Efficient and Equitable Airport Slot Allocation

Daniele Condorelli*

University College London

This paper studies slot allocation at congested airports in Europe. First, I discuss the inefficiencies of the current regulation, introduced as part of the liberalisation process of the air transport market. Then, I consider three marked based methods which are suitable to achieve a more efficient allocation of slots to airlines: congestion pricing, auctions and secondary trading. These methods are examined in terms of their ability to improve efficiency and in terms of their implications on the distribution of slots' scarcity rents. Special attention is drawn to complementarities between slots. Finally, I propose to auction slots periodically, allowing secondary trading well before the first auction takes place. By selling slots before the first auction incumbents can be partially compensated for the subsequent withdrawal of their slots. [JEL Classification: D45; D61; L93; R41]

1. - Introduction

Ever since the beginnings of commercial flight, the right to take off and land (*i.e.* a slot) was allocated on a first-come first-served basis with little or no coordination between carriers. However, later in the sixties, long queues of airplanes waiting to take off and land became common at major international airports at peak times.

Therefore in 1968, in order to avoid wasteful delays, the

Federal Aviation Authority (FAA) passed a rule that limited the number of slots at four major airports in the United States (La Guardia, Washington National, J.F. Kennedy and O'Hare International).

Efficient and non discriminatory rationing of available slots was not an issue at that time, and take-off and landing schedules were easily finalized through unanimous agreement from all involved carriers. The system worked well for a number of years but collapsed in the mid-eighties, soon after market deregulation produced an increase in the number of operating airlines. It was then evident that slot allocation required explicit regulation. In fact, the FAA introduced new rules in 1985, assigning slots to airlines on the basis of historical precedence and allowing secondary trading.

In Europe, slot allocation has been regulated since 1993, as part of the process of deregulation and liberalisation of the European air transport market. The system works as follows. In each Member State an independent authority (the coordinator) realizes the preliminary allocation of the available slots at each airport according to two main principles.

Grandfathering (historical precedence) with "use it or lose it": an airline that in a given season has effectively operated for at least the 80% of a series of slots has the right, upon request, to obtain the same series in the subsequent season.

Slot pool and new entrants: all slots that become available (due to the introduction of more efficient flight control technologies, due to the "use it or lose it" rule or because they are voluntarily returned to the coordinator) form the slot pool and are preferentially allocated to new entrants.[1]

Subsequently, representatives from all airlines, airports managers and coordinators meet in a worldwide conference organised by the International Air Transport Association (IATA). During the conference allocations are finalized through bilateral and multilateral exchanges of slots.

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[1] A new entrant is either an airline that would have less than five slots in the airport, if his demand for slots was met; or an airline which requests slots in order to operate a direct connection between two European airports, if not yet operated by at least two other companies.

The main difference with United States is that monetary exchanges are not permitted in Europe. Notwithstanding European regulations, in 1999 the High Court of the United Kingdom authorized some transactions of slots involving monetary compensations and opened the way to a grey market now operating at UK airports.[2]

Both in the United States and in Europe, slots are allocated for free to airlines, which pay an airport charge only in case of effective usage of the slot. Airport charges are regulated in order to limit the monopoly power of airport operators and are set to provide a fair return on the invested capital. Thus, by their own nature, airport charges do not serve the purpose of clearing the market for runaway capacity.

The current grandfathering system has two important virtues: it reduces transaction costs and allows carriers to plan long term operations. However it suffers from a fatal drawback: it does not guarantee allocative efficiency. This means that slots will not tend to flow in the hands of those who value them the most or, in other words, of those airlines with the lowest costs. In fact, grandfathering can not ensure that slots are assigned to airlines that are willing to pay the highest price for them, therefore allowing incumbents to squeeze out from the market efficient entrants. Moreover, the prohibition of monetary trading in Europe jeopardizes the hope that an efficient outcome will result from free trading, in the spirit of the so called Coase theorem.

The problem at stake is relevant. According to NERA (2004), a report prepared for the European Commission, about 20 European Airport appear congested during peak times (see page I of the report). NERA's report suggests that, by allocating slot competitively, passenger traffic at congested airports in Europe would increase by about 5% (see page VII of the report).

The following table reports data from Airports Council International (ACI) Europe (2004) and illustrates the situation at

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[2] 25/3/1999 UK High Court, R v Airport Coordination Limited *ex parte* The States of Guernsey Board of Transport.

