# Vertical Differentiation and Airline Alliances: The Effect of Antitrust Immunity*

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**Abstract**

This paper explores the impact of granting antitrust immunity (ATI) to airline alliances in a novel and realistic framework characterized by vertically-differentiated air services. Our theoretical model suggests that non-ATI alliances result in higher quality services at higher fares, whereas granting ATI produces the opposite effect. Using data on the transatlantic market over the period 2010-2017, our theoretical findings on service quality are empirically confirmed. We also relate our theoretical predictions on fares to the empirical results in Brueckner and Singer (2019). Our results indicate that alliances (ATI and non-ATI) concentrate a higher proportion of frequencies on high-quality routings, although airport congestion could mitigate this effect.

*Keywords*: alliance; antitrust immunity; vertical differentiation; double marginalization; congestion

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# 1 Introduction

Alliances constitute a distinguishing element of the air transportation industry since the deregulation of the sector. They adopt different forms depending of their scope and depth and may involve, among others, codesharing agreements (allowing carriers to market flights operated by a partner airline), seamless service to passengers (ensuring gate proximity and coordinating flight schedules so that passengers feel like flying on a single carrier), and mutual recognition of frequent-flyer programs among alliance partners.

Nevertheless, from an airline perspective, the main element explaining the incontrovertible success of alliances is probably their power to extend networks without investments by improving interline connectivity. In this matter, a crucial element for alliances is to be *immunized*, which means being granted antitrust immunity (ATI) so that partner carriers are allowed to make joint pricing decisions. However, granting ATI to carriers that are competitors in a number of airport-pair markets is far from obvious.

Building on the seminal paper by Brueckner (2001), the literature identifies two opposing effects associated with ATI airline alliances: a positive effect in *interline markets* (i.e. connecting markets) and a negative effect in *interhub markets* (also called gateway-to-gateway markets). In interline markets, nonaligned airlines choose individual *subfares* for their route segment, being the *interline fare* the sum of all subfares. Consequently, each airline applies an individual mark-up on their respective segment by ignoring the effect of their decisions on any other airline operating other segments of the interline market. This *double marginalization problem* stemming from the lack of coordination in determining subfares, yields (relatively) high interline fares. In these markets, ATI alliances imply a *complementary integration* allowing airlines to choose the coordinated interline fare maximizing their combined profit in the market. The overall effect is clearly procompetitive, as ATI alliances eliminate a double marginalization problem (i.e., a negative externality is internalized). Instead, in interhub markets, nonaligned airlines provide rival services as their networks overlap. Therefore, ATI alliances in these markets imply a sort of *horizontal integration* that produces anticompetitive effects. In reality, alliances involve both effects since potential partners provide interline services but they also compete in interhub markets. Acknowledging these mixed effects, carve-outs can be implemented to allow interline cooperation while preventing interhub cooperation, although some recent evidences question their effectivity (Gayle and Thomas, 2016).

Our study focuses on complementary alliances in interline connections and aims at disentangling the effect of ATI from any other consequence derived from the formation of alliances. To isolate the effects of ATI, we proceed in two steps. We analyze first the move from a no alliance situation to another where non-ATI alliances are formed. Then we study the effects derived from granting ATI to the existing alliances. We carry out our analysis by adopting a different and novel theoretical and empirical approach to model airline alliances (both ATI and non-ATI) that consider air services on a certain airport-pair market to be vertically differentiated. The existing literature has massively assumed either symmetric (e.g., Brueckner, 2001) or horizontally-differentiated air services (e.g., Flores-Fillol and Moner-Colonques, 2007). However, the reality shows that air services on most of the routings where airlines provide interline services are vertically differentiated in many aspects, flight frequency being the most important one. A low-cost transatlantic flight with poor frequency (e.g., with Norwegian) plus a short-haul flight either in the US or in Europe is clearly a worse option as compared to a combined high-frequency service provided by American Airlines.

At this point, it is important to clarify the difference between alliances and joint ventures. The main difference between them is that alliances are revenue-sharing agreements whereas joint ventures imply a deeper commitment as they also involve cost-sharing (acknowledging that revenue sharing constitutes a precondition for cost-sharing). Using a very intuitive model, Brueckner and Proost (2010) compare both types of agreements. Fageda et al. (2019a) develop further this analysis by proposing a unified framework to analyze a continuum of hybrid cooperation agreements along two dimensions: their degree of revenue sharing (scope of alliances) and their degree of cost sharing (scope of joint ventures).[1] Our analysis focuses on alliances with the ultimate purpose of identifying the consequences of granting ATI.

Our theoretical set-up builds on the literature on vertical differentiation initiated by Gabszewicz and Thisse (1979) and Shaked and Sutton (1982 and 1983) and summarized by Tirole (1988). We assume that consumer heterogeneity arises from different valuations of the frequency of air services. Although service quality includes many different dimensions on the ground (bag handling, gate location, connecting layover times) and in the air (flight schedules, in-flight services, legroom, seat characteristics), there is a clear consensus in the literature that convenient scheduling, characterized by adequate flight frequency, is the main quality attribute for airline services.[2] A higher flight frequency on a route is important because it reduces schedule delay (defined as the gap between a passenger's preferred and actual arrival times). Although some previous studies incorporate schedule delay in passengers' utility function as a negative term decreasing with flight frequency,[3] we include flight frequency in an additive manner (as in Flores-Fillol, 2009; Heimer and Shy, 2006; and Bilotkach *et al.*, 2013). This modeling choice allows applying a classical model of vertically-differentiated products to study complementary alliances in a setting where rival alliances can be formed. This is a relevant contribution of the paper. In our empirical application, we can also differentiate between high- and low-quality routings by using three different criteria: traffic share, routing distance, and flight frequency.

Our main theoretical findings can be summarized as follows. Non-ATI alliances (allowing allied partners to make joint decisions regarding flight frequencies) yield higher fares and frequencies. This is explained by the elimination of a double marginalization in frequencies, which raises coordinated frequencies. A higher service quality increases passengers' willingness-to-pay and yields higher fares. Differently, granting ATI to existing alliances (allowing allied partners to make joint decisions also regarding fares) yields a decrease in fares and frequencies. The reason is that the elimination of a double marginalization in fares logically results in lower fares, which comes together with a lower service quality. As a consequence, our model emphasizes the importance of immunizing alliances to achieve fare reductions. Finally, our results indicate that alliances (both ATI and non-ATI) tend to exacerbate the *quality gap*, which is defined as the difference between high- and low-quality routings in terms of service quality (i.e., flight frequency); however, airport congestion could mitigate this effect.

In our empirical application, we examine the frequency effects of alliances (both ATI and non-ATI) in the transatlantic market by considering routings with one stopover linking airports between US/Canada and Europe. The sample includes about $253,775$ one-way observations at the quarterly level from the first quarter of 2010 until the third quarter of 2017. Data for frequencies come from RDC Aviation (Innovata data) while data from the Official Airlines Guide (OAG) is used to identify one-stop routings having a minimum level of traffic. Then we can provide explicit tests of the frequency predictions developed in our theoretical model.[4] Overall, our empirical results confirm our theoretical predictions on the effects of non-ATI alliances and ATI alliances on flight frequencies and quality gap.

Finally, we relate our theoretical predictions on fares to the empirical results in Brueckner and Singer (2019), the most recent and comprehensive study on the fare effects of airline alliances. We conclude that their empirical results are fully consistent with our theoretical projections on the effects of ATI alliances. As for the effects of non-ATI alliances, the findings in Brueckner and Singer (2019) are less clear but do not seem to contradict our theoretical predictions.

The literature on airline alliances is not very extensive and mostly focuses on their effect on fares.[5] Brueckner (2001) shows that airline alliances reduce fares in interline airport-pair markets while the effect in interhub markets is the opposite. Brueckner (2003) finds that the presence of ATI is the main factor in the reduction of interline fares.[6] Brueckner and Proost (2010) study carve-outs in the airline industry, which are occasionally imposed by regulators when granting ATI to alliances and joint ventures in response to concerns about their potential anticompetitive effects. Instead, the main focus of our analysis (especially in our empirical application) is on the effect of alliances on flight frequencies and quality gap.

On the procompetitive effect of alliances in interline markets, there is a wide consensus in the literature. Evidence can be found in Brueckner and Whalen (2000), Whalen (2007), Brueckner *et al.* (2011), Calzaretta *et al.* (2017), Fageda *et al.* (2019a), and Brueckner and Singer (2019). Only Zou *et al.* (2011) conclude that fares could also increase in interline markets due to the improved transfer services and greater convenience for connecting passengers derived from airline alliances (such as shorter layover times, one-stop check-in, more flexible scheduling or shared frequent flyer programs) that would increase passengers' willingness to pay.

On the potential anticompetitive effect of alliances in interhub markets, the results in the existing literature are divergent. On the one hand, Oum *et al.* (1996), Park and Zhang (1998), and Brueckner and Whalen (2000), Wan *et al.* (2009), Gayle and Brown (2014), Calzaretta *et al.* (2017), and Fageda *et al.* (2019a) do not find evidence of anticompetitive effects of alliances in interhub markets. On the other hand, Gillespie and Richard (2012), Bilotkach and Hüschelrath (2013), and Alderighi *et al.* (2017) find the opposite result.[7] Finally, using a long sample period from 1997 to 2016, Brueckner and Singer (2019) find an anticompetitive effect of ATI alliances in interhub markets in the second part of the sample period, which comprises the years 2010-2016. In any case, they conclude that alliances are beneficial on balance.

The rest of the paper is organized as follows. The model is presented in Section 2 and the theoretical predictions on the effects of alliances are analyzed in Section 3. Our empirical application is reported in Section 4 and a brief conclusion closes the paper. The proofs of the theoretical model can be consulted in Appendix A.

# 2 The model

In this section, we analyze three different scenarios: *i*) *No alliance*; *ii*) *Non-ATI alliances*, which allow partner airlines to make joint decisions on the choice of flight frequencies; and *iii*) *ATI alliances*, under which partners collaborate in determining both fares and frequencies.

## 2.1 No alliance

Before any alliance process, let us consider an international context in which we have four carriers, each of them providing a non-stop air service between a spoke airport (A or B) and a hub airport (C or D), as shown in Fig. 1.

–Insert Fig. 1 here–

It is assumed that the only relevant demand is found in the airport-pair market AB, where airlines 1 and 3 (respectively 2 and 4) provide interline connecting services. Thus, the considered market is a duopoly and passengers choose whether to travel with carriers 1 and 3 through hub C or with carriers 2 and 4 through hub D. In fact, there is a demand for a composite good and each carrier chooses *monopolistically* a subfare (or partial price) $p_i$ with $i = 1, 2, 3, 4$ for its complementary input, so that the total fare in the market is either $p_1 + p_3$ or $p_2 + p_4$, depending on the routing.

The two competing air services are assumed to be vertically-differentiated, where quality is proxied by flight frequency. It is a common practice to consider flight frequency as the main quality attribute for airline services, as a higher frequency increases passengers' travel opportunities.[8] Bilotkach *et al.* (2013) propose a similar model to study cooperation between two rival airlines in a certain airport-pair market. Instead, we analyze the formation of complementary alliances in a set-up that allows differentiating between non-ATI and ATI alliances.

More specifically, we assume utilities to be $U_{13} = \sigma\frac{f_1+f_3}{2} - (p_1 + p_3)$ and $U_{24} = \sigma\frac{f_2+f_4}{2} - (p_2 + p_4)$, so that consumer heterogeneity arises from different valuations of product quality ($\sigma$), with $\sigma \sim U[1, z]$ and $z \geqslant 2$, with $z$ being a measure of preference dispersion. Flight frequency (i.e., service quality) on each of the routings ($f_i$) is given by the average frequency on the two involved segments.[9] Without loss of generality, it is assumed that the air service supplied by carriers 1 and 3 is characterized by a lower quality of service (and therefore it is offered at lower fares), so that $\frac{f_2+f_4}{2} > \frac{f_1+f_3}{2} > 0$ and $p_2 + p_4 > p_1 + p_3 > 0$.[10]

Denoting $d_f = \frac{f_2+f_4}{2} - \frac{f_1+f_3}{2} > 0$ the service *quality gap*, $d_p = p_2 + p_4 - p_1 - p_3 > 0$ the *fare gap*, and assuming fully-served markets,[11] the indifferent consumer's valuation of service quality is given by $\sigma_0 = \frac{d_p}{d_f}$, as depicted in Fig. 2.

