

Rustamdjan Hakimov; Heller, C.-Philipp; Kübler, Dorothea; Kurino, Morimitsu

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How to Avoid Black Markets for Appointments with Online Booking Systems[†]

By RUSTAMDJAN HAKIMOV, C.-PHILIPP HELLER, DOROTHEA KÜBLER,
AND MORIMITSU KURINO*

Allocating appointment slots is presented as a new application for market design. Online booking systems are commonly used by public authorities to allocate appointments for visa interviews, driver's licenses, passport renewals, etc. We document that black markets for appointments have developed in many parts of the world. Scalpers book the appointments that are offered for free and sell the slots to appointment seekers. We model the existing first-come-first-served booking system and propose an alternative batch system. The batch system collects applications for slots over a certain time period and then randomly allocates slots to applicants. The theory predicts and lab experiments confirm that scalpers profitably book and sell slots under the current system with sufficiently high demand, but that they are not active in the proposed batch system. We discuss practical issues for the implementation of the batch system and its applicability to other markets with scalping. (JEL C92, D47)

Allocation problems where money is not used to coordinate supply and demand have gained the attention of economists in recent decades. Well-known examples include the assignment of seats at schools and universities. A related problem

*Hakimov: University of Lausanne & WZB Berlin Social Science Center (email: rustamdjan.hakimov@unil.ch); Heller: NERA Economic Consulting (email: philipp.heller@nera.com); Kübler: WZB Berlin Social Science Center & Technical University Berlin (email: dorothea.kuebler@wzb.eu); Kurino: Keio University, Faculty of Economics (email: kurino@econ.keio.ac.jp). Liran Einav was the coeditor for this article. We would like to thank three anonymous referees for their insightful and constructive comments and clear guidance. Our special thanks go to Renke Fahl-Spiewack at the German Foreign Office who inspired us to work on this problem. We are grateful to Nina Bongé who helped us with conducting the experiments as well as Jennifer Rontganger and Christopher Eyer for copyediting. We thank Georgy Artemov, Péter Biró, Julien Combe, Bob Hammond, Akshay Arun Moorthy, Alex Nichifor, Siqi Pan, Antonio Romero-Medina, Yasunari Tamada, Masatoshi Tsumagari, Martin Van der Linden, Suvi Vasama, Tom Wilkening, Zhibo Xu, and participants of the Berlin Behavioral Economics Workshop, the European Behavioral Economics Meeting (EBEM) at the University of Bonn, the Conference of Behavioral Economics and the Economics of Inequality at the University of Edinburgh, and seminar participants at Keio University, Hitotsubashi University, UTS Sydney, University of Melbourne, University of St. Andrews, ECONtribute Bonn/Cologne, HSE St. Petersburg, DICE at Düsseldorf University, the MiddEX virtual seminar, and FAIR at the University of Bergen for their valuable comments. Dorothea Kübler gratefully acknowledges financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) through CRC TRR 190 “Rationality and Competition” and the Cluster of Excellence “Contestations of the Liberal Script” (EXC 2055) as well as the Leibniz SAW project MADEP. Rustamdjan Hakimov acknowledges financial support from the Swiss National Science Foundation project 100018_189152. Morimitsu Kurino acknowledges financial support from JPS KAKENHI (grant from Japan Society for the Promotion of Science), and F-MIRAI at the University of Tsukuba.

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involves scheduling appointments at public offices. Such appointments are provided for free and are necessary to access many essential public services, such as obtaining a visa or a driver's license, or renewing a passport. Lately, many authorities have introduced online booking systems that allow appointment seekers to book in advance and to avoid queues. Typically, these online booking systems are based on first-come-first-served rules: an authority offers time slots on a website, and appointment seekers visiting the website can pick any available (not previously booked) slot.

