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Are Deregulated Airports More Efficient?*

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Abstract

Picard et al. (2019) show that allocative inefficiency may occur in a private airport when passenger fees are regulated. In this paper, we investigate the presence of inefficiency in slot allocation when an airport faces no regulation over per-passenger charges. In the model, passengers favor peak times and the number of available peak-time slots is constrained by airport capacities. Consistent with empirical evidence, we find that fees deregulation solves allocative inefficiency by raising per-passenger fees. However, when the infrastructural resources appear to be more efficiently employed, the increase in fees leads to a fall in social welfare.

JEL classification: R41,H21,H23

Keywords: Slot allocation, Endogenous fee, Airport capacity

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1 Introduction

In the past decades, growth in air traffic has outstripped the development of runways and other passenger handling infrastructures. As a result, many airports worldwide have experienced critical shortages of infrastructure capacity.

To improve organizational efficiency, a recent topic in airport management regards the allocation of slots. Following the definition of the trade association for the world's airlines (International Air Transport Association, IATA), a slot is a permit that allows access to the full range of airport infrastructure necessary for departure or landing at a certain airport, within a specific time frame. The analysis of slot allocation focuses on relevant policies to allocate scarce airport slots in an efficient way.

In the literature on slot allocation, Picard et al. (2019) define "allocative inefficiency" as the situation where not all available peak slots are used. Consistent with recent empirical evidence,[1] they find that allocation inefficiency may arise if the airport is not heavily congested and the airport charge is small. In particular, allocative inefficiency emerges in a fully regulated private airport that obtains exogenous and uniform revenues from each passenger.[2]

In recent years though, the tendency of airport regulation is moving towards less governmental involvement. First, many traditionally public-owned airports have undergone privatization. Starting with the privatization of airports in the UK in the late 1980s, more and more airports have been (either fully or partially) privatized worldwide (e.g. Oum et al., 2004; Winston and Ginés, 2009). According to IATA (2017), the share of fully privately owned airports in Europe increased from 9% to 16% between 2010 and 2016 while the share of mixed ownership models increased from 13% to 25% over the same period.[3] As the ownership of airports changes from public to private, the goal of airports is expected to be shifting from social benefits to profit maximization.

Second, there are calls for the dismantlement of regulation and less-stringent price monitoring. As pointed out in ACI (2017), "The role of a regulator and its oversight function is to monitor and ensure there is no significant abuse of market power... Strict forms of price regulation result in allocative inefficiencies which affect economic incentives adversely." Thus, a "light-handed" approach to regulation is setting in. For instance, some airport authorities determine a ceiling on the increase in passenger revenues obtained from basic airport services.[4]

[1]See, among others, Zografos et al. (2013), Katsaros and Psaraki (2012) and Airports Council International Europe (2009).

[2]Throughout the paper, we will use the term *regulated* to the case where the passenger-based airport revenue is determined exogenously by policymakers throughout, and *unregulated* to the case where this revenue is determined by the airport.

[3]Worldwide, among the 100 busiest airports for passenger throughput, 46% have private sector participation. And 41% of global airport traffic is handled by airports that are managed and/or financed by private stakeholders (IATA, 2017).

[4]This then defines the maximum annual revenue per passenger for each year in the regulatory period (e.g., Airports Regulation Document 2017-2021, 2017)

To this matter, the most relevant regulatory point is the handling of per-passenger fees. Indeed, the airports' income in the past years was mainly based on passenger charges (i.e. passenger service charges, security, and transfer charges), rather than fees that apply directly to aircraft operators (ICAO, 2013).[5] In Europe, for example, airport passenger charges paid on the average airfare to fly from European airports more than doubled between 2006 and 2016 (ICAO, 2013; IATA, 2017). Given the growing importance of the per-passenger revenue, the analysis of the impact of the deregulation on this revenue on the overall airport slot strategy seems highly policy relevant.

The purpose of the present paper is to revisit the slot allocation problem in a setting where the airport is unregulated with no restrictions on the level of charges to passengers. The key assumption is that an airport can generate uniform per-passenger revenue, which reflects real world practice.[6] Traditionally airports levied a single uniform Departing Passenger Charge (DPC), payable by the airline, which was perceived to meet all the costs of providing terminal services.[7] Typically, airports do not charge passengers directly. Assuming reasonably competitive airline markets, there is every reason to think these charges are ultimately passed through to fares.

The framework is a natural sequel of Picard et al. (2019), where a congestible airport accommodates a number of independent destinations, each served by two competing airlines, and establishes slot allocation. Compared to Picard et al. (2019), we assume an "unregulated" airport, in the sense that it is free to set per passenger fees without any regulatory constraint.

Our findings show that allocative inefficiency resulting from unused peak slots, a possible outcome at a regulated private airport, would vanish at an unregulated private airport. This is so because when the private airport now has two managing instruments, it would prefer to distort price rather than slots. The distortion of price sets downward pressure on the distortion of allocative efficiency. As a result, no allocative inefficiency would appear with private airport ownership. Interestingly, in an unregulated environment, the airport revenue would never be set to a too low level by a private airport. These results are consistent with empirical regularities. For instance, Bel and Fageda (2010) find that the airports controlled by private companies that are not subject to regulation fix higher prices than regulated airports.

