

Market Structure and Quality Determination for Complementary Products: Alliances and Service Quality in the Airline Industry*

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Abstract

This paper explores the effect of market structure on quality determination for complementary products. The focus is on the airline industry and the effect of airline alliances on flight frequency, an important element of service quality. With zero layover cost, the choice of flight frequencies has the same double-marginalization structure as in the usual alliance model, leading to a higher frequency in the alliance case as double marginalization is eliminated, along with a lower full trip price and higher traffic. The surprising result of the paper emerges with high-cost layover time, where double marginalization in frequencies is absent and where an alliance reduces service quality via a lower frequency, with the full price potentially rising (in which case traffic falls).

Keywords: service quality; alliance; double marginalization; congestion

JEL Classification Numbers: D43; L13; L40; L93; R4

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1 Introduction

Analysis of the choice of product quality has a long history in industrial organization. In early work, Spence (1975) and Sheshinski (1976) showed that the product quality chosen by a monopolist can be higher or lower than the socially optimal quality, with the outcome depending on the shape of the demand curve. Swan (1970) and Levhari and Peles (1973) demonstrated, however, that if quality takes the form of product durability, then a monopolist and a competitive firm choose the same quality level, with the monopoly choice thus being socially optimal even though quantity is too low. Much subsequent research was devoted to exploring the robustness of this finding, with Schmalensee (1979) providing a survey.

Despite this attention to product-quality issues, the literature has mostly overlooked a highly relevant question: how does market structure affect quality determination for complementary products? For such products, consumption of one of the goods enhances the benefits from consumption of the other. As is well known, pricing of complementary goods by separate producers is inefficient due to (horizontal) double marginalization, with prices lower when both goods are produced by a single firm. When the qualities of the two complementary goods must also be chosen, production by separate firms widens the scope for double marginalization, which now affects quality as well as price. The intriguing question is then whether a change in market structure from separate to single-firm production has beneficial effects on prices and qualities. In other words, does a single producer offer both lower prices and higher qualities than separate firms in providing the complementary goods? Economides (1999) offers the only study of this question and reaches an affirmative answer, although his price conclusion depends on functional forms.

Given the importance of the link between market structure and complementary-product quality and its slender treatment in the previous literature, further research is clearly needed. Accordingly, the present paper offers a new analysis, one that is grounded in a particular industry where a noteworthy type of product complementarity exists that guides the formulation of the model. The industry is airlines, and the complementarity arises in trips that require the use of two different carriers. In particular, suppose that travel from city X to city Y cannot be carried out using a single airline. Instead, the passenger must first fly on airline 1, which provides service from city X to an intermediate airport H, then switching to airline 2, which provides service from H to Y. The two complementary products are then travel from X to H and travel from H to Y, and they represent perfect

complements that must both be consumed in making a two-airline XY trip.

Historically, such two-airline trips were provided by individual carriers operating at arm's length with minimal coordination. In the early 1990s, however, a market structure revolution occurred: international airline alliances came into being, with the goal of making two-carrier trips more like travel on a single airline. With a grant of antitrust immunity, alliances gained the ability to coordinate in setting fares and flight frequencies for such two-airline trips as if they were a single firm (before, airlines would set a separate *subfares* for their own portions of the trip and could not coordinate on schedules). The result was the elimination of double marginalization in fare setting, which characterized the pre-alliance world, leading to lower fares for XY-type trips.¹

The purpose of the paper is to analyze the effect of this market-structure change on the choice of airline *service quality*, as captured by the *flight frequencies* offered by the collaborating carriers. Although service quality includes many different dimensions on the ground (bag handling, gate location) and in the air (in-flight services, legroom, seat characteristics), higher flight frequency is an important quality attribute since it reduces schedule delay, defined as the gap between a passenger's preferred and actual arrival times.² With more frequent flights, a passenger can arrive closer to his or her preferred time.³ The

¹Chen and Gayle (2007) develop an alternate result by showing that codesharing may not eliminate double marginalization in markets where a codeshare partner also offers a competing direct service. The reason is that this airline has an incentive to soften competition for its own service by not eliminating the margin on its segment of the codeshare product. Gayle (2013) confirms empirically this theoretical prediction.

²Gayle and Thomas (2015) and Chen and Gayle (2019) explore empirically the effects of alliances and mergers on a different measure of service quality based on routing distance. A circuitous connecting trip through an inconveniently located hub yields a high routing distance and thus low service quality according to their measure.

³Given its importance, the recent literature has added a frequency dimension to theoretical models in studying issues such as airline network structure, schedule competition between carriers, intermodal competition, the emergence of regional jets, and the effects of mergers. Using a monopoly model, Brueckner (2004) studies the effect of network structure (hub and spoke vs. fully connected) on flight frequency. Brueckner and Flores-Fillol (2007) and Brueckner (2010) include scheduling decisions in models of airline competition. de Palma, Criado and Randrianarisoa (2018) model frequency competition between carriers serving nearby airports using a Hotelling model. An empirical study by Pai (2010) shows effect of route distance on flight frequency. Bilotkach, Fageda and Flores-Fillol (2010) analyze how intermodal competition (cars vs. air services) affects the relationship between route distance and flight frequency. Brueckner and Pai (2009) and Fageda and Flores-Fillol (2012a and 2012b) study the possible emergence of new point-to-point routes served by regional jets (offering higher frequencies) or by low-cost carriers (offering lower

question addressed by the paper is thus: what happens to the two carriers' flight frequencies on the XH and HY routes, and to the XY fare they charge, when the airlines become alliance partners? Does the XY fare beneficially fall and do flight frequencies beneficially rise? Or are other outcomes possible? As will be seen, the answer depends on aspects of passenger preferences.

The paper therefore provides what is, in effect, a theoretical case study of the impact of market structure on product quality, focusing on a particular industry where a specific type of product complementarity exists. The results are more broadly useful, however, given the sparsity of research on this question. The paper simultaneously advances the theoretical literature on airline alliances (partly built on Brueckner, 2001) and an associated empirical literature, both have which have solely focused on price effects (with the empirical literature confirming the predicted XY fare reduction).⁴

To capture service quality, the passenger demand function in the model incorporates aversion to both schedule delay, as discussed above, and connecting layover time.⁵ This disutility depends on the flight frequencies of the two carriers. When the frequencies are equal ex ante, as in the case of an alliance (which sets common values), layover time is zero and schedule delay is proportional to the reciprocal of the common frequency, as in the previous models that ignore flight connections. But when the carriers are nonaligned and choose their frequencies independently, the values differ ex ante, so that airline 1's arrivals at H are potentially mismatched with airline 2's departures, requiring a layover.

frequencies). Richard (2003) studies the effect of mergers on flight frequency, and Bilotkach, Fageda and Flores-Fillol (2013) examine the effects of the merger between Delta and Northwest on flight frequencies at the hubs dominated by the two airlines before the merger. Brueckner and Luo (2014) estimate reaction functions for carriers engaged in frequency competition. Borenstein and Netz (1999) study departure-time competition without focusing on flight frequency.

⁴The theoretical literature includes papers by Oum, Park and Zhang (1996), Park (1997), Park and Zhang (1998), Brueckner and Whalen (2000), Brueckner (2001), Park, Zhang and Zhang (2001), Hassin and Shy (2004), Bilotkach (2005), Heimer and Shy (2006), Zhang and Zhang (2006), Flores-Fillol and Moner-Colonques (2007), Brueckner and Proost (2010), and Fageda, Flores-Fillol and Theilen (2019). The empirical literature includes papers by Brueckner and Whalen (2000), Brueckner (2003), Whalen (2007), Wan, Zou and Dresner (2009), Brueckner, Lee and Singer (2011), Gillespie and Richard (2012), Gayle and Brown (2014), and Calzaretta, Eilat and Israel (2017). While these papers study international alliances, Bamberger, Carlton and Neumann (2004), Ito and Lee (2007), and Armantier and Richard (2008) study domestic alliances. Other papers based on different conceptual frameworks include Park and Zhang (1998 and 2000).

⁵See Luttmann (2017) for an estimation of the value of layover time in the US airline industry.

The challenge, then, is to derive an expression for passenger disutility from schedule delay and layover time in the no-alliance case, where frequencies differ *ex ante*. This derivation is a major contribution of the paper.

In order to show how the particular form of complementarity affects the analytical conclusions, we carry out the required derivation under two different polar-case assumptions that turn out to affect complementarity: a zero cost for layover time and a layover cost high enough so that passengers completely avoid layovers. The first case could apply to leisure passengers and second to business passengers. In both cases, the *ex-post* layover cost is zero, either by assumption (first case) or by choice (second case), so that passenger disutility (denoted g) consists entirely of schedule-delay cost. With zero-cost layover time, we show that g is proportional to the sum of the reciprocals of the individual carrier flight frequencies, so that the qualities of both products matter to consumers in a standard way. This disutility expression is added to the sum of the subfares charged by the carriers for their portions of the XY trip, leading to the full trip price. With this additive structure for both subfares and frequencies, we might expect that the standard double marginalization result on fares could also extend to frequencies, with frequency rising and the overall fare falling in moving from the no-alliance to the alliance case.⁶

Alternatively, with high-cost layover time, passengers choose flights whose arrival and departure times at the hub coincide so as to avoid any layover. In this case, we show that g is proportional to the reciprocal of the *minimum* of the two airline frequencies, so that only the one of the two product qualities matters despite complementarity. With the additive structure eliminated, we would no longer expect double marginalization in the choices of frequencies by nonaligned carriers. Exploration of this alternate case thus provides another perspective on product-quality determination for complementary goods, with consumers just caring about the quality of one good. This is the good with the lower quality, namely, the service offered by the airline with the lower of the two flight frequencies.

The results of the paper can be summarized as follows. With zero-cost layover time, an alliance raises flight frequency relative to the no-alliance case, in line with the predicted double marginalization story. Interestingly, however, the same conclusion need not apply

⁶It should be noted that an incomplete line of reasoning on the frequency impact of alliances would argue that a fare reduction from elimination of double marginalization would spur higher traffic and thus a need for more capacity in the form of higher frequencies. This argument ignores the effect of frequency on product quality and thus on demand. A fuller analysis that takes the demand effect into account is thus required.

to fares, with the overall fare being either higher or lower than in the non-alliance case. However, an alliance does beneficially reduce the full trip price (fare plus schedule-delay cost), thus yielding the same increase in traffic as in the standard model.

