possibly other terms in the code-sharing agreement will affect the choice of the optimal number of straddles.

Another analysis reflecting the effectiveness of the proposed mechanism is summarized in Table 8. Using the case when the two airlines' demands are independent of each other, Table 8 shows the proportion of flights having a full load factor corresponding to different numbers of straddles purchased by TC. With the blocked seat allotment method, only 33.6 % of the flights can fully utilize the capacity. By using the proposed mechanism, the proportion of 100 % seat utilization can be increased by more than 20 %. In this case illustration, given TC's demand pattern, TC needs to exercise one to three put/call options most of the time. Therefore, cases when TC purchases one to three straddles can significantly increase the load factor, consistent with the results in Fig. 7, Fig. 8, and Fig. 9 that most of the incremental benefit occurs when TC purchases one to three straddles.

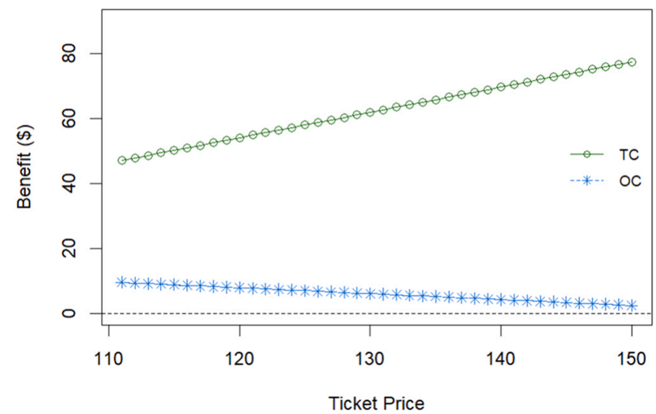

Fig. 11. Impact of Ticket Prices on Airlines' Expected Benefit ($\rho = 0$, $N = 4$, $\sigma_{TC} = 2$, and $\sigma_{OC} = 3$).

6.2. Impact of demand variability

We simulate three scenarios to examine the impact of the two airlines' demand variabilities, as shown in Table 9. Notably, the relevant range of the number of straddles, N, is $[1, 3\sigma_{TC} + 2]$, and in all three scenarios, the airlines' demand correlation equals 0.

Fig. 10 shows the impacts of the demand standard deviations on the airlines' expected benefits. When the standard deviations are larger, a higher level of benefit can be expected for TC, OC, and the alliance. As more win-win situations will exist, the option-based mechanism can play a more significant role in improving the blocked seat allotment. Furthermore, when the demand variabilities increase, TC's expected benefit increases faster than OC's expected benefit. As TC is the one who decides to exercise options, the option-based mechanism always provides a greater advantage to TC.

