Entry, Exclusion, and Expulsion in a Single Hub Airport System

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Airport congestion is best handled by peak period pricing. The most efficient means of implementing such a scheme is via some type of slot auction mechanism. This paper addresses the questions of what happens to slot prices when the number of competitors increases, as well as whether or not a financially strong firm can use the auctions to overpower its weaker rivals. Slot prices rise with the number of air carriers competing in the market. The paper also demonstrates that it is not feasible for financially strong carriers to attempt to use the auction process to either exclude potential rivals or to expel them from the market.

Perhaps one inevitable consequence of the deregulation of an air transportation system is increasing airport congestion. Although congestion has existed at certain airports for many years, the onset of deregulation has exacerbated the problem because of the entry of new air carriers into the market and the desire to increase the number of flights on particular links in the system. In a series of earlier papers, the authors have argued that the only viable long-term solution is a system of peak-load pricing, ideally implemented through periodic auction of the available capacity. Although this study is limited to the question of airport runway landing slots, its approach is valid for other forms of airport congestion as well.

One study (*1*) presented a simulation model of passenger traffic along individual links into a congested hub airport. This model permitted estimation of auction prices for runway slots at the hub at both peak and off-peak periods. The auction proposal raised a number of concerns, the most important being the possibility of collusion among incumbents aimed at excluding potential competitors.

This paper extends that analysis and focuses on some of the criticisms of the authors' earlier work. Initially, the focus is on the impact of increasing the number of carriers in the market. Of interest here is the effect of the number of carriers on auction prices, airport revenues, and passenger welfare. Attention is then turned to the possibility of financially powerful, established firms using the auction mechanism as a competitive tool to preclude the emergence of new carriers through excessively high bids. Closely related is another question of whether or not it is possible for strong firms to (in effect) expel their financially weaker rivals from specific markets.

The paper begins with an overview of both the auction mechanism and the underlying structure of the single hub model. Measures of system performance are examined in the next section, particularly the assumptions underlying the measurement of airport revenue from the slot auctions. This examination leads directly to a discussion of the conditions under which new entrants might be barred from the market. As a corollary, the possibility of an attempt by existing carriers to expel one or more of their competitors from the market is considered. The data used in the simulations and then the results are discussed. Finally, some concluding observations are presented.

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AUCTION METHOD OF ALLOCATION REVISITED

Slot auctions are seen as the most efficient means to implement the practice of peak-load pricing. This is the case because each profit-maximizing airline in a system can easily estimate the expected value of profit attached to each landing slot it might acquire. This is because the airline possesses detailed knowledge of the market structure of its routes and its cost structure. Thus, it can estimate the direct costs of participating in that route as well as the opportunity costs of reallocating aircraft from one route to another. It is anticipated that different airlines would submit different bids because of their differing perceptions of the market and because of their differing cost structures.

How would the auction process function? The initial step in the process would be for each airline to develop a draft schedule and to submit bids for the landing slots it wants to acquire. Each airline would, of course, operate in isolation. The airport authorities would receive the bids and place them in rank order. The airline submitting the highest bid would be awarded the property right to the slot for some predetermined period (i.e., two years). Should an airline be successful in all of its bids, it would then finalize its schedule. Otherwise, the airline could modify its draft schedule, or enter a slot aftermarket in the search for additional slots. The auction might be carried on twice yearly, with 25 percent of the slots available each time—if they were awarded for a 2-year period. Other combinations of frequency and the length of slot control are also possible.

In the absence of such auctions for airport capacity, it is necessary to simulate the process. This was done for a single hub system (*1*) and for a larger system as well (*2*). Only the single hub case is considered here. That simulation was solved both analytically and iteratively. The former solution produced some difficulties, the most fundamental being that the initial solution did not necessarily assign whole numbers of flights to each route and to each carrier. To ensure such an outcome, an iterative scheme was developed. Slots were distributed one at a time to the carrier and route that could earn the most extra contribution from one more flight. In a sense, the process may be regarded as an auction of each successive slot to the highest bidder, although no fee is necessarily collected.

Each airline is seen as facing two distinct markets—a time sensitive business market and a fare sensitive recreational market. Carriers operate within a peak period—the combination of a morning peak and a late afternoon peak—and an off-peak period consisting of the rest of the day. There are then, in principle, four distinct demand curves, all of which have been assumed linear for the sake of convenience. There are initially four airlines in the market each operating a different sized aircraft. Linear cost relationships have been assumed to simplify the analysis. Each airline seeks to maximize its contribution to overhead, that is, to maximixe the difference between its passenger revenue and its flight costs.

