Scoring Auctions: Are They the Key to Market-based Allocation of Airport Slots?

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ABSTRACT

Air transport has increased almost fifteen-fold worldwide in the last half-century (1970-2019) and is expected to return to this trend in the next few years, after falling from 4.558 billion passengers in 2019 to 1.809 billion passengers in 2020 due to the Covid-19 pandemic. Airport capacity has not kept pace with such growth and, therefore, more than two hundred major airports worldwide face capacity constraints and are "coordinated". Efficient allocation of scarce airport capacity is critical for air traffic growth, as well as for the overall air transport dynamic efficiency. However, the allocation of airport slots in Europe and elsewhere is still ruled by administrative processes, based on the IATA Worldwide Slot Guidelines, which follow historical precedence (called "Grandfather Rights") and time adjustments of historical slots. Several objections have been raised to the adoption of market mechanisms in slot allocation, as an alternative to administrative processes, and they are still rarely used. Despite often being suggested in the literature, the use of auctions for slot allocation has only been implemented in some local routes in China, and apparently this underemployment of auction mechanisms has been due to the reluctance of coordination authorities to face the risks that have been pointed out regarding airlines' long-term route planning, the usage costs related to excess slots, origin-destination pairing, and competition distortions. However, scoring auctions have never been considered and our research shows that their properties combined with an appropriate auction design could overcome most of those objections and mitigate the associated risks. Furthermore, the current drop in air traffic provides an opportune window for the introduction of auctions as a mechanism for the allocation of airport slots with minimal risks of disruption to airline business models.

IN 2019, A "NORMAL YEAR",[1] the aviation industry supported 11.3 million direct aviation jobs and a total of 87.7 million jobs worldwide (the sum of direct aviation jobs, indirect jobs, induced jobs, and tourism catalytic jobs – see next paragraph). It contributed, in a direct way to global GDP by an estimated

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[1] See ATAG (Sept 2020).

$US 961.3 billion (or around € 853 billion[2]). However, if we add to this direct contribution the indirect, induced and tourism catalytic contributions, the overall contribution rises to $US 3.5 trillion (or around € 3.1 trillion), which is around 4.1% of global GDP. In 2019, air freight reached 61 million tons accounting for $US 6.5 trillion (or around € 5.8 trillion), representing 35% of world trade by value that year in less than 1% by volume (ATAG, 2020). As we know, air freight focuses mostly on high value/low volume and the weight of merchandise.

In 2019, a total of 4.5 billion passengers and 58% of all international tourists travelled by air. Aviation activity has been increasing steadily for decades with the number of passengers growing at an average annual rate of 5.6% from 1970 to 2019 and air freight (ton/km) at a rate of 5.9% from 1973 to 2019[3].

Direct aviation jobs (i.e., jobs 'within the industry') include (i) Aviation operators, (ii) Other airport-based, or airport-related, workers: retail, car rentals, customs and immigration, freight forwarders, and some catering, (iii) Airline workers: flight and cabin crews, executives, ground services, check-in, training, and maintenance staff, (iv) Civil aerospace workers: engineers and designers of civil aircrafts, engines, and components, and (v) Air navigation service providers: air traffic controllers, engineers, and executives. Indirect jobs ('industry supply chain' jobs) include: (a) Off-site jobs: fuel suppliers, food and beverage suppliers, construction jobs, and transport providers, (b) Manufacturing jobs: computer components, and retail goods, (c) Services jobs: accounting firms, lawyers, call centers, and IT systems. Induced jobs ('use of direct and indirect employees') include jobs in the food and beverage sector, recreation and leisure, transport, housing, taxes, clothing, furniture, services, and telecommunications. Tourism catalytic jobs include jobs in hotels, entertainment, restaurants, museums, tourist attractions, tour operators, retail, and car rental[4].

However, and putting aside, for now, the shock from the Pandemic, growth of the air transport industry has been constrained by airport capacity limitations at some of the busiest airports in the world, especially in Europe, where slot demand clearly exceeds the installed capacity. Therefore, the allocation of the existing capacity, namely the available airport slots, has been an issue of major concern in the aviation industry throughout the last decades, in all those airports[5].

[2] We use the exchange rate of $US 1.1273 per 1 Euro, as of 20 December 2021. We use "billion" as equivalent to "a thousand million", i.e., 10^9. A trillion is equivalent to 10^{12}.

[3] *Vide* World Bank (2021).

[4] See ATAG (Sept 2020).