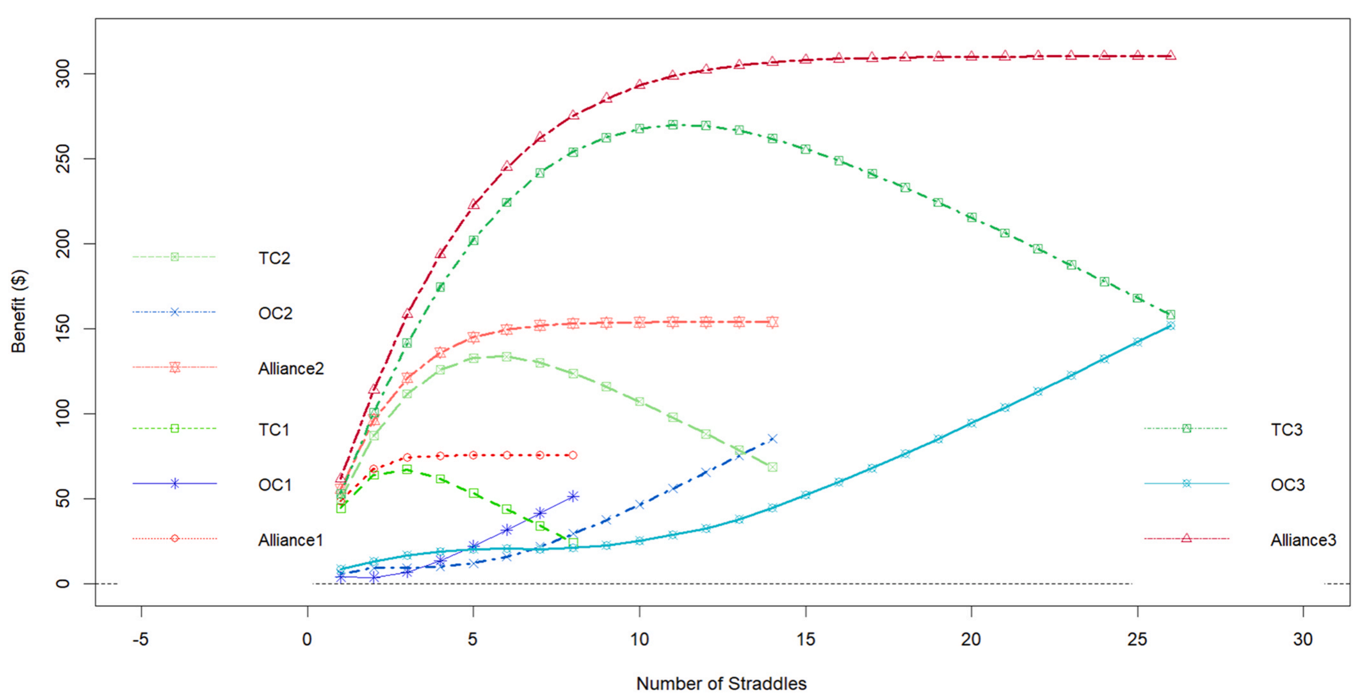

Fig. 10. Impact of σ_{TC} and σ_{OC} on Airlines' Expected Benefit ($\rho = 0$).

Table 10
Possible combinations of x and k values.

Combination	x	k	$x + k$
1	22	95	117
2	17	100	117
3	13	105	118
4	10	110	120
5	8	115	123
6	7	120	127
7	6.25	125	131.25

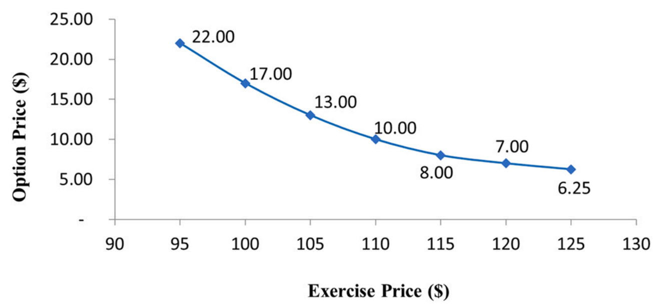

Fig. 12. Option Price x vs. Exercise Price k.

6.3. Impact of ticket prices

To examine the impact of TC and OC's ticket prices on the airlines' expected benefits, we vary P_{TC} and P_{OC} from $111 to $150 in increments of $1, respectively, in each simulation run of 1000 flights with $\rho = 0$, $N = 4$, $\sigma_{TC} = 2$, and $\sigma_{OC} = 3$.

Fig. 11 depicts the expected benefit TC and OC obtain, respectively. The lower bound of $111 is chosen because the option exercise price is modeled as $110. The exercise price is an internal transfer price, so it should usually be lower than the ticket price.

As analyzed in Table 4, P_{TC} is relevant to TC's expected benefit only when TC exercises call options. By exercising call options and obtaining more seats from OC, TC can realize additional revenue at the unit price of P_{TC}. Therefore, the higher the P_{TC}, the greater the expected benefit TC can obtain.

In contrast, P_{OC} affects OC's expected benefit in two ways. In Scenario 1, when TC exercises put options and OC has excess booking requests, OC can realize additional revenue at the unit price of P_{OC}. In such cases, P_{OC} is directly proportional to OC's expected benefit. However, in Scenario 2, when TC exercises call options and OC needs to sacrifice its demand, OC will incur costs at the unit price of P_{OC}. In those cases, P_{OC} is negatively correlated to OC's expected benefit. As we analyze the case when demand correlation equals 0, there are more Scenario 2 cases than Scenario 1 cases (i.e., the "both airlines need put options" and "only TC needs call options" cases when $\rho = 0$ in Table 6). Therefore, aggregately, the higher the P_{OC}, the smaller the expected benefit OC can obtain. Due to the two competing forces, the magnitude of the negative slope of OC's benefit line is smaller than the magnitude of the positive slope of TC's benefit line.

As both airlines offer tickets for the same flight, their ticket prices for the same fare class should not differ much. Nevertheless, the analysis above provides a perspective on how varying ticket prices can impact the benefits the code-sharing airlines can obtain from the proposed mechanism.

6.4. Impact of option price and exercise price

The option-related parameters are inter-transactions between the two airlines. Therefore, it is intuitive that the alliance's expected benefit will not be influenced by x and k. To simulate the impact of x and k on airlines' expected benefit, we borrow the x and k parameter settings from [48] and extract seven combination pairs, as shown in Table 10 and Fig. 12. As the highest ticket price in this case study is $130, the last x and k combination is chosen so that the sum of x and k is greater than $130. We demonstrate the results in Fig. 13, using the case when $\rho = 0$ and $N = 4$.

The option price, x, is always an expense for TC and revenue for OC. Therefore, TC always prefers a smaller x, whereas OC prefers a larger x.

The impact of the exercise price, k, depends on the option exercise decisions. When TC exercises put options, TC receives payment from OC at the unit price of k. In such cases, k is directly proportional to TC's expected benefit. When TC exercises call options to acquire more seats from OC, TC needs to pay OC at the unit price of k. In those cases, k is negatively correlated to TC's expected benefit.