In the analysis of social welfare, we then investigate the effect of liberalizing per-passenger fees using a

[5]The passenger-based revenues represent 63% of total aeronautical income according to ICAO (2013). In this regard, see Zhang (2012) and Czerny et al. (2017) for discussions about airport improvement fees, which are used to charge passengers for airport infrastructure development and/or debt repayment, are becoming a more important revenue source for airports.

[6]Airports are allowed to levy a uniform per-passenger fee for flight activities. Regarding passenger service charges, ICAO (2012) recommends that the "these (passenger service) charges should be levied through the aircraft operators where practicable. The need for consultations between airport entities and users at the local level with a view to alleviating collection problems should be emphasized."

[7]The charge covers all the terminal infrastructure, provision of check-in desks, baggage system and security screening. The DPC can be split into separate charges for passengers (mainly basic infrastructure and security screening), a fee per bag, rental of the check-in desk, self-service check-in kiosks, etc. All these charges are levied on the airline.

numerical simulation. The increase in per-passenger fee when the regulated counterparts were originally low generally leads to a fall in social welfare, which might question the liberalization of fees in the first place even if the use of resources is more efficient.

Related literature. The present study, to the best of our knowledge, is the first that combines the analysis of slots and pricing policies, and thus, it is related to both literatures.

In the literature on slot allocation, the reference paper is Picard et al. (2019). Similar to Picard et al. (2019), Barbot (2004) models different slot periods as vertically differentiated products with high or low quality, by letting airlines determine their number of flights. Verhoef (2010) and Brueckner (2009) evaluate the effect of the adoption of a slot allocation in comparison with the alternative policy of congestion pricing. Both contributions show that slot trading or auctioning and the first best congestion pricing give the same level of passenger volume and welfare. Unlike the present contribution, they do not let the airport allocate slots without charges. Verhoef (2010) and Brueckner (2009) are generalized by Basso and Zhang (2010), who introduce airport profits into the analysis. In this case, the adoption of slot allocation or congestion pricing brings about different results.

The literature on airport pricing policies is rich. To cite some relevant contributions, Ivaldi et al. (2015) and Martín and Socorro (2009) assume that airports negotiate prices with the airlines and charge them for the use of the aeronautical facilities at the airport, and they charge the passengers through the prices of non-aeronautical facilities. Lin and Zhang (2017) assumed private airports levy per-flight charges on hub carriers, which could be either movement-related or weight-related, and per-passenger charges to maximize profits. Czerny (2013) assumes in the area of aeronautical services, the airport is a monopoly provider and charges a price per passenger to airlines. Lin and Zhang (2017) assumed private airports levy per-flight charges on hub carriers, which could be either movement-related or weight-related, and per-passenger charges to maximize profits. Czerny (2013) assumes in the area of aeronautical services, the airport is a monopoly provider and charges a price per passenger to airlines. These papers, however, do not discuss the interplay between optimal per-passenger fee choice and slot allocation.

The remainder of this paper is organized as follows. The baseline model is presented in section 2. The results are outlined in section 3. Section 5 sets forth the conclusion.

2 The Model

The model setting is built on Picard et al. (2019). We examine an airport that has connections to N uncongested pair airports. Each market is served by two separate airlines, which offer a single flight. The model deals with single trip departing flights. Markets are indexed by market size z, which is distributed according to the cumulative distribution function G over the interval $[\underline{z}, \bar{z}]$.

Quality differential is characterized only by the departing time: there are two travel periods i, namely peak ($i = 1$) and off-peak ($i = 0$). A peak period represents the time window that consists of the most desirable travel times in a day, whilst an off-peak period contains all the rest time intervals.

The peak and offpeak times capacities are denoted as M and L. The offpeak period capacity is abundant and can accommodate airline demands regardless of peak period capacity ($M < 2N < M + L$). Conversely, the peak period is congested.

2.1 Passengers

In the airport, destinations attract heterogenous passenger demands. We assume that a destination $z \in [\underline{z}, \overline{z}]$ attracts z passengers and that destination demands are distributed according to the c.d.f. $G(z)$. Every destination market is vertically differentiated (Gabszewicz and Thisse, 1979). All potential passengers acknowledge and agree over peak load hours are preferable than the off-peak load hours at an equal price, i.e., slot qualities, denoted as s_0 and s_1 for offpeak and peak slots, respectively, are exogenously perceived: $s_1 > s_0 > 0$.

Passengers differ by their taste parameter $v \in [0, 1]$, v being uniformly distributed. They are endowed with the utility function: $U_i(v, p_i) = vs_i - p_i$ if they fly at peak ($i = 1$) or offpeak time ($i = 0$) with ticket price p_i.

2.2 Airline markets

In a destination market z two airlines, a and b, engage in seat (quantity) competition. Airline a sets its aircraft size $q^a(z)$ taking its rival's quantity $q^b(z)$ as given. Airline a's profit in airport pair z is

$$\pi^a(z) = [p^a(z) - \phi]q^a(z), \tag{1}$$

where $p^a(z)$ is its fare, ϕ is a per-passenger charge paid to the airport. Variable operating costs are normalized to zero. The airport gets a revenue ϕ per passenger.

