On the Equivalence of Congestion Pricing and Slot Auctioning at Congested Airports*

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Abstract

This paper analyzes the slot-auction approach to management of airport congestion. The rationale for the approach is that first-best pricing leads to tolls that are differentiated across carriers and therefore seems to be hard to implement; the hope is that slot-auctioning would lead to the first-best while avoiding the problems of perceived unfairness. By using an airline duopoly model with general demand and cost conditions, I show that slot-auctioning will not necessarily lead to the efficient outcome, contrary to previous results in the literature. Specifically, I show that: (i) slot auctioning does not lead to the exit of carriers that would be active in the first-best yet, if a carrier exits, the remaining carrier can and will exert market power (unless it has none), leading to social welfare losses (ii) even if slot auctioning does not lead to market foreclosure, it will not be efficient unless airlines have no market power, or are completely symmetric (iii) slot auctioning might lead to outcomes that are worse from a welfare point of view than doing nothing.

Keywords: Airport congestion, Congestion pricing, Slots, Slot Auctions

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1. Introduction

Traffic growth has outpaced capacity increases at major airports around the world and for the last several years airlines and passengers have increasingly been suffering from flight delays. Other than capacity expansions, perhaps the most suggested and discussed congestion remedy has been the pricing mechanism, where the social planner works to correct congestion externalities by setting congestion tolls. In the context of airports, recent literature has recognized the importance of air carriers' market power (Brueckner, 2002; Pels and Verhoef, 2004; Zhang and Zhang, 2008; Basso, 2008): on one hand, as is typical in Pigouvian tolls, the optimal airport charge would need to take into account uninternalized congestion; yet, with non-atomistic airlines the airport would charge a carrier only for the congestion it imposed on other carriers, owing to internalization of self-imposed congestion. Thus, this congestion effect will increase the optimal toll above airport's marginal cost, but below the level for atomistic carriers. On the other hand, since a carrier with market power restricts output, the optimal charge would include a term that decreases the toll, as a way to induce a lower marginal cost for airlines stimulating traffic. This subsidy to airlines is known as the market power effect. Clearly, which effect dominates depends on the case, but note that if it is market power, then actually there is no congestion problem but one of too little traffic. And since optimal pricing requires massive amounts of information and charging differentiated tolls to airlines, it is quite clear that implementing first-best prices may be quite controversial and complex.

In addition to pricing, other widely discussed congestion remedy has been auctioning the airports' slots. In fact the FAA proposed a move in this direction for the three New York airports, which are among the most congested and delay prone in the US, although the idea was eventually defeated (see Bernardino, 2009) . Proponents of these solutions have argued that by setting a number of slots, congestion problems would be obviously solved while by auctioning them it would be ensured that each slot goes to the airline which values it most. Therefore, these mechanisms would circumvent the information problem and perceived unfairness that congestion pricing has, while using secondary markets to achieve efficiency.[1] Yet, the exact way in which slot auctioning would take into account both congestion and, specially, the market power effect is unclear. Intuition borrowed from the input-preemption literature may help here to show how market power might lead to inefficiencies if one auctions slots: since slots are an essential input for production, it is clear that for any available slot that may become available, a monopoly incumbent carrier can outbid an entrant, since monopoly profits are higher than duopoly profits, leading to decreased competition. Can this be the case in the problem we consider? Three things are important to note: first, that in the case depicted there would not be a congestion

[1] For example Starkie (2008) argues that "The allocation of airport slots is frequently is sub-optimal. It is a situation that can be rectified however, by allowing airlines to trade slots in secondary markets".

problem because market power dominates. Second, that Brueckner (2009) recently showed analytically that first-best congestion pricing and slot auctioning are equivalent in terms of both the amount of traffic generated and total social welfare, as long as the fixed number of slots is optimally chosen; however, in Brueckner's model airlines did not have market power. Third, that in Verhoef (2010) indeed one airline left the other out of the market but in his model it was optimal –from the social planner's point of view– to actually allow only one airline (the low-cost one) to operate.