Let each airline currently operate a variety of flights, Q^*_{ij} on each of the n routes and within the capacity of the airport, N. Thus:

$$Q_{ij} + Q_{ij+n} = Q^*_{ij} \qquad (1)$$
$$\Sigma_i/\Sigma_j\, Q_{ij} < N$$

Only the Q^*_{ij} need be integers since Q_{ij} and Q_{ij+n} represent the portions of the flights that are drawn from the business and recreational markets, respectively. Temporarily treating Q^*_{ij} as the maximum number of flights available, each expression in Equation 1 becomes a "less-than-or-equal-to" constraint. A new optimizing solution will generate a set of shadow prices, m_{ij}, one for each airline on each of the n routes.

The Kuhn-Tucker conditions for this problem are:

$$W_{ij} = V_{ij} - m_{ij} < 0\text{: } Q_{ij}W_{ij} = 0$$
$$M = {}_{i\ j}(Q^*_{ij} - Q_{ij} - Q_{ij+n}) > 0\text{: } m_{ij}M = 0 \qquad (2)$$
$$m_{ij+n} = m_{ij} \qquad i = 1, \ldots, m\,;\, j = 1, \ldots, 2n$$

For most cases, solution is by a similar iterative procedure to the initial solution algorithm. However, if some, but not all, airlines supply a market on a particular route, the m_{ij} equation itself must be solved iteratively. A modified Newton-Raphson method was adopted and found to converge rapidly for the values considered.

The m_{ij} represent the value to each airline of an extra flight on the corresponding route. If additional runway capacity is available then the next slot is "awarded" to the carrier-route combination with the highest positive m. If no capacity remains, or if all shadow prices are zero, the solution is final. The last value for the maximum m_{ij} provides a second measure of the value of an extra unit of airport capacity.

It remains to provide a starting point for the solution routine. In principle the iteration procedure can start with all the Q^*_{ij} equal to zero. Slots could then be allocated one at a time. However, for a problem of any size, the computational time required is considerable. Each new m solution requires a lengthy iterative procedure of its own that is repeated for each additional slot. A more computationally efficient approach is to use the initial continuous solution as a starting point. Each noninteger volume Q^*_{ij} is rounded down, freeing up a small number of slots ($\leq 2nm$), which are allocated by means of the "m auction solution." Starting from zero remains an available method if the initial solution technique fails, or to mimic a particular auction procedure.

MEASURES OF PERFORMANCE

The behavior of the airport system may be evaluated differently by the airport, the carriers, the passengers, and by society as a whole. Hence, a number of performance measures are appropriate. Following directly from the solution process, various estimates of the slot auction prices are available.

Slot Prices

In a competitive bidding situation, the final bid does not represent the maximum price that any carrier will pay, but the highest price that would be paid by an unsuccessful bidder. This situation follows from the recognition that the successful firm will not bid against itself. It remains true for a variety of auction types including English, Dutch, sealed bid first price and sealed bid second price (*3*). Because all the m_{ij} are calculated, the actual price at auction can be extracted automatically during the solution process.

Various auction methods can be simulated by making small modifications to the algorithm. Thus, if the initial values of the Q^*_{ij} are set equal to zero, prices are generated that correspond to a slot-by-slot auction. If slots are auctioned in batches, then the solution method is readily modified to generate the corresponding prices and allocation.

Airport Revenue

As shown in other research (*2*) airport revenue depends on the form of the slot auction, particularly the size of the lots in which slots are sold. To preserve generality in the present analysis, all slots are deemed to be sold at the auction price for the final slot. Because the demand curves are downward sloping, the highest price paid by an unsuccessful bidder for the last slot provides a lower bound on the auction price of airport runway capacity. Thus airport revenue is the product of capacity and the appropriate m.

Revenue and Profit

The total contribution to total carriers' profit may be calculated by summing the individual carrier's contribution from each route and each period and subtracting the total revenue received by the airport. Because airport revenue is a lower bound, total contribution represents the maximum retained by the carriers.

Social Welfare

Within the model and the auction, the slot prices are determined by the profit maximization of the individual carriers. However, the performance of an air transportation system is normally considered in the broader context of how it serves society as a whole, or, at least, that part of society involved directly with air travel.

In this context an appropriate and widely used measure of social welfare is the sum of consumers' and producers' economic surplus. The relevant calculations for the present model are as follows:

For a single linear demand curve, $q = a - bp$, consumer surplus at quantity q is given by $q^2/2b$. The number of passengers using carrier i on route j is $g_{ij}Q_{ij}$ where g is the capacity of the relevant aircraft. Hence the total number of passengers on this route in this period is gQ, and total consumer surplus (CS) for the system is given by

$$CS = \Sigma_j (\Sigma_i g_{ij} Q_{ij})^2/2b_{ij} \text{ summed over both periods.} \quad (3)$$

For each aircraft size and route, cost per passenger is constant. Therefore, producer surplus for each carrier is simply the contribution to fixed cost, Π_k, and total producer surplus (PS) including payment to the airport is given by

$$PS = \Sigma_{ij} \Pi_{ij} \text{ summed over both periods.} \quad (4)$$

Consumer and producer surplus added together equals total surplus. It provides a useful means of gaging the impact on social welfare of market expansion.