[5] *Vide* e.g., "Slotting in: The enduring problem of airport capacity", in Airport Technology, 10 October 2019: «*The International Air Transport Association (recently) warned that governments need to take a more harmonized approach in allocating airport slots. Scrapping archaic slot guidelines might also help to alleviate longstanding capacity issues*». And: «*Many airports around the world are congested because they do not have enough capacity to meet demand from the airlines and other aircraft operators who wish to use them. An airport slot is basically permission to use the infrastructure (runway, terminal, apron, gates, etc.) of an airport to take off or land on a specific date and at a specific time. Slot allocation is used, at the most congested airports (known as Level 3*

Despite all the efforts to improve the existing allocation mechanisms and the alternative proposals put forward by academics, policy makers and other stakeholders, there are some indicators suggesting the existence of significant improvement opportunities in slot allocation and utilization efficiency (Ball et al., 2018). For airports with a capacity constraint, several authors have reported inefficiency and low-competition indicators such as high concentration levels as measured by the HHI index, evidence of foreclosure behaviour by slot holder airlines, air passenger fare premiums on routes to/from these airports, low slot utilization rates, and low airline operational efficiency indicators (e.g., NERA, 2004).

Different approaches have been adopted to explore better allocation mechanisms and setup incentives for efficient utilization of slots, either optimizing administrative allocation algorithms, promoting the secondary market for slot transactions, using slot pricing mechanisms or making use of auctions for the primary allocation of slots (e.g., NERA, 2004; ACCESS, 2014; Pickett & Hirst, 2020), but little has effectively changed and the Worldwide Airport Slot Guidelines (WASG), published by the Airports Council International (ACI), the International Air Transport Association (IATA) and the Worldwide Airport Coordinators Group (WWACG) (IATA, 2020), are still very closely followed by national policy rules, namely the EU legislation[6]. The industry-wide agreement with the WASG and the risk of introducing any type of disruption in the complex air transport system seem to be among the main reasons to refrain from testing alternative allocation mechanisms.

The Covid-19 pandemic crisis did not change the need for better use of scarce airport capacity, mainly in Europe, despite the consequent huge drop in air traffic. Compared to the prepandemic 2019 data, worldwide passenger air traffic in 2020 dropped by 60.2% to 1.8 billion passengers (from 4.5 billion in 2019) (IATA, 2021). For 2021, a partial recovery is expected, returning to 50.2% of the 2019 figures and, in 2022, it is expected to reach 71.7% of the 2019 activity level (ACI, 2021). For Europe, the impact was even more severe, and recovery is slightly slower. However, this demand-side shock is transitory and will soon disappear, as the aviation activity returns to its growing trend.

According to world air traffic forecasts, the aviation sector will return to its 2019 activity levels during the transition from 2023 to 2024 (ACI, 2021), and air traffic in Europe by 2024 (Eurocontrol, 2021). Base scenario forecasts also suggest that the aviation sector will roughly recover its prepandemic long-term growing trend with a two-year lag (ICAO, 2021; Airbus, 2021). Consequently, the pressure in demand vis-à-vis pre-Covid-19 capacity-constrained airports will soon become a serious issue as relevant as it was until 2019, and even more serious afterwards as air traffic will probably double the 2019 figures within 15 years.

or 'coordinated' airports), to allocate and manage limited capacity, with the aim of maximizing the efficiency of an airport» – vide Briefing Paper, Number 9062, "Airport slots", 27 November 2020, House of Commons, UK.

[6] Regulation (EEC) No. 95/93 (the Slot Regulation), as amended by Regulation (EC) No. 545/2009.

Nevertheless, the distressed capacity situation in Europe, since the second quarter of 2020, provides a short window of opportunity to test alternative allocation mechanisms with a reduced risk of disruption in the aviation industry, in particular when demand increases and remains close to installed capacity. Furthermore, the unavoidable adjustments in the airline supply structure and route profile will require additional flexibility in accessing the capacity of airports that should not be unnecessarily constrained by slot allocation mechanisms that are too rigid.

In this context, the objective of our paper is to present a synthesis of all the work already developed on auctions for primary allocation and to suggest adding scoring auctions as a way of overcoming some of the drawbacks that have been pointed out regarding the use of auctions in this sector, while keeping secondary markets active.

I. The Current Slot Allocation Mechanism

The allocation of airport capacity is the core of slot allocation mechanisms, as a "slot" is "a permission given by a coordinator for a planned operation to use the full range of airport infrastructure necessary to arrive or depart" (IATA, 2020, pp 10) in a capacity-constrained airport[7].