TABLE 1

Airport	Passengers ('000)	Capacity per hour	Slot allocated at IATA conference (100%)	Slots initially requested	Realized operations
Copenhagen	9,068	83	184,763	103.7%	93.8%
Dublin	7,346	44	115,256	100.3%	88.7%
Dusseldorf	7,300	38	129,468	107.3%	84.6%
Frankfurt	23,830	80	284,949	106.8%	95.6%
London Gatwick	14,760	46	177,211	134.3%	86.2%
London Heathrow	31,506	87	282,256	121.0%	97.3%
London Stansted	8,022	42	121,051	103.7%	86.2%
Madrid Barajas	17,024	78	253,875	108.5%	85.6%
Milan Linate	3,857	18	57,700	149.9%	85.3%
Milan Malpensa	7,701	70	164,937	104.7%	78.6%
Paris CdG	23,347	97	361,552	113.9%	82.4%
Schipol	20,366	106	275,000	106.6%	88.6%
Stockholm A.	8,228	76	172,900	108.3%	82.4%

Note: column 2 reports the total number of passengers served. Column 3 reports the capacity available at the ariports in terms of slots per hour. Column 4 reports the number of slots allocated at the IATA conference, which is a measure of the total available capacity at the airport. Column 5 reports the number of initially requested slots, as a percentage of the available slots. This column offers a measure of congestion at the airport. Column 6 reports the number of slots operated at the end of the season, as a percentage of the slot allocated at IATA conferences. This last column gives a measure of slots which are allocated but not used or slots which are returned but whose re-allocation has not been possible.

13 major European airports in the 2002 summer season (going from April to October).

Starting with an explanation of how the current system generates inefficiencies (section 2), this paper is dedicated to discuss some problems that arise in the effort of allocating slots more efficiently by using market mechanisms. The attention is focused on three market methods: increasing airport charges, auction of slots to airlines and free secondary trading with grandfathering. Their implications in terms of efficiency (section 3) and distribution of the slots' scarcity rents (section 4) are discussed thoroughly. Attention is focused on two main trade-offs which are faced by policymakers.

Efficiency vs Implementability: no practical mechanism exists that clears the market and allocates efficiently, because slots exhibit complementarities even within the same airport. The problem is that a series of *Walrasian* time specific prices for slots may not exist with complementarities. Thus, the first welfare theorem fails: with linear prices market clearing does not imply allocative efficiency. With complementarities, efficiency requires that slots should be priced in bundles or even non-anonymously. However, large efficient combinatorial auctions are impractical in many respects.

Incumbents vs New entrants: the introduction of a market mechanism induces a trade-off between the interests of incumbents and those of other parties, especially new entrants. Because property rights for slots are not defined, it is not clear who should appropriate the scarcity rents generated by the introduction of a market for slots. In fact, either slots are initially allocated to those airlines which hold them today in virtue of grandfathering, thus granting them huge windfall gains; or they are subtracted to incumbents and reallocated competitively, putting established airlines at risk.

In section 5, I conclude the paper by proposing a mechanism which tries to find a satisfactory compromise to the above mentioned trade-offs: *(i)* slots should be periodically reallocated through a combinatorial auction, simultaneously in the major congested European airports, and *(ii)* monetary trading should be allowed; *(iii)* before the first auction takes place a certain lapse of time should pass to allow incumbents to rationalize their networks, selling slots and monetizing part of the efficiency gains; *(iv)* revenues could be used to offset existing airport charges and develop new airport capacity.

The literature on the subject is not large. Starting in the sixties scholars have argued for the introduction of market systems for slot allocation. Levine (1969) proposed peak-load pricing to reduce waiting times for take off and landing induced by the queuing system. Grether, Isaac and Plott (1979) and (1981), studied the simple unanimity system and contributed to shape the 1985 reform in the United States. These authors were also the first to advocate the use of auctions.

The first to take on the challenge of designing an auction for slot allocation were Rassenti, Bulfin and Smith (1982). They propose a combinatorial auction for paired take off and landing slots. More recently, Ball Donohoue and Hoffman (2006), advocate the use of auctions and express concerns for both equity and efficiency of the resulting allocation. Among others, Colombo (2001) proposes to run yearly auctions where only a fraction of all slots is put up for sale. Jones, Marks and Viehoff (1993) informally identify the problem with demand externalities (*i.e.* complementarities) and provide, based on these, an interesting argument against the use of auctions. Finally, several technical reports have been written on the issue of slot allocation. Three of them appear more closely related to my work: DotEcon (2001) study the feasibility of auctions, NERA (2004) contains a general discussion on market mechanisms, and Mott MacDonald (2006) analyses secondary trading.