Thus, the research questions that drives this paper are: In an environment with perfect information, where the objective function is unweighted social welfare, is it possible that while having a congestion problem, market power from the part of the airlines make slot auctioning inefficient in terms of the allocation of slots to carriers and total traffic? if the answer is yes, can it worsen the situation with respect to the laissez-faire situation? And furthermore, can it happen that slot auctioning lead to anticompetitivemarket foreclosure? By using a general model for airlines demand and costs I show that: (i) slot auctioning does not lead to the exit of firms that would be active in the first-best yet, if firm exits, then the remaining firm can and will exert market power (unless it has none), leading to large social welfare losses (ii) even if slot auctioning does not lead to market foreclosure, it will not be efficient unless airlines have no market power, or are completely symmetric (iii) slot auctioning might lead to outcomes that are worse from a welfare point of view than the laissez-faire. I conclude then, that going ahead with slot auctioning assuming that secondary markets would achieve efficiency, without a clear analysis of the situation of the airlines using the airport and their market power (on a route by route basis!), is not a wise course of action.

2. The model: first-best and laissez-faire situations

Consider two airlines, which I denote by i and j, offering services out of a congestible airport and let me use h for expressions that are valid for both airlines. Each airline faces a demand given by $q_h(\rho_i, \rho_j)$, where q_h represent number of travelers per unit of time and ρ_h represents the full price they face, which here is given by the sum of the air ticket plus congestion costs, namely $\rho_h = t_h + \alpha D(f_i + f_j)$ with α being travelers value of time and f_h being the number of flights per unit of time that each airline offers.

The relationship between the number of travelers and the number of flights is given by $q_h = f_h S_h$, where S_h is the product between aircraft size and load factor. For simplicity – and is it is common in the airport pricing literature– I will assume that $S_i = S_j$ and without further loss of generality I set the common value to one. With this I can invert the system of direct demands to obtains inverse demands: $\rho_h(f_i, f_j) \equiv d_h(f_i, f_j)$ and then, from the definition of the full price, get:

$$t_h(f_i, f_j) = d_h(f_i, f_j) - \alpha D(f_i + f_j) \quad (1)$$

Note that equation equation (1) is quite general in that, in addition to allowing for the externality problem through the congestion term, it allows for both market power and product differentiation. For example, we can consider a linear demand system (LDS): $d_i(f_i, f_j) = a_h - b_h f_i - e f_j$ where $b_h \geq e$ indicates market power,$e = 0$ implies that airlines operate in different markets, $e = 1$ apply for perfectly homogeneous products, while intermediate values apply for imperfect substitutes.

The cost functions of airline h is then given by:

$$C_h(f_i, f_j) = c_h(f_h) + \beta_h D(f_i + f_j) f_h + P f_h \quad (2)$$

where P is any charge the airport makes that is non discriminatory. From (1) we can get revenues of airline i as $t_i f_i$ and therefore, using (2) we obtain airline h profit function as:

$$\pi_h(f_i, f_j) = d_h(f_i, f_j) f_h - c_h(f_h) - [\alpha + \beta_h] D(f_i + f_j) f_h - P f_h \quad (3)$$

The final ingredient we need for the objective function is consumer surplus, which is given by:

$$CS = \int_{\underline{\rho}}^{\overline{\rho}} \sum_{h=i,j} f_h(\rho_i, \rho_j) d\rho_h \quad (4)$$

Then, we obtain $SW(f_i, f_j) = \pi_i + \pi_j + CS$ by simply using (11) and (4).

$$SW(f_i, f_j) = \sum \left[d_i(f_i, f_j) f_i - c_i(f_i) - [\alpha + \beta_i] D(f_i + f_j) f_i - P f_i \right] + CS$$

The social optimum is obtained by taking first-order derivatives. If the optimum is interior, that is, both airlines produce flights, then the first-order condition for airline i is:

$$\begin{aligned} \frac{\partial SW}{\partial f_i} = & \frac{\partial d_i}{\partial f_i} f_i + d_i - c_i'(f_i) - [\alpha + \beta_i] D(f_i + f_j) - [\alpha + \beta_i] D'(f_i + f_j) f_i \\ & - \left[P + [\alpha + \beta_j] D'(f_i + f_j) f_j - \frac{\partial d_j}{\partial f_i} f_j - \frac{\partial CS}{\partial f_i} \right] = 0 \end{aligned} \quad (5)$$

while, the first-order condition for the second airline is analogous. As mentioned before, there will be conditions on the parameters and functions so that the first-best is interior, that is, for the values $f_i^*$and f_j^*obtained from $\frac{\partial SW}{\partial f_i} = 0$ and $\frac{\partial SW}{\partial f_j} = 0$ to be positive.