With high-cost layover time, an alliance reduces the overall fare, as in the standard model. But since the high-cost case does not exhibit the double-marginalization structure of the low-cost case with respect to frequencies, the opposite frequency impact occurs, with an alliance leading to a reduction in flight frequency. Because of lower frequency, the full trip price can either rise or fall, so that an alliance could lead to a reduction in traffic, in a surprising reversal of the standard result. The upshot is that, when a service-quality dimension involving flight frequencies is added to an alliance model, the conclusions it generates may be unfamiliar. More generally, these results show that, when the quality of only one of two complementary goods matters to consumers, single-firm production may lead to unexpected effects.

Our findings can be applied to analyze the effect of airline alliances on service-quality heterogeneity across business and leisure markets. The different values of time for these two passenger types affects their attitudes toward layover time and schedule delay. This difference generates a service-quality gap between business and leisure markets in the no-alliance case, with frequencies being higher in business markets. After an alliance is formed, the flight-frequency difference between the two types of markets narrows but does not disappear.

Finally, we add hub-airport congestion to the model. The literature on airport congestion shows that airlines internalize the congestion they impose on themselves, neglecting the congestion they impose on other airlines. Therefore, given that allied carriers will take into account the congestion imposed on their partners, alliances are expected to increase the extent of internalization. Since this internalization effect puts downward pressure on frequencies in the alliance case, it is conceivable that the positive alliance frequency effect in the absence of congestion (with zero-cost layovers) could be reversed when congestion is present. The results of the analysis show, however, that this conjecture is not upheld, with an alliance still leading to higher frequency and service quality when layover cost is zero.

The present paper complements the closely related work of Czerny, van den Berg and Verhoef (2016), which explores the effects of carrier cooperation on service frequency in a general model that can be interpreted as applying to airlines. In addition to being simpler,

our model differs by providing microfoundations that translate individual flight frequencies into overall service quality (as described above) rather than relying on an abstract general relationship.⁷

In order to orient the reader to the question being studied, section 2 of the paper provides an analysis of the effect of market structure on product quality for complementary goods that is more general than the subsequent airline analysis as well as more general than that of Economides (1999). The results show that the impact is ambiguous and depends on the form of preferences, in particular the sign of a demand cross-derivative. The analysis then proceeds to the airline model, showing again that the market structure impact is sensitive to assumptions on preferences, this time on the passenger's attitudes toward schedule delay and layover time. The analysis therefore does not resolve the general ambiguity of the market-structure effect, but it provides specific results for a particular and important industry context. Section 3 presents the setup for the airline model and derives the service-quality expression in the cases of zero-cost and high-cost layover time. Section 4 derives the conditions for profit-maximization in the no-alliance and alliance cases and provides a general analysis of alliance effects. Section 5 derives results under the assumption that demand is linear. Section 6 considers the effects of congestion, and section 7 offers conclusions.

2 A general model

Consider a model where consumers purchase two goods, z_1 and z_2 , that must be used in fixed proportions, here assumed to be 1:1. The goods can be sold either by two separate firms or a single firm. Each good is produced with a particular quality denoted by q_i , with $i = 1, 2$. Effective consumption is equal to $q_1 z_1 + q_2 z_2 = (q_1 + q_2)z$, where z is the common quantity purchased. Letting y denote income and p_1 and p_2 the prices charged by the two firms, consumer utility is $U(x, (q_1 + q_2)z) = U(y - (p_1 + p_2)z, (q_1 + q_2)z)$, where x is a third good. Maximizing utility yields a demand function for z given by $D(p_1 + p_2, q_1 + q_2)$, with D_p (the derivative with respect to the first argument) negative and D_q ambiguous in sign but assumed positive. Production cost for z_i is given by $c(q_i)z_i$, where $c', c'' > 0$, so that higher quality is more costly.

⁷In a related study that does not focus on flight frequencies, Bilotkach (2007) shows how allied carriers alter their schedules to reduce connecting times while also lowering the interline fare.

Consider first the profits of separate firms producing z_1 and z_2 . Normalizing the number of consumers at 1, the profit of firm i is equal to $(p_i - c(q_i))D(p_1 + p_2, q_1 + q_2)$, and its first-order conditions for choice of p_i and q_i are

$$D + (p_i - c(q_i))D_p = 0, \quad (1)$$

$$-c'(q_i)D + (p_i - c(q_i))D_q = 0. \quad (2)$$

Given symmetry, both firms choose the same prices and qualities, so that the equilibrium is given by (1)–(2) with the i subscripts removed and the arguments of D and its derivatives replaced by $2p$ and $2q$, where p and q are the common equilibrium values.

When a single firm produces both goods, it chooses common prices and qualities, earning a profit of $2(p - c(q))D(2p, 2q)$. The first-order conditions for p and q are

$$D + \alpha(p - c(q))D_p = 0, \quad (3)$$

$$-c'(q)D + \alpha(p - c(q))D_q = 0, \quad (4)$$

where $\alpha = 2$. Since the separate-firm equilibrium conditions are found by setting $\alpha = 1$ in (3)–(4), the difference between the separate-firm and single-firm outcomes can be derived by computing the comparative-static derivatives of p and q with respect to α .

First consider the effect of a change in α on p or q with the other variable held fixed. Denoting single-firm profit by π , the expression in (3) equals π_p . Differentiating (3), the derivative of p with respect to α holding q fixed is then

$$\frac{\partial p}{\partial \alpha} = - \frac{(p - c(q))D_p}{\pi_{pp}} < 0, \quad (5)$$

using the second-order condition $\pi_{pp} < 0$. Therefore, separate firms, which correspond to the lower α value of 1, set higher prices for z_1 and z_2 than a single firm. This result reflects the effect of double marginalization in prices.

Similarly, holding p fixed,

$$\frac{\partial q}{\partial \alpha} = - \frac{(p - c(q))D_q}{\pi_{qq}} > 0. \quad (6)$$

Therefore, separate firms set a lower value of q than a single firm, reflecting the effect of double marginalization in qualities. From these findings, we derive the next observation.

Claim 1 Relative to production of the two complementary goods by separate firms, single-firm production raises quality if price is fixed and lowers price if quality is fixed. Therefore, the usual double marginalization results emerge when one choice variable is held fixed.

When both p and q are chosen, their comparative-static derivatives are the solution to

$$\begin{pmatrix} \pi_{pp} & \pi_{pq} \\ \pi_{pq} & \pi_{qq} \end{pmatrix} \begin{pmatrix} \partial p / \partial \alpha \\ \partial q / \partial \alpha \end{pmatrix} = \begin{pmatrix} (p - c(q))D_p \\ (p - c(q))D_q \end{pmatrix}, \quad (7)$$

where the derivatives then depend on the sign of

$$\pi_{pq} = D_q - \alpha c'(q)D_p + 2\alpha(p - c(q))D_{pq}. \quad (8)$$

While the first two terms of π_{pq} are positive, the term D_{pq} , which gives the effect of q on the slope of the demand curve, is ambiguous in sign. Therefore, the sign of the comparative-static derivatives in (7) is ambiguous as well. This result is summarized below.

Claim 2 Relative to production of the two complementary goods by separate firms, single-firm production has ambiguous effects on price and quality when both variables are jointly determined.

Therefore, in a fairly general model, double marginalization due to the uncoordinated price and quality choices of separate firms yields intuitive effects when either price or quality is held fixed.⁸ But when both variables are chosen together, the difference between the price and quality choices of separate firms and those of a single firm cannot be determined unambiguously. Hence, as in some previous investigations of the effect of market structure on product-quality choices, this model leads to an inconclusive result.

It is worthwhile to ask whether this general ambiguity can be resolved in a model of particular industry where much more structure can be imposed on the product-complementarity relationship. Economides (1999) generated unambiguous conclusions on both price and quality via functional-form assumptions on costs, and the subsequent analysis will show that, in the airline case, the details of the model specification continue to matter in determining the effect of market structure on price and the quality of complementary products. While the analysis thus does not yield new general insights, it provides useful theoretical results for an important industry where a crucial type of complementarity exists.

3 The setup and the form of the g function

The analysis focuses on the simple network shown in Figure 1. Airline 1 operates route segment XH, and airline 2 operates route segment YH, but travel demand only exists in

⁸In Economides (1999), separate-firm production is also shown to yield a lower price holding quality fixed.

market XY, where passengers rely on interline service by airlines 1 and 2.

Passenger demand, which is for round trips, depends on the full price of the service, which in turn depends on the overall XY fare and a measure of service quality:

$$Q = D(\text{fare} + g[f_1, f_2]), \tag{9}$$

where Q is passenger traffic (common to both carriers), f_1 and f_2 are flight frequencies, and $D' < 0$. The function $g[\cdot]$ captures passenger disutility from schedule delay and layover time. The following subsections derive the precise functional form for $g[\cdot]$ under different alternate assumptions.

As in Brueckner (2004) and Brueckner and Flores-Fillol (2007), we avoid the complexities of spatial models by using a framework where consumers ultimately care about overall flight frequencies rather than the departure times of individual flights. This approach relies on the assumption that a passenger’s preferred arrival time is unknown prior to the purchase of the airline ticket and is thus viewed as random, being uniformly distributed around the clock. Under this assumption, schedule delay (the difference between a passenger’s preferred and actual arrival times) depends on flight arrival times but is otherwise random, although its expected value (which matters to the consumer) can be derived conditional on flight times. Note that, by assuming a uniform distribution of preferred arrival times, the model suppresses passengers’ actual preferences for peak-hour travel.

In addition to preferring less (expected) schedule delay, passengers also dislike layover time. Depending on the cost of layover time relative to the cost of schedule delay, different scenarios arise, which yield different functional forms for the function $g[\cdot]$. Two polar cases are considered, with the cost of layover time either equal to zero or equal to a large enough value that minimization of layover time is the passenger’s main goal, with schedule delay being a secondary consideration.