–Insert Fig. 2 here–

Passengers with a lower valuation of service quality purchase the lower-quality composite good (i.e., air service 13) and travelers with a higher valuation of service quality purchase the higher-quality composite good (i.e., air service 24). Since markets are fully-served, $U_{13}(\sigma = 1) \geqslant 0$ and $U_{24}(\sigma = \sigma_0) \geqslant 0$ require $\frac{f_1+f_3}{2} \geqslant p_1 + p_3$ and $\frac{d_p(f_2+f_4)}{d_f} \geqslant p_2 + p_4$, respectively. Since market shares are $\phi_{13} = \frac{\sigma_0-1}{z-1}$ and $\phi_{24} = \frac{z-\sigma_0}{z-1}$, demands are given by

$$\begin{aligned} q_{13} &= \underbrace{\frac{d_p - d_f}{(z-1)\, d_f}}_{\phi_{13}} H, \\ q_{24} &= \underbrace{\frac{z d_f - d_p}{(z-1)\, d_f}}_{\phi_{24}} H, \end{aligned} \tag{1}$$

where $H > 0$ stands for market size. Note that $d_f \leqslant d_p \leqslant z d_f$ is assumed to ensure non-negative quantities. A consequence of having fully-served markets is that either a higher quality gap ($d_f$) or a lower fare gap ($d_p$) imply a higher relative traffic volume since $q_{24} - q_{13} = \frac{(z+1)d_f - 2d_p}{(z-1)d_f} H$.

On the cost side, a flight's operating cost for carrier $i$ in the absence of congestion is given by $\theta f_i + \tau s_i$ where $s_i$ stands for carrier $i$'s aircraft size (i.e., the number of seats) on a given route. Parameters $\theta$ and $\tau$ are the marginal cost per departure (or aircraft-operation cost) and the marginal cost per seat, respectively. Cost per departure ($\theta f_i$) increases with frequency, reflecting decreasing returns as in Brueckner (2009).[12] This cost consists of fuel for the duration of the flight, airport maintenance, renting the gate at which passengers board and disembark, and the landing and air-traffic control fees. All seats are assumed to be filled, so that $s_i = q_k / f_i$, with $k = 13$ for $i = 1, 3$ and $k = 24$ for $i = 2, 4$. Therefore, the aircraft size on a route can be adapted given the airline's total traffic and the number of flights.[13] Note that the cost per seat, which can be written $\theta q_k / s_i^2 + \tau$, visibly decreases with $s_i$ capturing the presence of economies of traffic density (i.e., economies from operating a larger aircraft) that are unequivocal in the airline industry.

To measure airline congestion costs, it is important to note that the level of congestion experienced by carrier $i$ on a route is attributable to aircraft movements both at the hub airport and at the spoke airport. Aircraft movements are $f_1 + f_3$ at hub airport C, $f_2 + f_4$ at hub airport D, $f_1 + f_2$ at spoke airport A, and $f_3 + f_4$ at spoke airport B. As a consequence, congestion costs are $\eta(2f_1 + f_2 + f_3)$ for airline 1, $\eta(f_1 + 2f_2 + f_4)$ for airline 2, $\eta(f_1 + 2f_3 + f_4)$ for airline 3, and $\eta(f_2 + f_3 + 2f_4)$ for airline 4, with $\eta \geqslant 0$ being the congestion damage.

Thus, carrier 1's *operating cost per flight* becomes $\theta f_1 + \tau s_1 + \eta(2f_1 + f_2 + f_3)$ and, therefore, its total cost from operating on a route becomes $f_1[\theta f_1 + \tau s_1 + \eta(2f_1 + f_2 + f_3)]$. Using $s_i = q_k/f_i$, we obtain $c_1 = \theta f_1^2 + \tau q_{13} + \eta f_1(2f_1 + f_2 + f_3)$. Applying the same reasoning to carriers 2, 3, and 4, airline $i$'s profit $\pi_i = p_i q_k - c_i$ can be rewritten as

$$\begin{aligned}
\pi_1 &= (p_1 - \tau) q_{13} - f_1[\theta f_1 + \eta(2f_1 + f_2 + f_3)], \\
\pi_2 &= (p_2 - \tau) q_{24} - f_2[\theta f_2 + \eta(f_1 + 2f_2 + f_4)], \\
\pi_3 &= (p_3 - \tau) q_{13} - f_3[\theta f_3 + \eta(f_1 + 2f_3 + f_4)], \\
\pi_4 &= (p_4 - \tau) q_{24} - f_4[\theta f_4 + \eta(f_2 + f_3 + 2f_4)],
\end{aligned} \tag{2}$$

indicating that variable costs are independent of the number of flights. The analysis that follows assumes $\tau = 0$ without loss of generality (a similar approach is adopted in Kawamori and Lin, 2013; and Lin, 2015). Fares are therefore reinterpreted as mark-ups over marginal costs (all the computations with $\tau > 0$ are available from the authors on request).

Since fares can be adjusted more easily than frequencies, the model is solved sequentially, with flight frequency being selected before fares.[14] In this way, fares are chosen in a second stage conditional on frequencies, while frequencies are chosen in a first stage taking into account their impact on fares in the second stage. The outcome is a Subgame Perfect Nash equilibrium.

Proceeding by backwards induction, we solve the second stage of the game in which each airline chooses its $p_i$ as a function of $f_1$, $f_2$, $f_3$, and $f_4$. Plugging (1) into (2) and computing $\partial \pi_i / \partial p_i = 0$ for $i = 1, 2, 3, 4$,[15] the airlines' reaction functions are

$$\begin{aligned}
p_1 &= \frac{1}{2}(p_2 + p_4 - p_3 - d_f), \\
p_2 &= \frac{1}{2}(zd_f - p_4 + p_1 + p_3), \\
p_3 &= \frac{1}{2}(p_2 + p_4 - p_1 - d_f), \\
p_4 &= \frac{1}{2}(zd_f - p_2 + p_1 + p_3).
\end{aligned} \tag{3}$$

Rewriting these reaction functions in terms of $d_p$, we obtain $p_1 = p_3 = d_p - d_f$ and $p_2 = p_4 = zd_f - d_p$. Therefore, $p_1 = p_3 > 0$ and $p_2 = p_4 > 0$ since $d_f \leqslant d_p \leqslant zd_f$ has been assumed. Solving the system of equations in (3), we obtain the second-stage equilibrium fares

$$\begin{aligned} p_1 &= p_3 = \frac{(2z-3)\,d_f}{5}, \\ p_2 &= p_4 = \frac{(3z-2)\,d_f}{5}, \end{aligned} \tag{4}$$

which are always positive since $z \geqslant 2$. These equilibrium fares yield the fare gap

$$d_p = \frac{2\,(z+1)\,d_f}{5}, \tag{5}$$

that is always positive and gives rise to the following lemma.

**Lemma 1** *Airlines offering higher-quality services set higher fares and, therefore, the fare gap ($d_p$) increases with the quality gap ($d_f$). In addition, the fare gap rises with preference dispersion ($z$) since more heterogeneous consumers require more differentiated frequencies at more distinguished fares.*

After plugging (5) into (1), we directly obtain the equilibrium quantities given that traffic volumes are independent of flight frequencies in equilibrium. The reason is that the direct effect of $d_f$ on $q_{13}$ and $q_{24}$ is offset by its indirect effect through the fare gap. These equilibrium quantities are

$$\begin{aligned} q_{13}^n &= \frac{2z-3}{5\,(z-1)}H, \\ q_{24}^n &= \frac{3z-2}{5\,(z-1)}H, \end{aligned} \tag{6}$$

where superscript $n$ denotes the no alliance scenario. We can verify that $q_{24}^n > q_{13}^n$, which is a direct consequence of $d_f > 0$ because a higher flight frequency typically results in a higher traffic volume. Plugging (4) and (6) into (2) gives rise to the airlines' first-stage profit functions

$$
\begin{aligned}
\pi_1 &= \underbrace{\frac{(2z-3)^2 d_f}{25(z-1)}H}_{p_1 q_{13}^n} - f_1\left[\theta f_1 + \eta\left(2f_1 + f_2 + f_3\right)\right], \\
\pi_2 &= \underbrace{\frac{(3z-2)^2 d_f}{25(z-1)}H}_{p_2 q_{24}^n} - f_2\left[\theta f_2 + \eta\left(f_1 + 2f_2 + f_4\right)\right], \\
\pi_3 &= \underbrace{\frac{(2z-3)^2 d_f}{25(z-1)}H}_{p_3 q_{13}^n} - f_3\left[\theta f_3 + \eta\left(f_1 + 2f_3 + f_4\right)\right], \\
\pi_4 &= \underbrace{\frac{(3z-2)^2 d_f}{25(z-1)}H}_{p_4 q_{24}^n} - f_4\left[\theta f_4 + \eta\left(f_2 + f_3 + 2f_4\right)\right],
\end{aligned} \tag{7}
$$

which are functions of $f_1$, $f_2$, $f_3$, and $f_4$. The first term in the expressions is the margin, which is larger for airlines 2 and 4, given that $p_2 = p_4 > p_1 = p_3$ and $q_{24}^n > q_{13}^n$. By inspection of (7), it can be verified that $\partial\pi_1/\partial f_1 < 0$ and $\partial\pi_3/\partial f_3 < 0$. Therefore, airlines 1 and 3 will choose the minimum possible frequency (corner solution).

Given that markets are fully-served, this value of $f_1$ and $f_3$ will be the one making $U_{13}(\sigma = 1) = 0$, as shown in Fig. 2. This implies that $\frac{f_1+f_3}{2} = p_1 + p_3$ and therefore airline 1's reaction function is $f_1 = 2\left(p_1 + p_3\right) - f_3$. Applying symmetry in subfares (i.e., $p_1 = p_3$), we obtain $f_1 + f_3 = 4p_1$; and using (4) and applying symmetry in frequencies (i.e., $f_1 = f_3$ and $f_2 = f_4$) this reaction function becomes

$$
f_1 = 2\frac{f_2\left(2z-3\right)}{4z-1}. \tag{8}
$$

From $\partial\pi_2/\partial f_2 = 0$ and after applying symmetry,[16] the remaining reaction function is

$$
f_2 = \frac{H\left(3z-2\right)^2 - 50\eta f_1\left(z-1\right)}{50\left(z-1\right)\left(5\eta + 2\theta\right)}. \tag{9}
$$

The reaction functions have different slopes and yield a stable equilibrium outcome,[17] which allows us to compute the equilibrium service quality gap, which is

$$
d_f^n = \frac{H\left(3z-2\right)^2}{10\left(z-1\right)\left[\eta\left(24z-11\right) + 2\theta\left(4z-1\right)\right]}, \tag{10}
$$

which is always positive. To illustrate the properties of the equilibrium, we undertake a comparative-static analysis, which is summarized in the lemma that follows.

**Lemma 2** *The quality gap ($d_f^n$) falls with an increase in the congestion damage ($\eta$) or the fixed flight cost ($\theta$). The quality gap rises with market size ($H$) and the effect of preference dispersion ($z$) is ambiguous.*

The above lemma suggests that an increase in costs (fixed cost and congestion damage) has a more marked impact on the quality of carriers 2 and 4; as a consequence, the quality gap becomes narrower. Furthermore, it is also found that larger markets have a positive impact on service quality gap. These results seem to be driven by the fact that airlines 2 and 4 operate more flights (and higher traffic volumes), *which makes them more sensitive to changes in cost parameters and market size.*

Substituting in the second-stage choice variables, we can compute $p_1^n = p_3^n = \frac{f_1^n}{2}$, $p_2^n = p_4^n = \frac{(3z-2)d_f^n}{5}$,[18] and $d_p^n = \frac{2(z+1)d_f^n}{5}$, which are obviously positive.