2. - The Case for Efficiency

Pareto efficiency is the weakest (and so the most compelling) welfare criterion adopted by economists to rank different outcomes. An allocation (in our case: of slots to airlines) is Pareto efficient if no other allocation exists that could make someone better off without making anyone worse off. Therefore, inefficiencies represent a net waste to society. In a world in which monetary compensations are possible and where there are no income effects (*i.e.* where preferences are such that money enters additively in the utility function of agents), an allocation is efficient if and only if it maximizes the total value generated in the economy.

If we further assume that carriers' willingness to pay for a slot reflects the net increase in welfare that they are able to generate by using the slot, efficiency requires that slots go to airlines who are prepared to pay the highest price for them.[3]

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[3] We are assuming that carriers' willingness to pay for slots is aligned to social welfare. However, there are many reasons why this may not be the case. Most notably, some carriers may be willing to pay a lot for slots which guarantee market power in the downstream market for air transport (see BORENSTEIN S., 1988).

TABLE 2

VALUES

	A	B	C
First	a	b	c
Second	$a+d$	$b+d$	$c-d$

Note: a,b,c,d $\geq$ 0, c>d.

To illustrate this point, suppose that two airlines *First* and *Second* hold heterogeneous valuations for three slots *A*, *B* and *C* as summarized in Table 2.[4]

The value of a set of slots is the sum of values that they attribute to each slot (e.g. $v_F(AB) = a + b$). When $d > 0$ *Second* values *A* and *B* more than *First* does, while it values *C* less. Then an efficient allocation will assign *A* and *B* to *Second* and *C* to *First* realizing a maximum total value equal to $v_S(A,B) + v_F(C) = a + b + c + 2d$.[5]

The present European regulatory system generates substantial inefficiencies. On the one hand, grandfathering can not ensure that airlines holding slots are those which value them the most. On the other, since monetary trading is not permitted, there are no incentives for a company to pass slots to more efficient competitors. Continuing with the example in Table 2 (with $d > 0$), assume that *First* holds slots *A* and *C*, while *Second* holds slot *B*. With the current regulation an efficient allocation could not be achieved as *First* will not pass A for free to *Second*. On the contrary, if monetary exchanges were allowed, *First* could sell *A* to *Second* for a price $v_F(A) = a < P_A < a + d = v_S(A)$ and both airlines would be better off.

3. - The Efficiency Toolbox

This section discusses three market based systems in their ability to increase allocative efficiency. In particular, slots can be

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[4] It is not relevant whether slots belong to the same airport, to the same time period of time, etc.

[5] If $d=0$ then any allocation that assigned the three slots would be efficient as the maximum value in each case is equal to $a+b+c$.

more efficiently allocated from the beginning, either by *(i)* increasing airport charges up to market clearing prices; or by *(ii)* selling slots through an auction. Moreover, efficiency can be increased by *(iii)* allowing monetary trading of slots.

3.1. *Increasing Airport Charges*

Increasing airport charges at peak times, while reducing those in periods of low demand, would certainly help toward allocating slots more efficiently.[6] Ideally, competitive prices should work as suggested by the first fundamental theorem of welfare economics: clearing the market and allocating efficiently.

To fix ideas, suppose that at first there is only one slot for sale which has no value unless it is allocated to someone, then a *competitive equilibrium* would be a price such that only one bidder would find it profitable to buy the slot (*i.e.* the airline with the highest value for that slot).

When objects are heterogeneous (*i.e.* bidders may have demand for more than one object), the situation is more complex. However, the notion of competitive prices can still be extended. Roughly speaking, the idea is to find a set of prices such that there is no excess demand for any of the objects, and for which all objects are allocated.

When we try to apply this idea to slots, a problem occurs. In fact, competitive equilibrium prices may fail to exist in environments where it is very likely that the same slots be complements for some airlines, and substitutes for others. Unfortunately, if slots are not substitutes for all airlines, no system of individual prices will be able to clear the market and, at the same time, achieve an efficient allocation, according to the first welfare theorem (see, for example, Gul and Stacchetti, 1999 and Milgrom, 2000).[7]

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[6] To my knowledge, at present only Heathrow and Gatwick apply higher charges during peak times in Europe. This provision, however, does not fully eliminate excess demand (see Table 1).

[7] We say that slots are substitutes if increasing the price of some slots will never reduce demand on slots whose prices do not increase.

Table 3

VALUES

	A	B	AB
First	c	c	$2c+d$
Second	$c+0.6d$	$c+0.6d$	$c+0.6d$

Note: c, d > 0.