For example, one case in which the first-best is not interior is the one that Verhoef (2010) analyzes, namely, homogeneous airlines –which for the case of LDS happens when $e = 0$ and $b_i = b_j$), identical congestion costs $\beta_i = \beta_j = \beta$, and constant but different marginal costs c_h. In that case, it is optimal that only the airline with smaller marginal costs produce everything, while the other airline is (optimally) left out of the market.

The *Laissez-Faire* situation means that airlines can place as many flights as they desire, for a given price P per flight. In this case, the number of flights of each airline is given by the Cournot-Nash equilibrium.[2] This scenario can also be understood as slot sales, as in Brueckner (2009) and Verhoef (2010) or simply, the absence of congestion pricing.; in the end, this is just non-discriminatory pricing. This equilibrium is obtained by talking first-order conditions on airlines profits:

$$\frac{\partial \pi_i}{\partial f_i} = \frac{\partial d_i}{\partial f_i} f_i + d_i - c_i'(f_i) - [\alpha + \beta_i]\, D(f_i + f_j) - [\alpha + \beta_i]\, D'(f_i + f_j) f_i - P = 0 \qquad (6)$$

An interior Cournot-Nash equilibrium is obtained when $\frac{\partial \pi_i}{\partial f_i} = 0$ and $\frac{\partial \pi_j}{\partial f_i} = 0$ and the resulting traffic levels are positive. I denote the result by $f_i^C \geq 0$and $f_j^C \geq 0$.

Now, comparing equations (10) and (6) it is easy to see that an airline will take into accounts less aspects when pricing than what it is optimal. These effects have been discussed in detail before in the congestion pricing literature; see Brueckner (2002), Pels and Verhoef (2004) and Basso (2008). Hence, in order the achieve the first best, the planner would need to charge airline i the following three elements in addition to the airport marginal's cost:

- The *congestion effect*: $\left[\alpha + \beta_j\right] D'(f_i + f_j) f_j > 0$. This is charged in order to make airline j internalize the congestion it imposes on airline i's flights.
- The *business stealing effect*: $-\frac{\partial d_j}{\partial f_i} f_j > 0$. This is added to make airline i realize that when it increases its number of flights, it is partially taking business away from airline j.
- The *consumer surplus effect*: $-\frac{\partial CS}{\partial f_i} < 0$. This subsidy decreases airline's i marginal cost in order to induce an increase in production and fight allocative inefficiencies generated by market power.

As it is evident, the first two of these effects push the price to be larger than marginal cost while the third pushes in the the other direction. But, as one can easily suspect, it can be proven that the consumer surplus effect it is always larger that the business stealing effect,

[2] The assumption of Cournot competition between airlines is common in the airline economics literature and has some empirical support. See Basso and Zhang (2007) for details.

and actually, the sum of these two terms simplifies to something useful: $\frac{\partial d_j}{\partial f_i} f_j + \frac{\partial CS}{\partial f_i} = -\frac{\partial d_i}{\partial f_i} f_j$. [3] It is then the sum of *the business steeling* effect plus the *consumer surplus effect* what we call the *market power effect*, and it always tend to decrease the airport charge. With this, we can rewrite the first-order conditions in the first-best case as:

$$\frac{\partial SW}{\partial f_i} = d_i - c_i'(f_i) - [\alpha + \beta_i] D(f_i + f_j) - [\alpha + \beta_i] D'(f_i + f_j) \left[f_i + f_j\right] - P = 0 \qquad (7)$$