## 2.2 Non-ATI alliances

In this scenario, non-ATI alliances are formed between partner airlines (1-3 and 2-4).[19] There are many examples of non-immunized within the three big alliances, e.g., Air Berlin (Oneworld), Air Europa (SkyTeam) or Turkish Airlines (Star Alliance). We consider that partners are able to make joint decisions regarding flight frequencies, whereas their fares are determined independently. Thus, the second stage of the game remains as in the no alliance scenario, i.e., $q_{13}^a = q_{13}^n$ and $q_{24}^a = q_{24}^n$ (see (6)) where superscript $a$ denotes non-ATI alliances. In the first stage, allied carriers 1-3 jointly choose $f_1$ and $f_3$ and partners 2-4 jointly determine $f_2$ and $f_4$ to maximize

$$\pi_{13} = \underbrace{\frac{2(2z-3)^2 d_f}{25(z-1)}H}_{(p_1+p_3)q_{13}^a} - f_1[\theta f_1 + \eta(2f_1+f_2+f_3)] - f_3[\theta f_3 + \eta(f_1+2f_3+f_4)],$$

$$\pi_{24} = \underbrace{\frac{2(3z-2)^2 d_f}{25(z-1)}H}_{(p_2+p_4)q_{24}^a} - f_2[\theta f_2 + \eta(f_1+2f_2+f_4)] - f_4[\theta f_4 + \eta(f_2+f_3+2f_4)], \quad (11)$$

and again it can be verified that $\partial\pi_{13}/\partial f_1 < 0$ and $\partial\pi_{13}/\partial f_3 < 0$, meaning that the optimal $f_1$ and $f_3$ is obtained as a corner solution (i.e., $\frac{f_1+f_3}{2} = p_1 + p_3$). Consequently, we obtain the same reaction function for airline 1 as in the pre-alliance scenario (see (8)). From $\partial\pi_{24}/\partial f_2 = 0$ and after applying symmetry,[20] we obtain the remaining reaction function, which is given by

$$f_2 = \frac{H(3z-2)^2 - 25\eta f_1(z-1)}{50(z-1)(3\eta+\theta)}. \quad (12)$$

The equilibrium frequencies are obtained from these reaction functions.[21] The equilibrium service quality gap is therefore

$$d_f^a = \frac{H\,(3z-2)^2}{10\,(z-1)\,[2\eta\,(7z-3)+\theta\,(4z-1)]}, \tag{13}$$

which is always positive. The comparative-static analysis in the double non-ATI alliance case shows the same effects as in the pre-alliance scenario (i.e., see Lemma 2).

Finally, substituting in the second-stage choice variables, we can compute $p_1^a = p_3^a = \frac{f_1^a}{2}$ and $p_2^a = p_4^a = \frac{(3z-2)d_f^a}{5}$.[22] Since fares are chosen as in the pre-alliance case (i.e., second stage of the game), the fare gap is as in the previous scenario after replacing $d_f^n$ by $d_f^a$, which is obviously positive.

## 2.3 ATI alliances

When ATI alliances are formed, airlines are allowed to cooperate both in frequency and fare decisions. Every legacy carrier within the three big alliances is immunized on several airport-pair markets. Some examples are the ATI agreements involving American Airlines and British Airways-Iberia-Finnair (Oneworld), Delta and Air France/KLM-Alitalia-Czech Airlines (SkyTeam) or United and Brussels Airlines-Lufthansa-SAS-Austrian-LOT-Swiss-TAP (Star Alliance). Therefore, in the second stage, allied carriers 1-3 jointly choose $p_1$ and $p_3$ to maximize $\pi_{13} = \pi_1 + \pi_3$, and partners 2-4 jointly determine $p_2$ and $p_4$ to maximize $\pi_{24} = \pi_2 + \pi_4$, where $\pi_1$, $\pi_2$, $\pi_3$, and $\pi_4$ are given in (2). From the first-order conditions,[23] we obtain the airlines' reaction functions for the full fares $p_1 + p_3$ and $p_2 + p_4$ in the airport-pair market AB

$$\begin{aligned} p_1 + p_3 &= \frac{1}{2}\left[(p_2+p_4) - d_f\right], \\ p_2 + p_4 &= \frac{1}{2}\left[z d_f + (p_1+p_3)\right], \end{aligned} \tag{14}$$

which show that full fares are strategic complements. These reaction functions can be rewritten in terms of $d_p$, yielding $p_1 + p_3 = d_p - d_f$ and $p_2 + p_4 = z d_f - d_p$, which are positive since $d_f \leqslant d_p \leqslant z d_f$ has been assumed.

From (14), we obtain the following equilibrium full fares in the second stage

$$\begin{aligned} p_1 + p_3 &= \frac{(z-2)\,d_f}{3}, \\ p_2 + p_4 &= \frac{(2z-1)\,d_f}{3}, \end{aligned} \tag{15}$$

which yield the fare gap

$$d_p = \frac{(z+1)\, d_f}{3} \tag{16}$$

and identical comparative-static effects as in Lemma 1.

Equilibrium traffic volumes, which are independent of flight frequencies as in the previous scenarios, are

$$\begin{aligned} q_{13}^A &= \frac{z-2}{3\,(z-1)} H, \\ q_{24}^A &= \frac{2z-1}{3\,(z-1)} H, \end{aligned} \tag{17}$$

where superscript $A$ denotes ATI alliances. As before, the higher frequency supplied by partner airlines 2-4 implies $q_{24}^A > q_{13}^A$. Using (15) and (17), we obtain the airlines' first-stage profit functions

$$\begin{aligned} \pi_{13} &= \underbrace{\frac{H\,(z-2)^2\, d_f}{9\,(z-1)}}_{(p_1+p_3)q_{13}^A} - f_1\left[\theta f_1 + \eta\,(2f_1 + f_2 + f_3)\right] - f_3\left[\theta f_3 + \eta\,(f_1 + 2f_3 + f_4)\right], \\ \pi_{24} &= \underbrace{\frac{H\,(2z-1)^2\, d_f}{9\,(z-1)}}_{(p_2+p_4)q_2^A} - f_2\left[\theta f_2 + \eta\,(f_1 + 2f_2 + f_4)\right] - f_4\left[\theta f_4 + \eta\,(f_2 + f_3 + 2f_4)\right], \end{aligned} \tag{18}$$

where the optimal $f_1$ and $f_3$ are obtained as a corner solutions since $\partial\pi_{13}/\partial f_1 < 0$ and $\partial\pi_{13}/\partial f_3 < 0$. Using $\frac{f_1+f_3}{2} = p_1 + p_3$ and applying symmetry, we obtain

$$f_1 = \frac{(z-2)\, f_2}{z+1}. \tag{19}$$

From $\partial\pi_{24}/\partial f_2 = 0$ and applying symmetry,[24] we obtain the remaining reaction function, which is given by

$$f_2 = \frac{H\,(2z-1)^2 - 18\eta f_1\,(z-1)}{36\,(z-1)\,(3\eta+\theta)}. \tag{20}$$

As before, the reaction functions have different slopes and yield a stable equilibrium outcome,[25] which allows us to compute the equilibrium service quality gap

$$d_f^A = \frac{H\,(2z-1)^2}{6\,(z-1)\left[\eta\,(7z+4) + 2\theta\,(z+1)\right]}, \tag{21}$$

which is always positive. The comparative-static analysis in the ATI alliance case shows the same effects as in the no alliance and non-ATI alliance scenarios (i.e., see Lemma 2).

Substituting in the second-stage choice variables, we can compute $p_1^A = p_3^A = f_1^A/2$ and $p_2^A = p_4^A = \frac{d_f^A(2z-1)}{6}$.[26] Finally, the fare gap is $d_p^A = \frac{(z+1)d_f^A}{3}$, which is obviously positive.

Interestingly, a standard duopoly setting arises in the presence of ATI alliances, just as in Shaked and Sutton (1983). Therefore, we can verify that, in the case of minimum preference dispersion, intense fare competition drives the low service quality airline out of the market, i.e., when $z = 2$, the equilibrium fare for airline 1 is $p_1^A = p_3^A = 0$ and thus $q_{13}^A = 0$ and $\pi_1^A < 0$. Therefore, $z$ determines the number of airlines operating in the industry and, hence, the intensity of competition (regardless of demand size and fixed costs).[27]

# 3 The effects of alliances

In this section we first assess the effects of non-ATI alliances by comparing flight frequencies and fares in the pre and post-alliance scenarios. Then we replicate the same exercise in the move from non-ATI alliances to ATI alliances, which is tantamount to considering that the existing alliances are granted ATI. Finally, we analyze the impact of congestion on the results of these comparisons.

## 3.1 Non-ATI alliances

Let us denote $\Delta_{f_1}^{a-n} = f_1^a - f_1^n$, $\Delta_{f_2}^{a-n} = f_2^a - f_2^n$, $\Delta_{p_1}^{a-n} = p_1^a - p_1^n = \Delta_{f_1}^{a-n}/2$,[28] and $\Delta_{p_2}^{a-n} = p_2^a - p_2^n$. By observing these differences, it can be checked that all of them are positive. The following lemma summarizes the results of these comparisons.

**Lemma 3** *Non-ATI alliances yield higher fares and frequencies, i.e.,* $\Delta_{f_1}^{a-n} > 0$, $\Delta_{f_2}^{a-n} > 0$, $\Delta_{p_1}^{a-n} > 0$, *and* $\Delta_{p_2}^{a-n} > 0$.

Therefore, in a vertically-differentiated market, allowing allied partners to make joint decisions regarding flight frequencies yields higher fares and frequencies. This is explained by the elimination of a double marginalization in frequencies, which raises coordinated frequencies. A higher service quality increases passengers' willingness-to-pay and yields higher fares.

Equivalently, we can define $\Delta_{d_f}^{a-n} = d_f^a - d_f^n = \Delta_{f_2}^{a-n} - \Delta_{f_1}^{a-n}$.[29] The proposition below shows that the quality gap also increases after non-ATI alliances are formed.

**Proposition 1** *Non-ATI alliances increase the quality gap, i.e.,* $\Delta_{d_f}^{a-n} > 0$.

This proposition suggests that the differentiation between high and low quality air services is accentuated after non-ATI alliances, and more flights are channeled via the higher service-quality routing.[30] It can also be observed that the indifferent consumer $\sigma_0$ remains unaltered, which means that the market shares and the equilibrium quantities are the same before and after the alliance.[31]

## 3.2 ATI alliances

We consider the transition from non-ATI alliances to an ATI alliances since, typically, a certain degree of schedule coordination is a pre-condition for achieving deeper levels of cooperation. Proceeding in the same way as before, we can define $\Delta_{f_1}^{A-a} = f_1^A - f_1^a$, $\Delta_{f_2}^{A-a} = f_2^A - f_2^a$, $\Delta_{p_1}^{A-a} = p_1^A - p_1^a = \Delta_{f_1}^{A-a}/2$,[32] and $\Delta_{p_2}^{A-a} = p_2^A - p_2^a$. By observing these differences, it can be checked that all of them are negative. Then the following lemma summarizes the results of these comparisons.

**Lemma 4** *Both flight frequencies and fares decrease when alliances are granted ATI, i.e.,* $\Delta_{f_1}^{A-a} < 0$, $\Delta_{f_2}^{A-a} < 0$, $\Delta_{p_1}^{A-a} < 0$, *and* $\Delta_{p_2}^{A-a} < 0$.

This result indicates that granting ATI to existing alliances exerts a downward pressure on both service quality and airfares. Although the decrease in fares could be expected due to the elimination of a double marginalization in fares, the downward movement of frequencies seems more surprising. However, the findings in Lemma 4 show an alignment between fares and frequencies, which is consistent with the results in Lemma 3. The reason is that poorer frequencies are associated with a lower willingness to pay that exerts a downward pressure on fares. Besides, as shown in Flores-Fillol (2010), alliances induce their members to internalize the congestion imposed on their partners, which again exerts a downward pressure on fares.[33]

As in the previous comparison, we can define $\Delta_{d_f}^{A-a} = d_f^A - d_f^a = \Delta_{f_2}^{A-a} - \Delta_{f_1}^{A-a}$.[34] The proposition below shows that the quality gap increases as a consequence of granting ATI to existing alliances.

**Proposition 2** *The quality gap increases when alliances are granted ATI, i.e.,* $\Delta_{d_f}^{A-a} > 0$.

Therefore, even though the effect on fares and frequencies are the opposite as compared to the formation of non-ATI alliances, in both cases consolidation leads to a more pronounced differentiation in terms of service quality since more flights are channeled through the higher service-quality routing.[35] It can also be observed that the indifferent consumer $\sigma_0$ moves to the left, which means that the market share and the equilibrium quantity increases for the higher-quality service.[36]

Since Lemmas 3 and 4 yield opposite effects, to ascertain the overall effect of ATI alliances, we can look at the direct move from a pre-alliance scenario to another one where ATI alliances are formed. The corollary below summarizes the results of this comparison.