Passenger Revenue

A more direct measure of the level of operations is provided by the total passenger revenue generated by flights to and from the hub. Revenue here is a reflection of total passenger revenue miles and the fares for the different routes, both of which may be expected to respond to changes in the number of carriers.

BARRIERS TO ENTRY

In principle, the slot auction may be used to influence competition in two ways. Existing carriers may attempt to discourage potential entrants, or to drive an established carrier from the market. Because the periods are distinct, if the slots are auctioned separately, exclusion or expulsion may be attempted in peak, off-peak, or both periods.

It is assumed that all carriers operate with full and accurate knowledge of the effects of entry and exit. Thus an entry-preventing slot price is one that would reduce the potential entrant's contribution to zero. Specifically, if the market is served currently by m carriers, the entry-preventing price is found by resolving the system for $m+1$ carriers and dividing the last firm's contribution by the number of flights that it operates in the relevant period. Entry prevention is worthwhile if the profits of the m carriers, net of entry-preventing slot fees, exceed those that they would earn in the market with $m+1$ carriers and normal auction payments.

The slot fee necessary to exclude the m^{th} carrier is calculated in a similar way by dividing its contribution by the number of slots used. Exclusion will be worthwhile if reducing the system to $m-1$ carriers enables the remaining carriers to increase their own profits by an amount sufficient to pay the increased slot fees.

Raising slot fees above the marginal price calculated in the model would normally lead to a reduction in the number of slots actually used by the carriers to maximize their contributions to profit. However, exclusion and expulsion require that all slots be purchased at the appropriate price. This raises the question of how the purchase costs are apportioned by the carriers concerned. In the present analysis, carriers are assumed to optimize their operations, neglecting the larger fee and then paying for the slots used at the higher exclusion or expulsion price. In this way, the exclusion or expulsion "premium" is treated as a form of sunk cost. Because collectively they must buy all the slots, the carriers will continue to use them all if they would have done so without the extra fee.

THE DATA

The decision to examine the behavior of the model data was made in order to reflect, in a general way, part of a network in the North American context. Nó identification with a specific location is intended at this stage.

Carriers, Routes, and Markets

Computation focused on four or more carriers operating on some or all of eight "spokes" to the hub airport. Each of the routes differed in length from a short haul of 250 mi, increasing in increments of 250 mi, to a stage length of 2,000 mi. Demand on each route came from two markets: a relatively high-priced business market and the larger lower-priced recreational demand. To avoid generating results from peculiarities of demand, a "white noise" approach was adopted to the two types of market. Thus, basic demand for seats on route j was given by

business demand:

$$q_j = 6{,}400 - (5{,}000/d_j)p_j \quad j = 1, \ldots, n \quad (5)$$

recreational demand:

$$q_{j+n} = 20{,}000 - (160{,}000/d_j)p_{j+n}$$

d_j is the length of route j as before. In a sense demand price is simply "scaled up" as d_j increases.

Aircraft Size

Throughout the analysis, g was assumed to represent both the capacity of an aircraft and the number of fare-paying passengers actually onboard. This is for convenience only, and altering the load factor to less than 100 percent would simply shift the profit functions downward.

In general, each carrier might be expected to operate a mixed fleet of aircraft using different sizes on different routes. Aircraft capacity might also be varied between peak and off-peak services. However a distinction has yet to be drawn between each carrier. To avoid too many interacting effects, each carrier was identified with a particular size of aircraft. Carriers were deemed to have a sufficient number of aircraft of the designated capacity to operate as many flights as they wished. Fleet size does not appear as a constraint.

For investigatory purposes, four sizes of aircraft broadly appropriate to the route distances were selected. Thus the initial configuration consisted of four carriers operating single type fleets of 50, 100, 150, and 200 passenger aircraft.