Such online systems based on first-come-first-served rules are vulnerable to scalping. Scalpers are firms that book slots and sell them to appointment seekers. Typically, scalpers use software, or bots, to track the system and book slots immediately after they appear. Thus, the firms have a technological advantage when it comes to booking speed compared to appointment seekers. A black market for appointment slots implies that the political objective of providing equal access to the public service, independent of income, may be violated. Moreover, it can be argued that firms acting as intermediaries profit undeservedly from public services.¹

The vulnerability of the booking system originates from the fact that once slots become available, they can be booked on a first-come-first-served basis. Scalpers book any open slots with fake names or the names of their customers and sell them. For appointments booked under fake names, scalpers first cancel and then immediately book the slots under the names of their customers. This rebooking of canceled slots bypasses the barrier imposed by the ID verification of the booking system. Thus, while it might seem that ID verification would prevent scalping, the scalper's advantage of speed in the first-come-first-served system effectively circumvents it.

A number of prominent cases have surfaced recently where appointment slots at public offices were sold on the market. The introduction of an online booking system for appointments with the Irish Naturalisation and Immigration Service Center in Dublin led to scalping and a collapse of the system.² Bots have also been used by scalpers to book all the slots at the Préfectures in France where foreigners need to obtain their residence permit. Thus, appointment seekers cannot obtain slots directly but instead must buy them from the scalpers.³ Fees of up to US\$500 were paid to scalpers to get an appointment for a visa interview at the German consulates in Beirut, Tehran, and Shanghai.⁴

¹ One feature of scalping is that it can help to serve the buyers with the highest valuations. However, we are not looking for a solution that maximizes the sum of the valuations of appointment seekers who are served. Instead, we propose a system that guarantees equal access, is ex ante fair by relying on randomization, and is efficient in the sense that no slots are wasted.

² Sorcha Pollak, "Bots Used to Block Immigrants in Ireland from Making Visa Appointments," *Irish Times*, <https://www.irishtimes.com/news/social-affairs/bots-used-to-block-immigrants-in-ireland-from-making-visa-appointments-1.3620957> (accessed December 1, 2020).

³ Julia Pascual and Nicolas Corentin, "Titres de séjour: le prospère business de la revente de rendez-vous en préfecture," *Le Monde*, https://www.lemonde.fr/societe/article/2019/06/01/titres-de-sejour-le-business-de-la-revente-de-rendez-vous-en-prefecture-prospere_5470146_3224.html (accessed December 1, 2020).

⁴ Peter Maxwell, "Ein Termin in der deutschen Botschaft? Das kostet!," *Spiegel*, <https://www.spiegel.de/politik/ausland/iran-termin-ein-in-deutscher-botschaft-in-teheran-werden-verkauft-a-1041367.html> (accessed December 1, 2020). After the events received press coverage, we were contacted by the German Foreign Office to consider the problem. This was the starting point of our work. An increase in the demand for appointments played a crucial role in 2014 in Beirut where many Syrian refugees tried to get a visa. The German consulates observed that open slots were almost immediately taken and that there was a high proportion of no-shows for the booked appointments. The German Foreign Office implemented a number of changes, such as delaying the reopening of slots after their

Similar problems have been documented for appointments to obtain a driver's license at the Department of Motor Vehicles in some states in the United States.⁵ In Berlin, appointment slots at public offices were offered for money on a private website.⁶ In both instances, policymakers have tried to take legal action, but without success.

Appointments at public hospitals in China can be booked online, and the cost of service has to be paid at the moment of booking. Scalpers sell these appointments at prestigious hospitals for up to 50 times their face value.⁷ Thus, scalping can also be profitable when people pay for appointments if the price is not determined by supply and demand.

The allocation of appointment slots shares some similarities with, but also differs from, ticket markets for sporting events and concerts as well as air travel tickets. The organizers of sporting events and concerts often set prices below the market-clearing price out of fairness or image concerns, and thus face the challenge of resale markets and scalping. In contrast to these markets, the appointment slots have IDs attached to them, and scalping occurs despite this feature. We will show how our proposed booking system for appointments that are free of charge relates to but differs from solutions proposed for event ticketing (Bhave and Budish 2017, Leslie and Sorensen 2014, Courty 2019). Airline tickets for which scalping is not observed have IDs attached to them and are allocated through a first-come-first-served system. However, speed does not matter, since tickets are made available before the full demand is realized, and airlines do not make canceled tickets available for new customers at the old price.