To see the point, consider the following example. Two slots in two close periods of time are now available at a single airport. *First* and *Second* evaluate slots according to the following Table 3.

Then, slots are complements for *First* (e.g. because *First* hopes to profit from a time sensitive demand sector and needs to set up more than one flight within a very short period of time) and substitutes for *Second* (e.g. because *Second* only needs to schedule one flight in that period). Efficiency requires that both slots go to *First*. However no set of prices $\{P_A, P_B\}$ exists that allocate slots efficiently. In fact, we must have $P_A + P_B \leq 2c + d = v_F(A, B)$, otherwise *First* would not buy the two slots. However this implies that either $P_A < c + 0.6d = v_S(A)$ or $P_B \leq c + 0.6d = v_S(B)$ which means that *Second* will still demand one of the two slots and the market will not clear.[8]

Competitive equilibrium prices exist when slots are substitutes for all airlines. However, even if a competitive equilibrium exists another fatal problem arises. It seems quite difficult that airport operators or regulators will have the necessary information in each season to compute market clearing prices. Congestion pricing is useful when values are known in advance while the quantity available is unknown, as the latter is to be determined by market forces. In our case, however, the total available quantity of slots

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[8] Note that the two prices $P_A = c + 0.6d$ and $P_B = c$ would not clear the market because both *First* and *Second* will demand B. There are prices that clear excess demand but that do not form a competitive equilibrium because, contrary to the interest of the seller, some slot is left unsold; for example, if $P_A = c + 0.6d$ and $P_B = c + \varepsilon$ only slot A would be demanded by *Second* while slot B will not be sold.

is perfectly known in advance while prices (more precisely, the highest prices that airlines would be willing to pay for them) are not. This brings us to auctions.

3.2. *Auctions*

Auctions are mechanisms where the quantity for sale is known in advance and equilibrium prices are revealed from the rational and self interested interaction between market participants who privately hold the necessary information to compute them.

When equilibrium prices exist, auctions can be viewed as a practical implementation of the fictitious *Walrasian* auctioneer. In fact, if valuations for slots were substitutes for all airlines a simple *simultaneous ascending auction* would end up allocating the slots efficiently. In the simplest ascending auction format all slots would be put for sale simultaneously. Airlines would place irrevocable bids and prices would rise until the market clears.

A more subtle version of the simultaneous ascending format is the *clock auction*. In this case the auctioneer starts by announcing reservation prices for each slot. Bidders respond with the quantities desired at those prices. Then prices are increased for items in excess demand, while other prices remain unchanged. The process is repeated until there is no excess demand for any of the items.

However, as I mentioned in the previous section, it is very likely that slots will be complements, at least for some airlines. When this is the case the simultaneous ascending auction, which maintains linear pricing of slots through the process (*i.e.* the price of a bundle of slots is equal to the sum of the individual slot prices), will not work properly. In particular, the auctioneer will face a trade off between the *exposure problem* (the risk for bidders of paying too much for a slot that is useless without the complement slot) and the possibility of not selling some slots at the end of the auction.

Consider again the clock auction. Under complementarities,

it may happen that at some point demand equals supply for one slot but it exceeds supply for a complementary slot. Then the auctioneer would keep the price of the first slot constant, while increasing the price of the complementary one. However demand for the first slot may decrease as a result of the increase in price of the complement. Now two cases are conceivable: either the auctioneer restricts the changes that a bidder is allowed to make in its demand from round to round, (e.g. by asking that demand for a slot cannot be reduced unless the price of the slot increases), thereby creating the exposure problem; or the auctioneer poses fewer restrictions on demand changes and accepts that some slot may not be sold at the end of the auction.[9]

This problem can be better illustrated looking at the following example in Table 4.

In a clock auction, *First* and *Second* will continue to demand both A and B until $P_A = P_B = x$. At this point the auctioneer will rise both prices by a small amount ε, setting $P_A = P_B = x + \varepsilon$. Now, because $P_A = P_B > 2x = v_S(A,B)$, *Second* will demand only one of the two slots, say A, while *First* will still demand both of them. The auctioneer will rise again the price of A to $P_A = x + 2\varepsilon$, while keeping the price of B unchanged. However, while *First* will continue to demand both slots, *Second* will now switch his demand from A to the cheaper B. Afterwards, the auctioneer will increase the price of B only. This process will continue until

TABLE 4

VALUES

	A	B	AB
First	x	x	$2x+d$
Second	$x+0.6d$	$x+0.6d$	$2x$

$x, d > 0$.

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[9] In principle, the auctioneer could act to reduce the price for the first slot again but then the auction would cycle and possibly never end.