According to WASG, whenever airport capacity, established by the infrastructure manager as the number of available slots per period of time (an hour, or half an hour) based on the technical operational conditions, cannot meet the demand, that airport is categorized as a "level 3 airport" or a "coordinated airport"[8]. Among the 198 airports in this category worldwide, 102 (52%) are in

[7] An 'airport slot' can be defined as a permission to use the infrastructure (runway, terminal, apron, gates, and so on) of an airport to take off or land on a specific date and at a specific time. Slot allocation is used at the most congested airports to allocate and manage limited capacity, with the aim of maximizing the 'efficiency of an airport'. In the Council Regulation (EEC) No. 95/93, a 'slot' is defined as the scheduled time of arrival or departure available or allocated to an aircraft movement on a specific date at a coordinated airport", where a 'coordinated airport' is an airport where a coordinator has been appointed to facilitate the operations of air carriers operating or intending to operate at that airport. A coordinated airport is also referred to as a 'level 3 airport'. In the USA, the term 'slot' means 'a reservation for an instrument flight rule takeoff or landing by an air carrier of an aircraft in air transportation.' In the EU, as mentioned above, the working definition of a slot is more demanding: a 'slot' means the entitlement of an air carrier to use the full range of airport infrastructure necessary to operate an air service at a coordinated airport on a specific date and time for the purposes of landing and takeoff. The EU working definition of a 'slot' includes not only access to a takeoff or landing slot, but also associated airport infrastructure. This is left out of the US definition. Hence, in the US such resources must be obtained by separate means. In the existing environment, dominated by 'Grandfather Rights, "other" such resources are already available to slot holders – see Ball *et al*. (2018).

[8] If the excess demand is expected to occur only during some periods of time and can be solved by agreed adjustments in flight scheduling, airports are categorized as "level 2 airports", and all those where there is excess capacity, are categorized as "level 1 airports".

Europe[9], which accounts for only 27% of all international airports in the world, in contrast, for instance, with the US that accounts for 20% of all international airports but only 7% of level 3 airports (IATA, 2021). This clearly shows the particular relevance of scarce airport capacity management in Europe.

In level 3 airports, an independent airport coordinator must be appointed to manage that scarce capacity allocating slots to airlines and other aircraft operators, applying the rules established in WASG. That is, an airport coordinator is a natural or legal person, both functionally and financially independent from any interested party, including governments, airlines, and airports, who is responsible for allocating airport slots and monitoring their use in a neutral, transparent, and non-discriminatory way[10]. These rules are closely followed by the US and the EU legislation and are supported by two rules: the 'Grandfather Rights' rule (an 'historic precedence' rule), and the 'use-it-or-lose-it' rule. The former states that slots are allocated to flight operators that already had those same slots assigned in the previous correspondent IATA season, following the historical scheduling in that airport[11]. The latter introduces a (light) constraint to the 'Grandfather rights' rule, as it states that this rule only applies to slots (or a series of slots) that have been effectively used by the flight operator for at least 80% of the allocated time slots. This is why the 'use-it-or-lose-it' rule is also known as the '80/20 rule'.

All the slots that are not allocated by applying those two rules, newly created slots or slots that for some reason have become available, join a slot pool and are allocated to airlines by the coordinator based on a set of hierarchical rules that include 50% of the slots for new entrants, consideration of year-round operations, and several other factors such as the type of consumer or market served, connectivity, competition issues, etc. These multi-objective (potentially conflicting) factors provide additional degrees of freedom for considering public interest aspects related to slot allocation, other than the reservation of certain slots for regional services or services with public service obligations. A comprehensive description of the entire allocation process can be found in Zografos et al. (2017) and in Ribeiro et al. (2019).

Finally, the WASG also include a four-day Slot Conference twice a year, where all operators with slots are allowed to change slots, in order to implement

[9] Excluding Russia (4 level 3 airports and 67 international airports), where most airports are located outside the geographic European region.

[10] See EU Airport Regulation – Regulation 95/93 (EEC), Article 4.

[11] The Worldwide Airport Slot Guidelines state that « (…) *historic slots may not be withdrawn from an airline to accommodate new entrants or any other category of aircraft operator. Confiscation of slots for any reason other than proven, intentional slot misuse is not permitted*». On the other hand, under EU Rules the 'use-it-or-lose-it' rule can be suspended under certain extraordinary circumstances. It was suspended several times in the past 20 years, including after the 9/11 terror attacks in 2001, the launch of the Iraq War in 2003, the outbreak of SARS in 2003, and the global financial crisis in 2009. The European Commission suspended the rule for the summer and winter seasons in 2020/21 because of the Coronavirus pandemic – see Pickett & Hirst (2020).

schedule adjustments considering the slot allocation in all airports, provided that the respective coordinator agrees with those changes.

Despite WASG formally invoking efficiency, non-discrimination, the promotion of competition (or non-distortion), and allowing for adjustments through slot changes in the conferences, this administrative allocation mechanism is far from being economically efficient, and has been criticized for not allocating the slots to those users that value them the most, not promoting the efficient use of the allocated slots, for distorting competition in the airline industry, and for not effectively preventing excessive delays, among other criticism[12] (see e.g., Gillen & Morrison, 2008; Ball et al., 2018).