Operating Cost

The linear cost function in Equation 2 permits considerable flexibility in terms of cost variation between routes and carriers. However, for the present analysis, the following simplified version was used:

$$\text{cost of flight by carrier } i \text{ on route } j = c + d_j (f + hg_{ij}) \qquad (6)$$

To obtain "reasonable" values for f and h, two steps were involved. Canadian Transport Commission data (*4*) provided operating costs per mile for 11 medium and large aircraft types. Representative passenger capacities for each of these types were obtained from *Aviation Week and Space Technology* (August 19 and September 9, 1985). Linear regression provided values for f and h as follows:

$$\text{cost of flight by carrier } i \text{ on route } j = d_j (2.2031 + 0.0247g_{ij}) \qquad (7)$$

Support for this straight line form is good with an R^2 of 0.97. However, costs for small aircraft may be understated because none were included in the original estimation.

Parameter c was set equal to zero in the basic cost Equation in 6 and remained available to introduce a landing/take-off fee as required. Other costs not sensitive to either stage length or aircraft size could be incorporated into this constant term as well.

Airport Size

Following Borins (*5*), a single runway fully used and with a full complement of airport services is able to support 40 aircraft movements per hour. Each peak period is considered to last 2 hr and therefore, a single runway represents a peak capacity of 80 slots if it is fully supported. Consolidating the two peak periods produces a total peak capacity of 160 slots. If the airport is closed between midnight and 7:00 a.m., there are 13 hr (or 520 slots)for off-peak traffic.

RESULTS

As noted previously, the basic configuration consisted of four carriers each operating aircraft of a different size. With the demand specified, these carriers were found to use all the available capacity in the off-peak as well as the peak period. However, the auction price for an off-peak slot was about 5 percent of the peak price.

Increasing the Number of Carriers

To assess the impact of increased competition for landing slots, the number of carriers was increased by adding successive carriers with aircraft of a particular size. The effects of the expansion on the various measures of performance mentioned earlier are summarized in Table 1. The first line of data in the table indicates the basic four-carrier configuration, and the entry in the second column indicates that the fourth carrier uses 200-seat aircraft. For convenience, a number of

TABLE 1 IMPACT ON SLOT PRICES AND CERTAIN WELFARE MEASURES OF ADDITIONAL FIRMS

Firms		Slot Price		TAR	TFP	ratio TAR / TAR+TFP	$CS	$TS	$TPR	TPRM
#	cty	peak	off-p	x$10,000			x 10,000			
4	200	47327	2587	892	2789	0.2423	1787	5468	2572	12499
5	50	47327	2887	907	2765	0.2471	1788	5460	2559	12321
6	50	47327	3108	919	2747	0.2506	1789	5455	2551	12216
7	50	47327	3334	931	2729	0.2543	1792	5452	2545	12174
8	50	47327	3479	938	2720	0.2565	1791	5449	2541	12102
5	100	54822	3067	1037	2599	0.2851	1811	5446	2545	12426
6	100	58654	3250	1107	2480	0.3087	1841	5428	2516	12413
7	100	59159	3477	1127	2402	0.3194	1872	5402	2481	12327
8	100	60490	3548	1152	2374	0.3268	1881	5407	2475	12337
5	150	53072	2854	998	2566	0.2799	1894	5458	2507	12992
6	150	58428	3104	1096	2338	0.3192	1988	5423	2437	13289
7	150	60796	3387	1149	2209	0.3421	2045	5403	2393	13469
8	150	64592	3661	1224	2070	0.3715	2085	5379	2356	13496
5	200	48214	2125	882	2554	0.2567	2026	5462	2433	13747
6	200	52214	2004	940	2261	0.2936	2209	5410	2306	14529
7	200	51643	1739	917	2136	0.3003	2324	5376	2224	15020
8	200	52428	1904	938	2044	0.3145	2379	5361	2185	15301

TAR:	Total Airport Revenue	CS:	Consumer Surplus
TFP:	Firms' Total Contrib'n to Profit	TS:	Total Surplus
TPRM:	Total Passenger Revenue Miles	TPR:	Total Pax Revenue

the measures are also illustrated. Only the integer values of the abscissa are valid, but the points have been joined by smooth curves for clarity. Thus Figure 1 shows the impact of expansion on the peak slot price. Carriers operating small (50-seat) aircraft have no impact on peak traffic because it is only profitable for them to use the airport during the off-peak period. Slot prices are higher for the intermediate-sized aircraft because peak fares do not fall as rapidly as with the largest entrants. Total contribution to profit is shown in Figure 2. Contribution falls as competition increases with the effect most pronounced for the entry of the carriers with the largest aircraft. Figure 3 shows the growth in total consumer surplus as the number of carriers increases. This, too, is influenced noticeably by the size of the entrant carriers. The increase in consumer surplus is outweighed by the decline in the airlines' net revenue and thus total surplus decreases as more carriers compete for the same airport capacity. This results even in the absence of explicit congestion costs. Further experimentation with expansion using successive carriers with aircraft of different sizes produced similar results.