**Corollary 1** *Departing from a pre-alliance situation, ATI alliances yield an increase in fares and frequencies on the high service-quality routing whereas the effects on the low-quality routing are unclear.*

Therefore, the positive effect of non-ATI alliances on fares and frequencies on the higher service-quality routing dominate the countervailing effect associated to granting ATI. As for the overall effect of ATI alliances on the quality gap, the joint observation of Propositions 1 and 2 gives rise to the corollary below.

**Corollary 2** *Departing from a pre-alliance situation, ATI alliances yield an increase in the quality gap.*

This is a straightforward result since both moves (from no alliance to non-ATI alliances and from non-ATI alliances to ATI alliances) produce an increase in quality gap.

## 3.3 The role of congestion

Having explained the effects of airline alliances, we now shift our attention to the analysis of congestion in order to determine its impact on the reorganization of fares and flight frequencies after the formation of airline alliances. More precisely, its seems natural to wonder about the effect of congestion in the concentration of flights on the high-quality routing after non-ATI alliances are formed (see Lemma 3). The result of this analysis is summarized in the proposition that follows.

**Proposition 3** *Airport congestion mitigates the concentration of frequencies through the higher-quality routing induced by the formation of non-ATI alliances, i.e.,* $\partial\Delta_{f_1}^{a-n}/\partial\eta < 0$ *and* $\partial\Delta_{f_2}^{a-n}/\partial\eta < 0$.

Thus, congestion may serve to prevent the concentration of flight frequency on the higher service-quality routing induced by alliances by creating incentives to use the poorer service-quality connection more intensively.

Another natural question has to do with the effect of congestion on the accrued quality gap associated with alliances (see Propositions 1 and 2 along with Corollary 2).

**Proposition 4** *Airport congestion moderates the increase in quality gap that follows alliances (both non-ATI and ATI), i.e.,* $\partial\Delta_{d_f}^{a-n}/\partial\eta < 0$*,* $\partial\Delta_{d_f}^{A-a}/\partial\eta < 0$*, and* $\partial\Delta_{d_f}^{A-n}/\partial\eta < 0$*.*

The above proposition reveals that congestion reduces this asymmetry in terms of quality gap.

# 4 Empirical application

In this section, an empirical application is proposed to test the effects of alliances on frequencies and quality gap in interline connections. We first discuss some details about the sample and then explain the estimated equation along with the obtained results. Finally, we incorporate a subsection where we relate our theoretical predictions on fares with the empirical results in Brueckner and Singer (2019), the most recent and comprehensive study on the effect of airline alliances on fares.

## 4.1 Data

The sample considers one-stop routings (operated by one or several airlines) linking airports between US/Canada and Europe.[37] The routings are non-directional, being the origin a US/Canadian airport and the destination a European airport. Therefore, the routings included in our database are at the airport-pair level.[38] Two different types of routings can be found in our sample: *i*) the ones connecting at a US/Canadian hub airport, e.g., the routing from Albuquerque to Amsterdam through Washington-Dulles, and *ii*) the ones connecting at a European airport, e.g., the routing from Atlanta to Athens via Amsterdam. In both cases, the routing is composed by a long-haul transatlantic segment and a short-haul segment within US/Canada or Europe.

As a control variable, we include a dummy that takes the value 1 for itineraries having a layover at a North American hub airport. In the previous examples, this variable would take the value 1 on the routing from Albuquerque to Amsterdam through Washington-Dulles, and 0 on the routing from Atlanta to Athens via Amsterdam. Note that only flights operated by the hub airline are designated as hub airport. This means that, for example, flights operated by Delta from Atlanta receive the hub designation but flights operated by

American Airlines do not receive it. We provide a list of airlines (involved in alliances) with their corresponding hub airports in Table B.1 in Appendix B.

The sample includes about $253,775$ one-way observations at the quarterly level from the first quarter of 2010 until the third quarter of 2017, with data on total traffic. Due to the lack of information for frequencies on certain routings, we finally have $227,957$ observations. With the purpose of having a feasible dataset, only routings with a minimum of 100 passengers per quarter are considered. The analysis is restricted to urban areas with a population exceeding $300,000$ inhabitants, given that the comparable source of population data for both US/Canadian and European cities follows this criterion.

Data on traffic come from OAG and include one-stop routings. Supply data (flight frequency and distance measured in kilometers) come from RDC Aviation (Innovata data). Population at both routing endpoints is also included in the analysis, using data at the urban level from United Nations (World Urbanization Prospects). We also account for GDP per capita at both routing endpoints, using data at the country level from the World Bank (World Development Indicators). Our sample of routings includes the US and Canada in North America and almost every European country.

As a control variable, we include a dummy for routings having an open skies agreement between the origin and destination countries (information comes from the US Department of State and Transport Canada). Open skies agreements between the US and Europe incorporate EU countries plus Norway, Switzerland, Turkey, Albania, Bosnia and Herzegovina, Georgia, Macedonia (since the last quarter of 2012), Serbia (since the third quarter of 2015), and Ukraine (since the last quarter of 2015). As for the Canada-Europe agreements, they involve EU countries plus Switzerland (since the last quarter of 2010).

*Methodology to construct the frequency variable.* As pointed out in footnote 9, it seems unclear how to model the effect of frequencies for connecting passengers from first principles. However, the two main natural approaches are the *mean* frequency and the *minimum* of the airline frequencies in the involved route segments. Brueckner and Flores-Fillol (2019) study in depth the microeconomic foundations of each alternative. Consequently and with the purpose of providing robust empirical results, we consider both approaches. More precisely, we compute *i*) the mean frequency between the short-haul and the long-haul segment weighted by distance and *ii*) the minimum frequency that is usually associated to the long haul segment of the routing. The mean approach is consistent with our theoretical model (also adopted in Flores-Fillol, 2010; Bilotkach *et al.*, 2013; Kawamori and Lin, 2013; Lin, 2015; and Czerny *et al.*, 2016) and has the advantage of being more comprehensive, as it incorporates both segments of the routing. Instead, the minimum frequency only considers one of the two segments of the routing (usually the long-haul one). Thus, our baseline regressions consider the mean frequency as dependent variable and we include a specification having the minimum frequency as dependent variable as a robustness check.

Data on traffic is at the airline-routing level and provides information about carriers operating on the long-haul route segment, so that no information on carriers operating on the short-haul route segment is available. For example, on the routing Albuquerque-Washington-Amsterdam, we just know that the Washington-Amsterdam flight is operated by United. Therefore, some assumptions on the short-haul segment are needed to compute the mean frequency. We proceed in the following way. First, we consider the flight frequency of the airline operating the long-haul segment. Second, to determine the frequency on the short-haul segment, we combine the flights provided by the airline serving the long-haul segment with those provided by its alliance partners. Finally, the mean frequency of the routing is computed as the mean value of the frequencies on both route segments weighted by the distance of each of them. For example, consider the routing operated by Air France/KLM between Albuquerque and Paris-CDG via Atlanta. The distance of the segment Alburquerque-Atlanta is 2037 kilometers (22.4% of the routing distance) and the distance of the segment Atlanta-Paris is 7055 kilometers (77.6% of the routing distance). During the second quarter of 2013, SkyTeam partners operated 203 flights on the route Albuquerque-Atlanta while Air France/KLM operated 182 flights on the route Atlanta-Paris. Adding up the frequencies on both segments multiplied by their respective weight (in terms of routing distance) leads to a mean flight frequency of 186.7 flights.

*Online and interline routings.* We can distinguish between *online* services (when both segments are operated by the same airline) and *interline* services (when each of the segments is operated by a different airline). More precisely, online services include *i*) routings where the long-haul segment is operated by a US/Canadian carrier and the connection between flights takes place at one of its hub airports in the US/Canada (e.g., El Paso-Dallas-Madrid where the long-haul segment is operated by American Airlines); and *ii*) routings where the long-haul segment is operated by a European carrier and the connection between flights takes place at one of its hub airports in Europe (e.g., Seattle-Frankfurt-Naples where the long-haul segment is operated by Lufthansa). Thus, some few online routings in our sample could be in fact operated by two different airlines (more precisely, by two European airlines within the same alliance). However, this is not a major limitation since our main purpose is to study cooperation between US/Canadian and European airlines.[39]

Since US/Canadian carriers do not operate in the intra-European market and European carriers do not operate in the US/Canadian domestic market, *interline* services occur when a US/Canadian airline and a European airline operate each of the two segments on a routing. In terms of our sample, this happens *i*) when the long-haul segment is operated by a US/Canadian carrier and the connection between flights takes place at a European gateway (e.g., Atlanta-Amsterdam-Stockholm where the long-haul segment is operated by Delta), or *ii*) when the long-haul segment is operated by a European carrier and the connection between flights takes place at a US/Canadian gateway (e.g., Albuquerque-Atlanta-Paris where the long-haul segment is operated by Air France/KLM).

*Airlines in ATI and non-ATI alliances.* For each of the three big alliances (Oneworld, SkyTeam, and Star Alliance), our sample contains *ATI agreements* between at least one US/Canadian partner and one European partner.[40] More precisely, there are ATI agreements within *i*) Oneworld, between American Airlines and British Airways-Iberia-Finnair; *ii*) SkyTeam, between Delta and Air France/KLM-Alitalia-Czech Airlines; and between Delta and Virgin Atlantic;[41] and *iii*) Star Alliance, between United and Air Canada (and Continental until its brand was collapsed into that of United) and Brussels Airlines-Lufthansa-SAS-Austrian-BMI (until it went bankrupt)-LOT-Swiss-TAP.

As for *non-ATI alliances*, US Airways is the only non-immunized US/Canadian carrier in our sample. This airline was a member of Star Alliance until the first quarter of 2014, when it became a member of Oneworld from the second quarter of 2014 (when it merged with American Airlines) to the third quarter of 2015 (when its brand was collapsed into that of American Airlines). Differently, there are several non-immunized European carriers within each of the three big alliances. More precisely, within *i*) Oneworld: Air Berlin, S7, and Aer Lingus (since the last quarter of 2015 when it was acquired by IAG); *ii*) SkyTeam: Air Europa, Aeroflot, and Tarom; and *iii*) Star Alliance: Adria Airways, Croatia Airlines, Turkish Airlines, and Aegean (since the third quarter of 2010).[42]

Finally, the main unallied airlines in our sample include Jet Airways, Norwegian, Emirates, Arkefly, Air Transat, and Aer Lingus (until the third quarter of 2015).

*ATI and non-ATI routings.* Taking into account the information about ATI and non-ATI alliances, we can classify interline routings in our sample (where a US/Canadian airline and a European airline cooperate) into three categories: ATI, non-ATI, and no alliance. *ATI routings* include two hubs of airlines involved in an ATI agreement (e.g., Atlanta-Amsterdam-Stockholm, operated by Delta and Air France/KLM). *Non-ATI routings* incorporate two hubs of airlines engaged in a non-ATI alliance (e.g., Atlanta-Madrid-Bilbao, operated by Delta and Air Europa).[43] In the remaining routings, we consider that interline cooperation takes place between unallied carriers. This may be the case of routings where the long-haul segment is operated by an unallied airline (e.g., Montreal-Lisbon-Paris, operated by Air Transat) or routings that link hubs of airlines in different alliances (e.g., Washington-Boston-Madrid, with the long-haul segment being operated by Iberia). Most interline routings between unallied carriers refer to the latter situation.

Finally, it is important to underline the importance of online observations in our sample. In particular, we have $211,206$ observations for online routings and $42,569$ for interline routings. Within the interline routings, we can identify $33,100$ observations for ATI routings, $2,524$ for non-ATI routings, and $6,945$ for no alliance routings.