We first study a typical online system for scheduling appointments. We present a model of the first-come-first-served ("immediate") system where slots can be booked instantaneously, and solve for an equilibrium in this system. We demonstrate that in equilibrium scalpers can profitably book and sell slots to appointment seekers under reasonable parameters of the first-come-first-served system.

We propose an alternative system that collects applications in real time, and randomly allocates the slots among applicants ("batch" system). The system works as follows: a set of slots (batch) is offered, and applications are collected over a certain time period, e.g., for one day. At the end of the day, all slots in the batch are allocated to the appointment seekers. Thus, the allocation is in batches, not immediate as in the first-come-first-served system. In the case of excess demand, a lottery decides who gets a slot. If a slot is canceled, this slot is added to the batch in the next

cancellation, increasing the number of slots, outsourcing the services to private firms, and allocating some slots via email. However, scalpers are still active. See also "Privatsache Visavergabe" from October 18, 2017.

⁵ Michael Cabanatuan, "DMV Investigates Startup That Has Disrupted Appointment Process," *San Francisco Chronicle*, <https://www.sfchronicle.com/bayarea/article/DMV-investigates-startup-that-has-disrupted-13064509.php> (accessed December 1, 2020).

⁶ Hannar Beitzer, "Für kostenlose Termine zahlen," *Süddeutsche Zeitung*, <https://www.sueddeutsche.de/panorama/berliner-buergeraemter-zahlen-fuer-kostenlose-termine-wegen-chaos-1.2581163> (accessed December 1, 2020).

⁷ Yang Wanli, "Top Medical Authority Says Appointment Scalpers Will Be Punished," *China Daily*, http://www.chinadaily.com.cn/china/2016-01/28/content_23281382.htm (accessed December 1, 2020); and Catherine Wong, "Ticket Scalpers Selling Hospital Appointments: Beijing Police Arrest 29 Members of Gang Using Official Booking Apps to Recruit Customers," *South China Morning Post*, <https://www.scmp.com/news/china/society/article/1928186/ticket-scalpers-selling-hospital-appointments-beijing-police> (accessed December 1, 2020).

allocation period, e.g., the following day. Thus, the scalper cannot transfer the slot from the fake name to the customer by way of cancellations and rebookings.

We show that under reasonable parameter restrictions, the scalper not entering the market is the unique equilibrium outcome of the batch system. The intuition for this result is that, keeping the booking behavior of the scalper fixed, a seeker has the same probability of getting a slot when buying from the scalper as when applying directly. Flooding the market with fake applications increases the probability that the scalper will receive many slots, but he cannot make sure that he gets slots for his clients, and he cannot transfer slots to the names of the clients. Thus, given the booking choice of the scalper, the seekers will always prefer to apply directly if the price for the scalper's service is positive.

The batch system has two important features relative to the immediate system: first, it eliminates the importance of speed, and second, it prevents the possibility of transferring the identity of the slots booked under fake names to the names of the clients through cancellations and rebookings. Both features are necessary to avoid scalping. To see this, consider two alternative systems where only one of the two features holds, respectively. First, if the scalper is faster than the seekers but cannot transfer the identity of slots, he can still profitably operate in the market if seekers ask the scalper to book slots on their behalf (as in our experiment and in the case of train tickets in India discussed in Section IIIC). Second, in a batch system where speed does not matter but bookings do not require identification, the scalper can flood the market with fake applications, is virtually guaranteed to receive all slots under fake names, and can sell the slots to seekers in a secondary market. This holds true for some ticket markets for sporting events and concerts (as discussed in Section IIIC).

The first feature of the batch system, namely eliminating the relevance of speed, parallels the proposal by Budish, Cramton, and Shim (2015) to replace continuous-time trading at financial exchanges with frequent batch auctions. Similar to Budish, Cramton, and Shim (2015), we show that an allocation system where speed determines the priorities creates an advantage for the scalper. In our setup, however, there is an additional drawback to speed: it makes ID verifications irrelevant, which is novel. While batch auctions transform competition on speed into competition on price, the batch booking system transforms competition on speed into equal access via lotteries. For equal access via lotteries to be effective, ID checks are needed: these checks are not necessary when an auction is used to eliminate scalping.