2.3 The airport

The analysis considers both a private and a public airport. The private airport proposes a slot allocation and airport charge that maximize its revenues:

$$\Pi = \int_{\underline{z}}^{\bar{z}} \phi[q^a(z) + q^b(z)] N dG(z). \tag{2}$$

2.4 Timing and equilibrium concept

The timing is as follows. In the first stage, the airport sets per passenger fees. In the second stage, the airport only allocates slots for peak and offpeak travel periods. A sequential relationship between these two operations reflect the fact that, while slot allocation is determined on daily basis, per passenger fees are generally pre-set for a certain time period.[8] In the third stage, the airlines operating in airport pairs non-cooperatively choose their seat supplies based on the slot allocation. The equilibrium concept is the sub-game perfect Nash equilibrium.

3 Results

3.1 Airline competition

In the market stage, the competing airlines of each destination simultaneously choose their aircraft seat capacity. Airport per-passenger revenue is taken as given. When both flights depart at the same time range, subscript $i \in \{0, 1\}$ denotes the capacity seats of both airlines. By contrast, in a market where flights go both on peak and offpeak time, subscripts 01 and 10 denote the capacity seats of the airline operating in the offpeak and peak time, respectively. Thus, the equilibrium seat capacities in different (offpeak, peak) and same time periods are $q^a(z) = zq_{01}, q^b(z) = zq_{10}$ and $q^a(z) = q^b(z) = zq_i$, respectively, where

$$q_i = \frac{s_i - \phi}{3s_i}, \text{ for every } i \in \{0, 1\}, \tag{3}$$

$$q_{01} = \frac{s_1 s_0 - \phi\,(2s_1 - s_0)}{(4s_1 - s_0)\, s_0}, \tag{4}$$

$$q_{10} = \frac{2s_1 s_0 - \phi}{4s_1 - s_0}. \tag{5}$$

Comparing the quantities of the different market configurations, we get:

$$q_{10} > q_1 > q_0 > q_{01}, \tag{6}$$

$$q_{01} + q_{10} > 2q_0, \tag{7}$$

$$q_{01} + q_{10} > 2q_1 \iff \phi < \hat{\phi} \equiv \frac{s_0 s_1}{6s_1 - 2s_0}. \tag{8}$$

[8] Since there is no strategic interaction between the first and second stages, the results do not change if the airport choices are simultaneous.

Inequalities in (6) say that peak flights carry larger numbers of passengers than offpeak ones; this difference is more acute when airlines are allocated to different travel periods. Inequalities (7) and (8) indicate that differentiated airlines supply more passengers than offpeak airlines regardless of ϕ, and may supply more passengers than peak airlines if ϕ is sufficiently small, respectively.

Condition

$$0 < \phi < \bar{\phi} \equiv \frac{s_0 s_1}{2s_1 - s_0} \tag{9}$$

ensures that both airlines coexist in a destination market, regardless of which slots they obtain. One may notice that $\hat{\phi} < \bar{\phi}$.

3.2 Regulated airport

In the second stage, the airport sets the optimal slot allocation. In a regulated airport, per-passenger fees are established by an external authority. The regulated airport maximizes its profits by allocating peak slots subject to the limited capacity.

We denote by $n_0(z), n_{01}(z)$ and $n_1(z) \in \{0, 1\}$ the airport's decision variables to allocate respectively an offpeak/offpeak, peak/offpeak and peak/peak configuration in market z. Only one of these decision variables takes a value of 1, while the other two take zero value: $n_0(z) + n_{01}(z) + n_1(z) = 1$. The airport problem is:

$$\max_{n_0(\cdot), n_{01}(\cdot), n_1(\cdot)} \phi \int_{\underline{z}}^{\bar{z}} z[2q_0 n_0(z) + (q_{01} + q_{10})n_{01}(z) + 2q_1 n_1(z)]NdG(z), \tag{10}$$

subject to

$$\int_{\underline{z}}^{\bar{z}} [n_{01}(z) + 2n_1(z)]NdG(z) \leq M, \tag{11}$$

and $n_0(z) + n_{01}(z) + n_1(z) = 1$. Replacing $n_0(z)$ from the latter identity and pointwise maximizing with respect to n_{01} and n_1, one readily finds the marginal incentives to set either two different slots or two peak slots for city pair z:

$$\mathcal{L}_{01} = z\phi(q_{01} + q_{10} - 2q_0) - \mu = 0, \tag{12}$$

$$\mathcal{L}_1 = 2z\phi(q_1 - q_0) - 2\mu = 0, \tag{13}$$

where $\mu \geq 0$ is the Khun Tucker multiplier of the capacity constraint (11). We have $\mathcal{L}_{01} = 0$ and $\mathcal{L}_1 = \mathcal{L}_{01}$ for

$$z_{01} = \frac{\mu/\phi}{q_{01} + q_{10} - 2q_0} \text{ and } z^* = \frac{\mu/\phi}{2q_1 - (q_{01} + q_{10})} \tag{14}$$

respectively.