II. Alternative Approaches for Slot Allocation

Given the complexity of the coordinator's allocation task, some software tools are available but do not provide optimization capabilities (Jorge et al., 2021) while several authors have proposed optimization algorithms and models that differ in the optimization criteria, the priority rules considered, the type of airport capacity constraints addressed, and other aspects of the optimization process design (Zografos et al., 2012; Zografos & Jiang, 2019; Ribeiro et al., 2019; Fairbrother et al., 2020; Jiang & Zografos, 2021; Katsigiannis et al., 2021), as described in the recent literature review by Katsigiannis & Zofrafos, 2021.However, even though the implementation of these optimization algorithms might look simple and could contribute to some improvement in the slot allocation process, slot utilization and airport congestion consequences (Katsigiannis & Zografos, 2021), the optimization of the administrative allocation process does not address the core problem of economic inefficiency.

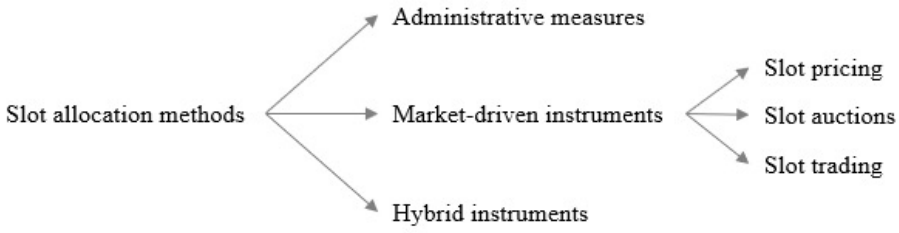
Most of the proposed models are constrained by having to comply with the WASG and are not based upon information related to slot valuation by users and slot providing costs, failing to allocate such a scarce resource to its most valuable use. They are still administrative allocation methods.

Nevertheless, these optimization efforts are useful to relate capacity variables, slot requests and operational variables at congested airports, but also to highlight the tradeoffs between the multiple objectives in slot allocation and in airport capacity management. Developing these models while considering "efficiency" (in its various operational forms, namely different schedule displacement variables), "fairness" (with distinct concepts and metrics) and "acceptability" by the stakeholders, also illustrates the complexity of the multi-objective problem of airport slot allocation.

[12] There have been cases where some airlines have flown empty flights or ghost flights simply to retain their slots – see Pickett & Hirst (2020).

To consider real alternatives[13], one must look at market-driven instruments, which include slot pricing, slot auctions and slot trading, or even hybrid instruments combining administrative and market-driven approaches (Figure 1), as described by Madas & Zografos (2008), and Zografos et al. (2017, 2019).

Figure 1
Approaches to slot allocation



Source: Zografos et al. (2019)

The use of pricing mechanisms for clearing the market, leveling supply and demand is common in most markets. Increasing prices usually solve excess demand situations (both by reducing demand and stimulating supply) and the use of peak-load prices (or congestion pricing) is shown to be efficient when demand exceeds supply capacity for some periods of time (Steiner, 1957), but it is rarely adopted for allocating airport slots, partly because the aviation sector is much more complex than the usual stylized pricing models and the required information for setting optimal dynamic price structures is not easily accessible.

Several authors have suggested the use of congestion pricing, but its merits compared to other slot allocation approaches are not consensual as they depend on the assumption regarding the demand for slots, airline pricing policy, airline market structure/concentration/differentiation, airport integration in the airport's network, information available for slot price setting and other modeling and market details (Avenali et al., 2015; Basso et al., 2010; Brueckner, 2009; Czerny, 2010; Czerny & Zhang, 2014; Daniel, 2014; Ball et al., 2018; Noto, 2020). Setting appropriate congestion prices in a dynamic setting is a highly complex problem, even if this allocation mechanism has the advantage of allowing an increased carrier scheduling flexibility and reducing the incentives for airlines to hoard airport slots (Ball et al., 2018).

Additionally, the use of prices to manage demand and accommodate airport capacity usually faces constraints from economic regulation of the airport

[13] Here, the term "real alternatives" refers to a conceptual perspective, which does not consider their implementation viability from a public policy perspective.

business, as at most level 3 airports, airport tariffs, including slot prices, are regulated to control the monopoly power of airports, directly or indirectly capping slot prices, either using an incentive or a cost-plus regulation model (Forsyth, 2008; Verhoef, 2010). However, some argue that the use of congestion pricing, if appropriately designed, might be compatible with the existing regulatory practice (Daniel, 2011; Verhoef, 2010). The debate on the benefits of congestion pricing is enriched by those arguments that suggest combining congestion pricing with other mechanisms to improve efficiency, as each of the different alternatives alone is not sufficient (Noto, 2020).

Theoretically, part of the primary allocation efficiency problems could be mitigated by a secondary market for slot trading among all flight operators with slot permits that are attributed in the primary allocation, irrespective of the primary allocation mechanism used. In a secondary market, slots can be swapped, transferred, or even shared between airlines, as part of a commercial arrangement. When the availability of pooled slots is limited, as in heavily congested airports, slot trading provides an opportunity to improve efficiency in slot allocation as it increases its user value, even if it is only temporarily, and only if it does not threaten the competitively advantageous position held by the airline that controls the slot (as it would if transferred to a potential competitor).