Barriers to Entry—Excluding a Potential Entrant

It was argued earlier that it may be possible and profitable for the existing four carriers to exclude a potential entrant by bidding up the price of slots to the point where a new carrier could make no contribution to profit. This involved solving the model for five carriers and computing the appropriate slot prices for the peak and off-peak periods. These prices were then used to calculate the reduced net contribution for the four carriers. This contribution was compared with the net contribution that would be earned by each of the same carriers if entry occurred and the slots were auctioned among the five carriers.

An airline with 100-seat aircraft has a potential for entry in both periods. The results of the simulations are given in Table 2. The first entry (Number of Slots) shows the number of slots that would be used by a new entrant and its contribution. From this can be calculated the exclusion price per slot. The impact of the new entrant is to increase the price of a peak slot by about $1,000 and the off-peak price by almost

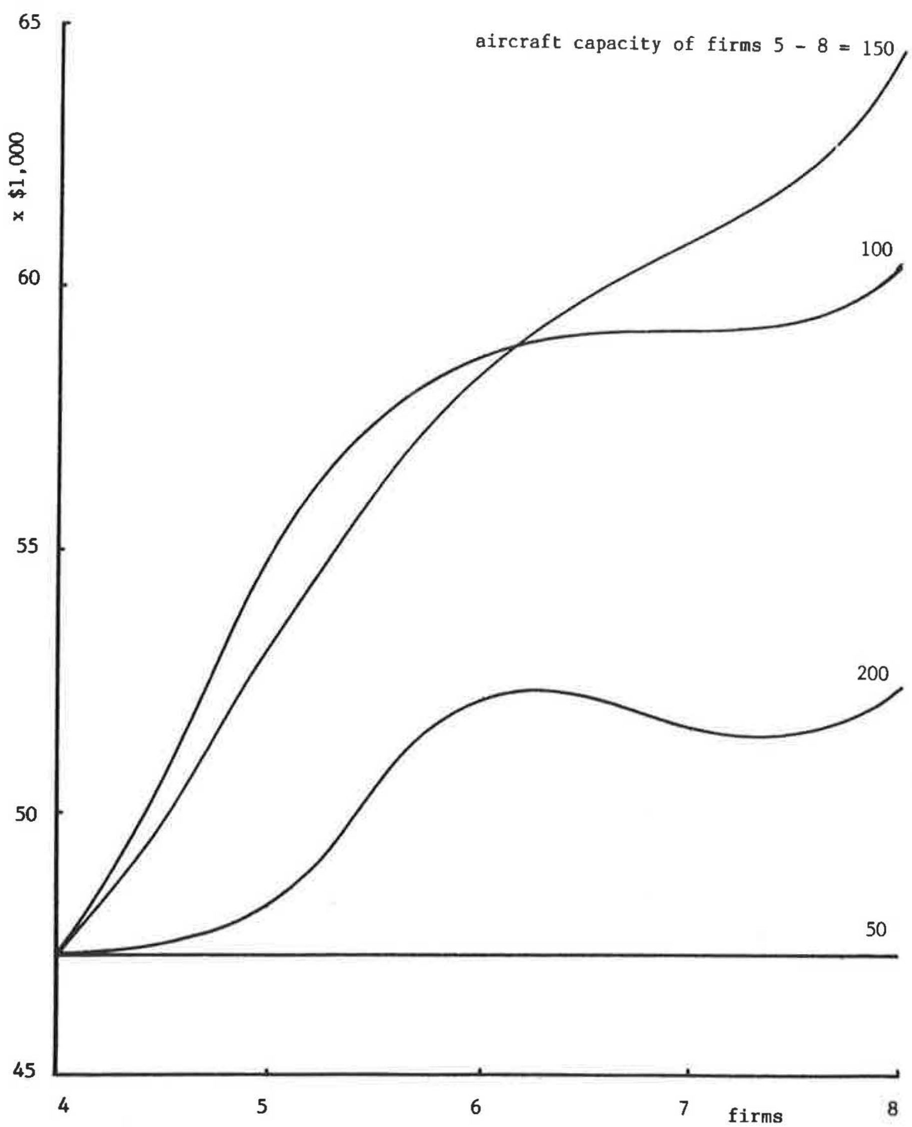

FIGURE 1 Peak slot price.