The solution to this problem depends on the level of per-passenger fees. From equation (8), we know that, when $\phi < \hat{\phi}$, the flow of passengers is larger in the peak/offpeak configuration than in the peak/peak and offpeak/offpeak configuration: $q_{01} + q_{10} > 2q_1 > 2q_0$. As illustrated in the first panel of Figure 1, it follows that the marginal profit of letting one flight into the peak slot $\mathcal{L}_{01}$ is always larger than that obtained by allowing two peak flights $\mathcal{L}_1$. In this case, the airport never allocates two peak slots on two flights to a same destination z. It allocates two different slots if $\mathcal{L}_{01} \geq 0$, i.e. $z \geq z_{01}$, and allocates two offpeak slots otherwise. We obtain the discriminatory allocative schedule, defined as follows:

Definition 1 *A discriminatory allocative schedule grants at most one peak flight per destination market. It allocates a peak/offpeak configuration to high demand destinations with $z > z_{01}$ and an off-peak/off-peak configuration to low demand ones with $z \leq z_{01}$.*

Next consider $\phi > \hat{\phi}$. By equation (8), the peak slots generate the highest market outcome among all three allocation profiles: $2q_1 > \max\{q_{01} + q_{10}, 2q_0\}$. As illustrated in the second panel of Figure 1, the marginal profit $\mathcal{L}_1$ increases in z faster than $\mathcal{L}_{01}$ and becomes larger than the latter iff $z \geq z^*$. Under this condition, the airport prefers to allocate two peak slots compared to two different slots. On the other hand, the marginal profit $\mathcal{L}_{01}$ is positive for $z \geq z_{01}$. Under this condition, the airport prefers to allocate different slots rather than two offpeak slots. Then the airport grants two peak slots to large market destinations and none to small ones. Destinations with intermediate market sizes receive only one peak slot. In other words, there is a mixture of all three patterns in this case, according to the following definition.

Definition 2 *A balanced allocative schedule grants a peak/peak configuration to high demand destinations $z > z^*$, a peak/offpeak configuration to inter-mediate demand ones $z \in [z_{01}, z^*)$ and an offpeak/offpeak to low demand ones $z \leq z_{01}$.*

The following proposition summarizes the allocative schedule based on the level of regulated fees.

Proposition 1 (Picard et al. (2019)) *If the regulated fees are $\phi < \hat{\phi}$, the private airport implements a discriminatory allocative schedule. Otherwise, it implements a balanced allocative schedule.*

Proposition 1 replicates the result in Picard et al. (2019). It allows us to make some considerations about allocative inefficiency, defined as follows.

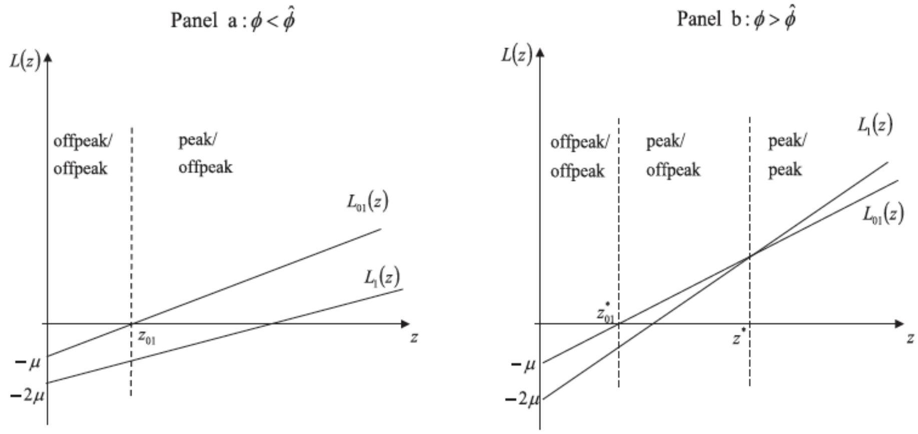

Figure 1: Marginal profits of shifting one or two flights to the peak period

Definition 3 *Allocative inefficiency describes the situation where airports restrain their supply of peak slots strictly below their capacity levels.*

Figure 1 shows the solution for low regulated fees ($\phi < \hat{\phi}$, panel a) and high regulated fees ($\phi > \hat{\phi}$, panel b). By Proposition 1, allocative inefficiency occurs when the discriminatory allocative schedule is implemented, that is, when $\phi < \hat{\phi}$. In this case, some peak slots may not be used if the peak slots are relatively abundant ($2N > M > N$). When the capacity constraint is not binding ($\mu = 0$), the airport allocates different slots to each city pair since $\mathcal{L}_{01} > 0$. It leaves peak slots empty although there is a demand for it. Zografos et al. (2013) and Zografos et al. (2012), among others, found empirical evidence for slot misuse, confirming that allocative inefficiency exists at some airports. By contrast, when regulated fees are sufficiently high, $\phi > \hat{\phi}$, allocative inefficiency does not emerge.

3.3 Unregulated airport

This section outlines the innovative results of the paper, by examining the effect of liberalizing per-passenger fees on the two situations presented above.