$P_A = P_B = 2x + d + \varepsilon < v_F(A,B)$. Here there are two possibilities: either *(i) First* is allowed to withdraw from both items at once (even if the price of only one of them increased in the last stage) and thus one slot will be left unsold or *(ii) First* cannot revise his schedule for the slot whose price did not increase in the last round and the auction ends allocating one slot to each bidder, with *First* paying more than his value for the slot.[10]

Notwithstanding these problems, the ascending format has already performed well in a variety of contexts such as the sale of 3G mobile phones spectrum or electricity procurement. As a matter of fact, the clock ascending auction has been used to run a mock auction for slots at New York's La Guardia airport, where the Federal Aviation Administration is evaluating a market based approach to slot allocation.

From a theoretical perspective, though, abandoning linear pricing is a necessary condition to achieve an efficient allocation of complement objects from the start. The case is stronger for slots, because the impact of the exposure problem on efficiency may be substantial while the possibility of underselling is a rather serious problem with perishable items (slots which are not allocated at the auction cannot be reallocated in subsequent auctions).

In theory, the ideal solution is offered by the Vickrey auction. Named after the seminal contribution of Vickrey (1961), this design is able to achieve in equilibrium the efficient allocation of a set of goods even in the presence of complementarities and regardless of the information held by each bidder about competitors (*i.e.* bidders do not need to form expectations about other bidders' values). In the Vickrey auction each bidder submits an entire list of valuations, one for each possible bundle of items. Then the auctioneer selects the efficient allocation on the basis of the reported values and asks all bidders to pay the opportunity cost of their participation (*i.e.* each bidder pays the difference between the value of the efficient allocation that would have been selected if he reported a value

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[10] Observe that, in anticipation of this possibility, *First*, who does not know the values of *Second*, will bid less aggressively from the start and, again, efficiency will not be attained.

equal to zero for all bundles and the value that his opponents obtain in the efficient allocation selected by the auctioneer by considering all reports).[11] To fix ideas consider the example in Table 4 and assume that $0.6d < x$. Under the Vickrey scheme both *First* and *Second* would bid truthfully and *First* would get both A and B (*i.e.* the efficient allocation is obtained) and pay $v_S(AB) - v_S(\emptyset)$ = $2x$. In fact, if *First* reported zero for the three bundles both A and B would go to *Second*, while *Second* obtains no benefit in the efficient allocation with true reports. Now, suppose that Second tried to obtain one object by misreporting. He would have to report a value of $x + d$ for one of the two objects in order to switch the efficient allocation from "both A and B to *First*" to "A to *First* and B to *Second*". However he would lose money, as he would pay a sum which is greater than his value for B: $v_F(AB) - v_F(A) = x + d$ > $x + 0.6d = v_S(B)$.

While the Vickrey auction is attractive in theory, it suffers from a number of defects that hinder its successful application. The main issue, in my view, is that in order to submit a whole set of valuations for n slots, all airlines would need to evaluate $2^n - 1$ possible combinations of slots, but this number gets astronomical as n grows large.[12]

A vastly growing literature in economics, management and computer sciences is dedicated to devise a more practical auction format that would solve some of the Vickrey auction faults, while partially keeping its benefits (*i.e.* achieving efficiency and extreme strategic simplicity). Two formats are likely to attract considerable interest in the near future: the first-price package auction and the clock-proxy auction.

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[11] When there is only one object for sale this correspond to the second-price auction, as the opportunity cost is now the value of the object to the losing bidder.

[12] Furthermore, bidders are forced to reveal a great deal of confidential information about slot valuations which they may not like to declare (see ROTHKOPF M. - TEISBERG T. - KAHN E., 1990). Moreover, other problems arise in the presence of complementarities (for details see AUSUBEL L.M. - MILGROM P., 2006): the mechanism may select an allocation which is not in the core, thus creating incentives to renegotiate ex-post; apart from being non linear, prices may be non anonymous (*i.e.* two bidders that submitted the same bid on a particular time slot may end up paying very different amounts for the same slot); and bidders can profit by shill bidding (creating fictitious companies to participate in the auction) or collusive behaviour.

In the first-price package auction bidders submit bids for package of slots (for example, "I bid x to buy slot A and slot B, but I won't pay anything unless I get both") and the auctioneer selects the feasible combination of bids which achieves the maximum value. Then every winner pays his own bid. With complete information this auction also has an efficient Nash equilibrium.[13] Not by chance, the granddad of combinatorial auction design is an early proposal of Rassenti, Bulfin and Smith (1982) for a sealed-bid first-price package auction of paired take off and landing slots.