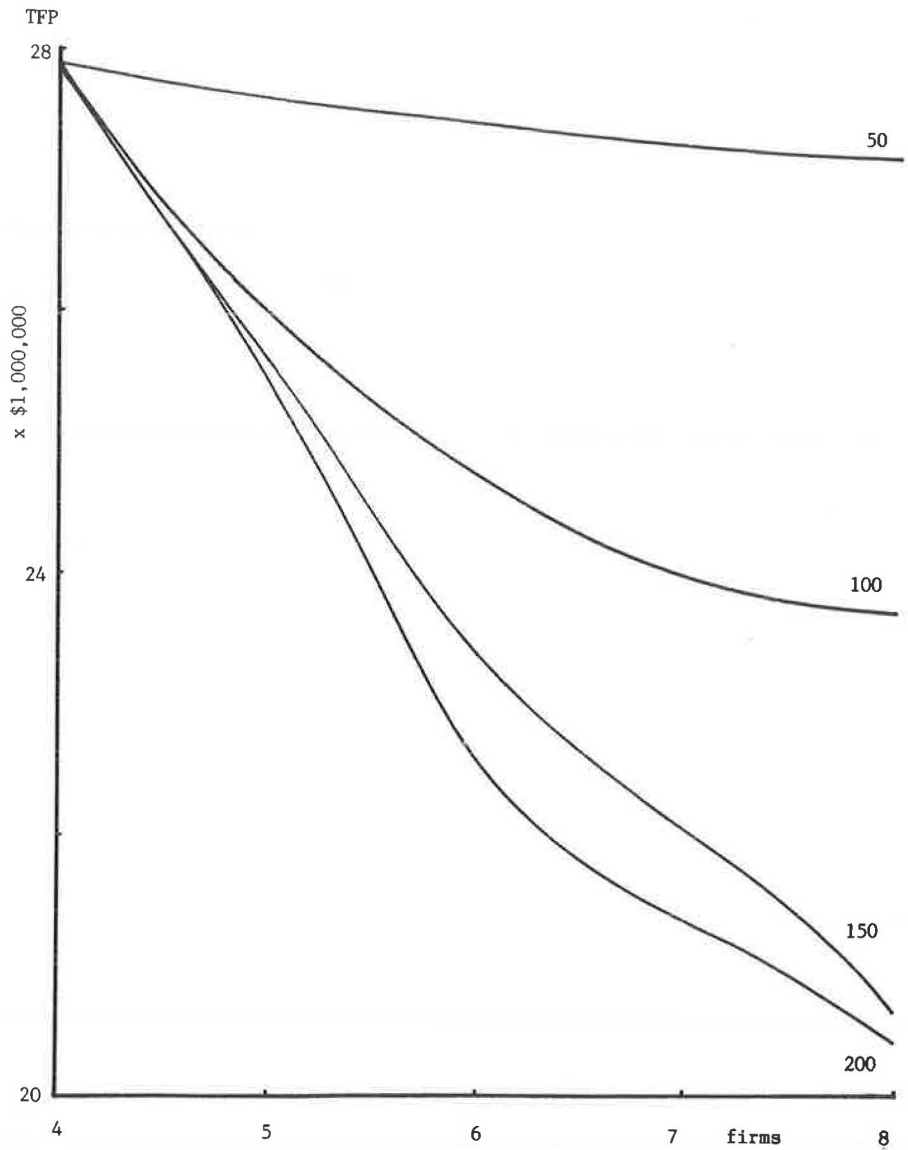

FIGURE 2 Total contribution to profit (TFP).

$3,000. To exclude a potential entrant, the existing carriers would have to purchase all slots at these prices, reducing their contributions both peak and off-peak. The second entry (A/C capacity: peak) compares the total contribution earned by the industry at peak where there is entry and where entry is precluded by outbidding potential entrants for the available capacity. The final entry (A/C capacity: off peak) provides the same comparision for the off-peak period.

A comparision of the total net contributions—with and without entry—demonstrates that exclusion is not profitable in either period for any of the carriers in the short run. However, in the long run, preventing entry of another carrier with aircraft with a capacity of 100 causes the existing carriers with aircraft with a capacity of 50 and 100 to exit. Thus the market would be reduced to a duopoly of the 150- and 200-seat carriers. At this stage, the slot price must be sufficient to deter the entry of a 100-seat carrier into the duopoly (Table 3). This table presents the same information as did Table 2, but for the long-run case.

As before, a comparision of the total net contributions shows that exclusion is not profitable in either period for either carrier. Thus exclusion of a 100-seat entrant is unprofitable both in the short and the long runs. Similar results hold for potential entry by a carrier operating 150-seat aircraft.

The case for a 200-seat entrant is less clear. Exclusion is not profitable for any of the carriers in the short run. In the long run, preventing entry of another carrier with aircraft with a capacity of 200 causes the existing carrier with aircraft with a capacity of 50 and 100 to exit and the 150-seat carrier remains in the off-peak period only. Thus the market would be reduced to a monopoly in the peak period and a duopoly of the 150- and 200-seat carriers, off-peak. At this stage the slot price must be sufficient to deter the entry of a 200-seat carrier from these markets. The results of this analysis are given as in Table 4.