3.3.1 Low fees

In the first stage, the airport maximizes its objective function by choosing the level of per-passenger fees ϕ^*. Notice that, the airport choice strictly depends on the slot allocation schedule. Hence, once obtained the optimal level of per passenger fees, the airport must verify whether this is consistent with the allocation choice, that is, if ϕ lies in the range determined by the equilibrium allocation. Finally, the airport must evaluate if ϕ^* ensures an interior solution in the market stage: $\phi^* \lesseqgtr \widehat{\phi}$.

We start with case $\phi < \widehat{\phi}$. In this case, we know that if the fee satisfies $\phi^* < \widehat{\phi}$, airport will assign 0 slots to the markets with size $z \leq z_{01}$ and one slot to markets with size $z > z_{01}$. Given the equilibrium slot allocation, we may rewrite the airport problem in the first stage as follows:

$$\max_{\phi} \phi \Bigg[\int_{\max(z_{01},0)}^{1} z(q_{01}+q_{10})NdG(z) + \int_{0}^{\max(z_{01},0)} z(2q_0)NdG(z) \Bigg], \tag{15}$$

where $z_{01} = G^{-1}(1-\frac{M}{N})$. Notice that the airport charge does not affect the allocation pattern, rather only the market outcome (passenger volume) for a given market configuration. In other words, setting the charge would not affect the number of peak slots any market would receive, as this is determined exogenously by N, M and z.

The optimal fee is determined by the first-order condition of (15) with respect to ϕ. We denote this optimal fee as ϕ_a^*, then ϕ_a^* can be written as:

$$\phi_a^* = \frac{s_0}{4} \frac{\alpha_1(9s_1 - 3s_0) + \alpha_2(8s_1 - 2s_0)}{[3\alpha_1 s_1 + \alpha_2(4s_1 - s_0)]}, \tag{16}$$

where $\alpha_1 = \int_{\max(z_{01},0)}^{1} zNdG(z) > 0, \alpha_2 = \int_{0}^{\max(z_{01},0)} zNdG(z) > 0.$ [9]

If the number of destinations is small ($N < M$), the capacity constraint is not binding, $z_{01} = 0$, thus all destinations will each receive one peak slot. Given this, the airport chooses the optimal charge so as to maximize $\phi \int_0^1 z(q_{01}+q_{10})NdG(z)$. On the contrary, if the number of destinations is large ($N > M$), only the largest M destinations will each receive a peak slot, in which case the airport chooses optimal charge to

[9] The second order condition is always respected:

$$\frac{\partial^2 \Pi\left(n_k^*\right)}{\partial \phi^2} = -\frac{4s_1\alpha_1}{s_0(4s_1 - s_0)} - \frac{4\alpha_2}{3s_0} < 0.$$

maximize $\phi[\int_{z_{01}}^{1} z(q_{01}+q_{10})NdG(z) + \int_{0}^{z_{01}} z(2q_0)NdG(z)]$. As a function of α_1 and α_2, ϕ_a^* represents the optimal per-passenger fee for both configurations.

The next step is to verify if the optimal fee ϕ_a^* is consistent with the allocation optimal conditions outlined in Proposition 1, more precisely, whether the necessary condition to ensure equilibrium allocation ($0 < \phi_a^* < \hat{\phi}$) holds. It can be verified that the optimal charge falls out of the parameters' range which supports this allocation pattern:

$$\begin{aligned}\phi_a^* - \hat{\phi} &= \frac{s_0}{4}\left[\frac{s_1(9\alpha_1+8\alpha_2)-s_0(3\alpha_1+2\alpha_2)}{s_1(3\alpha_1+4\alpha_2)-\alpha_2 s_0} - \frac{2s_1}{3s_1-s_0}\right] \\ &= \frac{s_0}{4}\frac{3\alpha_1\left(s_0^2-6s_0s_1+7s_1^2\right)+2\alpha_2\left(2s_1-s_0\right)\left(4s_1-s_0\right)}{\left[s_1(3\alpha_1+4\alpha_2)-\alpha_2 s_0\right]\left(3s_1-s_0\right)} > 0,\end{aligned}$$

which violates the condition $\phi < \widehat{\phi}$. In other words, this allocation profile is not an equilibrium. The following proposition summarizes the result.

Proposition 2 *Suppose all markets are served by duopoly airlines, and the airport is private and unregulated. Then the airport never sets a too low per-passenger fee,* $\phi^* \leq \widehat{\phi}$.

The striking consequence of Lemma 2 is that allocative inefficiency is eliminated once the airport is unregulated and obtains one more management tool (fee setting) in addition to slot distribution. The intuition is as follows.

When the airport is under a regulatory regime, the unique airport's instrument is peak slot allocation. When regulated fees are low, the airport finds it convenient to keep some peak slots unused to expand the airport-pair markets, thus attracting a larger number of passengers who are willing to fly at offpeak times. This is natural: since the fee does not change between low and high valuation passengers, the airport chooses to expand the passenger numbers, even if this strategy leaves slots unused.