3.1 The form of g with zero-cost layover time

Consider outbound flights from X to H (airline 1) and from H to Y (airline 2). We assume that the carriers evenly space their flights around the clock, represented by time circle. This pattern is shown in Figure 2, which illustrates a case where $f_1 > f_2$.

Suppose that layover cost is zero, so that the passenger considers only schedule delay in choosing flights, a case that could apply to leisure passengers, who have a low value of time. Focusing on outbound flights originating at X, the expected arrival schedule delay

depends only on airline 2's flight frequency, regardless of the relative values of f_1 and f_2 , as will be demonstrated by considering Figure 3. In the figure, the arrows show the arrival times of airline 1's flights at the hub H as well as the departure times of airline 2's flights. With air travel assumed to be instantaneous without loss of generality, airline 2's flight departure time from H and arrival time at Y are the same. The figure also shows the passenger's preferred arrival time.

Suppose that $f_1 \geq f_2$, as shown in panel I of Figure 3. The passenger prefers flight B of airline 2, which arrives closest to her preferred time, but the passenger is indifferent between flights A and B of airline 1 since they both allow a connection with flight B of airline 2. The longer layover generated by flight A is immaterial since layover cost is zero. The upshot is that additional flights of airline 1 generate no benefit for the consumer, with expected schedule delay depending only on the gap between airline 2's flights, which equals T/f_2 . Expected schedule delay is 1/4 of this gap, or $T/4f_2$.

When $f_1 < f_2$ (panel II), the passenger takes flight A of airline 1 and waits costlessly at the hub airport to take flight B of airline 2, which minimizes her schedule delay. Again, expected schedule delay depends only on f_2 , and the cost of this delay is given by $\delta T/4f_2$, where $\delta > 0$ is the schedule-delay cost parameter. Using $\gamma \equiv \delta T/4$, the previous expression can be rewritten as γ/f_2 .

In the inbound direction (the return trip from Y to X), the roles of the airlines are switched, so that expected inbound schedule delay is γ/f_1 . Average schedule-delay cost in both directions, which gives travel disutility g given the absence of layover costs, is then

$$g[f_1, f_2] = \frac{1}{2} \left[\frac{\gamma}{f_1} + \frac{\gamma}{f_2} \right]. \quad (10)$$

3.2 The form of g with high-cost layover time

When layover time is costly (as for business travelers), the passenger's main goal is to minimize it, with schedule delay being a secondary consideration. In order to analyze this case without severe complications, additional assumptions about the spacing of flights are needed. In particular, we assume that when the carriers operate the same numbers flights, with $f_1 = f_2$, the flights operate at the same time. When $f_1 > f_2$, the extra flights of airline 1 evenly fill the gaps between airline 2's flights, as shown in Figures 2 and 3. Airline 1's flights are thus given by the rule $f_1 = 2^k f_2$, where $k = 0, 1, 2, \dots$, so that airline 1's flight density increases with k . Note that under this rule, f_1 doubles with each successive

increase in k , with the extra flights filling in the gaps between airline 1's existing flights. The opposite pattern occurs when $f_1 < f_2$ with $f_2 = 2^k f_1$. Similar reasoning applies to inbound flights, whose volume exactly matches that of outbound flights for each airline.

It is important to note that, as long as flights on the XH and YH routes are evenly spaced, the additional flight-spacing assumptions above are not needed in analyzing the zero-cost layover case (even though they were adopted in drawing Figure 3). The reason is that, since the frequency on the second leg of an XY trip (either outbound or inbound) is all that matters, no connection between the flight patterns on the XH and YH routes need be assumed. But in order to compare the outcomes in the two layover-cost cases, the analysis of the cases needs to be carried out under the same set of assumptions, with the flight-spacing assumptions then imposed generally.

Starting with the case where $f_1 \geq f_2$, it is easy to see that a passenger will always choose flights whose arrival and departure times coincide so as to avoid any layover, as shown in Figure 4. Consider panel I and assume again that the passenger's preferred arrival time lies between flights A and C of airline 2. Then, depending on the exact location of the preferred time, the passenger will choose either flight A or C of airline 1 along with the corresponding flight of airline 2 (the C flights will be chosen in the case shown in the figure), incurring a zero layover. In this case, flight B of airline 1 is irrelevant, as in Figure 3-I, and the expected schedule delay is again γ/f_2 .

Consider now the case where $f_1 < f_2$, as in panel II of Figure 4. Despite the presence of flight B of airline 2, the passenger will make the same choice as in panel I, combining either the A flights or the C flights of the two airlines. When the preferred arrival is as shown, the C flights will be used, leading to a zero layover and the schedule delay shown in panel II. This choice is made even though a shorter schedule delay would be achieved by taking airline 1's A flight and connecting to airline 2's B flight. But since this option involves a layover equal to the gap between airline 1's A flight and airline 2's B flight, it will be shunned in favor of the option with no layover. In contrast to panel I, it is now airline 2's B flight that is irrelevant, and the result is that expected schedule delay equals 1/4 of the gap between airline 1's flights. Expected schedule-delay cost is then γ/f_1 . Combining the results from the two panels of Figure 4, expected schedule-delay cost for the outbound trip is thus $\gamma/\min\{f_1, f_2\}$.

Applying the same reasoning for inbound flights, we get the same schedule-delay expressions: γ/f_2 for $f_1 \geq f_2$ and γ/f_1 for $f_1 < f_2$, expressed again as $\gamma/\min\{f_1, f_2\}$. With

the same outbound and inbound expressions, the average schedule-delay cost in both directions is given by this common expression. Since layover costs are zero given that no layovers are incurred, the g function again consists only of schedule-delay costs and is given by

$$g[f_1, f_2] = \frac{\gamma}{\min\{f_1, f_2\}}. \quad (11)$$

The proposition below summarizes the difference between the g functions in (10) and (11).

Proposition 1 *With both zero-cost and high-cost layover time, the g function consists only of schedule-delay costs. With zero-cost layover time, the g function is proportional to the average of the reciprocals of the carriers' flight frequencies, as in (10). With high-cost layover time, the g function is proportional to the reciprocal of the minimum of the carriers' flight frequencies, as in (11). Thus, depending on the magnitude of the layover cost, the quality of only one of the two complementary airline products may matter to consumers.*

It should be clear that, without the previous flight-spacing assumptions, analysis of the high-cost layover case would be intractable. Arbitrary numbers of flights and arbitrary alignments of the airlines' equally spaced flights would generally lead to a situation where positive layover time must be incurred. The passenger would then need to trade off layover time against schedule delay, with the resulting magnitudes depending on how closely the flight alignments of the two carriers match up, something that cannot be characterized in general. In such a case, the consumer's choice of flights cannot be determined without knowing the details of the flight patterns, precluding a general solution to his choice problem. The previous flight-spacing assumptions, however, cut through this indeterminacy, leading to a simple solution.

While most of the subsequent analysis focuses on the two polar cases from Proposition 1, the analysis in section 5.4 below considers the case where some passengers have a zero cost of layover time and some have a high cost. The passenger mix is characterized by the share μ of passengers in the zero-cost group. Once results for the two polar cases have been derived, conclusions for the mixed case follow easily.

3.3 Airline costs

On a single route segment, airline i 's cost to operate a flight in both directions is given by $\theta + \tau s_i$, where s_i is carrier i 's aircraft size, as measured by the number of seats, θ is a

fixed cost independent of aircraft size, and τ is the marginal cost per seat (as in Brueckner, 2004). Under this specification, cost per seat realistically falls with aircraft size, leading to economies of traffic density.

Assuming a 100% load factor, airline i 's flight frequency, aircraft size, and passenger traffic Q are all related by the equation $s_i f_i = Q$, which says that aircraft size times the number of flights equals traffic (recall that passenger traffic is the same for both carriers). Note that s_i is an airline choice variable, which is appropriate given that the demands of airlines ultimately determine the nature of aircraft supplied by manufacturers. While s_i is thus endogenous, its value is determined residually once Q and f_i are known. Therefore, carrier i 's total cost is $f_i(\theta + \tau s_i)$ or, equivalently,

$$c_i = \theta f_i + \tau Q, \tag{12}$$

indicating that variable costs depend just on Q , being independent of the number of flights.

Note how the cost function in (12) differs from the one in the general model of section 2. Instead of quantity Q being multiplied by a quality cost function, the quality variable f_i enters additively, as if it were a fixed cost (this structure also appears in Economides, 1999).

4 The general demand model

This section develops the profit-maximization conditions for the no-alliance and alliance cases under the general-demand specification in (9). In the alliance case, where $f_1 = f_2 = F$, the g function reduces to γ/F with both zero-cost and high-cost layover time, which means that the alliance conditions are the same in the two cases. The non-alliance profit-maximization conditions, however, differ between the cases. As a result, the no-alliance conditions are derived first for the two cases, with the common alliance conditions derived subsequently.

4.1 No-alliance conditions with zero-cost layover time

Taking into account the form of $g[\cdot]$ with zero-cost layover time (from (10)), demand in (9) becomes

$$Q = D \left(p_1 + p_2 + \frac{1}{2} \left[\frac{\gamma}{f_1} + \frac{\gamma}{f_2} \right] \right), \tag{13}$$

where the overall fare is composed of two subfares (p_1 and p_2) that the carriers choose in noncooperative fashion, following previous alliance models. Note that, as in the general model, the demand function in (13) depends on the sum of prices and the sum of the quality variables (the inverse frequencies). In addition, the cross-partial derivative between price and quality is positive.

Airline 1's profit is therefore $\pi_1 = p_1 Q - c_1$, an expression that can be rewritten using (12) and (13) as

$$\pi_1 = (p_1 - \tau) D \left(p_1 + p_2 + \frac{1}{2} \left[\frac{\gamma}{f_1} + \frac{\gamma}{f_2} \right] \right) - \theta f_1. \quad (14)$$

The corresponding expression for carrier 2 is given by interchanging subscripts.