It is profitable for the 200-seat carrier to maintain its monopoly in the peak period, although the maintenance of the duopoly in the off-peak period is unattractive to either

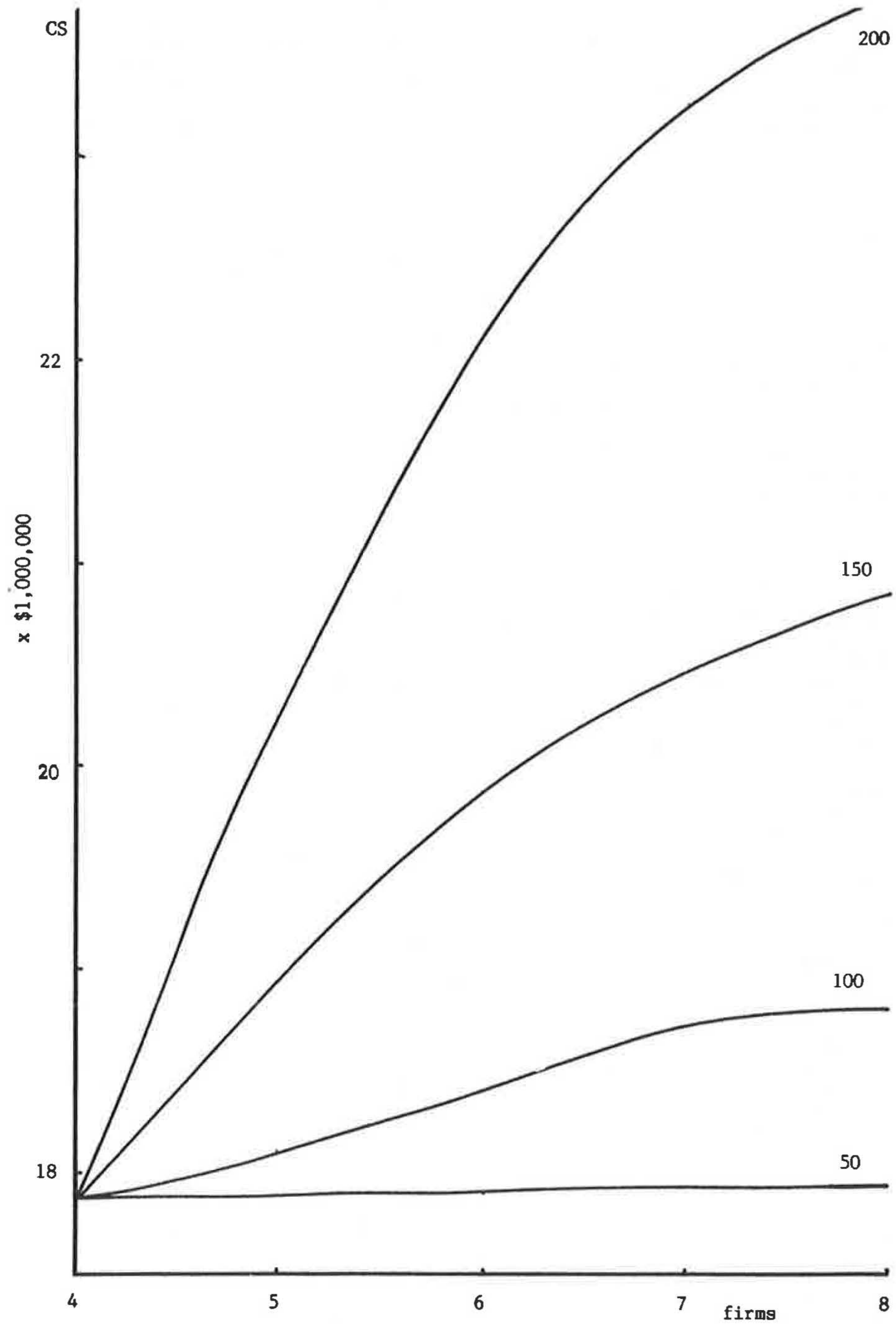

FIGURE 3 Consumer surplus.

firm. Attempting to exclude a second 200-seat carrier from the off-peak period causes the 150-seat carrier to exit leaving a monopoly in both periods. The situation in the off-peak period with a potential 200-seat entrant is given in Table 5.

Exclusion is profitable in the peak period. It is not profitable for the 200-seat carrier to attempt to exclude other carriers from the off-peak market in the long run unless it is necessary to do so in order to maintain the monopoly in the peak period.