When the airport faces no fee regulation, it has two substitutable instruments to extract airlines' surplus: fees and slot allocation. For this allocation schedule, the airport would manipulate fees in such a way that the given schedule is not optimal anymore. In turn, by excluding the discriminatory allocative schedule, allocation inefficiency is also precluded.

3.3.2 High fees

Having shown that case (i) is not an equilibrium, we now turn to examine case (ii) where $\phi^* > \hat{\phi}$ (panel *b* of Fig.1). Here, there can be up to three possible allocation patterns, depending on the market size. In particular, adding a peak slot always generates positive marginal profit to the airport, thus constraint (11) is binding at the optimum, from which we can derive $z^* = 2 - \frac{M}{N} - z_{01}^*$. Substituting z^* into the objective function and converting the constrained optimization to an unconstrained, one obtains:

$$\max_{\phi} \phi \Big[\int_{z^*}^{1} z(2q_1)NdG(z)) + \int_{z_{01}^*}^{z^*} z(q_{01}+q_{10})NdG(z) + \int_{0}^{z_{01}^*} z(2q_0)NdG(z) \Big], \tag{17}$$

where z^* and z_{01}^* are the roots of $\mathcal{L}_{01}(z) = \mathcal{L}_1(z)$ and $\mathcal{L}_{01}(z) = 0$, respectively. From the binding constraint $G(z^*) + G(z_{01}^*) = 2 - M/N$, z^* and z_{01}^* can be written as:

$$\begin{aligned} z^*(\mu,\phi) =& \frac{\mu}{\phi[2q_1 - (q_{01}+q_{10})]}, \\ z_{01}^*(\mu,\phi) =& \frac{\mu}{\phi[q_{01}+q_{10}-2q_0]}. \end{aligned} \tag{18}$$

From the first-order condition, we can calculate ϕ^* and, in the Appendix, we show that $\phi^* > \hat{\phi}$: the optimal fee exceeds the critical value that supports an equilibrium, $\phi > \widehat{\phi}$. Hence, there exists a unique equilibrium solution for case (ii). The optimal fee and allocation pattern is depicted in the following proposition.

Proposition 3 *Suppose all markets are served by duopoly airlines, and the airport is private and unregulated. The airport sets a balanced slot allocation with an optimal fee ϕ^*.*

Proof. in Appendix. ■

Proposition 3 states that the airport never chooses a too low per-passenger fee such that passenger number in peak/peak market surpasses peak/offpeak market, and that allocation is always efficient. Liberalizing per passenger fees might thus overcome the allocative inefficiency of low per-passenger fees. The reason is clear. The airport now has an additional pricing variable to control the airlines' passenger number decisions, which makes it unnecessary to reduce the number of slots employed.

4 Welfare comparison

In this section, we evaluate the impact of liberalizing per-passenger fees on welfare. Social welfare W is represented by the sum of the airport' profits Π, passenger surplus PS and airlines' profits:

$$W = \Pi + PS + n_1 (\pi_{01} + \pi_{10}) + 2 (n_2 \pi_1 + n_3 \pi_0). \tag{19}$$

Since airport and airline operating costs are normalized to zero, airport profits come from total per-passenger fees, whereas airline profits are ticket income less total per-passenger fees paid to the airport. In turn, passenger surplus is represented by the total gross utility generated from flying minus all ticket payments. Since monetary transfers between airlines and airport cancel out, and so do transfers between passengers and airlines, then social welfare equals the sum of passengers' gross utility in all N destination markets. Hence, the total welfare in an airport pair z, $w^a(z)+w^b(z)$, amounts to the gross passenger surplus obtained under the equilibrium seat supplies $q^a(z)+q^b(z)$.

When the airport assigns the airlines of destination z to the same type of time period $i \in \{0,1\}$, each flight generates a welfare level $\frac{1}{2}\int_{1-2q_i}^{1} vs_i z\mathrm{d}v$. Conversely, when it assigns airlines to different time periods, the offpeak flight generates a welfare level equal to $\int_{1-q_{01}-q_{10}}^{1-q_{10}} vs_0 z\mathrm{d}v$ while the peak flight yields $\int_{1-q_{10}}^{1} vs_1 z\mathrm{d}v$. Welfare levels thus correspond to zw_{ij}, where

$$w_i = \frac{(s_i-\phi)(2s_i-\phi)}{9s_i}, \tag{20}$$

for two flights in the same time period $i \in \{0,1\}$, and

$$w_{01} = \frac{[s_1(s_0-2\phi)+s_0\phi]\,[3s_1s_0+\phi\,(2s_1+s_0)]}{2s_0\,(4s_1-s_0)^2}, \tag{21}$$

$$w_{10} = \frac{s_1(2s_1-s_0-\phi)(6s_1-s_0+\phi)}{2\,(4s_1-s_0)^2}, \tag{22}$$

for two flights in different time periods. When regulated fees are $\phi > \widehat{\phi}$, the slot configuration schedule does not change after fees liberalization, and thus social welfare is the same when fees are regulated or not. We thus focus on the case in which regulated fees are $\phi < \widehat{\phi}$. In particular, we investigate the difference between social welfare with regulated and unregulated fees in relation to variations of ϕ. Considering the appropriate equilibrium allocation schedule, social welfare in (19) with regulated fees when $\phi < \widehat{\phi}$ can be rewritten as:

$$W_{reg} = \int_{\max(z_{01},0)}^{1} z(w_{01}+w_{10})NdG(z) + \int_{0}^{\max(z_{01},0)} z(2w_0)NdG(z). \tag{23}$$

Conversely, social welfare with unregulated fees can be rewritten as:

$$W_{unreg} = \int_{z^*}^{1} z(2w_1)NdG(z)) + \int_{z_{01}^*}^{z^*} z(w_{01}+w_{10})NdG(z) + \int_{0}^{z_{01}^*} z(2w_0)NdG(z), \tag{24}$$

We consider separately the cases where $M > N$ or $M < N$.