## 4.2 Estimation

We estimate an equation where the dependent variable is *the mean* flight frequency offered by airline $a$ on routing $k$ in period $t$

$$\begin{aligned} freq_{akt} = {} & \alpha + \beta_1 online_{akt} + \beta_2 non\text{-}ATI\_all_{akt} + \beta_3 ATI\_all_{akt} + \beta_4 dist + \\ & \beta_5 pop\_origin_{kt} + \beta_6 pop\_destin_{kt} + \beta_7 GDPpc\_origin_{kt} + \beta_8 GDPpc\_destin_{kt} + \\ & \beta_9 HHI_{kt} + \beta_{10} non\text{-}stop\_route_{kt} + \beta_{11} open\_skies + \beta_{12} NA\_hub_{kt} + \gamma' airline + \\ & \lambda' year + \mu' quarter + \upsilon' airport\_origin + \varphi' airport\_destin + \varepsilon_{akt}, \end{aligned} \tag{22}$$

where all continuous variables are expressed in logs. It should be recalled that the frequency of air services is our proxy for service quality (as in Bilotkach *et al.*, 2013).

The main explanatory variables in the equation are the ones capturing the different levels of cooperation between airlines on the routing ($online$, $non\text{-}ATI\_all$, and $ATI\_all$), being *no alliance* the reference case.[44] According to our theoretical predictions, frequencies and quality gap should be higher on non-ATI routings as compared to no alliance routings (see Lemma 3 and Proposition 1). Furthermore, frequencies should be lower on ATI routings as compared to non-ATI routings (see Lemma 4), although the quality gap should be higher (see Proposition 2). Our frequency equation is estimated as a gravity model due to the strong correlation between demand and supply. Therefore, we take account of the population and GDP per capita at both routing endpoints as demand shifters (variables $pop\_origin$, $pop\_destin$, $GDPpc\_origin$, and $GDPpc\_destin$).

Distance is also included as an explanatory variable. A negative relationship is expected since demand is expected to be lower on longer routings.

Furthermore, we also bring in three variables that account for the effect of competition intensity on frequencies: the Herfindahl-Hirschman Index ($HHI$ variable), the non-stop dummy (*non-stop_route* variable), and the open skies dummy (*open_skies* variable).

The HHI variable is constructed as the sum of the square traffic market shares of each airline-routing on an airport-pair (airport-pairs consist of an origin and a final-destination airport). Thus, some airlines may also offer point-to-point services on the short-haul segment that our HHI variable is not able to capture.[45] Given that we are considering many routings with different stop-over airports to serve each airport-pair (i.e., origin and final destination airports), the potential endogeneity bias of our HHI variable should be modest. In any case, to account for the potential endogeneity bias of HHI, we include a specification where it is dropped and another one where it is lagged one-year (more details in the following subsection).

The non-stop dummy takes the value one if the airport-pair is also served non-stop, so that there is competition between one-stop and non-stop services. The open skies dummy takes the value one whenever an open skies agreement is in place between the origin and destination countries.

Finally, we include a dummy variable that takes the value one for routings channeled through a North American hub airport (*NA_hub* variable). Unreported year, quarter, airline, and airport fixed effects are also added in the regressions. Standard errors are robust to heteroscedasticity and clustered by route (airport-pair level).

Table 1 shows the descriptive statistics of the variables included in equation (22).

–Insert Table 1 here–

As mentioned above, a high proportion of routings involve online services whereas a high proportion of interline services are ATI routings. Average frequencies are relatively high with more than one flight every two days and, as expected, the average routing distance is also high given that our sample is based on transatlantic connections. Population and income are higher for the origin airport (in the US/Canada) than for the destination airport (in Europe). The descriptive statistics on Table 1 suggest that competition on many routings in our sample may be intense as *i*) the HHI is relatively low, *ii*) about one third of routings compete with non-stop services, and *iii*) most routings are affected by open-skies agreements. Finally, about 40% of routings include a US/Canadian hub airport while that the rest of itineraries have a layover at a European hub airport.

We run regressions for the entire sample and for subsamples differentiating between high and low-quality routings. In the subsamples, we exclude those routings competing with non-stop services to avoid a distortion in the differentiation between high and low-quality routings.

In our analysis of quality gap, we use three different measures to distinguish between high- and low-quality routings. First, we use a measure based on the traffic share in each airport-pair. Following this criterion, the routing with the maximum market share in terms of traffic is considered to be high-quality, while the remaining routings are classified as low-quality. Second, we use a measure based on the routing distance (in total kilometers).[46] Following this approach, for each airport-pair, the routing characterized by the shortest distance is considered to be high-quality, while the remaining routings are classified as low-quality. Finally, we use a measure based on flight frequency. In this case, for each airport-pair, the routing having the higher frequency is considered to be high-quality, while the remaining routings are classified as low-quality.

We use these three different measures with the ultimate purpose of producing robust results, as each of them has certain advantages and drawbacks. The advantage of the traffic share measure is that it captures different quality attributes, including frequencies and total travel times. A potential shortcoming is that it may be affected by market power effects. However, such potential distortion should be modest in one-stop airport-pairs as, generally, passengers have several alternatives (i.e., routings) to reach their final destination. It should also be recalled that equation (22) incorporates three explanatory variables that control for the intensity of competition on the routing (the $HHI$, the *non-stop_route*, and the *open_skies* variables). Focusing now on the measure based on the routing distance, it has the benefit of not being affected by any market-power distortion. However, it has the disadvantage of being disconnected from our theoretical model (which does not include any route-distance consideration). Finally, the measure based on flight frequency has the advantage of being consistent with our theoretical analysis. Its main drawback has to do again with market-power distortions (in the same way as the traffic share measure); furthermore, a distinction between high- and low-quality routings based on values of the dependent variable may impose additional difficulties in the identification of the quality gap, due to the remarkable difference in frequencies between the two subsamples (for all types of routings).

As an example of the traffic share measure in the distinction between high- and low-quality routings, consider the airport-pair Kansas City-Rome Fiumicino during the third quarter of 2017. The high quality-routing is Kansas City-Atlanta-Rome, with the long-haul segment being operated by Delta. The low-quality routings include those having *i*) Chicago, Charlotte, and Dallas as gateways and the long-haul segment being operated by American Airlines; *ii*) Chicago as gateway and the long-haul segment being operated by United; and *iii*) Detroit as gateway and the long-haul segment being operated by Delta. For the same airport-pair, the high-quality routing in terms of flight frequency remains the same (i.e., Kansas city-Atlanta-Rome, with the long-haul segment being operated by Delta). Instead, the high-quality routing in terms of distance has Detroit as gateway, with the long-haul segment being operated by Delta. The high-quality routing in terms of traffic share comprises 360 passengers, while the rest of routings have 200 passengers or less. In terms of routing distance, the high-quality routing is $7,500$ kilometers long, while the distance of the remaining routings exceed $7,800$ kilometers. Finally, the high-quality routing in terms of flight frequency encompasses 279 flights, while the rest of routings have 150 flights or less.

## 4.3 Results

Our first set of results analyze the effect of alliances (ATI and non-ATI) on flight frequency; then we look at their impact on quality gap.

### 4.3.1 Effects of alliances on flight frequency

Table 2 shows the estimation of different specifications of equation (22) using the entire sample. Column I shows the results of the baseline regression. To account for the potential endogeneity bias of HHI, column II drops the variable while column III includes one-year lagged values of HHI.[47] Finally, column IV uses the minimum frequency as dependent variable. In all specifications, results for the cooperation variables are consistent with the predictions provided by our theoretical model.

–Insert Table 2 here–

Regarding control variables in the baseline regression, frequencies are lower on longer routings, a finding that is typically explained by the existence of a lower demand along with the exploitation of distance economies. We also find lower frequencies in the presence of non-stop flights that represent a more convenient (i.e., faster) air service.

Frequencies are lower when the coefficient of the HHI variable reflects higher levels of concentration, while they are higher on routings in the liberalized environment implied by open skies agreements. Thus, stronger competition leads to higher frequencies as expected. However, these competition effects do not seem to be strong because the HHI and open skies variables are not statistically significant.

We also find higher frequencies on routings whose gateway is a North American hub. As expected, frequencies are higher on routings characterized by more populated and richer destinations; instead, population and income do not seem to work as expected for origin airports. At this point, it is important to recall that all regressions include airport fixed effects that may be capturing a remarkable part of the effect associated with these variables.

We now focus on the cooperation variables, which are the most relevant ones in our analysis. The online variable yields mixed results, as the sign of its coefficient depends on the measure of frequency being used as dependent variable. Indeed, this coefficient is positive and statistically significant when the mean frequency is taken as dependent variable (except for the specification with one-year lagged values of HHI), while it becomes negative and statistically significant in the specification that considers the minimum frequency as dependent variable. Hence, it seems that online routings are characterized by a relatively high frequency on the short segment (i.e., the intra-European or intra-American segment of the routing) and a relatively low frequency on the long segment (i.e., the transatlantic route).

More importantly, we find that non-ATI alliances lead to higher frequencies in comparison to the no alliance case, as predicted by our theoretical model (see Lemma 3). In our baseline regression, frequencies are 24% higher under non-ATI alliances. This difference remains very similar when dropping the HHI variable while it is reduced to 17% when the HHI variable is lagged one year (in this latter regression, we lose $69,906$ observations). Finally, when we consider the minimum frequency as dependent variable, frequencies under non-ATI alliances are 18% higher in comparison to the no alliance case.

Frequencies associated to ATI alliances are lower as compared to non-ATI alliances, a finding that it is again in line with our theoretical predictions (see Lemma 4). In our baseline regression, frequencies under ATI alliances are 21% higher in comparison to the no alliance case (as compared to the 24% increase produced by non-ATI alliances). These frequency differences between non-ATI and ATI alliances are similar when dropping the HHI variable. In the specification where the HHI variable is lagged, ATI alliances raise frequencies by 13% whereas non-ATI alliances yield a 17% increase. Finally, when we consider minimum frequency as dependent variable, differences are even more pronounced: ATI alliances only increase frequencies by 5% while non-ATI alliances produce a 18% boost. We also report the Wald test in Table 2 with the null hypothesis of no statistical differences between the coefficients *non-$ATI\_all$* and $ATI\_all$. We reject the null hypothesis in all specifications, confirming our theoretical prediction suggesting that granting ATI to existing alliances exerts a downward pressure on service quality.

As explained above (in Subsection 4.1), routings affected by alliances (either ATI or non-ATI) include two hubs of airlines within the same alliance. Therefore, the network configuration under analysis is either spoke1-hub1-hub2 or or hub1-hub2-spoke2, as we focus on one-stop routings. In such network structure, although the nature of alliances is complementary (and thus their effect should be procompetitive), there could be an *interference* from the interhub connection (i.e., on the route hub1-hub2) where alliances could produce anticompetitive effects (by exerting a downward pressure on frequencies). Looking at our empirical results, this potential interference from the interhub connection could cause a certain underestimation of the positive effect of alliances on frequencies with respect to the no alliance case. Thus, our focus on one-stop routings should not call into question our empirical results that confirm our theoretical predictions suggesting that alliances raise service quality in comparison to the no alliance situation. Furthermore, this potential interference should not distort the comparison between non-ATI and ATI alliances, as both types of alliances would be similarly affected. Consequently, our empirical analysis on the quality gap that is presented hereunder should not be affected.

#### 4.3.2 Effects of alliances on quality gap

Table 3 shows the results of estimates of the quality gap using the three mentioned measures to distinguish between high- and low-quality routings.

–Insert Table 3 here–

We observe an increase in quality gap in the transition from no alliance to non-ATI alliances, as frequency differences between these two scenarios become more pronounced on high-quality routings. This result holds regardless of the measure used to distinguish between high- and low-quality routings. When using the traffic share measure, flight frequencies under non-ATI alliances are 32% higher on high-quality routings with respect to the no alliance case, while this difference shrinks to 22% on low-quality routings. When using the measure based on routing distance, non-ATI alliances yield an increase in flight frequency of 25% on high-quality routings and 20% on low-quality routings. Finally, when using the measure based on flight frequency, non-ATI alliances raise frequencies by 27% on high quality routings and 22% on low-quality routings. Thus, we can conclude that our theoretical predictions on the effect of non-ATI alliances on quality gap (see Proposition 1) are empirically confirmed.