However, such slot trade is subject to some restrictions. According to the Worldwide Airport Slot Guidelines (WASG, 2020), slot transfers between airlines may only take place where they are not prohibited by the laws of the relevant country. Slots may only be transferred to another airline that is serving or planning to serve the same airport. The transfer of newly allocated slots, which are slots other than historic slots or changed historic slots, is not permitted until such slots have been operated for two equivalent seasons. This is to prevent airlines from taking advantage of an enhanced priority, such as new entrant status, to obtain slots simply to transfer them to another airline. Airlines engaging in a slot transfer must notify the coordinator of every transfer. The coordinator will confirm the feasibility of the transfer and amend its database. If the transfer involved compensation the following details must be made available to relevant stakeholders, if requested and published on the coordinator's website for transparency purposes only: (a) the names of the airlines involved; (b) the slot times transferred; and (c) the period of the transfer (e.g., period of operation, seasons, permanent/temporary, etc). IATA sponsors scheduling conferences where air carriers can negotiate various types of temporary slot swaps to accommodate such scheduling needs.

III. The Use of Auctions in Slot Allocation

Auctions as a resource allocation mechanism have been used in society for centuries. They have been used to allocate all sorts of goods and services, from the acquisition of public goods and services to spectrum allocation in telecoms, from their use in the energy and transport sectors, to the sale of art objects (usually

through an ascending, or English, auction) and flowers (as in the descending, or Dutch, auction).

They have also been under consideration for airport slot allocation at least for the last forty years since in the early 80s Rassenti et al. (1982) used airport slots as an example in the use of combinatorial auctions[14]. The aim has been to improve the efficiency of airport slot allocation. The body of research and applied work on auctions have experienced enormous growth since the seminal work of W. Vickrey (1961), bringing a modern game theoretic approach to the study of auctions, with major contributions from P. Milgrom, R. Wilson, and other prominent economists.

Given the complexity of the aviation sector and the specificities of airport slots – as the products to be auctioned, and whose definition is an issue in itself – researchers have proposed different auction designs to overcome the usual challenges within the aviation context. As expected, a slot auction has to deal with allocation efficiency/the revenue maximization question, the private value/common value dichotomy, with substitutability/complementarity of auctioned products, with bidders' potential collusion or strategic/opportunistic behavior, coupled with all the other details that have to be dealt with in real life.

In slot auctions, there are elements of *private value*, the value of a slot or a combination of slots is a specific airline's business or an airline's private information, and differs from one airline to the other. However, there are also elements of *common value*, when the possibility of slot changes among airlines or the participation in airline alliances or air transport network effects are considered, which depend on aviation sector valuation insights (Ball et al, 2018). The disaggregation of slot value in a "use value" and a "foreclosure value" (Mayo et al., 2016) also captures this double private/common value characteristic of slot valuation. This means that auctioning slots requires more complex auction models than the relatively simple sealed bid auction model, implying a trade-off between simplicity in auction implementation (and corresponding attractiveness) and the use of the right tools to address common value situations, where mechanisms of information discovery are relevant (Ball et al., 2018; Milgrom, 2021).

Slot values are also dependent on strong complementarities between slots at one time window and another time window in the same day (or the same time window in another day of the week), between a series of slots in some daily time windows, or the most basic complementarity between a landing and a takeoff slot at the same airport in close enough time windows or between a takeoff slot at the origin airport and a compatible landing slot at the destination airport. Slot complementarity brings additional complexity to auction design, calling for combinational auctions or simultaneous multi-product auctions, with specific rules to mitigate distortions caused by bidders' exposure risk or strategic biding behavior such as *parking*, in the latter case (Ausubel et al., 2006; Milgrom, 2021).

[14] Combinatorial auctions are auctions in which participants can bid on combinations of items or packages. They draw on the disciplines of economics, operations research, and computer science – see P. Cramton et al. (2005).

Regarding the main purpose of an auction, it is consensual that it is an efficient allocation of the product being auctioned and not the auctioneer's revenue maximization, given that the corresponding airlines' rent extraction cannot simply be transferred to the airport business, which is subject to cost-oriented or price/revenue cap economic regulation (Forsyth et al., 2008). Furthermore, if the revenue happens to be captured by the State, it would be transferred downstream anyway leading to an increase in air transport prices, reflecting on the final consumer the distortions caused by airport capacity adjustment difficulties (Forsyth et al., 2008).