Each carrier simultaneously chooses its subfare and flight frequency to maximize profit, treating the other carrier's values as given. Focusing on the symmetric equilibrium, we set $p_1 = p_2 = P/2$ and $f_1 = f_2 = F$ after computing first-order conditions for the choice of p_1 and f_1 , where P is the overall fare for the XY trip and F is the common frequency on both route segments. These conditions can be rewritten as⁹

$$D + \left(\frac{P}{2} - \tau \right) D' = 0, \quad (15)$$

$$- \left(\frac{P}{2} - \tau \right) \frac{\gamma}{2F^2} D' - \theta = 0. \quad (16)$$

After rearrangement, the first condition says that the fare is set optimally when marginal revenue as a function of P equals the marginal cost of a seat, τ . The second condition says that F is set optimally when fixed cost per flight (θ) equals the revenue gain from an extra flight.

4.2 No-alliance conditions with high-cost layover time

With high-cost layover time, $g[\cdot]$ is given by (11), so that demand in (9) becomes

$$Q = D \left(p_1 + p_2 + \frac{\gamma}{\min\{f_1, f_2\}} \right), \quad (17)$$

⁹It can be shown that the first-order condition for f_1 found by ignoring the rule $f_1 = 2^k f_2$ and just differentiating with respect to f_1 is the same as the condition that emerges when the rule is used and differentiation occurs with respect to k . In the latter case, however, k is treated as continuous, not integer valued, so that the resulting condition should be viewed as an approximation.

a formulation that differs from the general model given the presence of the *min* function. Carrier 1's total cost is again given by (12), and using these expressions, airline 1's profit becomes

$$\pi_1 = (p_1 - \tau) D \left(p_1 + p_2 + \frac{\gamma}{\min\{f_1, f_2\}} \right) - \theta f_1, \quad (18)$$

while carrier 2's profit expression comes from interchanging subscripts in (18).

Finding the Nash equilibrium in frequencies is less straightforward than before because of the presence of the *min* function. To derive carrier 1's best frequency response function, suppose that the subfares in (18) are equal, as they will be in equilibrium, so that the frequency choices are symmetric for the two carriers. Let f^* denote the f_1 value that maximizes (18) under the assumption that $f_2 > f_1$, in which case the frequency term in (18) equals γ/f_1 . It is then easy to see that the optimal f_1 equals f^* for $f_2 > f^*$, while the optimal value equals f_2 for $f_2 \leq f^*$. In the latter case, raising f_1 toward f^* is desirable, but once f_2 is reached, further increases yield no benefit under the *min* function. The resulting best-response function for carrier 1 is shown as the solid curve in Figure 5. Carrier 2's best-response function is the mirror image of 1's function, shown as the dotted curve in the figure, which coincides with 1's function over a portion of the 45-degree line. From the figure, it is clear that any (f_1, f_2) pair lying where the best-response functions coincide is a Nash equilibrium in frequencies. We assume that, since the equilibrium at (f^*, f^*) yields the highest profit for each carrier among these multiple equilibria, this is the equilibrium that will be selected.

The resulting optimality condition for f_1 , which gives the common f under symmetry, is then the same as the condition yielding f^* , which comes from replacing $\min\{f_1, f_2\}$ by f_1 in (18) and differentiating. As before, this condition and the first-order condition for p_1 are evaluated under symmetry, with $p_1 = p_2 = P/2$ and $f_1 = f_2 = F$. The resulting conditions are

$$D + \left(\frac{P}{2} - \tau \right) D' = 0, \quad (19)$$

$$- \left(\frac{P}{2} - \tau \right) \frac{\gamma}{F^2} D' - \theta = 0. \quad (20)$$

Note that the the first condition is the same as the condition under zero-cost layovers (see (15)), whereas the second condition differs in the absence of a 2 factor multiplying F^2 (see (16)).

4.3 Alliance conditions

The alliance maximizes joint profit, which is split equally between both partners. As in the standard model, the allied entity chooses an overall fare P . Since the alliance also sets a common flight frequency F on both route segments, while operating inbound and outbound flights at the same time, layover cost is identically zero, not being affected by the cost of layover time. The upshot is that profit-maximization conditions for an alliance are independent of layover cost, being the same in the zero-cost and high cost cases. With common route frequencies, (average) schedule delay is γ/F , so that demand is given by

$$Q = D\left(P + \frac{\gamma}{F}\right), \quad (21)$$

Joint profit is then written

$$\Pi = (P - 2\tau) D\left(P + \frac{\gamma}{F}\right) - 2\theta F, \quad (22)$$

where the 2 factors are needed because the alliance operates two route segments. Note that, while the same full price $(P + \gamma/F)$ emerges in the symmetric no-alliance equilibrium, here it appears in the original optimization problem.

After dividing by 2, the first-order conditions for the choices of P and F are

$$\frac{D}{2} + \left(\frac{P}{2} - \tau\right) D' = 0, \quad (23)$$

$$-\left(\frac{P}{2} - \tau\right) \frac{\gamma}{F^2} D' - \theta = 0. \quad (24)$$

4.4 Unified statement of the profit-maximization conditions

To analyze the effect of alliances on fares and frequencies, we first gather the previous results in two unified statements of the profit-maximization conditions, one for the case of zero-cost layover time and the other for the high-cost case. Then, we can carry out a comparative-static analysis of the equilibrium conditions for the two cases to determine the fare and service-quality effects of alliances.

4.4.1 Zero-cost case

Combining (15), (16) and (23), (24), the unified statement of the profit-maximization conditions for the case of zero-cost layover time is

$$\alpha D + \left(\frac{P}{2} - \tau\right) D' = 0, \quad (25)$$

$$-\left(\frac{P}{2} - \tau\right) \frac{\gamma}{2\alpha F^2} D' - \theta = 0, \quad (26)$$

where the parameter α takes the value $1/2$ in the alliance case and 1 when carriers are nonaligned.

To get a sense of the different frequency incentives of an alliance and nonaligned carriers, consider the frequency choices in the two cases implied by (26) when P is held fixed at a common value. In the no-alliance case, $\alpha = 1$ makes the expression $\gamma/2\alpha F^2$ equal to $\gamma/2F^2$ and thus smaller than its value of γ/F^2 in the alliance case (where $\alpha = 1/2$). This difference leads to a smaller no-alliance F , holding P fixed. That outcome reflects the fact that, in the no-alliance case, a change in a carrier's frequency affects only half of the frequency portion of the full price rather than the entire frequency portion, which accounts for the 2 in the denominator of the previous no-alliance expression and its absence in the alliance expression. This difference is the essence of double marginalization, where noncooperative behavior leads carriers to ignore beneficial spillovers from their choices on the other carrier, thus setting their decision variable at too low a value. While this discussion holds P fixed, the ultimate frequency difference between the no-alliance and alliance cases must account for differences in P .

The α factor in (25) reflects double marginalization by nonaligned carriers in the choice of fares. In considering a higher subfare p_1 , airline 1 ignores the effect on airline 2's revenue, thus choosing a value higher than the one that would maximize joint profit (the alliance's goal). Therefore, relative to the alliance case, the LHS of (25) is larger in the absence of an alliance (with $\alpha = 1$ instead of $1/2$) and thus reaches zero at a higher value of P .

4.4.2 High-cost case

Combining (19), (20) and (23), (24), the unified statement of the profit-maximization conditions for the case of high-cost layover time is

$$\alpha D + \left(\frac{P}{2} - \tau\right) D' = 0, \quad (27)$$

$$-\left(\frac{P}{2} - \tau\right) \frac{\gamma}{F^2} D' - \theta = 0, \quad (28)$$

where the parameter α again takes the value 1/2 in the alliance case and 1 when carriers are nonaligned.

Note the differences relative to the zero-cost case: although the first condition remains the same, the 2 multiplying F^2 is absent in the second condition and α does not appear, with α present only in the first condition. The absence of α in (28) affects the previous argument regarding frequency incentives. In contrast to the previous discussion for the zero-cost layover case, an alliance and nonaligned carriers will now choose the same F value when P is held fixed at a common value. This outcome reflects the fact, explained above, that the Nash equilibrium choice of F has carrier 1 ignoring the *min* function and choosing f_1 in isolation. But since this is the same choice made by the alliance in choosing a common F on the two route segments, the optimality conditions are then the same. As a result, the difference between the alliance and no-alliance values of F arises only through differences in P , which affect the F solution in (28). Thus, in contrast to the zero-cost layover case, double marginalization in the no-alliance frequency choices is absent, although it is still present in the choice of subfares.

4.5 The effects of alliances on the fare and frequency

In the general model developed so far, comparative-static analysis of the equilibrium conditions for the zero-cost and high-cost layover cases can be carried out to determine the fare and service-quality effects of alliances in the two cases. The derivatives $\partial P/\partial\alpha$ and $\partial F/\partial\alpha$ can be computed to gauge the effect of a change in α on the equilibrium fare and frequency in moving from the alliance to the no-alliance case. In doing the calculations, it is important to recognize the equilibrium conditions for the alliance case are the direct derivatives of alliance profit function with respect to P and F , which means that the alliance second-order conditions can be used for the comparative-static analysis,

which increases α , starting at the alliance value of $1/2$ and moving toward the no-alliance value of 1 . By contrast, because symmetry has been imposed in generating the no-alliance equilibrium conditions, the second-order conditions for that case cannot be derived simply by differentiating these conditions with respect to P and F . A return to the underlying profit-maximization problem is required.

The computation requires total differentiation of the two sets of alliance equilibrium conditions (25)-(26) or (27)-(28), with respect to P , F and α , evaluating the results at $\alpha = 1/2$. Denoting the expressions in the alliance equilibrium conditions by Π_P and Π_F (using the same notation for the zero-cost and the high-cost cases), their derivatives are Π_{PP} , Π_{PF} , Π_{FP} , and Π_{FF} , where the double subscript denotes second derivative. Then, for $\alpha = 1/2$, the following second-order conditions are assumed to hold:

$$\Pi_{PP}, \Pi_{FF} < 0 \text{ and } \Lambda = \Pi_{PP}\Pi_{FF} - \Pi_{PF}\Pi_{FP} > 0. \quad (29)$$

To proceed, we adopt

Assumption 1 $\Pi_{PF} = \Pi_{FP} > 0$, which is true under a linear-demand specification.