Barriers to Entry—Expulsion of an Existing Carrier

For simplicity it is assumed that expulsion can take place in the absence of the threat of simultaneous entry by other carriers. Thus the expulsion decision can be considered in isolation. Although a variety of potential exclusion scenarios were considered in the analysis, only the "workhorse" case is considered here. This is the case involving a carrier using

TABLE 2 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING POTENTIAL ENTRY BY A 100-SEAT CARRIER

Entrant:		Peak	Off-peak
Number of Slots	(1)	24	72
Total Contribution	(2)	1716144	559058
Exclusion price per slot	(3)=(2)/(1)	71506	7765

PEAK:

A/c Capacity	50	100	150	200
Without Entry	0	(56534)	1440426	3183399
With Entry:	0	413582	2147699	4097148

OFF-PEAK:

A/c Capacity	50	100	150	200
Without Entry:	(117470)	(12632)	210472	674204
With Entry	52205	343844	899745	1467699

TABLE 3 IMPACT ON CONTRIBUTIONS OF EXLUSIONARY BIDDING POTENTIAL ENTRY OF THE 100-SEAT CARRIER—LONG RUN

Entrant:		Peak	Off-peak
Number of Slots	(1)	37	127
Total Contribution	(2)	2589187	958191
Exclusion price per slot	(3)=(2)/(1)	69978	7545

Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	2085159	3512960
With Entry:	–	838092	2818636	4779220

Off-Peak:

A/c Capacity	50	100	150	200
Without Entry:			216873	916776
With Entry:	–	696962	1316202	1831083

TABLE 4 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING POTENTIAL ENTRY OF THE 200-SEAT CARRIER—LONG RUN

Entrant:		Peak	Off-peak
Number of Slots	(1)	79	169
Total Contribution	(2)	8439549	1443487
Exclusion price per slot	(3)=(2)/(1)	106830	8541

Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	–	11394531
With Entry:	–	–	–	6193701

Off-Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	(64159)	679601
With Entry:	–	–	1372484	1358632

TABLE 5 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING OFF-PEAK POTENTIAL ENTRY OF THE 200-SEAT CARRIER

Entrant:	Off-peak
Number of Slots (1)	222
Total Contribution (2)	2343576
Exclusion price per slot (3)=(2)/(1)	10557

Off-Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	–	1657367
With Entry:	–	–	–	2359994

Combining Peak and Off-Peak:

Without Entry:	–	–	–	13051898
With Entry:	–	–	–	8537278

TABLE 6 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING ATTEMPTS TO EXPEL THE 100-SEAT CARRIER

Excluded Firm:	Peak	Off-peak
Number of Slots (1)	37	127
Total Contribution (2)	2589187	958191
Exclusion price per slot (3)=(2)/(1)	69978	7545

Peak:

A/c Capacity	50	100	150	200
With Exclusion:	–	–	2085159	3512960
Without Exclusion:	–	838092	2818636	4779220

Off-Peak:

A/c Capacity	50	100	150	200
With Exclusion:	–	–	216873	916766
Without Exclusion:	–	696962	1316202	1831083

100 seat aircraft. It is referred to as the "workhorse" case because of the fact that it was the ready availability of this size aircraft that made possible the expansion of the airline industry in the period following deregulation of the U.S. airline industry.

Excluding the carrier with 100-seat aircraft implies excluding the carrier with 50-seat aircraft as well. The results of this simulation are given in Table 6. Using the auction mechanism to expel the 100-seat carrier in either period is not profitable for either of the remaining carriers. The total net contribution would be smaller after expulsion.

It should be noted that the largest carrier could attempt to expel its rivals. The results here are mixed. It would be profitable for the 200-seat carrier to expel its rivals only in the off-peak market. In such a case, the largest carrier would buy all of the off-peak slots, but use only 334 of them. It would then reap monopoly profits sufficient to make expulsion worthwhile.

CONCLUSION

The model discussed in this paper has a number of severe limitations. In particular, it treats a single hub airport as an isolated system, unconstrained by any other part of the transportation network. Moreover, each type of demand is characterised by a simple linear form with price directly related to distance. Each carrier operates a single size of aircraft, and there are no explicit congestion costs at the hub other than the rigid limitation on the number of available slots. However, within this framework, the results permit a few tentative conclusions.

During the peak period, when slots are at a premium, most of them will be used by larger aircraft. This would appear to be indicated by efficiency considerations as well as the profit motivation of the model. However smaller aircraft remain viable in the off-peak period. Increasing the number of carriers using a hub appears to benefit the consumers of air travel and to increase the airport's share of net revenue via the slot auction. Moreover there appears to be little incentive for existing carriers to use the slot auction to restrict entry into the market, except in an extreme case. If barriers to entry are used they may be expected to take other, less costly forms.

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