This limitation in the transfer of congestion/external cost from using airport capacity at level 3 airports is similar to the one experienced when adopting congestion prices, and constrains the benefits associated with these two market-based mechanisms. In addition, several other sources of market imperfections limit the contribution of auctions to improve slot allocation efficiency, as described by K. Button (2008). Firstly, despite the European Single Market and air transport liberalization, competition between airlines is far from perfect, namely (but not only) due to 'Grandfather Rights' in slot allocation. The airlines' willingness to pay for slots during auction bidding phases is not a perfect guide to measure social welfare changes, irrespective of how well designed the auction may be. Secondly, slot allocation and use might be related to social objectives/benefits – such as air transportation serving some territories and communities, integration in the global hub-and-spoke networks, etc. – that can outweigh, or at least must add to, private benefits, creating a deviation between the social optimum and market equilibrium. Finally, the nature of airport assets – regarding their alternative uses, long active lives, indivisibilities, sharing among aviation and non-aviation activities, as well as the environmental-social-territorial impact in the surrounding areas – make decisions over capacity very difficult and challenging, with uncertain effects on global efficiency and intergenerational justice.

These factors limit the potential efficiency benefits from using auctions to allocate airport slots, and add to the risk of disrupting airline business practices, creating general resistance among decision makers and stakeholders concerning the use of auctions, based on which the use of auctions at the New York airports was postponed indefinitely in 2008 and no other cases have been tried until 2015, when an auction in the Chinese domestic market was conducted (Sheng et al., 2015). The fact that this limited experience in China[15] is the only effective case of slot allocation by auctioning does not help to dissipate doubts regarding

[15] In 2016, the Civil Aviation Administration of China (CAAC) initiated a trial slot auction scheme for domestic flights at Guangzhou Baiyun and Shanghai Pudong Airports. Auction winners retained the slots for three years – https://www.routesonline.com/news/29/breaking-news/268813/china-gambles-on-slot-auctions/. Furthermore, in November 2011 when US Airways and Delta Air Lines were required by the US Department of Treasury to divest a total of 48 slots, or 24 slot pairs, at Ronald Reagan Washington National Airport and New York LaGuardia Airport, the US Federal Aviation Administration employed simple auction mechanisms to execute these transactions, for which the buyers and sellers were airlines. These were secondary market transactions where the government played a forcing role – see M. Ball *et al.* (2018). However, these are particular cases.

auction benefits (unknown), when compared to the consolidated administrative allocation mechanisms (already known).

However, most of the evoked causes of auction inefficiencies also apply to the other slot allocation mechanisms, which means that the merits of adopting auctions should be analyzed by the incremental benefits to the existing inefficient situation and not by the differential between the expected slot auction effective efficiency results and the theoretical perfect competition efficiency outcome.

Bearing this in mind, despite the tendency to reject this option by many aviation agents, auctions are seen by most of the researchers as potentially providing a better way of achieving improved welfare (compared to the existing practice), at least in some circumstances (Button, 2008; Basso et al., 2010; Sheng et al., 2015; Ball et al., 2018).

Literature on Airport Slot Auctioning

The definition of the object to be auctioned is the starting point for slot auctioning and it requires a redefinition of the rights associated with slots, not necessarily regarding the rights to use the airport infrastructure and all the connected services necessary for aircraft landing and takeoff and passengers, luggage, and cargo handling, but the duration of those rights. The combination of the existing definition of slots with the 'Grandfather Rights' rule almost configures a *de facto* property right of incumbent airlines over airport slots, as that right perdures over time provided that a slot is used on at least 80% of occasions during one season. This is not easily compatible with auctioning those slots (the vast majority of slots in level 3 airports), unless airlines are compensated. However, even for auctioning the (minority) slots in the pool, not under the 'Grandfather Rights' rule, a redefinition of slots is recommended, otherwise the auction would occur only for those slots that occasionally end up in the pool. The usual assumption made in literature is that the slot should be a time limited right, say 5 to 25 years, so that each year a certain percentage of slots are auctioned (DotEcon, 2001; Ball et al., 2018).

Concerning the auction design, slot auction proposals have been largely inspired by electromagnetic spectrum auctions, which were first conducted in the USA by the Federal Communications Commission (FCC) in July 1994 and generalized worldwide as the main procedure to allocate (limited time) rights to use spectrum for communication services. Product complementarities are among the many similarities between spectrum rights and slots and justify focusing on simultaneous auctions or combinational auctions, the two main approaches to deal with the issue.

Adopting combinational auctions is attractive as it allows each bidder to bid based on its own valuation for many different combinations of slots, exploring all possible (and feasible) complementarities between slots, without facing the exposure risk (Day et al., 2012), and, simultaneously, allows the auctioneer to compute the "best" combination of bids from all the bidders, by running a winner's determination algorithm (Ausubel et al., 2002; Day et al., 2012). The challenge is to limit the number of possible bids for each bidder to keep the optimization

problem computable and the bidding process intelligible (not too costly) for all bidders (Ausubel et al., 2002; Day et al., 2012; Milgrom, 2021). Additionally, this type of auction is not the most suitable to deal with the *common value* aspect of slots, as there is no price discovery mechanism.