Note that Π_{PF} has the sign of $-\left[\alpha D' + (P/2 - \tau) D''\right]$, evaluated at $\alpha = 1/2$. Therefore, Assumption 1 seems reasonable because one would expect the negative sign of D' to dominate in determining the sign of this expression, in which case it would be positive.

In the zero-cost layover case, $\Pi_{P\alpha} = D > 0$ and $\Pi_{F\alpha} = \left(\frac{P}{2} - \tau\right) \frac{\gamma}{2\alpha^2 F^2} D' < 0$. Therefore, using Cramer's rule, the impacts of a change in α on P and F are given by

$$\frac{\partial P}{\partial \alpha} = \frac{\overbrace{-\Pi_{P\alpha}\Pi_{FF}}^{>0 \quad <0} + \overbrace{\Pi_{PF}\Pi_{F\alpha}}^{>0 \quad <0}}{\Lambda}, \quad (30)$$

$$\frac{\partial F}{\partial \alpha} = \frac{\overbrace{-\Pi_{PP}\Pi_{F\alpha}}^{<0 \quad <0} + \overbrace{\Pi_{P\alpha}\Pi_{FP}}^{>0 \quad >0}}{\Lambda}. \quad (31)$$

As can be seen from inspection of (30) and (31), these derivatives are ambiguous in sign, just like in the general model considered in section 2. Note that this ambiguity is present even though a sign for Π_{PF} (analogous to π_{pq} in (8)) has been assumed.

Moving to the high-cost layover case, $\Pi_{P\alpha} = D > 0$ (as before) but $\Pi_{F\alpha} = 0$. Hence,

the impacts of a change in α are now simpler:

$$\frac{\partial P}{\partial \alpha} = \frac{\overbrace{-\Pi_{P\alpha}}^{>0} \overbrace{\Pi_{FF}}^{<0}}{\Lambda} > 0, \quad (32)$$

$$\frac{\partial F}{\partial \alpha} = \frac{\overbrace{\Pi_{P\alpha}}^{>0} \overbrace{\Pi_{FP}}^{>0}}{\Lambda} > 0. \quad (33)$$

These derivatives show a clear effect of an alliance in the high-cost layover case, where an increase in α (movement away from the alliance case) raises P and F , with an alliance thus yielding a lower fare and a lower frequency. Summarizing these results yields

Proposition 2 *Under Assumption 1, formation of an alliance leads to a lower fare and lower frequency in the high-cost layover case, while having ambiguous effects in the zero-cost layover case.*

Thus, the only general result on the service-quality effect of an alliance is unexpected: flight frequency falls in the high-cost layover case when an alliance is formed. To gain further insight, we now put more structure on the model to generate determinate results in the zero-cost layover case, and to provide some additional results in the high-cost layover case. We use a linear demand specification, which is widely applied in theoretical work on airline economics (see, e.g., Brueckner, 2004; and Brueckner and Flores-Fillol, 2007). The advantage is that clear analytical solutions can be derived directly from first principles. Additionally, the linear-demand set-up can show the effect of an alliance on the full price $P + \gamma/F$ and the traffic volume Q .

5 A linear demand model

In the material that follows, we assume that the demand function in (9) takes the form

$$Q = a - b(\text{fare} + g[f_1, f_2]), \quad (34)$$

where $a, b > 0$. Microfoundations yielding this linear demand function have been developed in previous papers (see, for example, Brueckner, 2004).

5.1 Zero-cost layover time

With zero-cost layover time, (34) becomes

$$Q = a - b \left(p_1 + p_2 + \frac{1}{2} \left[\frac{\gamma}{f_1} + \frac{\gamma}{f_2} \right] \right). \quad (35)$$

With $D' = -b$, the zero-cost layover conditions in (25) and (26) reduce to

$$\alpha \left[a - b \left(P + \frac{\gamma}{F} \right) \right] - \left(\frac{P}{2} - \tau \right) b = 0, \quad (36)$$

$$\frac{P}{2} - \tau = \frac{2\alpha\theta}{b\gamma} F^2. \quad (37)$$

Plugging P from (37) into (36), the following condition for F emerges:

$$\underbrace{(a - 2b\tau) F - b\gamma}_{L(F)} = \underbrace{\frac{2\theta}{\gamma} (2\alpha + 1) F^3}_{C(F)}. \quad (38)$$

Using (38), the equilibrium frequency is found graphically, as seen in Figure 6. The F^* solution occurs at the intersection between the linear function $L(F)$ on the RHS and the cubic expression $C(F)$ on the LHS. It is easy to verify that $a - 2b\tau > 0$ must hold, so that the linear function is upward sloping. There are three possible solutions to (38), two of them positive, but compliance with the second-order conditions makes the second positive solution relevant (details are in Appendix A).

Some comparative-static results that apply to both the alliance and no-alliance cases can be obtained by simple inspection of (38) along with Figure 6. Higher demand (an increase in a), rotates the line in Figure 6 counterclockwise and thus raises frequency, a natural conclusion. An increase in the demand slope b (which leads to the reverse line rotation as well as a downward shift), has the opposite effect. Higher fixed or variable costs also have natural effects on F : a higher marginal seat cost τ rotates the line downward, reducing F , while a higher flight fixed cost θ has the same effect since it raises the level of the cubic curve. An increase in the disutility of schedule delay γ seems to produce an ambiguous effect on F (since it shifts both the line and the cubic curve downward), but a more thorough analysis shows that F increases with γ . Therefore, frequency rises in response to a higher passenger sensitivity to schedule delay.¹⁰

¹⁰The proof of $\partial F/\partial\gamma > 0$ is as follows (a similar proof can be found in Brueckner, 2004). Equating (38) to 0, we can compute $\partial F/\partial\gamma = [2\theta(2\alpha + 1)F^3/\gamma^2 + b]/\Psi$, where $\Psi = 6\theta(2\alpha + 1)F^2/\gamma - (a - 2b\tau)$.

With the comparative-static effects of a , b , τ , θ , and γ understood, attention now shifts to the effects of alliances. The impact of an alliance on F can be easily ascertained graphically by plotting (38) for the no-alliance ($\alpha = 1$) and the alliance ($\alpha = 1/2$) cases, as shown in panel I of Figure 7. The cubic function in the alliance case $C(F)|_a$ is lower than $C(F)|_{na}$, so that the equilibrium F is larger: $F_a^* > F_{na}^*$, where subscripts a and na denote alliance and no-alliance equilibrium values.

It is impossible, however, to determine the direction of the alliance fare effect, as can be seen by referring to (37). Since reducing α from 1 to 1/2 raises F , the change in the magnitude of the RHS expression is ambiguous, making the change of P on the LHS also ambiguous. However, the alliance's effect of the full price of travel can be derived. Eliminating $P/2 - \tau$ in (36) using (37) yields

$$\underbrace{a - b \left(P + \frac{\gamma}{F} \right)}_Q = \frac{2\theta}{\gamma} F^2. \quad (39)$$

Since the alliance raises F , the LHS of (39) rises as well, implying a higher traffic level Q and lower full price $P + \gamma/F$. Therefore, even though the alliance may not lead to a lower fare, the full price of travel falls and traffic rises, just as in the standard alliance model where service quality is not a concern of passengers. Summarizing yields the following proposition.¹¹

Proposition 3 *Under zero-cost layover time, an alliance leads to higher service quality (a higher F) than in the no-alliance case, although the fare P may rise or fall. However, the full price of travel falls with an alliance, raising traffic Q . As a result, consumer welfare increases, and since carrier profit rises as well, the alliance is welfare improving.*

Note that, while the general ambiguity of the alliance fare impact is not resolved in the linear case, a determinate frequency impact now emerges along with a conclusion regarding the impact on the full price and traffic.

Taking into account that compliance with the second-order condition requires the cubic function to be steeper than the linear one in (38), we conclude that $\Psi > 0$ (see Appendix A for the details). Finally, using again the equilibrium condition in (38) to rewrite the previous derivative, we obtain $\partial F/\partial \gamma = (a - 2b\tau)F/\gamma\Psi$, which is always positive.

¹¹The effect of the alliance on the optimal aircraft size is unclear. With both Q and F rising, the change in $s = Q/F$ is ambiguous.

5.2 High-cost layover time

With high-cost layover time, the linear demand in (34) becomes

$$Q = a - b \left(p_1 + p_2 + \frac{\gamma}{\min\{f_1, f_2\}} \right), \quad (40)$$

and the high-cost layover conditions in (27) and (28) are now

$$\alpha \left[a - b \left(P + \frac{\gamma}{F} \right) \right] - \left(\frac{P}{2} - \tau \right) b = 0, \quad (41)$$

$$\frac{P}{2} - \tau = \frac{\theta}{b\gamma} F^2. \quad (42)$$

Eliminating P in (41) using (42), we obtain the following condition for F :

$$(a - 2b\tau) F - b\gamma = \frac{\theta}{\gamma} \left(\frac{1}{\alpha} + 2 \right) F^3. \quad (43)$$

The comparative-static properties of a , b , τ , θ , and γ are as in the zero-cost layover case. As for the effect of alliances, panel II of Figure 7 shows the graphical representation of this equilibrium condition for $\alpha = 1/2$ and $\alpha = 1$. The relationship between the curves is opposite to the one in the zero-cost layover case, with $C(F)|_a$ now higher than $C(F)|_{na}$, implying $F_a^* < F_{na}^*$, so that the alliance leads to a reduction in F rather than an increase.

Since, in contrast to case of zero-cost layover time, (42) does not involve α , the RHS of this condition falls in moving to an alliance, implying that P must fall as well. A reduction in P is, of course, the usual effect of an alliance, but it is now accompanied by a reduction, rather than an increase, in service quality. Furthermore, in contrast to the case of zero-cost layover time, the alliance has an ambiguous effect on the full price of travel and thus on Q . Eliminating $P/2 - \tau$ in (41) using (42) yields an analog to (39), where the RHS is replaced by $\theta F^2/\alpha\gamma$. Since F falls as α drops from 1 to 1/2, the change in the RHS is ambiguous, implying an ambiguous alliance effect on the LHS. Therefore, in contrast to usual beneficial effect of alliances on traffic, which also emerges in the case of zero-cost layover time, Q may fall with high-cost layover time. Summarizing yields

Proposition 4 *With high-cost layover time, an alliance leads to a lower fare P as well as lower service equality (a lower F). The full price of travel may either rise or fall, implying that traffic Q may decrease. Although carrier profit rises, this ambiguity makes the change in overall welfare ambiguous.*

This proposition confirms the result obtained in the general model and provides further insights concerning the full price and traffic volume.