Now, as explained in the introduction, it is not always true that an airport faces a *congestion problem:* It is perfectly possible that airlines choose collectively a total number of flights that is smaller than the total traffic there would be in the first-best case; and if that happens, then the problem is obviously not one of rationing a scarce input anymore. Here, we will say that there is indeed a congestion problem when $f_i^C + f_j^C > f_i^* + f_j^*$ and, obviously, this problem will exist for some parameters and functional forms but not others. For example, a sufficient condition for a congestion problem to emerge is that the market power effect is dominated by the congestion effect for both airlines and all levels of traffic, namely $[\alpha + \beta_h] D'(f_i + f_j) f_h > \frac{\partial d_h}{\partial f_h} f_h$ for $h = i, j$, which would ensure that $f_h^C > f_h^*$. A particular case of this is what Brueckner (2009) studies, where the market power effect is always zero. Yet, it is quite clear that this is far from being a necessary condition. For example, one can envision cases in which it happens, simultaneously, that $f_i^C + f_j^C > f_i^* + f_j^*$ while $f_i^C > f_i^* > 0$ and $f_j^* > f_j^C > 0$. Moreover, it is perfectly possible for the Cournot Nash equilibrium to be interior, while in the first-best only one airline operates, as in Verhoef (2010): since he consider homogeneous airlines but different marginal costs, it happens that, in the first-best, only the most efficient airline should operate, while being heavily subsidized since the market power effects is at its maximum. The total traffic under laissez-faire though, is larger than in the first best, and has both airlines operating.

Obtaining general conditions under which a congestion problem exists with a non-zero market power effect is not possible without considering specific functional forms and even in that case it is no easy to graph the relevant parameter space without making further simplifying assumptions. For example, even if one assumes a linear demand system, constant marginal costs and a linear delay function D, the conditions obtained are rather not informative nor intuitive. Hence, what I will do instead of finding the conditions in general is to check and then impose the conditions for a congestion problem to exist in the examples that I use below, when studying the efficiency of slot auctioning.

[3] Proof: Taking derivative of equation (4), we get $\frac{\partial CS}{\partial f_i} = -f_i \frac{\partial \rho_i}{\partial f_i} - f_j \frac{\partial \rho_j}{\partial f_i} = -f_i \frac{\partial (t_i + \alpha D)}{\partial f_i} - f_j \frac{\partial (t_j + \alpha D)}{\partial f_i}$. Then, replacing t_i and t_j with (1), we finally get $\frac{\partial CS}{\partial f_i} = -f_i \frac{\partial d_i}{\partial f_i} - f_j \frac{\partial d_j}{\partial f_i}$ from where the result follows.

3. Efficiency of Slot Auctioning: interior equilibria

In the slot auctioning mechanism, the airport authority decides ex-ante the number n of slots it will auction. Hence, if all slots are used, airlines already know what delays to expect when bidding for slots, irrespective of how the slots end up being split between them. This idea is part of the central reasoning on the efficiency conjecture of slot auctioning: by fixing the number of slots before the auction, the externality is avoided. Now, with respect to the auction process itself, there is indeed large literature on multi-units auctions and how asymmetric information and strategic behavior may affect the outcome. But since Brueckner (2009) and Verhoef (2010) considered a perfect information environment, I shall consider one as well; the idea is to show how market power affects efficiency even without considering informational aspects. Now, with complete information, the bidding behavior of airlines for each slot is quite simple, as explained in Brueckner (2009) and Verhoef (2010): for each additional slot airlines are willing to bid up to the marginal profit of acquiring that slot, namely:

$$\frac{\partial \pi_i^{SA}}{\partial f_i} = \frac{\partial d_i}{\partial f_i} f_i + d_i - c_i'(f_i) - [\alpha + \beta_i] D(n) \tag{8}$$

where SA stands for Slot Auctioning. In the first-best each airline's traffic level is given by f_i^* and f_j^*; it follows that a necessary condition for the SA equilibrium to be efficient is that the total number of slots has to be such that $n = f_i^* + f_j^* \equiv n^*$ and that all of this slots are actually used, meaning that a congestion problem as define above actually exists; I therefore make the assumption, from the time being, that the number of slots is set to the first-best total traffic while the total traffic under the laissez-faire would be larger.[4] Now, observe from (8) that the marginal benefit is decreasing in the number of slots an airline already has as long as marginal costs do not decrease too sharply and the demand function is not *too* concave. In particular, a linear demand system and constant marginal costs are sufficient conditions for (8) to decrease with f_i. This imply that the willingness to pay for an extra slot most likely diminishes as airlines acquire more and more slots. It is then easy to find the conditions for an interior allocation of slots after the auctioning process, irrespective of the specifics of how it took place. For the SA equilibrium to lead to a situation where both airlines end up with a positive number of slots, the equilibrium allocation has to fulfill that airlines have equal (and positive) marginal profits, namely:

[4] The two assumptions are important: first, if n^* is larger than the laissez-faire total traffic, the airlines will simply stop bidding before all the slots are gone. Second, if a congestion problem do exist but from the start the number of slots is not set to the first-best total traffic, then the SA equilibrium simply cannot be first-best. A different question, related to the second point is, *if* SA does not lead to the first- best, what would be the best choice of *n?* This question is tacked later.

$$\frac{\partial d_i}{\partial f_i} f_i^{SA} + d_i - c_i'(f_i^{SA}) - [\alpha + \beta_i] D(n^*) = \frac{\partial d_j}{\partial f_j} f_j^{SA} + d_j - c_j'(f_j^{SA}) - [\alpha + \beta_j] D(n^*) > 0 \quad (9)$$

$$f_i^{SA} > 0 \quad , \quad f_j^{SA} > 0 \quad , \quad f_i^{SA} + f_j^{SA} = n^*$$

Note that this equilibrium is *trading-proof*, in that airlines have no incentives to trade slots. In what remains of this section I assume that the conditions for the SA equilibrium to be interior hold. I can thus move to the comparisons with the first-best allocation and, in fact it is enough to look at interior first-best equilibrium: if the first-best is not interior, then slot auctioning cannot be efficient. From (10) an interior first-best has to fulfill the following two conditions:

$$d_h - c_h'(f_h) - [\alpha + \beta_h] D(n^*) = [\alpha + \beta_i] D'(n^*) [f_i + f_j] + P \quad (10)$$

Noting that the right hand side of (10) has the same value for both conditions, it follows that an interior first-best fulfills:

$$d_i - c_i'(f_i^*) - [\alpha + \beta_i] D(n^*) = d_j - c_j'(f_j^*) - [\alpha + \beta_j] D(n^*) \quad (11)$$

A careful look at what makes equation (9) different from (11) lead to the first proposition in this paper:

Proposition 1. *If an a situation where there is a congestion problem, that is $f_i^c + f_j^c > f_i^* + f_j^*$, the slot-auctioning process ends up with a positive number of slots for both airlines, then the slot-auctioning equilibrium is efficient only if (i) for both airlines the market power effect is nil, that is $\frac{\partial d_h}{\partial f_h} = 0$, or (ii) airlines are completely symmetric, both in terms of cost functions and demands.*

Hence, in general, slot-auctioning will not be efficient and there are only two exceptions. The first exception –when airlines have no market power– is the main finding in Brueckner (2009); the second case has not been described before and it is also very specific: airlines have to be completely symmetric, both in demand and cost functions. Note that in this case, while slot auctioning would lead to an efficient outcome, given the symmetry of the case and that a congestion problem exists, a positive uniform positive price would also achieve the first best.

The next important issue relates to the relevance of Proposition 1, something that can be framed through two questions: First, how often can SA be inefficient, that is, how large is the parameter space where this happens? The reason why the answer is not direct is because, in addition to market power, we need a congestion problem to exist, which puts restrictions on parameter values. Second, even if is slot-auctioning does not lead to the first-best allocation, is it always better than the laissez-faire? This is important from a policy point of view because it might be the case that SA does not lead to the first-best yet it is still a desirable policy because, on one hand it is implementable in reality, and on the other hand it does improve the situation.

It happens that it is not hard at all to create examples where the conditions in Proposition 1 for SA to be inefficient hold, showing that the scope for inefficiency is quite large. And the additional conditions require for SA to be welfare worsening with respect to the laissez faire are not too stringent either.Consider the following example, whose algebra is simple to manage and is therefore omitted:

Example 2. We assume that airlines provide service in markets that are unrelated in demand terms, and only one airline face a non-perfectly elastic demand, that is, inverse demand functions are given by $d_1 = k\,a - b_1 f_1$, $d_2 = a$. Also suppose that both marginal costs are constants, equal and without further loss of generality equal to zero, that $\beta_i = \beta_j = \beta$, and that the delay function is linear, namely $D(x) = x$. Then airlines traffic, obtained by first-order conditions for the first-best and the laissez faire, and by equation (9) for slot-auctioning, are given by:

$$f_1^* = \frac{a(k-1)}{b_1} \qquad f_2^* = \frac{a\left(b_1 - 2(k-1)(\alpha+\beta)\right)}{2b_1(\alpha+\beta)}$$

$$f_1^C = \frac{a(2k-1)}{4b_1 + 3(\alpha+\beta)} \qquad f_2^C = \frac{a\left(2b_1 - (k-2)(\alpha+\beta)\right)}{\left(4b_1 + 3(\alpha+\beta)\right)(\alpha+\beta)}$$

$$f_1^{SA} = \frac{a(k-1)}{2b_1} \qquad f_2^{SA} = \frac{a\left(b_1 - (k-1)(\alpha+\beta)\right)}{2b_1(\alpha+\beta)}$$

Sufficient conditions (necessary for the case of the first-best) for these traffics to be strictly positive are $k > 1$ and $b_1 > 2(\alpha+\beta)(k-1)$. If these conditions hold, then it is direct to check that $\left(f_i^c + f_j^c\right) - \left(f_i^* + f_j^*\right) = \frac{a(2k-1)}{8b_1+6(\alpha+\beta)} > 0$, and therefore there is indeed a congestion problem, and therefore slot trading will not be efficient since the conditions of Proposition 1 are not met. It is then quite clear that the scope for SA to be inefficient, in terms of the parameter space, is quite large, even if one focus only on two parameters.

To understand where the inefficiency comes from, one can easily check that: $f_1^C < f_1^*$and $f_2^* < f_2^C$, which means that it is the airline 2 the one actually congesting, while airline 1 is exerting market power. However, after slot auctioning it is always the case that $f_1^{SA} < f_1^C$, namely, airline 1 contracts his output further, something that moves in the exact opposite direction of the first-best allocation. Furthermore, if $k > \frac{3}{2}$,then it is also true that $f_2^* < f_2^{SA} < f_1^C$which shows that the *congesting* airline will have even more flights than before.[5]

[5]The reader may have noted that as b_1 approaches 0, we do not obtain that SA coincides with the first-best.

Next, replacing the obtained traffic values for SA and the laissez-faire, one can easily compute and then compare social welfare levels. It is a matter of algebra to show that, whenever $b1 > \bar{b}(k, \alpha, \beta)$, with $\bar{b}$ given by:

$$\bar{b} = \frac{(4k-5)}{4}(\alpha+\beta) + \sqrt{\frac{(2k-1)^2(16k-17)(\alpha+\beta)^2}{16(4k-5)}}$$

SA will lead to a smaller welfare level value than the laissez-faire. The value of $\bar{b}$ is increasing in k and, for example, when $k = 2$ one obtains$\bar{b} = \frac{3(1+\sqrt{5})}{4}(\alpha+\beta)$. Hence, in terms of the parameter space, the scope for SA to decrease welfare below what it is obtained in the laissez-faire is large, and this is not even including the costs associated to implementing a policy of slot auctioning. .

An idea that may be lingering in the reader's mind is that, if SA is no longer efficient in the first-best sense, then assigning $n^* = f_i^* + f_j^*$ to the number of slots is not really the optimal thing to do. Could it be the case that if the number of slots is optimized instead of being set to the total traffic in the first-best, SA improves and does always better than the *laissez-faire*? The answer is also no. For instance, in Example 2 above, if the planner optimizes n given the airlines behavior (i.e. Equation (9) but with a variable n), what one obtains is in fact that $n^{SA} = n^*$ and therefore[6], in this case, SA is still worse than the laissez-faire even after optimizing the number of slots. Obviously, since in some cases SA can be efficient, there are also many cases in which SA does in fact perform better than the laissez-faire.

Finally one may wonder if, in fact it may not be the case that an optimized uniform price –a second-best pricing policy– actually improves things much over the laissez-faire; it happens however that for the example considered, the optimal uniform price is always negative, something that may be considered as non-implementable.