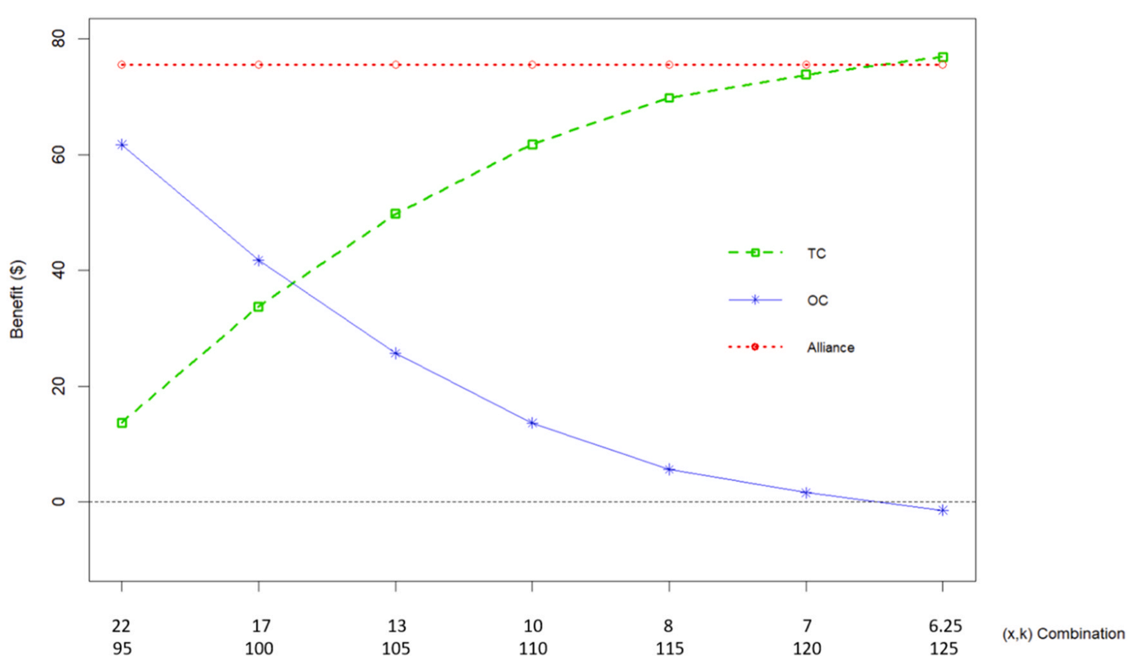

Fig. 13. Impact of x and k on Airlines' Expected Benefit ($\rho = 0$, $N = 4$).

As we analyze the case when demand correlation equals 0, there are more cases where TC exercises put options than TC exercises call options (421 vs. 419 flights in Table 6). Therefore, the overall effect is that TC prefers a smaller x and a larger k. As shown in Fig. 13, TC's expected benefit increases when x decreases and k increases.

With the same rationale, k also impacts OC's expected benefit in two ways. When TC exercises put options, OC needs to pay TC at the unit price of k. In such cases, k is negatively correlated with OC's expected benefit. When TC exercises call options, OC receives payment from TC at the unit price of k. In those cases, k is directly proportional to OC's expected benefit. In this case illustration, because there are more cases where TC exercises put options than cases where TC exercises call options, OC's expected benefit decreases when x decreases and k increases.

7. Conclusion

For the case of two airlines forming a code-sharing alliance with a single flight leg, we propose an option-based capacity control mechanism to improve the blocked seat allotment method. The option here refers to the concept of a straddle, an advanced option strategy in finance. When the actual demands of TC and OC differ from what is expected, the reallocation of seats between the two carriers can be realized through exercising put or call options. The newly designed mechanism combines the options strategies with the traditional blocked seat allotment approach to tackle both downward and upward demand variations of TC. The use of options adds flexibility to the capacity control process for the code-sharing airlines and thus can help increase the revenue of the alliance.

We formulate an analytical model to calculate the benefit obtained by the code-sharing airlines. We also design simulation procedures that help explore the effectiveness of the proposed mechanism when TC purchases different numbers of straddles. The simulation results demonstrate scenarios where the option-based mechanism benefits the airlines. We also analyze the impacts of various parameters, including demand correlation, demand variability, ticket prices, option price, and exercise price, on the expected benefit the airlines can obtain. Notably, the proposed mechanism is better suited for a complementary alliance setting. Code-sharing airlines can benefit more when their demands are weakly positively correlated, independent, or negatively correlated. Moreover, the proposed mechanism is more effective when demand variabilities are large. With more demand uncertainties, the option-based procedure can better adjust the misalignment between the pre-determined seat allocations.

One case illustrates that when airlines' demands are independent of each other, the option-based mechanism can increase the proportion of code-sharing flights having a full load factor by more than 20 %. Even though the mechanism creates a win-win situation for both airlines in some but not all situations, it is a risk-hedging mechanism that improves the pre-determined blocked seat allotment approach.

As this study only discussed a random sample of 1000 flights with specific parameter settings, the extent to which the ticket prices, option price, and exercise price impact the airlines' expected benefit may vary for other samples. It would be valuable for future research to explore the dynamics involved in the proposed mechanism and identify the optimal number of straddles under different scenarios. Furthermore, this work only considers the single-fare class problem. Future research can be conducted to examine seat allocation issues in code-sharing alliances with multiple fare classes.

Data availability

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

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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