Recalling the earlier discussion of frequency incentives, the source of the lower alliance frequency is clear in the high-cost layover case. As explained earlier, the common form of (42) for the alliance and no-alliance cases meant that differences in F arise solely through differences in P between the cases. Thus, the smaller P in the alliance case is the source of the lower frequency.

The analysis with linear-demand thus shows that, in a model where flight frequencies capture service quality, the cost of layover time is crucial in determining the effects of airline alliances. When layover cost is zero, the usual double marginalization phenomenon in the no-alliance case suggests that an alliance should reduce the fare and raise frequency. While the predicted negative fare effect does not emerge, frequency does rise and its increase is sufficient to reduce the full price, benefiting passengers and raising traffic volume. When layover cost is costly, the additive reciprocal frequencies are replaced by the reciprocal of their minimum value, thus eliminating the double marginalization structure. Therefore, an alliance reduces rather than raises frequency, leading to a possible increase in the full price and a reduction in traffic.

Another way to understand these results is by considering the effect of frequency on passengers' willingness-to-pay for travel, as reflected in the position of the demand curve. In the zero-cost layover case, the increase in service quality (the higher F) under an alliance raises willingness-to-pay by shifting the demand curve outward. While this shift would tend to raise the fare, the elimination of double marginalization creates downward fare pressure, and these opposing effects make the direction of the fare change ambiguous. By contrast, the lower alliance frequency in the high-cost layover case lowers willingness-to-pay and tends to reduce the fare. Combined with the double-marginalization effect, the result is an unambiguous fare reduction in moving to an alliance.

5.3 Comparison

Since the alliance frequency is the same in both the zero-cost and high-cost layover cases, while the no-alliance frequency is lower (higher) than the alliance frequency in the zero-cost (high-cost) layover cases, we can state

Corollary 1 *The no-alliance frequency is lower in the zero-cost layover case than in the high-cost case, with the alliance frequency lying between the two no-alliance values.*

The corollary is illustrated in Figure 8, where superscript 0 refers to zero-layover cost and H to high-layover cost.

5.4 Allowing a mix of passenger types

It is possible to consider an intermediate (and more realistic) case between the two polar cases described above. Suppose now that a proportion $\mu \in (0, 1)$ of passengers has a zero cost of layover time while the rest are high-cost passengers. In such a case, the demand function would be

$$Q = \mu \left\{ a - b \left(p_1 + p_2 + \frac{1}{2} \left[\frac{\gamma}{f_1} + \frac{\gamma}{f_2} \right] \right) \right\} + (1 - \mu) \left\{ a - b \left(p_1 + p_2 + \frac{\gamma}{\min\{f_1, f_2\}} \right) \right\}. \quad (44)$$

Given that the alliance analysis is independent of layover-cost considerations, it remains unaltered in the case of a passenger mix. Focusing on the no-alliance case, the first-order condition for P remains unchanged, as it is independent of layover cost (see (36) and (41)). But the first-order condition for F becomes

$$\frac{P}{2} - \tau = \frac{2\alpha\theta}{b\gamma(2 - \mu)} F^2, \quad (45)$$

indicating that a higher proportion of zero-cost layover passengers exerts downward pressure flight frequency. Eliminating P , the equilibrium condition for F becomes

$$(a - 2b\tau) F - b\gamma = \frac{6\theta F^3}{\gamma(2 - \mu)}. \quad (46)$$

Since the LHS expression is the same linear function as in the previous cases, the effect of passenger mix is therefore determined by the cubic expression on the RHS. Note the zero-cost and the high-cost expressions can be recovered by substituting $\mu = 1$ and $\mu = 0$, respectively (as depicted in Figure 8). The advantage of the current analysis consists in having a continuum of F equilibrium values between the two polar cases F_{na}^{*0} and F_{na}^{*H} , depending on the passenger mix μ .

The cubic expression on the RHS of (46) can be compared with the one under an alliance to ascertain the alliance effect for any passenger mix. From this comparison, it follows that $F_{na}^* < F_a^*$ for $\mu > 1/2$, $F_{na}^* > F_a^*$ for $\mu < 1/2$, and $F_{na}^* = F_a^*$ for $\mu = 1/2$, yielding

Proposition 5 *The effect of an alliance on flight frequency depends on the passenger mix. If passengers with a zero cost of layover time are the majority ($\mu > 1/2$), then an alliance leads to higher service quality (a higher F). But an alliance reduces service quality when passengers with high cost of layover time are the majority ($\mu < 1/2$).*

Since waiting for a connecting flight at a hub airport is likely to be more costly for business than for leisure passengers, we can view the zero-cost layover passengers as leisure passengers and the high-cost layover passengers as business passengers.¹² City-pair markets can then be classified into two categories: *business city-pair markets*, with a majority of business travelers ($\mu < 1/2$); and *leisure city-pair markets*, with a majority of leisure passengers ($\mu > 1/2$). From the preceding analysis, it follows that business city-pair markets will have higher flight frequencies than leisure markets in the absence of an alliance.¹³ But after an alliance is formed, the new entity coordinates flight schedules by setting a common F that eliminates layover time. From Proposition 5, we can then assert that an alliance will lead to a higher frequency in leisure markets and a lower frequency in business markets. Thus, an alliance eliminates airline responses to layover-cost heterogeneity across markets.

We could extend the business/leisure distinction to include a passenger's disutility of schedule delay, as reflected in the value of γ (which would be larger for business passengers).¹⁴ Since an increase in γ raises frequency regardless of layover cost or alliance status (see footnote 10), it follows that the larger γ in business markets will further widen the no-alliance frequency gap between business and leisure markets that already exists due to differences in layover cost.

Therefore, different passenger time valuations, operating through both layover and schedule-delay costs, generate a service-quality gap between business and leisure markets in the no-alliance case. However, in contrast to layover-cost differences, differences in γ continue to have an effect once an alliance is formed, with business markets served by an alliance having higher frequency than leisure markets. Consequently, only partial convergence between business and leisure city-pair markets can be expected as a consequence of

¹²While layovers with children may be taxing, thus suggesting the reverse relationship for some leisure passengers, we suspect that layovers are more costly for business passengers on average.

¹³Brueckner and Pai (2009) and Fageda and Flores-Fillol (2012a) study the emergence of new point-to-point routes from the use of regional jets that allow higher frequencies in business city-pair markets.

¹⁴The same assumption motivates the analysis in Brueckner and Pai (2009) and Fageda and Flores-Fillol (2012a and 2012b).

airline alliances.

5.5 Adding interalliance competition

While the current model does not include competition between alliances, the approach of Brueckner and Whalen (2000) could be used to add it. In modeling competition, their framework includes brand loyalty, which allows an alliance (or a pair of nonaligned carriers) to raise fares without losing all of its traffic to the competitor.¹⁵ In the present setting, interalliance competition would require an additional carrier pair (i.e., airlines 3 and 4) serving the XY market, with these carriers either nonaligned or operating as alliance partners. As in Brueckner and Whalen (2000), the analysis would consider equilibria where two sets of nonaligned carriers compete, where two alliances compete, or where a set of nonaligned carriers competes with an alliance. In addition to choosing fares, carriers would set flight frequencies as well. An analysis parallel to the current one could be carried out, although the results would presumably differ in various (possibly major) details. This extension could be the subject of future work.

6 Congestion

In this section, we extend the analysis to account for congestion at the hub airport. The literature on airport congestion shows that airlines internalize the congestion they impose on themselves while neglecting the congestion they impose on other airlines.¹⁶ Therefore, alliances are expected to increase the extent to which congestion is internalized, given that allied carriers will take into account the congestion imposed on their partners. As a consequence, in a framework where service quality is not a factor, flight frequency is expected to decrease as compared to the case without congestion (as shown in Flores-Fillol (2010)). In the present model, where service quality matters, we would expect this effect to put downward pressure on frequency.

Given that an alliance yields a higher frequency under zero-cost layover time (Proposition 3) but lower frequency under high-cost layover time (Proposition 4), the analysis

¹⁵Brand loyalty could arise either from institutional factors such as frequent flier programs, or from idiosyncratic consumer preferences for particular aspects of airline service that may differ across carriers.

¹⁶Some relevant contributions on the phenomenon of congestion internalization are Brueckner (2002), Mayer and Sinai (2003), and Flores-Fillol (2010).

of the latter case is straightforward because the post-alliance internalization of congestion will reinforce the already reported decrease in frequency. However, the analysis of the case with zero-cost layover time is more interesting given that an alliance yields two conflicting effects on flight frequency: a positive one from the service quality effect and a negative one due to greater internalization of congestion. Consequently, the analysis that follows concentrates on low-cost layover case, where the existence of these opposing effects suggests that the previous positive flight-frequency effect could be reversed.

Congestion at the hub airport depends on the number of aircraft movements, given by $f_1 + f_2$. Therefore, the per-flight congestion cost for each of the carriers is a function $H(f_1 + f_2)$ with $H' > 0$ and $H'' \geq 0$, as in Brueckner and Van Dender (2008).¹⁷ Taking into account hub congestion, the cost function in (12) now becomes

$$c_i = \theta f_i + \tau Q + f_i H(f_1 + f_2), \quad (47)$$

for $i = 1, 2$. Hence, carrier 1's profit function in the no-alliance case is given by (14) with the congestion-cost term $f_1 H(f_1 + f_2)$ subtracted. In a similar way, alliance profit is given by (22) with the term $2FH(2F)$ subtracted.