The clock-proxy auction, recently developed by Ausubel, Cramton and Milgrom (2006), mixes the clock ascending auction with package bidding. This format works as well as the Vickrey auction when goods are substitutes (it allocates efficiently and has an *incomplete information* equilibrium in dominant strategies) while it alleviates some problems of the Vickrey format when goods are complements (see footnote 12). The auction develops in two phases. In the first clock phase the auction works as a standard simultaneous-ascending clock auction with bidders having the possibility of revising their schedule. The proxy phase, which is essentially an ascending package auction, serves to correct the possibility that the outcome is inefficient or that some slots are left unsold. The starting prices are those obtained in the clock auctions. Then, bidders report their values only for packages of interest to an automated proxy. Finally, the proxies play a simulated ascending package auction. In each round the proxy submits a bid for a package that maximizes the profit for the airline, while the auctioneer selects the provisional final allocation by maximizing revenue and announces the prices. Then proxies place another bid but they cannot reduce the amount bid on packages for which they have already bid. The auctioneer selects another provisional allocation and the process continues until no new bid is submitted by the proxies. Under *complete information* this proxy phase has an efficient Nash equilibrium as the first-price sealed bid package auction.

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[13] See BERNHEIM D.B. - WHINSTON M. (1986) for the equilibrium analysis of the auction.

3.3 *Secondary Trading*

In two seminal papers, Coase (1959, 1960) convincingly argued that in a zero-transaction cost world (where information is complete, trading is costless and capital markets are perfect) the initial distribution of property rights has no effect on their final allocation, as *laissez-faire* will always yields efficient outcomes. The argument goes as follows: regardless of the initial allocation, the ultimate allocation must be efficient; otherwise someone could propose to implement a different Pareto improving outcome that would be accepted by everyone.

One might be tempted to conclude that it does not really matter how slots are initially distributed since, if monetary exchanges are permitted, efficiency will be attained in any case. In fact, airlines will sell slots that generate low net revenues to airlines wanting to operate services with higher net revenue. However, although the logic behind the argument is certainly valid, the violation of some of its assumptions mitigates the strength of the conclusion.

In particular, it is well known that asymmetric information might prevent the occurrence of efficient exchanges that would otherwise take place. Under the same assumptions on preferences postulated in this paper, Myerson and Satterthwaite (1983) showed that, when information is private, there is no bargaining protocol that guarantees that trade will take place when it is efficient (unless it is known in advance that trading will be Pareto improving). In particular, assume that *First* holds slot A and that $v_F(A) = x \leq 1$, while $v_S(A) = y \leq 1$. Furthermore, assume that *First* and *Second* do not know each other's value for A but both assess it as a random variable somehow distributed in the interval $[0,1]$. Assume that all this is commonly known. A *bargaining protocol* is any game, possibly dynamic, played by *First* and *Second* whose outcome prescribes who gets the object and who pays what to whom. The Myerson and Sattherwaite theorem states that there exists no bargaining protocol that works for every x and y, which is efficient (*i.e.* assigns the object to *Second* if $y > x$ and leaves it to *First*

otherwise) and it is acceptable by both (*i.e.* if the object change hands, *Second* does not pay more than *y* and *First* does not get less than *x*).

The same argument led the Federal Communication Commission staff to prefer auctions over lotteries in the allocation of spectrum frequencies. When those advocating lotteries were suggesting that the sole inclusion of the right to resale spectrum was sufficient to achieve efficiency, economists advocating auctions pointed out that when asymmetric information exists auctions can efficiently allocate while there is no guarantee that efficiency will be achieved only by bilateral trading (see Milgrom, 2004).

It is important to stress that a centralized marked for slots with many buyers and many sellers would not be equivalent to an auction with a unique seller (e.g. the regulator) of the kind described in the previous section. In fact, with many buyers and many sellers, and complementarities the *core* may be empty. The core is the set of allocations of slots and money with the property that no coalition can do better by trading on its own. This means that no matter what centralized trading mechanism a designer might propose, if the participants have enough information, there is always some coalition among them that can do better by refusing to cooperate in favour of negotiating on their own. Let's see this point with the following example in Table 5.

Let's assume that slot *A* and *B* belong to two different sellers who are willing to sell them for any price above zero. Suppose that *First* gets both *A* and *B* and pays strictly less than $x + d$. Then, one of the two sellers must get less than *x* and therefore would be willing to sell his slot to *Second*. Suppose, instead that *Second* gets *A* from one seller for a price less than *x*. Then *First* would offer *x* to the same seller and a price less than *d* to the other seller in order to secure both slots.