By contrast, simultaneous multiple round auctions provide a mechanism of price discovery as bidders observe in each round the relative value of all slots being auctioned, but require well designed activity rules[16] to mitigate the exposure risk (i.e., the measure of potential future loss resulting from a specific activity or event), bidders' strategic behavior that might decrease social welfare, and undersell risk (Ausubel, 2004; Milgrom, 2021).

While Rassenti et al. (1982) proposed a basic combinational auction, most recent research suggests that a hybrid auction format, in a multi-stage approach in line with the Clock-Proxy model developed in Ausubel et al. (2006) may be the best-suited approach for airport slot allocation (Ball et.al, 2018). The Clock phase is a simultaneous clock auction in which the auctioneer announces linear prices for all slots, and bidders respond with their desired quantities, in successive rounds until there is no excess demand for any slot. This phase is useful for price discovery for *common value* elements of slot valuation and might be robust to exposure risk and strategic behavior risk, namely by selecting the right activity rule (Ausubel et al., 2006). Milgrom's final Proxy phase is based on package bidding, where a proxy agent submits bids on behalf of the bidders and the auctioneer announces the provisory winners maximizing the revenue from all compatible bids, successively until no new bid is submitted (Ausubel et al., 2006). By combining these two phases it is possible to reduce bidders' calculation costs in the complex package biding by providing a price (value) discovery mechanism, to mitigate the risk of withholding demand and underselling, as there is no incentive for demand reduction at the Proxy phase, and to simultaneously deal with the substitutability and complementarity of airport slots (Ausubel et al., 2006).

However, at the Proxy phase, the auction design must specify the winner determination rule as well as the payment determination rule, two aspects that are still subject to intense debate. Regarding the former, the criteria might simply be the maximization of the auctioneer's revenue, but that does not consider efficiency or perceived fairness, or any other aspects that are considered important when the allocation of public resources (or slots) is at stake, situations that might claim for a different formulation of the winner determination rule (Ball et al., 2020; Day and Cramton, 2012), and that could imply multidimensional selection criteria in the case of airport slots.

Regarding the payment determination rule the problem is probably even more complex, as the Vickrey second price approach that unlinks the winner's payment

[16] According to P. Milgrom (2021), and in the context of spectrum auctions, the activity rule states that a bidder cannot bid for a larger amount of spectrum rights in any round than it had bid in the previous round. This rule prevents a bidder from waiting to see what others were doing before making its own commitments, it helps the auction to develop meaningful prices before bidders must make their final bids, and shortens what could otherwise be an untenably lengthy process.

from their bidding values, while straightforward in a sealed-bid second-price single product auction, is quite challenging in combinational auctions, if one aims to preserve strong incentive properties without becoming impractical on grounds of computation requirements, perceived fairness, balanced payments, and collusion risk, (Ausubel, 2004; Day and Milgrom, 2008; Day and Cramton, 2012; Milgrom, 2021), resulting in many proposed alternatives (Ball et al., 2018). We note that the potential risk of very low revenue, also observed in some spectrum auctions should not be overvalued in the slot auction context, as the impacts caused by extra costs for airlines have been regarded as a drawback to using auctions for slot allocation.

To overcome the "extra cost" argument and improve the stakeholders' acceptability of auctioning slots, Ball et al. (2018) advocate that "*(1) auction revenues should be used to offset associated landing fees; (2) any excess funds should be invested into the local or regional air transportation system (or perhaps in other modes that could divert traffic from that system); (3) the manner in which auction revenues will be dispersed should be described in a legally binding document in advance of the execution of the auction*" (pp. 195). Along the same line of thought, one could divert auction proceeds from the airport regulated company and find alternative uses for those proceeds, such as financing airport capacity expansion or financing an environmental fund to compensate those affected by an airport's negative externalities (Sentance, 2003; Forsyth et al., 2008).

Several other aspects of the auction model proposed by Ball et al. (2018) are designed to improve the acceptability of this allocation mechanism, such as the 20-year lease slots that imply auctioning only 5% of the slots under the 'Grandfather Rights' each year, compensating those slot holders, eliminating restrictions on slot use, improving airport facilities, and so forth. We strongly support such a transition approach, irrespective of the specific design adopted, as from a public policy perspective only implementable alternatives will be considered.

Finally, it is worth noting that it is generally recognized that slot allocation must consider public interests, including competition, allocation and use efficiency, as well as externalities and other relevant dimensions in the aviation sector, as pointed out in the academic literature that considers all the alternative slot allocation mechanisms. However, these concerns are treated by introducing constraints on the slots themselves (for instance, reserving slots for some purposes) or in relation to the slot allocation mechanisms, either in the optimization of administrative algorithms (Jiang et al., 2021), or vis-à-vis the winner determination rule (Day et al., 2012), or any other aspect of the allocative mechanism design, despite the fact that some recognize that these restrictions reduce the efficiency of the final output.