Moving to the linear-demand case to assess the effect of alliances on fares and service quality, the H function is also assumed to be linear, so that $H = \eta(f_1 + f_2)$ in the no-alliance case and $H = 2\eta F$ in the alliance case, with $\eta > 0$ being the congestion-damage parameter. Analysis of the first-order conditions yields the following equilibrium condition for F :

$$\underbrace{(a - 2b\tau)F - b\gamma}_{L(F)} = \underbrace{\frac{2(2\alpha + 1)F^3}{\gamma} \left[\theta + \left(\frac{1}{\alpha} + 2 \right) \eta F \right]}_{G(F)}, \quad (48)$$

where the LHS is not affected by congestion, being the same linear function $L(F)$ as in (38). By contrast, the RHS is now a quartic function $G(F)$ due to the presence of the additional congestion term (see Figure 9). There are two possible positive solutions to (48), but compliance with the second-order conditions makes the second solution relevant.¹⁸

It is easy to check that $G(F)|_a$ is lower than $G(F)|_{na}$ in the positive quadrant, so that the equilibrium frequency is larger with an alliance, with $F_a^* > F_{na}^*$. Therefore, the

¹⁷For the sake of simplicity, we assume no passenger congestion costs. See Flores-Fillol (2010) for an analysis including both airline and passenger congestion costs.

¹⁸The proof showing that only the second positive solution is relevant follows exactly the procedure described in Appendix A. Details are available from the authors on request.

previous result, a higher frequency under an alliance, is preserved despite the offsetting effect from internalization of congestion.

As in the absence of congestion, the direction of the alliance fare effect cannot be determined, but the expression for the total traffic, equal to

$$\underbrace{a - b \left(P + \frac{\gamma}{F} \right)}_Q = \frac{2F^2}{\gamma} \left[\theta + \left(\frac{1}{\alpha} + 2 \right) \eta F \right], \quad (49)$$

reveals that the full price $P + \gamma/F$ falls and traffic Q rises with an alliance. This conclusion follows because an alliance leads to a smaller value for the RHS since it reduces α and also increases F . Consequently, the LHS rises as well, implying a lower full price and higher traffic.

It is also important to note that the presence of congestion reduces both F_a^* and F_{na}^* relative to their values in the absence of congestion, reflecting full or partial internalization of congestion. This outcome is due to the upward shift of the quartic functions for both the alliance and no-alliance cases when $\eta > 0$ relative to their positions when $\eta = 0$, shifts that move both intersections to the left. Note, however, that the magnitude of $\left(\frac{1}{\alpha} + 2\right)\eta$ captures the extent of the shift in the curves and thus the magnitude of the reductions in F associated with congestion. The shift is larger with an alliance ($\alpha = 1/2$) than in the no-alliance case ($\alpha = 1$).

All of these results are summarized as follows:

Proposition 6 *Under zero-cost layover time,*

- i) Alliances yield two conflicting effects on flight frequency: a positive one derived from the double marginalization effect and a negative one due to greater internalization of congestion. The first effect dominates, so that an alliance leads to higher service quality (a higher F), a lower full price of travel and higher traffic, just as in the absence of congestion.*
- ii) The presence of congestion reduces frequency in both the alliance and no-alliance cases relative to the no-congestion case, but the alliance reduction is larger, reflecting greater internalization of congestion.*

7 Conclusion

This paper has explored the effect of market structure on quality determination for complementary products. The focus is on the airline industry and the effect of airline alliances

on flight frequency, an important element of service quality. The analysis fills a gap in the literature on airline alliances while providing a needed extension to the product-quality literature, which has mostly ignored the case of complementary products.

The analysis must tackle the problem of distilling the potentially different flight frequencies of two nonaligned carriers into a single service quality measure, which is done by using alternate polar-case assumptions on layover costs. With zero layover cost, the choice of flight frequencies has the same double-marginalization structure as in the usual alliance model, leading to a higher frequency in the alliance case as double marginalization is eliminated, along with a lower full trip price and higher traffic. The surprising result of the paper emerges with high-cost layover time, where double marginalization in frequencies is absent and where an alliance reduces service quality via a lower frequency, with the full price potentially rising (in which case traffic falls).

Therefore, the paper offers a decidedly mixed message on the service-quality effects of alliances. Although the zero-cost layover case offers a welcome confirmation of existing results establishing the benefits of alliances, the possibility of an adverse effect remains.

The paper also shows that nonaligned carriers adjust frequencies to suit passenger preferences in business and leisure markets, while an alliance is less responsive to such preference differences. This finding could suggest that alliances may have greater incentives for other kinds of business/leisure segmentation, as compared to nonaligned carriers.

A caveat is that, by simplifying the route structure, our model ignores transoceanic interhub markets such as New York-London (see Brueckner, 2001). In reality XY traffic would pass through two hubs, H and K, with X connected to H and Y connected to K, and with the XY trip requiring use of the transoceanic HK segment in addition to XH and KY (both airlines would serve the HK route). Two existing empirical studies, Alderighi and Gaggero (2014) and Bilotkach and Hüschelrath (2012), study the frequency impact of an alliance's presence on such HK routes, finding a positive effect.¹⁹ However, because our model lacks this kind of route structure, our results cannot be directly linked to this empirical finding. Building an empirically relevant model of alliance flight frequencies would require a more complex network, and development of such a model could be a task for future work, using this paper as a foundation.

Thus, this paper opens new avenues for research on airline alliances, while pointing to

¹⁹This finding may be more related to the need for greater interhub capacity to handle the alliance-stimulated traffic in XY-type markets than to product-quality effects like those analyzed in this paper.

the need for more study of product-quality determination in the provision of complementary goods. Further study of the service-quality impacts of alliances, both theoretical and empirical, can increase our understanding of the impacts of these important airline linkages and perhaps better inform the actions of the regulators who oversee them. Study of quality determination in contexts outside the airline industry where product complementary matters is also likely to be worthwhile.

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Figures

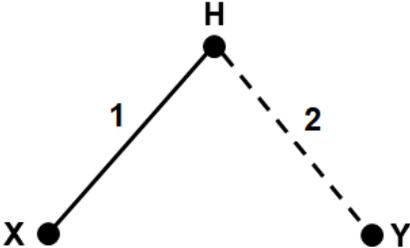


Figure 1: The network.

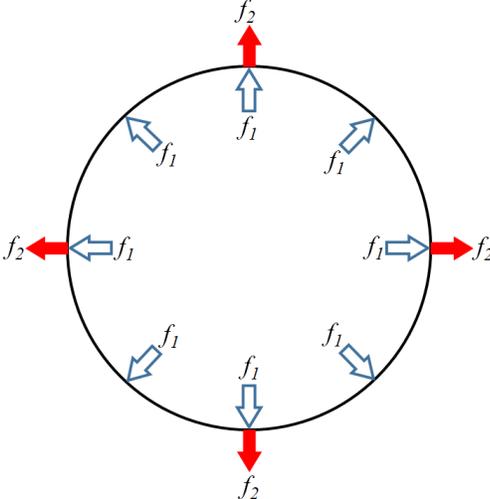


Figure 2: Illustration of the case $f_1 \geq f_2$.

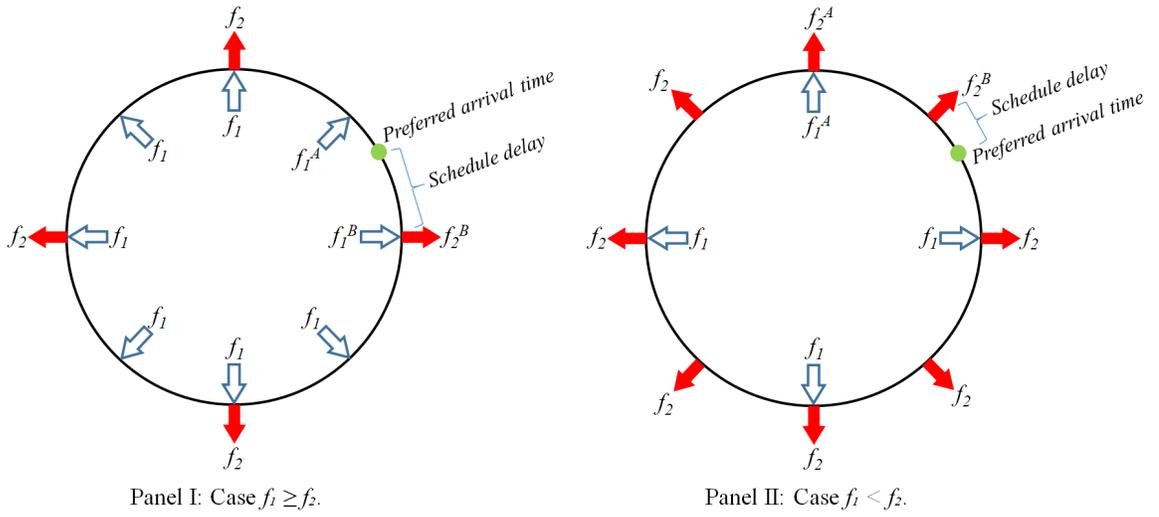


Figure 3: Expected schedule delay under zero-cost layover time.

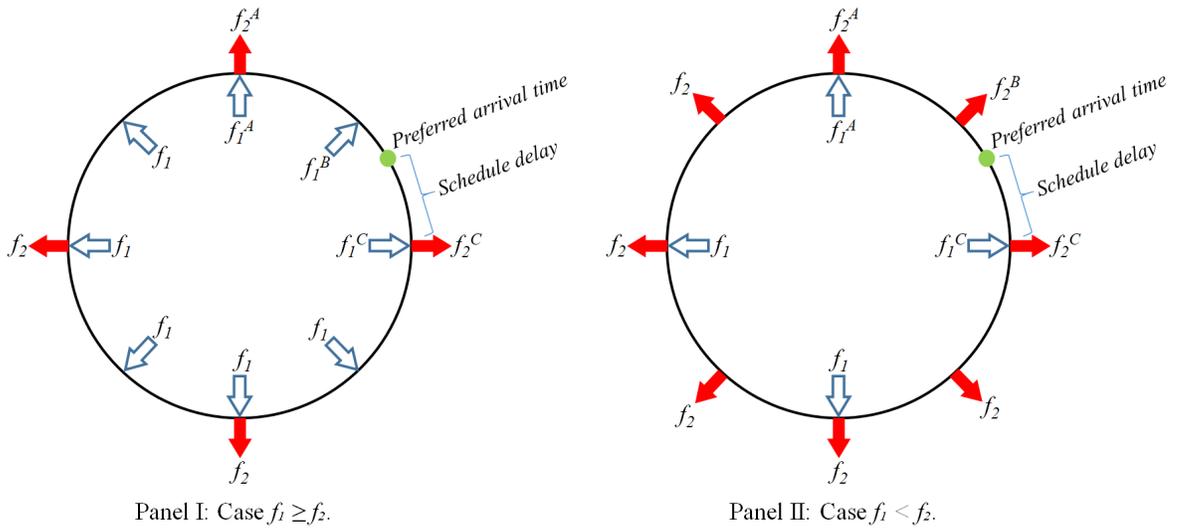


Figure 4: Expected schedule delay under costly layover time.