When $M > N$, we compare $W_{reg}|_{\phi=\widehat{\phi}}$, i.e, the lowest possible social welfare with regulated fees, with the highest possible level of unregulated fees, $W_{unreg}|_{M=2N}$. We get

$$W_{reg}|_{\phi=\widehat{\phi}} - W_{unreg}|_{M=2N} = \frac{Ns_1\left(16s_0^2-51s_1s_0+63s_1^2\right)}{144\,(3s_1-s_0)^2} > 0,$$

which is a sufficient condition for every $\phi < \widehat{\phi}$ and $M \in (N,2N)$.

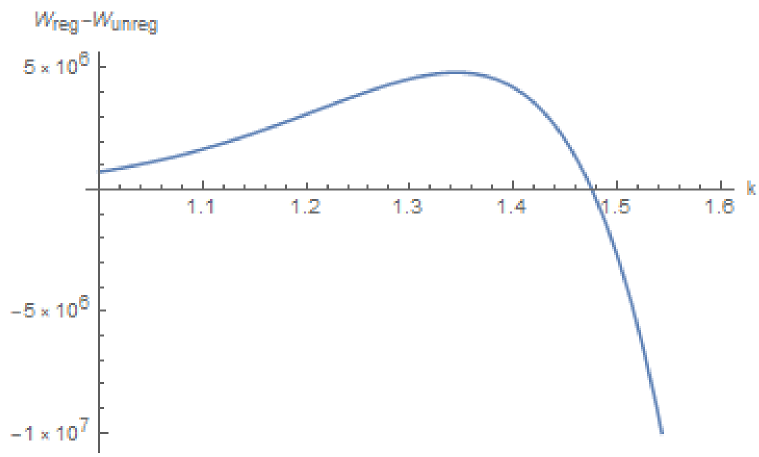

Figure 2: Difference in welfare among regulated and unregulated airport

Proposition 4 *Suppose $M > N$ and regulated fees are $\phi < \widehat{\phi}$. Then per-passenger fees liberalization always leads to a fall in social welfare.*

Proposition 4 shows that, when the number of peak slot is high, social welfare falls after the liberalization of per-passenger fees. This result differs from Picard et al. (2019), in which allocative inefficiency amounted to both disuse of slots and a welfare diminishing effect.[10] The regulated fees here improve social welfare even if they imply an inefficient use of the airport infrastructures.

Consider next the case where $M < N$. In this case, the lowest possible social welfare with regulated fees is given by $W_{reg}|_{\phi=\widehat{\phi},N=0}$, while the highest possible welfare with unregulated fees is given by $W_{unreg}|_{M=N}$. By comparing the two social welfares we get

$$\begin{aligned} W_{reg}|_{\phi=\widehat{\phi},M=0} - W_{unreg}|_{M=N} \propto & 1024s_0^{11} - 26052s_1s_0^{10} + 279039s_1^2s_0^9 - 1605773s_1^3s_0^8 + \\ & 5186880s_1^4s_0^7 - 8507850s_1^5s_0^6 + 3122311s_1^6s_0^5 + 9174039s_1^7s_0^4 - \\ & 8388654s_1^8s_0^3 - 2585052s_1^9s_0^2 + 2021688s_1^{10}s_0 + 593568s_1^{11}. \end{aligned}$$

For convenience, we rename $s_1 = ks_0$ where $k > 1$ represents the gain from traveling at peak rather than offpeak time. In this way, we obtain that $W_{reg}|_{\phi=\widehat{\phi},M=0} - W_{unreg}|_{M=N} > 0$ for $1 < k \leq 1.476$.

Proposition 5 *Suppose $M < N$ and regulated fees are $\phi < \widehat{\phi}$. Then per-passenger fees liberalization leads to a fall in social welfare when the difference in qualities between flying at peak or offpeak times is not too high.*

[10] In Picard et al. (2019), inefficiency was determined by the comparison with the allocation configuration chosen by a public airport.

Figure 2 shows the difference in welfare levels between a regulated and unregulated airport as a function of k. Compared to Proposition 4, here there is no allocative inefficiency because, given $M < N$, the airport uses all the available peak slots. Therefore unregulated per-passenger fees have no effect on the efficient use of the airport infrastructure. Nonetheless, liberalizing per-passenger fees might improve social welfare, if the gain from flying at peak times, measured by k, is sufficiently high.