4. Efficiency of Slot Auctioning: non-interior equilibria

In Section 3. we showed that when market power is present, it is perfectly possible for a slot-auction process to be less than efficient and furthermore, it may actually worsen the situation as compared to the laissez-faire. Yet, that analysis was explicitly made for situa-

But this happens because, in a setting of low b1 and constant marginal costs, the SA equilibrium is not interior. I treat non-interior SA equilibrium in Section 4.but, in nay case, if i were to consider linear and increasing marginal cost instead of constant, then it is indeed true that that as b_1 approaches 0, SA approaches the first-best. That case, while simple, is cumbersome in terms of algebra so I sided with simplicity of exposition.

[6]It is not true in general that $n^{SA} = n^*$; in the case of Example 2 it is enough to make $\beta_i \neq \beta_j$ to obtain $n^{SA} \neq n^*$. The example with identical β was chosen precisely because it shows the point without introducing further calculations and ensures second-order conditions in the first-best.

tions in which the SA equilibrium is interior and, therefore, it does not address the issue of *market foreclosure*, that is, a situation in which one airline overbids the other for all slots that are auctioned. We know in fact that a situation like this can happen, as documented by Verhoef (2010): he considered two airlines offering perfect substitutes, but differing both in marginal and congestion costs, and indeed it happen that the efficient airline outbid the other, leaving it outside the market. In the case of perfect substitutes, however, when airlines only differ in efficiency, it is also true that in the first-best only the most efficient airline would produce.

It seems then reasonable to ask whether market foreclosure under SA is always efficient, in that the foreclosed airline would also be out in the first-best, or it could be inefficient, in that it leaves out of the airport an airline that would be active in the first-best. The answer is as follows:

Proposition 3. *If the slot-auctioning process leads a carrier to exit the market, then in the first-best that carrier will be inactive as well, irrespective of the degree of product differentiation.*

Proof. What we need to prove is: if $\frac{\partial \pi_i^{SA}(f_i,f_j,n)}{\partial f_i} > \frac{\partial \pi_j^{SA}(f_i,f_j,n)}{\partial f_j} \quad \forall f_i, f_j$ and $\forall n$ such that $f_i + f_j = n$, then $\frac{\partial SW(f_i,f_j)}{\partial f_i} > \frac{\partial SW(f_i,f_j)}{\partial f_j} \quad \forall f_i, f_j$. This means that if irrespective of the number of slots chosen by the planner, airline j never obtains a slot, then it has to be also true that it is never optimal to assign traffic to airline j in the first-best .

Recall then that the marginal revenue of an extra slot under SA for an airline is given by (8), that is $\frac{\partial \pi_h^{SA}}{\partial f_h} = \frac{\partial d_h}{\partial f_h} f_h + d_h - c_h'(f_h) - [\alpha + \beta_h] D(n)$, and assume that $\frac{\partial \pi_i^{SA}(f_i,f_j,n)}{\partial f_i} > \frac{\partial \pi_j^{SA}(f_i,f_j,n)}{\partial f_j} \quad \forall f_i, f_j,\ f_i + f_j = n$ holds. Then, in particular the inequality holds for $f_i = n$ and $f_j = 0$. We then obtain:

$$\frac{\partial d_i(n,0,n)}{\partial f_i} n + d_i(n,0) - d_j(n,0) - c_i'(n) + c_j'(0) + \left[\beta_j - \beta_i\right] D(n) > 0 \tag{12}$$

Note that, in order for (12) to hold for all n it has to be true that $\beta_j \geq \beta_i$, otherwise the inequality would not hold for large values of n.[7] Next, we need to show that if (12) holds, then $\frac{\partial SW(f_i,f_j)}{\partial f_i} > \frac{\partial SW(f_i,f_j)}{\partial f_j} \quad \forall f_i, f_j$. But since from (7) we can see that $\frac{\partial SW}{\partial f_h}$ decreases with $f_h$as long as the cost function is not *too concave* –that is, economies of scale are not too pervasive– it is actually enough to show that $\frac{\partial SW(f_t,0)}{\partial f_i} > \frac{\partial SW(f_t,0)}{\partial f_j}$ holds for all values of f_t, as this imply the previous inequality. Hence, using (7) for $\frac{\partial SW}{\partial f_h}$ what we need to prove is:

$$d_i(f_t,0) - d_j(f_t,0) - c_i'(f_t) + c_j'(0) - + \left[\beta_j - \beta_i\right] D(f_t) + \left[\beta_j - \beta_i\right] f_t D'(f_t) > 0 \tag{13}$$

But since $\frac{\partial d_i}{\partial f_i} < 0$ and equation (12) holds $\forall n$, then $d_i(f_t,0) - d_j(f_t,0) - c_i'(f_t) + c_j'(0) -$

[7] Under non-stringent conditions, the SA marginal profit of an airline is decreasing as the number of slots it has increases, so one could actually assume that the inequality holds for $f_i = n$ and $f_j = 0$, which would imply that it holds $\forall f_i, f_j,\ f_i + f_j = n$.