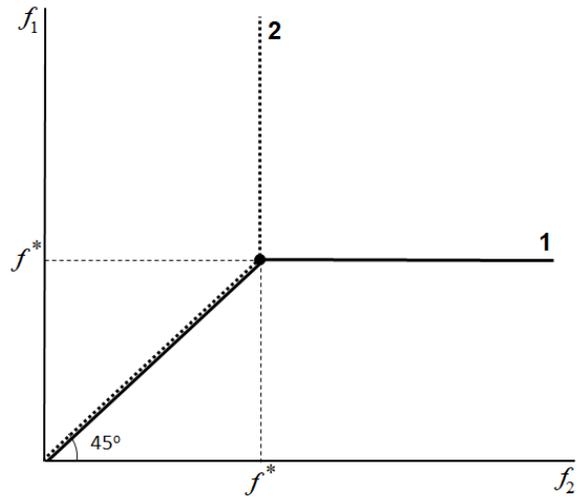


Figure 5: Airlines' best-response functions.

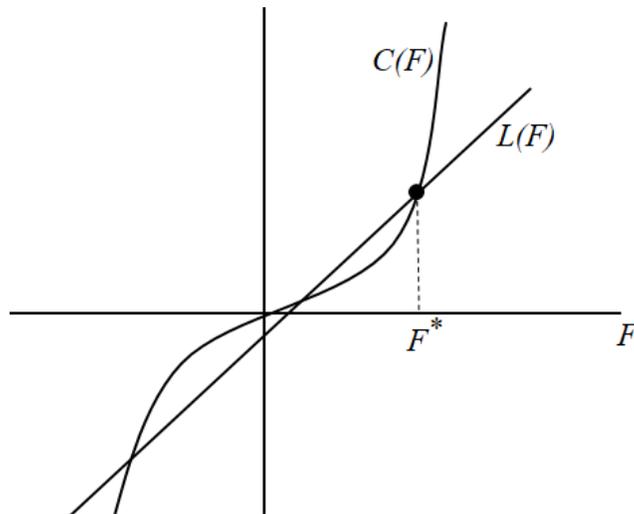


Figure 6: The F solution.

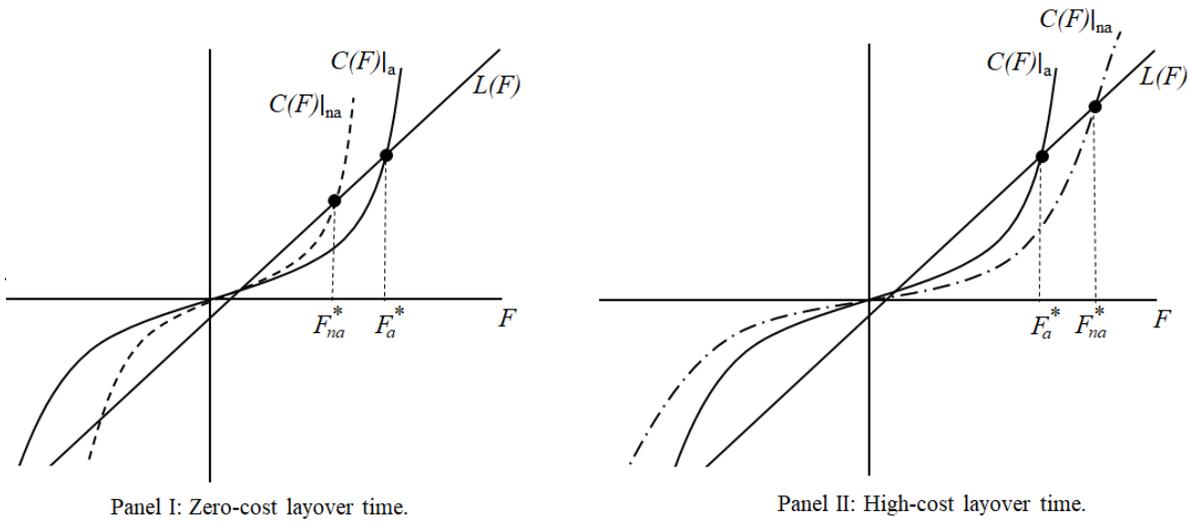


Figure 7: The effect of alliances on F .

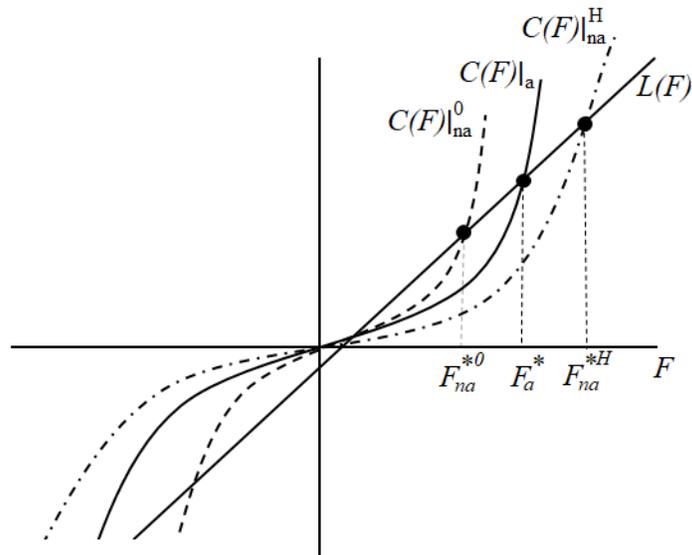


Figure 8: Comparing the equilibrium frequencies.

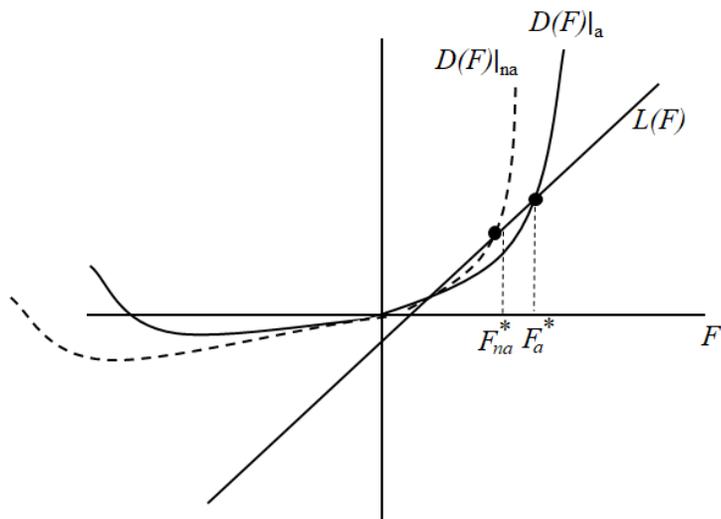


Figure 9: The effect of alliances on F under zero-cost layover time and congestion.

A Appendix: Second-order conditions and optimal F in the linear-demand case

An analysis of the second-order conditions for the linear-demand case reveals that the second possible solution in Figures 6-8 is always the optimum.

A.1 No alliance

A.1.1 Zero-cost layover time

As mentioned above, the equilibrium frequency is found at the intersection between a linear and a cubic expression (see Figure 6). At the second positive solution in the no-alliance case (i.e., $\alpha = 1$), the cubic function is steeper than the linear one, implying $\frac{18\theta}{\gamma}F^2 > a - 2b\tau$, which can be rewritten as $\frac{18\theta}{\gamma}F^3 > (a - 2b\tau)F$. Using the condition in (38), this inequality becomes

$$b < \frac{12\theta}{\gamma^2}F^3. \quad (\text{A1})$$

Positivity of the Hessian determinant requires $\gamma < 8F\left(\frac{P}{2} - \tau\right)$, which can be rewritten using (37) as

$$b < \frac{16\theta}{\gamma^2}F^3. \quad (\text{A2})$$

Therefore, satisfaction of (A1) implies satisfaction of the second-order condition in (A2). At the first positive solution in Figure 6, where the linear function is steeper than the cubic function ($b > \frac{12\theta}{\gamma^2}F^3$) the second-order condition may or may not be violated. If we rule out situations with two local maxima (which are possible if the second-order condition holds at both intersections), the second solution is the relevant one in the zero-cost no-alliance case.

A.1.2 High-cost layover time

At the second positive solution in the no-alliance case (i.e., $\alpha = 1$), the cubic function is again steeper than the linear one, implying $\frac{9\theta}{\gamma}F^2 > a - 2b\tau$ or $\frac{9\theta}{\gamma}F^3 > (a - 2b\tau)F$. Using (43), this inequality becomes

$$b < \frac{6\theta}{\gamma^2}F^3. \quad (\text{A3})$$

Positivity of the Hessian determinant requires $\gamma < 4F \left(\frac{P}{2} - \tau\right)$, which can be rewritten using (42) as

$$b < \frac{4\theta}{\gamma^2} F^3. \quad (\text{A4})$$

Therefore, the second-order condition can only be satisfied at the second solution in the high-cost no-alliance case (this outcome, which is not guaranteed, is assumed).

A.2 Alliance

Repeating these steps for the alliance case (i.e., $\alpha = 1/2$), where the zero-cost and the high-cost layover cases converge, the cubic function is steeper than the linear one at the second positive solution, implying

$$b < \frac{8\theta}{\gamma^2} F^3. \quad (\text{A5})$$

Since positivity of the Hessian determinant requires exactly the same condition, the second-order condition holds only at the second intersection in the alliance case.