Scoring auctions: a viable alternative?

Motivated by this concern with making slot auctions as attractive as possible for all stakeholders, while keeping their efficiency promoting properties, we consider if the use of scoring auctions could be beneficial, as long as this type of auction is conceived to deal with more than one goal in the objective function and

does not introduce constraints as occurs in the abovementioned auction models. A scoring auction is an auction in which the allocation of the project is determined not only by prices, but by a combination of the prices and the quality of the bidders' proposals.

We are aware that scoring auctions have been studied and used almost exclusively in procurement situations, where the auctioneer (the buyer) looks for some good or service at the minimum cost, but whose utility function is also influenced by other attributes of that good or service, generally aggregated as a "quality" feature. However, since the seminal work of Y-K Che (1993), the theory and practice of scoring auctions have substantially benefited from the work of F. Branco (1997), J. Asker & E Cantillon (2008), M. Wang & Sh. Liu (2014) and T. Nishimura (2015), to mention but a few. Their research has extended the analysis to cover multiple attributes, different assumptions on bidders' private information, distribution properties, cost structures, as well as the buyer's utility function, in addition to auction design and optimality aspects (Dastilar, 2014; Chetan et al., 2019).

It is interesting to acknowledge that prior to the introduction of scoring auctions by Y.-K. Che (1993), the quality attributes were already treated in procurement auctions as each bidder was required to submit a "technical proposal" detailing all the attributes of the service/good. However, that information was used as a prequalification instrument for the admission of bidders that met a minimum quality threshold of the price bidding phase of the procedure (Chetan et al., 2019). All relevant attributes, other than price, were therefore introduced in the decision-making process only as a constraint, limiting the buyer's utility, as it did not allow the price-quality offer that best fit the buyer's utility function to be selected.

There seems to be a clear analogy with the existing slot auction theory that addresses multi-objective slot allocation issues by introducing constraints in the models, as described above. On these grounds, the use of scoring auctions in the context of airport slot allocation could provide some interesting insights. The creation of a value function – the 'score' – would accommodate efficiency concerns coupled with all the other auctioneers' concerns, which could result in a winner determination rule in any combinational auction or package bidding phase.

In such a case, the auction design would have to be adjusted. A multi-round auction where bidders bid for packages of auctions offering a price for the package and a corresponding vector of attributes related to the use designated for the planned slots – the type of aircraft, the type of service, number of passengers, etc. – would allow the auctioneer to compute the utility value of each package given all compatible combinations of bidders' packages, given a previously defined value function (auctioneer utility). During each round, the auctioneer would announce a provisional allocation of slots and bidders would be given the opportunity to submit new bids incorporating that provisional slot allocation. With the new bids, the auctioneer could run the winner determination rule and the process would be repeated until the closing rule was applied, in a similar

manner to the proxy phase in a clockproxy auction. This would be followed by some payment determination rules.

The determination of the multidimensional value function could benefit from using Macbeth multi-criteria methodology (Bana and Costa et al., 1994, 2012), and the Collaborative Value Modeling (Vieira et al., 2020) would provide a robust methodology for the participation of several airport stakeholders in the definition of that value function – the "score" for the score auction.

Finally, the fact that additional dimensions other than the price/auctioneer's revenue would be considered in slot allocation, e.g., in the winner determination rule, could lead to an auction revenue lower than the one resulting from a clockproxy auction, softening the revenue impact critique that some authors have been trying to overcome.

IV. Conclusion

Air traffic of both cargo and passengers has been very important for the world economy for many years, and despite the current crisis due to the Covid Pandemic, it will rebound and will continue to increase at a healthy rate, possibly meeting increasingly demanding environmental standards at the same time. The current drop in air traffic presents a small window of opportunity to rethink the current administrative airport slot allocation mechanism, especially given the disruption to air traffic that is presently lower than under normal circumstances. Price congestion mechanisms and different types of auction mechanisms have been analyzed as alternative ways to allocate such slots, with the goal of promoting greater competition and efficiency in the allocation of such scarce resources in the so-called level 3 airports, particularly numerous in Europe. There have been some instances of slot allocation through auction mechanisms, but they are far from being or even becoming the norm due to various criticism directed at such mechanisms by many stakeholders, as well as due to their complexity. We propose exploring the viability of scoring auctions as a mechanism for the allocation of airport slots, taking into account the already substantial academic literature on resource allocation mechanisms in general, and on congestion pricing and combinatorial auctions in particular, and considering the multiple goals to be achieved by a slot allocation mechanism that must perform effectively under a public policy perspective and be acceptable to most stakeholders, while achieving an equilibrium that is as efficient as possible and socially acceptable.

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