Based on a parameterized version of the model, we conducted a set of lab experiments. We find that the scalpers' choices in the experiment are in line with the theoretical predictions: scalpers only persistently and profitably enter the market in the immediate system when demand is high, i.e., when there are enough appointment seekers to cover the scalper's costs. Furthermore, in line with the theory, the experiments show that the proposed batch system does not allow the scalpers to make a profit, and that market entry is rare. Finally, the batch system leads to higher average welfare for the seekers than the immediate system, as predicted.

For the actual implementation of the proposed batch system, certain features of the design are crucial. We discuss these practicalities such as the length of the time interval in which applications for a batch of slots are possible in Section III. We also

discuss possible alternative measures to fight scalping and show that they do not preclude scalping under the first-come-first-served system or have other undesirable features. Finally, we discuss a range of other markets with scalping, such as train tickets, limited edition sneakers, and tickets for sporting events, and consider the potential usefulness of the batch system in these cases. The main takeaway is that the applicability of the batch system depends on whether identity checks can be implemented.

Related Literature.—The importance of speed in high-frequency trading has led to enormous investments in fast data connections around the world. This feature relates our contribution to a proposal for the redesign of financial exchanges by Budish, Cramton, and Shim (2015), as discussed above.⁸

Our paper speaks to the literature on the sale and resale of tickets for sporting events, concerts, popular restaurants, etc. Marketing tools introduced by the organizers of sporting events have blurred the difference between primary and secondary markets (for a survey, see Courty 2017). Courty (2019) proposes a centralized ticket exchange where fans can return tickets that are then randomly allocated to other fans.

Often, economists take the development of secondary markets as evidence of underpricing by the original seller and therefore suggest increasing prices or running auction-like mechanisms to prevent secondary market sellers from profiting. Auctions can be used for ticket sales to reduce arbitrage profits, as in Bhave and Budish (2017). Alternatively, random allocations of tickets priced below the market-clearing rate are used, for instance, for the soccer World Cup final, for Wimbledon, and for some baseball games in the MLB. More generally, Chakravarty and Kaplan (2013) show that lotteries can be an optimal allocation rule when no payments are collected.

Speed can be decisive in online auctions where sniping aims at minimizing the time between the bid and the end of the auction. While sniping can be addressed by endogenous or unknown auction closing times (Roth and Ockenfels 2002; Ockenfels and Roth 2006; Ariely, Ockenfels, and Roth 2005; Malaga et al. 2010), the scalping of appointments cannot be prevented by keeping the exact time of the release of new slots unknown. The software monitoring the booking websites all but guarantees that the scalper will get every available slot.

When there is no possibility of monetary transfers, the assignment of appointment slots is a house allocation problem studied in the matching literature (Shapley and Scarf 1974, Hylland and Zeckhauser, 1979, Abdulkadiroğlu and Sönmez 1998).⁹ The existing models cannot analyze the emergence of black markets, and we therefore present a new model. Finally, this paper is part of a growing experimental literature on matching markets surveyed by Roth (2016) and Hakimov and Kübler (2020), as well as experimental work on the role of market intermediaries for corruption and collusion, as in Cason (2000) and Drugov, Hamman, and Serra (2014).

⁸Relatedly, batch and serial processing of offers in decentralized labor markets are studied by Roth and Xing (1997), where batch processing helps to overcome congestion and thus improves market outcomes.

⁹Experiments on house allocation and random serial dictatorship have been conducted by Chen and Sönmez (2002); Guillen and Kesten (2012); and Hugh-Jones, Kurino, and Vanberg (2014).

I. The Model

We build a simple model of appointment allocation in the presence of scalpers, focusing on how design choices can reduce the profitability of scalping. The proofs of all results are in online Appendix Section A.