Even if a secondary market alone cannot produce an efficient outcome, a liquid European slot market would contribute towards a more efficient allocation of slots. In fact, notwithstanding informational asymmetries and emptiness of the core, slot trading in United

TABLE 5

VALUES

	A	B	AB
First	0	0	$x+d$
Second	x	x	x

Note: $x > d > 0$.

States and United Kingdom has been beneficial in many respects. MottMcDonald (2006), a report prepared for the European Commission, suggests that slot trading has been effective both in fostering competition, and in facilitating new entry and increase airplanes' sizes. In particular, slot trading generally results in the substitution of short-haul services operated by small aircrafts with long haul services, operated by larger aircrafts.[14]

4. - Welfare Distribution

Assuming that the market mechanisms studied in the previous section (congestion pricing, auctions and secondary trading) are able to implement a more efficient allocation of slots to airlines, this section analyses their implications in terms of the distribution of the welfare.

According to the definition given in section 2, the *value* of the slot is the highest value that someone would be prepared to pay for it. Therefore, if slots are inefficiently allocated, part of their value is dissipated. Meanwhile, the existing value is appropriated by airlines who operate on the basis of the historical precedence scheme.

If secondary trading was permitted at European airports without operating any initial redistribution of slots, incumbent airlines would benefit from the possibility of placing slots within

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[14] UK data suggest that the average aircraft size increased some 81% from 139 to 250 seat per traded slot (see MOTT-MCDONALD, 2006, vol. I, 5.2.2.II).

their liquid assets or selling them to the best offerer. Therefore, incumbents will appropriate most of the available efficiency gains by selling those slots that generate profits which are lower than what other carriers are prepared to pay for. As a result, the entire value of slots would be allocated to incumbent airlines. To understand the value of slots under the current grandfathering rules, it is useful to look at the recent UK experience with monetary trading. Rose (2003) suggests that British Airways acquired four series of daily slots for about 16 million GBP, while Virgin Atlantic acquired two series of daily slots for about 13 million GBP.

One way to reduce the economic rents to incumbency would be to place a one-shot lump-sum tax on every slot before allowing secondary trading to take place. For each slot, the carrier who holds it according to the current grandfathering rules would decide *either* to keep it and pay the tax *or* return it without paying the tax. Returned slots could be reallocated through an auction. The tax should be modulated according to the expected value of each slot, in order to leave to incumbents only a certain fraction of the total surplus. The tax, being one-shot and lump-sum, will not affect incentives to efficient trade. In fact, efficiency will be attained despite the level of the tax: even if a carrier decides to keep the slot and pay the tax, he is still willing to sell the slot to any carrier who can profit from it more than he does.

For example, suppose that *First* holds slot *A* and $v_F(A) = x$ while $v_S(A) = y$. Suppose that *First* is required to pay a tax t if he decides to keep the slot, while otherwise the slot is put for sale with an English auction.[15] Clearly, *First* will return the slot if and only if $t > max\{x, y\}$. In this case the slot will be subsequently reallocated in the auction: to *First* at a price equal to y if $x > y$; or to *Second* at a price of x if $y > x$. The regulator collects all proceedings but the more efficient carrier still enjoys part of the scarcity rents. *First* will keep the slot if $t \leq max\{x, y\}$, but he will sell

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[15] In an English auction, the auctioneer takes larger and larger bids from the customers until non one increases his bid. In equilibrium, the bidder with the highest valuation for the object wins and pays approximately the second highest valuation for the object.

it thereafter to *Second* if $y > x$, at the price of y. In the latter case, *First* will make a profit equal to $y - t$. Note that when $t = y - x$ *First* is neither worse off nor better off, when the situation is compared to the case where grandfathering applies but no secondary trading is allowed.

Alternatively, if slots were subtracted to their current holders and allocated through an auction, incumbent airlines would have to pay for a resource that they were previously entitled to use for free. In fact, referring to the previous example, the outcome would be the same as in the case where $t > max\ \{x, y\}$. Therefore, according to equilibrium behaviour in a English auction, if $y > x$ *First* will suffer a net loss of x, the regulator will collect x and *Second* will gain $y - x$, by obtaining the slot and paying y. If, instead, $x - y$, then *First* would keep the slot but would suffer a loss of y, which is the payment collected by the regulator.