$\left[\beta_i - \beta_j\right] D(f_t) > 0$. And since $\left[\beta_j - \beta_i\right] f_t D'(f_t)$ is also positive, then (13) always holds, which finishes the proof. □

What Proposition 3 tells us is that it will not happen that an airline who would be active in the first-best will be left out of the market by an auctioning process so, this generalizes Verhoef (2010) result to different demand and cost conditions. Clearly, the parameter space where market foreclosure may occur is large, but that has to be intersected with the parameter space where there is indeed a congestion problem (or SA, for the purposes of solving congestion would not have been called for). The remaining parameter space is still fairly large. If for example we consider:

Example 4. (a) Inelastic and unrelated demands, i.e. $d_i = a_i$, $d_j = a_j < a_i$, $\beta_i = \beta_j = \beta$, a linear delay function $D(x) = x$, and constant and equal marginal costs, or (b) $d_i = a_i - b_i f_i$, $d_j = a_j < a_i$, and constant and equal marginal costs, we obtain market foreclosure under SA (and in the first-best), while having a congestion problem under laissez-faire.

Note that in these two examples, airlines produce completely differentiated products since $e = 0$, that is, foreclosure occurs despite the fact that airlines are not really competing in the market, they just compete for space in the airport.

Now, perhaps the most concerning issue about possible foreclosure is that, if a slot auctioning processes put in place to attack a congestion problem, nothing will stop the remaining airline from exercising market power: as each slot is made available, it will always be airline i the one that wins the slot since it has a higher marginal profit. And when its marginal profit equals zero, and therefore the willingness to pay is zero, the other airline will have a negative willingness to pay. But the number of slots airline i has is the one that makes its marginal profit equal zero, that is, the monopoly number of slots. It is then clear then that, because of market power welfare losses can be very large, unless of course the airline has zero market power in as Example 4a.

5. Conclusions

For airports, perhaps the most suggested and discussed congestion remedy has been the pricing mechanism. As the literature developed, it became clear the importance of air carriers' market power: on one hand because non-atomistic airlines would partly internalize congestion. On the other hand because a carrier restricts output to exert market power making the congestion problem less acute than when airlines are atomistic or face elastic demands. Overall, it is clear by today that first-best pricing requires both massive amounts of information and differentiated airport tolls making its implementation quite controversial and complex if not impossible.

In the light of this discussion –and certainly of many other problems of allocation of airport capacity–, many authors and authorities have argued that a slot -auctioning process might be able to restore the first-best; the only real complexity the planner would face is setting the number of slots to be auctioned to the right level, while the auction process would ensure an efficient outcome. Importantly, the mechanism would circumvent the information problem and perceived unfairness that pricing has. In fact the FAA proposed a move in this direction for the three New York airports, which are among the most congested and delay prone in the US, although the idea was eventually defeated.

Some important papers have shown theoretical support for the claim yet they did not really took into account market power, –which is in fact what complicates the matter– while another did considered market power, but in a homogeneous product framework, something that may not seem to be realistic because airlines may share the airport but do not compete necessarily in all city-pair markets. By using a quite general model for airlines demand and costs I show that: slot-auctioning does not lead to the exit of firms that would be active in the first-best yet, if firm exits, then the remaining firm can, and will exert market power (unless it has none). Social welfare losses can be large in this case. On the other hand, even if slot-auctioning does not lead to market foreclosure, it will not be efficient unless airlines have no market power, or are completely symmetric. Furthermore slot-auctioning can be worse than the laissez-faire, that is, implementing the policy (which is costly) may well end up decreasing welfare. It follows that a general policy of slot-auctioning at an airport does not seem a wise thing to do without a clear analysis of the situation of the airlines using the airport and their market power (on a route by route basis!)

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