There are n (**appointment**) **seekers**, indexed by $i \in \{1, \dots, n\}$, who need a service from a central authority. The central authority meets the seekers face-to-face to provide the service, and offers m (**appointment**) **slots**. The m slots can be obtained by any agent, not only the seekers. We represent non-appointment-seeking agents by one firm, called the **scalper**.¹⁰

A **booking system** operated by a central authority is a procedure to allocate m slots to applicants. A system accepts applications with applicant IDs. **ID checks** are performed during the appointment, that is, the correct name and passport number have to be in the system. A seeker can submit at most one application for a slot with her ID, as the booking system can detect multiple entries of the same name. We assume that the scalper can costlessly create fake IDs that do not refer to any existing appointment seekers. He has to replace them with the IDs of seekers in order to sell the slots. The central authority cannot distinguish true seekers from fake seekers based on the application for a slot.

Each seeker i has a value of v_i of obtaining an appointment for any of the m slots. This value is the seeker's private information and is called her type. Each v_i is independently and identically distributed along some interval $[\underline{v}, \bar{v}]$ according to the commonly known distribution function F where $\underline{v} > 0$. We normalize the value of getting no slot to zero, and assume that F has a continuous density $f \equiv F'$ with full support.

There is a (**black**) **market** for scalping in which the scalper can enter or remain inactive. The entry cost is $c > 0$.¹¹ If the scalper decides to enter the market, he can submit as many applications to the booking system as he wants, up to Q . Here, Q represents the capacity constraint of the scalper to create fake applications. For analytical simplicity, we assume that Q is sufficiently large so that $Q > n$. In the market the scalper sets the monopoly price for the service of procuring a slot for a seeker. We denote by p the price paid by a seeker to the scalper. We assume that the set of feasible prices is a compact set included in the set of positive numbers, denoted by $\mathcal{P} \subseteq \mathbb{R}_{++}$.

Seekers observe the price and decide whether to buy a slot from the scalper. Under any booking system, if the scalper successfully secures a slot for a seeker, the seeker obtains the slot. If not, the scalper reimburses the seeker for the price she has paid. How slots are booked depends on which system is in place.

¹⁰We refer to the scalper by the male personal pronoun and to a seeker by the female personal pronoun.

¹¹We assume that the cost is fixed, and can be interpreted as an investment in the technology, i.e., the programming of bots that search for and book slots. In our model, the game lasts for one period. In reality, the scalper might be active for many periods if the cost for the scalping technology was paid once. However, the booking systems include captchas and other security features and are constantly updated. Thus, scalpers have to regularly invest in the software. Scalpers may also have to pay wages to persons who sell slots to customers, which is another source of costs accruing in every period.

Each seeker i 's payoff depends on her valuation and the price, as well as whether she obtains a slot:

$$\text{seeker } i\text{'s payoff} = \begin{cases} v_i & \text{if she obtains a slot directly,} \\ v_i - p & \text{if she buys a slot at price } p \text{ from the scalper,} \\ 0 & \text{if she does not obtain a slot.} \end{cases}$$

The scalper obtains no utility from an appointment slot, but can profit from selling slots to the seekers. His payoff from selling $m' \in \{0, \dots, m\}$ slots to the seekers is

$$\text{scalper's payoff} = \begin{cases} m'p - c & \text{if he sells } m' \text{ slots to seekers,} \\ 0 & \text{if he is not active.} \end{cases}$$

We assume that the seekers and the scalper are risk neutral.

Under any system, a seeker can either apply for a slot directly or buy the service of the scalper, not both. The former is called a **direct applicant**, while the latter is called a **buyer**. Let n_b be the number of buyers, and n_d be the number of direct applicants, such that $n_b + n_d = n$. The number of applications by the scalper is denoted by n_s where $n_s \leq Q$, and s is the number of slots secured by the scalper where $s \leq n_s$. The likelihood that the scalper gets s slots and the likelihood of a direct applicant getting a slot depends on the booking system in place.