Even if slots must be subtracted from incumbents, it would still be possible to design auction rules that redistribute part of the expected earnings on the basis of the initial slot holding of the companies involved in the auction. This is possible without upsetting incentives if the regulator is risk neutral and has sufficient information on the expected revenue that will be generated by the auction.[16]

Finally, increasing airport charges up to market clearing prices would have the same distributional effect as an auction. In fact, roughly speaking, market prices would reach levels such that only those bidders who would obtain slots in a simultaneous ascending auction would be prepared to pay. A relevant difference between congestion pricing and the auction mechanism is the timing of payments. While airport charges are paid every time the slot is used, an auction would assign the property of the slot for a much longer period of time.

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[16] In order for incentives to operate properly, the sum which is distributed must be independent of the outcome of the auction and calculated in order to guarantee that auction proceedings will be sufficient in expectation to recover its value. This is the same logic behind the properties of the expected externality mechanism suggested by D'ASPREMONT C. - GERARD VARET L.A. (1979).

5. - Conclusions and a Way Forward

The two previous sections can be briefly summarized as follows. A secondary market alone would not be able to produce an efficient allocation of slots to airlines. In fact, informational asymmetries and dispersed ownership of slots may prevent efficient trading to take place, even when a centralized market is in place. Furthermore, unless a tax is levied on slot holdings before allowing any secondary trading, incumbents would fully appropriate the value of slots, putting new entrants at a financial disadvantage. Congestion pricing can help in mitigating excess demand at peak hours but it is not a suitable instrument to solve the efficiency problem. It simply doesn't work well for our purposes, neither in theory nor in practice. In particular, it is highly implausible that regulators will have the necessary information to set market clearing prices for slots. An auction seems the most appropriate tool to implement an efficient allocation of slots to airlines, but a careful combinatorial design is needed to deal with complementarities. Moreover, the subtraction of slots from incumbents may be highly disruptive for the transport market, even though incumbents may be partially compensated for the loss if the revenue of the auction is used to their benefit.

Building on the previous analysis and trying to conciliate the interests of incumbents and new entrants, I conclude the paper with a draft proposal on how to allocate slots more efficiently at European airports. In brief: all slots should be re-allocated periodically through a combinatorial auction; some time before the first auction takes place, and thereafter, secondary trading should be allowed; proceedings from the auction should be collected by the regulator and partly employed to reduce airlines' costs.

We have discussed in length that a combinatorial auction, for example the clock-proxy format, would be a good solution to the problem of running a large sale of airport slots. Slots at major European congested airports should be allocated simultaneously in order to deal with complementarities across airports.

Auctions should take place periodically and the exact number of years between each auction should be determined with further research. For instance, if slots were reallocated in each season, airlines would have to revise their network structure frequently and the volatility of their costs would increase, bringing an increase in the cost of capital. Conversely, it would not be wise to auction slots only once and for all, leaving the duty to the secondary market to correct for changes in valuations of slots. First, if slots were allocated indefinitely, their market price would jump to very high levels because the value would discount an indefinite use of the slot. Therefore, enormous financial resources would be necessary to operate in the air transport market: while all incumbents would risk bankruptcy in the effort to acquire slots, small airlines may fall short of budget to obtain any interesting slots. Second, as we have seen, a secondary market alone is not the most appropriate instrument to achieve an efficient allocation.

Of course, secondary trading should be authorized thoroughly to allow airlines to revise their position and sell slots acquired by mistake or that become useless at some point in time before a new auction takes place.

The key point of the design consists in running the first auction only after secondary trading has been authorized. This would allow incumbents rationalize their network structure by selling those slots which are inefficiently allocated to them. The exact number of years between the introduction of secondary trading and the first auction should be determined with further research in order to guarantee to incumbent airlines a fair compensation for the subsequent withdrawal of slots.

Proceedings from the auction should be collected by the regulator and used to offset existing airport charges for the entire period before the next auction takes place. Moreover, it would be advisable to subsidize off-peak flights, in order to reduce demand for peak slots. In the short-run, both measures would partially compensate airlines for the payments they make in the auction. The remaining revenue could be used to finance the development of new airport capacity, thus reducing in the long-run the prices of slots.

In this paper we carefully avoided the discussion of competition policy issues. However, two points deserve major attention before concluding. First, antitrust scrutiny would be needed to avoid the exploitation of market power by incumbent airlines, both during the operation of secondary trading and at the auction. Second, compatibly with state aid rules, it may be useful to reserve slots in the auction to encourage entry in particular routes or to guarantee specific public service obligations.

At first glance the proposal above seems to me a viable compromise. However, competition policy issues and many of the complex technicalities of the air transport market have been ignored. Further research is needed, keeping in mind that in market design, evil is in the details.

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