Shifting now our attention to ATI alliances, measures based on traffic share and routing distance show that these alliances lead to an increase in quality gap with respect to the non-ATI and the no alliance scenarios, an empirical finding that is again consistent with our theoretical projections (see Proposition 2 and Corollary 2). More precisely and departing from the no alliance case, the traffic-share measure shows a frequency rise of 32% associated to ATI alliances, an increase that is reduced to 16% on low-quality routings. Similarly, the routing distance measure shows a frequency boost of 31% and 14% on high- and low-quality routings, respectively. Therefore, we can conclude that these two measures (traffic share and routing distance) reveal a substantially differentiated effect of ATI alliances on high- and low-quality routings, being much stronger on high-quality routings. Instead, the measure based on flight frequency exhibits no difference between high- and low-quality routings, being frequencies 21% higher under ATI alliances on both types of routings. As pointed out in Subsection 4.2, the remarkable difference in frequencies between the two subsamples may impose difficulties in the identification of the quality gap.

Overall, the results of our empirical application clearly confirm the predictions suggested by our theoretical model on the effects of non-ATI alliances and ATI alliances on flight frequency and quality gap.

### 4.4 Discussion of our theoretical predictions on fares using the empirical results in Brueckner and Singer (2019)

Fare data provided by OAG have many inconsistencies that advise against testing empirically our theoretical predictions and fare data from the US Department of Transportation in international markets are only available for US citizens. However, we can relate our theoretical predictions to the empirical results in Brueckner and Singer (2019), the most recent and comprehensive study on the effect of airline alliances on fares.

Brueckner and Singer (2019) benefit from a rich dataset over 20 years composed by the USDOT fare data plus confidential fare data reported to the USDOT by non-US carriers as a condition of receiving ATI or joint venture status. Although they also report the fare effects of alliances in interhub markets (or gateway-to-gateway markets), we will focus on their results in interline markets (or connecting markets), which are the focus of our study (both theoretically and empirically).

Our theoretical predictions suggest that non-ATI alliances (allowing allied partners to make joint decisions regarding flight frequencies) yield higher fares and frequencies (see Lemma 3). This is explained by the elimination of a double marginalization in frequencies, which raises coordinated frequencies. A higher service quality increases passengers' willingness-to-pay and yields higher fares. Brueckner and Singer (2019) find that non-ATI alliances produce a slight fare reduction of 0.7% (this figure is even lower for the subsample of transatlantic itineraries, with a reduction of 0.4%). Instead, in the case of business-class itineraries, this effect becomes positive implying a fare increase of 2.7% (remaining negative for economy-class itineraries).

Our theoretical predictions about granting ATI to existing alliances (allowing allied partners to make joint decisions also regarding fares) yield a decrease in fares and frequencies (see Lemma 4). The reason is that the elimination of a double marginalization in fares logically results in lower fares, which comes together with a lower service quality. Brueckner and Singer (2019) obtain a clear fare reduction associated with ATI alliances of 6.4% with respect to the interline fares determined by nonaligned carriers (this fare reduction is stronger for the subsample of transatlantic itineraries, reaching 10.2%), a finding that is in line with past studies on airline alliances in interline markets.

All in all, we can conclude that the results in Brueckner and Singer (2019) are fully consistent with our theoretical findings on the fare effects of ATI alliances. As for the fare effects of non-ATI alliances, their empirical results are less clear but do not seem to contradict our theoretical predictions.

# 5 Concluding remarks

In a novel framework characterized by vertically-differentiated air services, we have analyzed both theoretically and empirically the effect of granting ATI to international airline alliances. Our theoretical results suggest that non-ATI alliances result in higher quality services at higher fares, whereas granting ATI to existing alliances exerts a downward pressure on service quality and fares. Our empirical application confirms these theoretical predictions.

Given that fare data provided by OAG have many inconsistencies, we relate our theoretical predictions on fares to the empirical results in Brueckner and Singer (2019). Their empirical results are fully consistent with our theoretical projections on the effects of ATI alliances and do not contradict our theoretical predictions on the effects of non-ATI alliances

Our theoretical and empirical results also indicate that alliances (ATI and non-ATI) tend to concentrate a higher proportion of frequencies on high-quality routings, thus exacerbating the quality gap. Instead, airport congestion could mitigate this effect. Since high-quality routings are mostly operated by legacy carriers, this finding gives them an additional reason to expand and deepen their multilateral agreements. However, smaller carriers could experience a worsening in competitive terms after signing in big alliance groups, which could be a concern for them and for competition authorities.

The extension of our study to other transcontinental markets could be a possibility to assess the generality of our empirical results (that are based on the transatlantic market). Finally, as our focus is on one-stop routings, an interesting extension would be to extend our analysis to two-stop itineraries of the type spoke1-hub1-hub2-spoke2. This realistic network structure (suggested in Brueckner, 2001) should allow to clearly differentiate the effects of alliances on spoke-to-spoke and hub-to-hub markets.

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# Notes

[1]See Fageda *et al.* (2019b) for an analysis of joint ventures in the transatlantic market.

[2]See Bilotkach *et al.* (2010), Brueckner (2004 and 2010), Brueckner and Flores-Fillol (2007), Brueckner and Pai (2009), Brueckner and Luo (2014), de Palma *et al.* (2018), Fageda and Flores-Fillol (2012a and 2012b), and Pai (2010).

[3]See Brueckner (2004), Brueckner and Flores-Fillol (2007), and Fageda and Flores-Fillol (2012a).

[4]Unfortunately, fare data provided by OAG have many inconsistencies that advise against testing empirically our theoretical predictions. Fare data from the US Department of Transportation in international markets are only available for US citizens.

[5]See Bilotkach (2019) for a recent exhaustive review on the effects of airline alliances.

[6]Other studies on alliances that assume product differentiation include Brueckner and Whalen (2000), Hassin and Shy (2004), Bilotkach (2005), Zhang and Zhang (2006), Heimer and Shy (2006), and Flores-Fillol and Moner-Colonques (2007).

[7]Gillespie and Richard (2012) and Bilotkach and Hüschelrath (2013) identify a potential anticompetitive effect in the presence of ATI alliances, whereas Alderighi *et al.* (2017) find higher fares in non-stop markets associated with codesharing agreements.

[8]See footnote 2 for a complete review of the airline-economics literature where quality is proxied by flight frequency.

[9]From first principles, it is unclear how to model the effect of frequencies for connecting passengers. The two main natural approaches seem to be either the *average* frequency or the *minimum* of the two airline frequencies. Brueckner and Flores-Fillol (2019) study in depth the microeconomic foundations of both approaches and suggest that the average frequency arises in the presence of costless layover time (i.e., leisure passengers) whereas the minimum frequency arises in the presence of costly layover time (i.e., business passengers). They conclude that the average approach (which is adopted in Flores-Fillol, 2010; Bilotkach *et al.*, 2013; Kawamori and Lin, 2013; Lin, 2015; and Czerny *et al.*, 2016) produces more sensible results.

[10]In equilibrium, these conditions are always satisfied under all the considered scenarios.

[11]In a general framework, Wauthy (1996) derives a complete characterization of quality choices in a duopoly model of vertical differentiation without assuming ex ante a partially or fully-served market. Instead, we assume fully-served markets to derive clear analytical solutions from first principles.

[12]A similar formulation is used in Heimer and Shy (2006), Flores-Fillol (2009), and Bilotkach *et al.* (2013).

[13]As in Brueckner (2004), Brueckner and Flores-Fillol (2007), Bilotkach *et al.* (2013), and Fageda and Flores-Fillol (2015).

[14]Brueckner and Flores-Fillol (2007) and Bilotkach *et al.* (2013) also analyze the sequential case.

[15]Since $\frac{\partial \pi_1}{\partial p_1} = \frac{H}{d_f(z-1)}(-p_1 + d_p - d_f)$, $\frac{\partial \pi_2}{\partial p_2} = \frac{H}{d_f(z-1)}(-p_2 - d_p + zd_f)$, $\frac{\partial \pi_3}{\partial p_3} = \frac{H}{d_f(z-1)}(-p_3 + d_p - d_f)$, and $\frac{\partial \pi_4}{\partial p_4} = \frac{H}{d_f(z-1)}(-p_4 - d_p + zd_f)$, the second-order conditions are satisfied by inspection.

[16]Since $\frac{\partial \pi_2}{\partial f_2} = \frac{(3z-2)^2}{50(z-1)}H - 2\theta f_2 - \eta(f_1 + 4f_2 + f_4)$, the second-order conditions are satisfied by inspection.

[17]The equilibrium flight frequencies are given by $f_1^n = f_3^n = \frac{H(3z-2)^2(2z-3)}{25(z-1)[\eta(24z-11)+2\theta(4z-1)]} > 0$ and $f_2^n = f_4^n = \frac{H(3z-2)^2(4z-1)}{50(z-1)[\eta(24z-11)+2\theta(4z-1)]} > 0$. Although these expressions have a complex intuitive explanation (because

$f_1^n = f_3^n$ arises from a corner solution), we observe that both of them increase with market size ($H$).

[18]The equilibrium fares $p_1^n = p_3^n$ (corner solution) are given by $\frac{f_1^n + f_3^n}{2} = p_1^n + p_3^n$, which becomes $p_1^n = p_3^n = \frac{f_1^n}{2}$ after applying symmetry. On the other hand, we obtain $p_2^n = p_4^n = \frac{(3z-2)d_f^n}{5}$.

[19]Therefore, we do neither study the asymmetric case in which two parters form an alliance and the other partners remain unallied, nor the equilibrium in alliance formation (in which partner airlines would have three possible strategies: to form non-ATI alliances, to form ATI alliances and to remain unallied). Such an analyses are complex and involve cumbersome computations that can only be solved by means of numerical simulations.

[20]Since $\frac{\partial \pi_{24}}{\partial f_2} = \frac{(3z-2)^2}{25(z-1)}H - 2\theta f_2 - \eta\left(f_1 + 4f_2 + f_4\right)$, the second-order conditions are satisfied by inspection.

[21]The equilibrium flight frequencies are given by $f_1^a = f_3^a = \frac{H(3z-2)^2(2z-3)}{25(z-1)[2\eta(7z-3)+\theta(4z-1)]} > 0$ and $f_2^a = f_4^a = \frac{H(3z-2)^2(4z-1)}{50(z-1)[2\eta(7z-3)+\theta(4z-1)]} > 0$. Although these expressions have a complex intuitive explanation (because $f_1^a = f_3^a$ arise from a corner solution), we observe that both of them increase with market size ($H$).

[22]The equilibrium fares $p_1^a = p_3^a$ (corner solution) are given by $\frac{f_1^a + f_3^a}{2} = p_1^a + p_3^a$, which becomes $p_1^a = p_3^a = \frac{f_1^a}{2}$ after applying symmetry. On the other hand, we obtain $p_2^a = p_4^a = \frac{(3z-2)d_f^a}{5}$.

[23]Since $\frac{\partial \pi_{13}}{\partial p_1} = \frac{\partial \pi_{13}}{\partial p_3} = \frac{H}{d_f(z-1)}\left[(p_2 + p_4) - 2\left(p_1 + p_3\right) - d_f\right]$ and $\frac{\partial \pi_{24}}{\partial p_2} = \frac{\partial \pi_{24}}{\partial p_4} = \frac{H}{d_f(z-1)}\left[(p_1 + p_3) - 2\left(p_2 + p_4\right) + z d_f\right]$, the second-order conditions are satisfied by inspection.

[24]Since $\frac{\partial \pi_{24}}{\partial f_2} = \frac{H(2z-1)^2}{18(z-1)} - \eta\left(f_1 + 4f_2 + 2f_4\right) - 2\theta f_2$, the second-order conditions are satisfied by inspection.

[25]The equilibrium flight frequencies are given by $f_1^A = f_3^A = \frac{H(2z-1)^2(z-2)}{18(z-1)[\eta(7z+4)+2\theta(z+1)]} > 0$ and $f_2^A = f_4^A = \frac{H\left[z\left(4z^2-3\right)+1\right]}{18(z-1)[\eta(7z+4)+2\theta(z+1)]} > 0$. Although these expressions have a complex intuitive explanation (because $f_1^A = f_3^A$ arises from a corner solution), we observe that both of them increase with market size ($H$).

[26]The equilibrium fares are given by $p_1^A + p_3^A = \frac{f_1^A + f_3^A}{2}$ (corner solution), which becomes $p_1^A = p_3^A = f_1^A/2$ after applying symmetry. On the other hand, we obtain $p_2^A + p_4^A = \frac{d_f^A(2z-1)}{3}$, which yields $p_2^A = p_4^A = \frac{d_f^A(2z-1)}{6}$.

[27]More generally, Shaked and Sutton (1983) report the *finiteness result*: there can be at most a finite number of firms with a positive market share in the industry.