5 Conclusion

In this paper we have carried forward the problem of allocative inefficiency. Starting from the findings of Picard et al. (2019) for airports with regulated per-passenger fees, we have evaluated the welfare effects of liberalization. Whenever unregulated per-passenger fees have a positive effect on an efficient use of airport infrastructure, it worsens the welfare level. Liberalization might have positive effects on welfare only if the number of peak slots available is relatively limited, and the passengers' benefit from flying at peak times is sufficiently higher than the offpeak alternative. We hope, with our findings, to provide guidance to airport regulators.

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Appendix

Maximization by slots

Using $n_0 = 1 - n_{01} - n_1$, the Lagrangian function can be written as

$$\mathcal{L} = \phi \int_{\underline{z}}^{\bar{z}} z[2q_0(1-n_{01}-n_1) + (q_{01}+q_{10})n_{01} + 2q_1 n_1]NdG(z) - \mu[\int_{\underline{z}}^{\bar{z}} (n_{01}+2n_1)NdG(z) - M]$$

To ease the exposition, we suppress the z argument in n. μ is the Kuhn-Tucker multiplier associated with the capacity constraint. Note that the capacity constraint can be re-formulated as $\mu \int_{\underline{z}}^{\bar{z}} ((n_{01}+2n_1)N - M)dG(z)$, we then rewrite Lagrangian function in a more compact form:

$$\mathcal{L} = \int_{\underline{z}}^{\bar{z}} \phi z[2q_0(1-n_{01}-n_1) + (q_{01}+q_{10})n_{01} + 2q_1 n_1] - \mu\left(n_{01} + 2n_1 - \frac{M}{N}\right) NdG(z). \qquad (25)$$

Notice that n_k are continuous functions in the range [0,1], and eventually take values of either 0 or 1 because the objective function and constraint is linear in $\{n_0, n_{01}, n_1\}$.

Using pointwise maximization with respect to n_{01} and n_1, one gets

$$\begin{aligned}\mathcal{L}_{01} =& z\phi(q_{01}+q_{10}-2q_0) - \mu = 0,\\ \mathcal{L}_1 =& 2z\phi(q_1 - q_0) - 2\mu = 0,\end{aligned}$$

The second order derivative of airport's profit with respect to ϕ is:

$$\int_{\underline{z}}^{\bar{z}} -2\left(\frac{2n_0}{3s_0} + \frac{2n_1}{3s_1} + \frac{2n_{01}s_1}{s_0(4s_1-s_0)}\right) zNdG(z) < 0, \qquad (26)$$

for $n_k(z) = 1$ and $n'_k = n''_k = 0$ where $k \neq k' \neq k'' \in \{0, 1, 01\}$.

Proof of Proposition 3

The first-order condition is:

$$\begin{aligned}\pi_{2,\phi} \quad =& \quad \frac{s_0^3\left(-\left(s_1\left(M^2-4MN+2N^2\right)+4N^2\phi\right)\right)+s_1 s_0^2\left(s_1\left(3M^2-12MN-4N^2\right)-4\phi\left(M^2-4MN-4N^2\right)\right)}{6Ns_0\left(s_0-4s_1\right)^2 s_1}\\ &+\frac{2s_1^2 s_0\left(s_1\left(-M^2+4MN+12N^2\right)+8M\phi(M-4N)\right)-12s_1^3\phi(M-2N)^2}{6Ns_0\left(s_0-4s_1\right)^2 s_1}\\ =& \quad 0.\end{aligned}$$

Solving with respect to ϕ, we get

$$\phi^* = \frac{s_0 s_1 \left[2s_1^2\left(12N^2+4MN-M^2\right) - s_1 s_0\left(4N^2+12MN-3M^2\right) - s_0^2\left(2N^2-4MN+M^2\right)\right]}{4\left[3s_1^3(2N-M)^2+4s_1^2 s_0 M(4N-M) - s_1 s_0^2\left(4N^2+4MN-M^2\right)+N^2 s_0^3\right]}. \tag{27}$$

We then compare ϕ^* and $\hat{\phi}$, obtaining

$$\phi^* - \hat{\phi} = \frac{s_0 s_1\left(4s_1-s_0\right)\Delta_1}{4\left(3s_1-s_0\right)\Delta_2},$$

where :

$$\Delta_1 = M(4N-M)(s_1-s_0)(3s_1-s_0)+6N^2 s_1(2s_1-s_0),$$

$$\Delta_2 = 3s_1^3(2N-M)^2+4s_1^2 s_0 M(4N-M) - s_1 s_0^2\left(4N^2+4MN-M^2\right)+N^2 s_0^3$$

A quick glance shows that $\Delta_1 > 0$, while $\Delta_2 > 0$ because the last part is positive, while the first three parts are:

$$\begin{aligned} s_1 s_0^2\left(M^2-4N^2-4MN\right)+3s_1^3(M-2N)^2+4s_1^2 s_0 M(4N-M) &> \\ s_1 s_0^2\left[\left(M^2-4N^2-4MN\right)+3(M-2N)^2+4M(4N-M)\right]& \\ = s_1 s_0^2 \cdot 8N^2 > 0.& \end{aligned}$$

Hence $\phi^* > \hat{\phi}$.