[28]Recall that in both scenarios we have a corner solution for $f_1$, so that $\frac{f_1 + f_3}{2} = p_1 + p_3$. In equilibrium, this condition becomes $p_1 = \frac{f_1}{2}$ and, therefore, $\Delta_{p_1}^{a-n} = p_1^a - p_1^n = \left(f_1^a - f_1^n\right)/2 = \Delta_{f_1}^{a-n}/2$.

[29]Note that $\Delta_{d_f}^{a-n} = d_f^a - d_f^n = (f_2^a - f_1^a) - (f_2^n - f_1^n) = (f_2^a - f_2^n) - (f_1^a - f_1^n) = \Delta_{f_2}^{a-n} - \Delta_{f_1}^{a-n}$. Equivalently, we can also define $\Delta_{d_p}^{a-n} = \Delta_{p_2}^{a-n} - \Delta_{p_1}^{a-n} = \Delta_{p_2}^{a-n} - \Delta_{f_1}^{a-n}/2$ (since $\Delta_{p_1}^{a-n} = \Delta_{f_1}^{a-n}/2$).

[30]It can also be checked that the price gap ($\Delta_{d_p}^{a-n}$) also increases after non-ATI alliances are formed. Since the high-quality service becomes relatively more expensive, we cannot think of a consolidated entity favoring the high-quality service to the detriment of the low-quality service.

[31]The indifferent consumer is given by $\sigma_0 = \frac{d_p}{d_f}$ and, in both scenarios, $d_p = \frac{2(z+1)d_f}{5}$. Therefore, the indifferent consumer becomes $\sigma_0 = \frac{2(z+1)}{5}$, which yields the market shares $\phi_{13} = \frac{2z-3}{5(z-1)}$ and $\phi_{24} = \frac{3z-2}{5(z-1)}$, and the equilibrium quantities $q_{13}^n = q_{13}^a = \frac{2z-3}{5(z-1)}H$ and $q_{24}^n = q_{24}^a = \frac{3z-2}{5(z-1)}H$.

[32]Again, we have a corner solution for $f_1$ in both scenarios which implies $\frac{f_1 + f_3}{2} = p_1 + p_3$. In equilibrium, this condition becomes $p_1 = \frac{f_1}{2}$ and, therefore, $\Delta_{p_1}^{A-a} = p_1^A - p_1^a = \left(f_1^A - f_1^a\right)/2 = \Delta_{f_1}^{A-a}/2$.

[33]The literature on congestion-pricing does not provide an unambiguous answer to the question of whether a hub operator will self-internalize the congestion externality (see Daniel, 1995; Brueckner, 2002; Mayer and

Sinai, 2003; Rupp, 2009; and Fageda and Flores-Fillol, 2017).

[34]Note that $\Delta_{d_f}^{A-a} = d_f^A - d_f^a = (f_2^A - f_1^A) - (f_2^a - f_1^a) = (f_2^A - f_2^a) - (f_1^A - f_1^a) = \Delta_{f_2}^{A-a} - \Delta_{f_1}^{A-a}$. Equivalently, we can also define $\Delta_{d_p}^{A-a} = \Delta_{p_2}^{A-a} - \Delta_{p_1}^{A-a} = \Delta_{p_2}^{A-a} - \Delta_{f_1}^{A-a}/2$ (since $\Delta_{p_1}^{A-a} = \Delta_{f_1}^{A-a}/2$).

[35]The effect on the price gap ($\Delta_{d_p}^{a-n}$) is unclear.

[36]Given that $d_p^a = \frac{2(z+1)d_f^a}{5}$ and $d_p^A = \frac{(z+1)d_f^A}{3}$, the indifferent consumer in each of the cases is given by $\sigma_0^a = \frac{d_p^a}{d_f^a} = \frac{2(z+1)}{5}$ and $\sigma_0^A = \frac{d_p^A}{d_f^A} = \frac{(z+1)}{3}$ with $\sigma_0^A < \sigma_0^a$. Hence, market shares under ATI alliances become $\phi_{13}^A = \frac{z-2}{3(z-1)}$ and $\phi_{24}^A = \frac{2z-1}{3(z-1)}$, and the equilibrium quantities are $q_{13}^A = \frac{z-2}{3(z-1)}H$ and $q_{24}^A = \frac{2z-1}{3(z-1)}H$, with $q_{13}^A < q_{13}^a$ and $q_{24}^A > q_{24}^a$.

[37]The European airports include non-EU countries like Russia, Turkey, Ukraine, and other smaller countries.

[38]See Brueckner *et al.* (2014) for a discussion on the difference between airport-pair markets and city-pair markets. More precisely, they propose a methodology to determine when several airports in a catchment area should be grouped with the purpose of determining relevant city-pair markets.

[39]Indeed, our interline routings require the cooperation between a North American and an European airline. Differentle a few online routings could imply the cooperation between either two European carriers or two North American carriers.

[40]According to the US Department of Transportation, all ATI agreements between US/Canadian and European carriers were signed before the considered period of our data.

[41]Although Northwest was also involved in ATI agreements, its brand was collapsed into Delta before the considered period.

[42]There are some few observations where the long-haul segment (usually through a European gateway) is operated by a non-European Star Alliance partner (Air India, Air New Zealand and Singapore Airlines).

[43]Madrid is the hub of Air Europa, which is a non-immunized SkyTeam partner of Delta.

[44]Airlines decide to join alliances (both ATI and non-ATI) strategically and from a global network perspective and not based on specific route characteristics. Indeed, when two airlines join the same alliance, they are cooperating simultaneously on all routes on which one or the other (or both) operate. Therefore, this decision is made at the airline level and not the route level. Thus, cooperation variables are included in the model as exogenous variables.

[45]The $HHI$ variable is based on the shares of each airline-routing on an airport-pair. For example, there are several routings offered by different airlines to connect Boston with Barcelona, including European gateways (e.g., Amsterdam, Paris, Madrid or London) and US/Canada gateways (e.g., New York, Washington, Philadelphia or Toronto). The share of each of these airline-routings is used to build the $HHI$ variable. However, competition from low-cost airlines on the short-haul segment is not captured by the $HHI$ variable, e.g., Jet Blue's flights on the Boston-New York segment or Transavia's flights on the Amsterdam-Barcelona segment.

[46]Chen and Gayle (2019) stress that itinerary flight distance-based measures are good indirect indicators of service quality because they capture the *directness* of travel itineraries, as nonstop flights between the origin and destination are characterized by the shortest itinerary flight distance.

[47]Using lagged values of HHI should mitigate the potential endogeneity problem. In addition, as pointed out in Fukui (2019), it makes the analysis more realistic, as it is difficult for carriers to change their route structures rapidly. Instead, Whalen (2007) implements an instrumental variables procedure using

lagged values of the HHI variable as instruments. Both approaches should lead to equivalent results. For convenience, we prefer to include lagged values of the HHI variable as an explanatory variable. The implementation of instrumental variables in our context would have practical difficulties as different types of fixed effects (year, quarter, airline and airports fixed effects) are also included in the regression.

## Figures and Tables

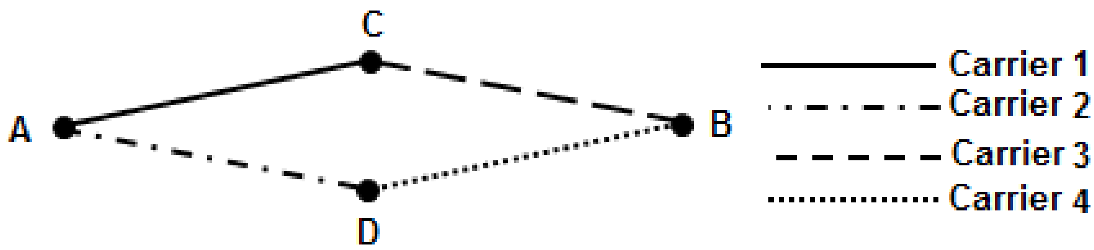


Fig. 1: Network

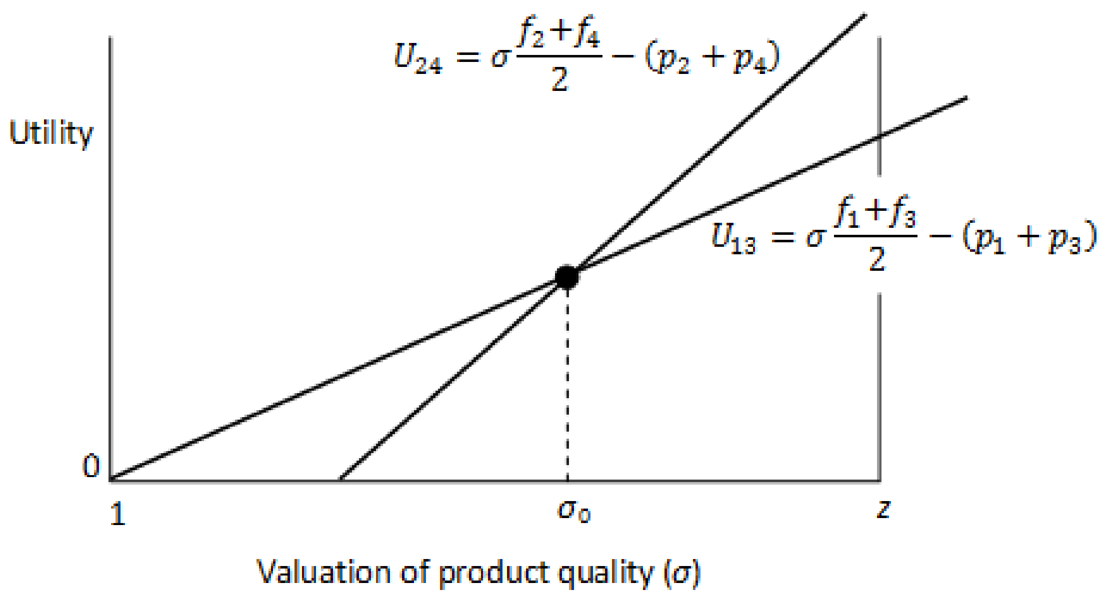


Fig. 2: Utilities

**Table 1. Descriptive statistics of the variables used in the empirical analysis**

| | Average | Standard error | Observations |
|---|---|---|---|
| ***mean freq*** | 209.58 | 132.35 | 228,275 |
| ***minimum freq*** | 130.57 | 98.29 | 249,480 |
| ***online*** | 0.83 | 0.38 | 252,677 |
| ***non-ATI_all*** | 0.01 | 0.09 | 252,677 |
| ***ATI_all*** | 0.13 | 0.33 | 252,677 |
| ***no alliance*** | 0.03 | 0.16 | 252,677 |
| ***dist*** | 7,009.53 | 1,119.84 | 251,732 |
| ***pop_origin*** | 6,177.35 | 5,555.53 | 252,677 |
| ***pop_destin*** | 3,328.70 | 3,619.31 | 252,344 |
| ***GDPpc_origin*** | 50,046.85 | 1,475.65 | 252,677 |
| ***GDPpc_destin*** | 39,015.68 | 16,462.41 | 252,677 |
| ***HHI*** | 0.38 | 0.27 | 252,677 |
| ***non-stop_route*** | 0.29 | 0.45 | 252,677 |
| ***open_skies*** | 0.95 | 0.20 | 252,677 |
| ***NA_hub*** | 0.40 | 0.48 | 252,677 |

Note: The total number of observations for online and interline routings is 211,206 and 42,569, respectively. Within the interline routings, we can identify 33,100 observations for ATI routings, 2,524 for non-ATI, and 6,945 for no alliance.

**Table 2. Effects of ATI and non-ATI alliances on flight frequency (entire sample)**

| | Baseline (I) | No HHI (II) | One-year lag HHI (III) | Minimum frequency as dependent variable (IV) |
|---|---|---|---|---|
| ***online*** | 0.04 (0.01)*** | 0.04 (0.01)*** | -0.05 (0.02)** | -0.16 (0.008)*** |
| ***non-ATI_all*** | 0.24 (0.02)*** | 0.24 (0.02)*** | 0.17 (0.02)*** | 0.18 (0.01)*** |
| ***ATI_all*** | 0.21 (0.01)*** | 0.21 (0.01)*** | 0.13 (0.02)*** | 0.05 (0.009)*** |
| ***dist*** | -1.75 (0.05)*** | -1.75 (0.01)*** | -1.83 (0.01)*** | -0.28 (0.01)*** |
| ***pop_origin*** | -0.27 (0.05)*** | -0.27 (0.03)*** | -0.19 (0.04)*** | -0.33 (0.03)*** |
| ***pop_destin*** | 0.19 (0.06)**** | 0.14 (0.02)**** | 0.16 (0.03)*** | -0.10 (0.07) |
| ***GDPpc_origin*** | 0.24 (0.24) | 0.24 (0.24) | 0.52 (0.26)** | 0.95 (0.25)*** |
| ***GDPpc_destin*** | 0.14 (0.02)*** | 0.14 (0.02)*** | 0.16 (0.03)*** | -0.02 (0.02) |
| ***HHI*** | -0.0003 (0.01) | - | 0.003 (0.004) | -0.02 (0.04)*** |
| ***non-stop_route*** | -0.01 (0.002)** | -0.01 (0.002)** | -0.008 (0.002)*** | -0.0001 (0.002) |
| ***open_skies*** | 0.005 (0.01) | 0.005 (0.007) | 0.008 (0.008) | 0.03 (0.008)*** |
| ***NA_hub*** | 0.22 (0.003)*** | 0.22 (0.004)*** | 0.22 (0.005)*** | -0.12 (0.004)*** |
| **intercept** | 16.92 (2.70)*** | 16.93 (2.70)*** | 14.77 (2.96)*** | -0.34 (2.86)*** |
| **year FE** | YES | YES | YES | YES |
| **quarter FE** | YES | YES | YES | YES |
| **airline FE** | YES | YES | YES | YES |
| **airport FE** | YES | YES | YES | YES |
| **$R^2$** | 0.56 | 0.55 | 0.57 | 0.51 |
| **obs.** | 227,957 | 227,957 | 158,051 | 248,427 |
| **Test *non-ATI_all=ATI_all*** | 4.47** | 4.47** | 4.56** | 132.00*** |

Notes: Standard errors in parenthesis (robust to heteroscedasticity and clustered by route). Statistical significance at 1% (***), 5% (**), 10% (*). The reference case for cooperation variables is an interline service (i.e., no alliance).

**Table 3. Effects of ATI and non-ATI alliances on quality gap (subsamples)**

| | Traffic share (1) | | Routing distance (2) | | Flight frequency (3) | |
|---|---|---|---|---|---|---|
| | **High-quality routings** | **Low-quality routing** | **High- quality routings** | **Low-quality routing** | **High- quality routings** | **Low-quality routing** |
| ***non-ATI_all*** | 0.32<br>(0.03)*** | 0.22<br>(0.02)*** | 0.25<br>(0.02)*** | 0.20<br>(0.03)*** | 0.27<br>(0.03)*** | 0.22<br>(0.02)*** |
| ***ATI_all*** | 0.32<br>(0.02)*** | 0.16<br>(0.02)*** | 0.31<br>(0.02)*** | 0.14<br>(0.02)*** | 0.21<br>(0.02)*** | 0.21<br>(0.02)*** |
| **controls** | All | All | All | All | All | All |
| **$R^2$** | 0.66 | 0.55 | 0.61 | 0.56 | 0.76 | 0.55 |
| **obs.** | 61,342 | 99,950 | 60,228 | 101,057 | 63,368 | 92,771 |

Notes: Standard errors in parenthesis (robust to heteroscedasticity and clustered by route). Statistical significance at 1% (***), 5% (**), 10% (*). The reference case for cooperation variables is an interline service (i.e., no alliance). Quality of routings defined in terms of traffic share (1), airport-pair distance (2), and flight frequency (3).

# A Appendix: Proofs

**Proof of Lemma 1.**

Straightforward. ■

**Proof of Lemma 2.**

$\frac{\partial d_f^n}{\partial \eta} < 0$, $\frac{\partial d_f^n}{\partial \theta} < 0$, $\frac{\partial d_f^n}{\partial H} > 0$, and $\frac{\partial d_f^n}{\partial z} \lesseqqgtr 0$ are observed by inspection of (10) given that $z \geqslant 2$.

■

**Proof of Lemma 3.**

▶ $\Delta_{f_1}^{a-n} = 2\,(2z-3)\,\Omega > 0$, given that $\Omega \equiv \frac{H(3z-2)^2[5\eta(2z-1)+\theta(4z-1)]}{50(z-1)[\eta(24z-11)+2\theta(4z-1)][2\eta(7z-3)+\theta(4z-1)]} > 0$.

▶ $\Delta_{f_2}^{a-n} = (4z-1)\,\Omega > 0$.

▶ $\Delta_{p_1}^{a-n} = \Delta_{f_1}^{a-n}/2 = (2z-3)\,\Omega > 0$.

▶ $\Delta_{p_2}^{a-n} = (3z-2)\,\Omega > 0$. ■

**Proof of Proposition 1.**

$\Delta_{d_f}^{a-n} = \Delta_{f_2}^{a-n} - \Delta_{f_1}^{a-n} = 5\Omega > 0$. ■

**Proof of Lemma 4.**

▶ $\Delta_{f_1}^{A-a} = -H\frac{\Psi+\Phi}{\Gamma} < 0$, because

$\Psi \equiv -2\eta\,(582 + z\,\{z\,[1539 - z\,(434z - 165)]\, -1853\}) > 0$,

$\Phi \equiv -\theta\left\{482 - z\left[1577 + 4z\left(62z^2{+}28z - 363\right)\right]\right\} > 0$ and

$\Gamma \equiv 450\,(z-1)\,[\eta\,(7z+4) + 2\theta\,(z+1)]\,[2\eta\,(7z-3) + \theta\,(4z-1)] > 0$.

▶ $\Delta_{f_2}^{A-a} = \frac{-H\eta(6-z\{44+z[z(1695-868z)-762]\})-H\theta(z+1)(4z-1)[47+2z(31z-58)]}{\Gamma} < 0$.

▶ $\Delta_{p_1}^{A-a} = \Delta_{f_1}^{A-a}/2 < 0$.

▶ $\Delta_{p_2}^{A-a} = \frac{-2H\eta(z\{1417+z[z(270+301z)-1626]\}-363)-H\theta(2z\{629+2z[z(107+43z)-387]\}-313)}{2\Gamma} < 0$. ■

**Proof of Proposition 2.**

$\Delta_{d_f}^{A-a} = H\frac{\Upsilon+\Theta}{M} > 0$, because

$\Upsilon \equiv \eta\,\{z\,[250 + z\,(91z - 256)]\, -78\} > 0$,

$\Theta \equiv \theta\,\{2z\,[44 + z\,(13z - 41)]\, -29\} > 0$, and

$M \equiv [\eta\,(7z+4) + 2\theta\,(z+1)]\,[2\eta\,(7z-3) + \theta(4z-1)] > 0$. ■

**Proof of Corollary 1.**

▶ $\Delta_{f_1}^{A-n} = H\frac{\eta(1414+z\{2z[3414+z(66z-1585)]-5331\})+2\theta(266+z\{2z[663+z(38z-353)]-1001\})}{W} \lesseqqgtr 0$ with

$J \equiv 450\,(z-1)\,[\eta\,(7z+4)+2\theta\,(z+1)]\,[\eta\,(24z-11)+2\theta\,(4z-1)] > 0.$

▶ $\Delta_{f_2}^{A-n} = H\frac{\Lambda+\digamma}{J} > 0$, because

$\Lambda \equiv \eta\,(z\,\{669+z\,[z\,(1195+132z)-1512]\}-131) > 0,$

$\digamma \equiv 2\theta\,(z+1)^2\,[11+z\,(76z-63)] > 0$, and

$J > 0.$

▶ $\Delta_{p_1}^{A-n} = \Delta_{f_1}^{A-n}/2 \lesseqqgtr 0.$

▶ $\Delta_{p_2}^{A-n} = H\frac{W+V}{2J} > 0$, because

$W \equiv \eta\,(851+2z\,\{z\,[3126+z\,(699z-2270)]-1917\}) > 0,$

$V \equiv \theta\,(338+4z\,\{z\,[612+z\,(157z-457)]-377\}) > 0$, and

$J > 0.$ ■

**Proof of Corollary 2.**

Straightforward. ■

**Proof of Proposition 3.**

▶ $\frac{\partial\Delta_{f_1}^{a-n}}{\partial\eta} = -\,(2z-3)\,\Xi < 0$, given that

$\Xi \equiv \frac{H(3z-2)^2\left[10\eta^2(2z-1)(7z-3)(24z-11)+4\eta\theta(4z-1)(7z-3)(24z-11)+\theta^2(4z-1)^2(32z-13)\right]}{25(z-1)[\eta(24z-11)+2\theta(4z-1)]^2[2\eta(7z-3)+\theta(4z-1)]^2} > 0.$

▶ $\frac{\partial\Delta_{f_2}^{a-n}}{\partial\eta} = -\frac{(4z-1)}{2}\Xi < 0.$ ■

**Proof of Proposition 4.**

▶ $\frac{\partial\Delta_{d_f}^{a-n}}{\partial\eta} = -\frac{5}{2}\Xi < 0.$

▶ $\frac{\partial\Delta_{d_f}^{A-a}}{\partial\eta} = -H\frac{\Sigma}{30(z-1)[\eta(7z+4)+2\theta(z+1)]^2[2\eta(7z-3)+\theta(4z-1)]^2} < 0$, given that

$\Sigma \equiv 2\eta^2\,(7z-3)\,(7z+4)\,\{z\,[250+z\,(91z-256)]-78\}+$

$4\eta\theta\,(7z-3)\,(7z+4)\,\{2z\,[44+z\,(13z-41)]-29\}+$

$\theta^2\,[308+z\,(4z\,\{125+z\,[545+2z\,(91z-305)]\}-1165)] > 0.$

▶ $\frac{\partial\Delta_{d_f}^{A-n}}{\partial\eta} = -H\frac{\Pi}{30(z-1)[\eta(7z+4)+2\theta(z+1)]^2[\eta(24z-11)+2\theta(4z-1)]^2} < 0$, given that

$\Pi \equiv \eta^2\,(7z+4)\,(24z-11)\,\{z\,[400+z\,(291z-556)]-103\}+$

$4\eta\theta\,(7z+4)\,(24z-11)\,\{z\,[64+z\,(53z-91)]-17\}+$

$4\theta^2\,[152+z\,(z\,\{545+z\,[890+z\,(1592z-2215)]\}-625)] > 0.$ ■

# B Appendix: List of airlines in alliances with their corresponding hub airports

**Table B.1. Hub airports of airlines in alliances**

| Airline | Airports |
|---|---|
| Adria Airways | Ljubljana |
| Aegean | Athens |
| Aeroflot | Moscow-Sheremetyevo |
| Air Berlin | Berlin-Tegel, Dusseldorf |
| Air Canada | Montreal, Toronto, Vancouver |
| Air Europa | Madrid |
| Air France/KLM | Amsterdam, Paris-CDG |
| Aer Lingus | Dublin |
| Alitalia | Rome Fiumicino |
| American Airlines/US Airways | Charlotte, Chicago-O'Hare, Dallas-FW, Los Angeles, Miami, New York-JFK, Philadelphia, Phoenix, Washington-R. Reagan |
| Austrian Airlines | Vienna |
| BMI | London-Heathrow |
| British Airways | London-Heathrow |
| Croatia Airlines | Zagreb |
| Czech Airlines | Prague |
| Delta | Atlanta, Denver, Detroit, Los Angeles, New York-JFK, Memphis, Minneapolis, Salt Lake City |
| Finnair | Helsinki |
| Iberia | Madrid |
| Lufthansa | Frankfurt, Munich |
| LOT | Warsaw |
| S7 | Moscow–Domodedovo |
| SAS | Copenhagen, Stockholm, Oslo |

**Table B.1. Hub airports of airlines in alliances (cont.)**

| Airline | Airports |
|---|---|
| SN Brussels | Brussels |
| Swiss | Zurich |
| TAP | Lisbon |
| Tarom | Bucharest |
| Turkish Airlines | Istanbul |
| United/Continental | Chicago-O'Hare, Denver, Houston, Los Angeles, New York-Newark, San Francisco, Washington-Dulles |
| Virgin Atlantic | London Heathrow |