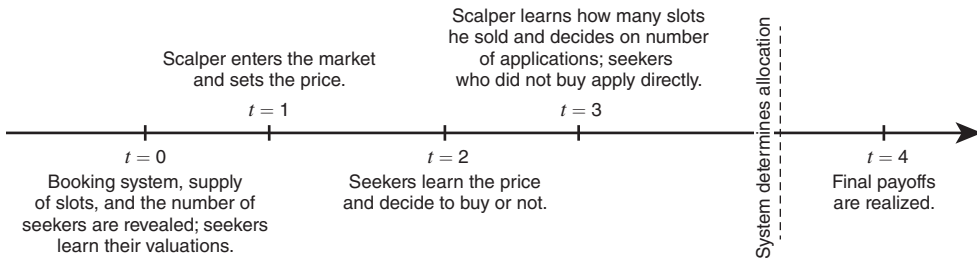
The timeline of the game under any booking system is summarized in Figure 1. Panel A shows the sequence of actions in case the scalper enters the market while panel B shows the sequence in case he does not. The timing of the game is as follows.

- In $t = 0$, seekers learn their valuations privately.
- In $t = 1$, the scalper chooses whether to enter the market, which is observable. If he enters, the scalper sets the price for a slot that is observable, and the game continues at $t = 2$ (panel A of Figure 1). If the scalper does not enter the market, the game continues at $t = 3$ (panel B of Figure 1).
- In $t = 2$, if the scalper has entered the market, the seekers simultaneously decide whether to buy a slot from the scalper or apply for slots directly through the booking system. The number of buyers is observable for the scalper.
- In $t = 3$, if the scalper has entered the market, he chooses the number of applications n_s up to capacity Q for the booking system. Those seekers who did not buy the scalper's service apply directly to the booking system. The number of such seekers is denoted by n_d . If the scalper did not enter, all seekers apply for slots directly, and thus $n_d = n$ and $n_s = s = 0$.
- In $t = 4$, the booking system is run and payoffs are realized.

The order of moves regarding the booking of slots by the scalper and the buying decisions of seekers is not crucial for our main results, and we discuss the consequences of changing the order for each booking system in what follows.

The strategy of the scalper determines whether he enters the market and at which price he offers the slots. It also determines the number of his applications for each combination of price p and number of buyers n_b . Every seeker observes the scalper's decision regarding entry and price, and then decides whether to buy from the scalper or to apply for a slot directly.

Panel A. Timeline if scalper enters the market



Panel B. Timeline if scalper does not enter the market

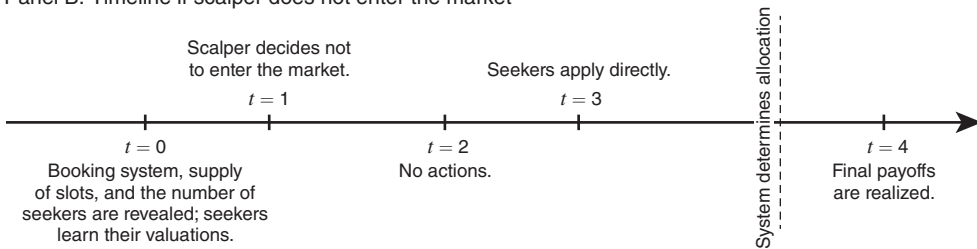


FIGURE 1. THE TIMELINE OF THE GAME

We will solve for a symmetric Bayesian Nash equilibrium, or a symmetric equilibrium in which all seekers use a symmetric strategy, i.e., a strategy that depends only on types and prices, not on the names of seekers.

A. Immediate Booking System

The **immediate system** models a first-come-first-served online booking system. In such a system, an application is only observable for the designer if it results in the booking of a slot. Thus, the maximum number of observable applications is m , i.e., $n_s + n_d \leq m$.¹² The scalper has a technological advantage over the seekers in the sense that he can secure himself any number of slots up to the total supply with the help of bots, $s = n_s \leq m$. Importantly, the scalper can transfer these slots to seekers who must pay for his service. This is possible by canceling the slot with the fake ID and then immediately rebooking it under the name of the seeker.¹³

For the sake of simplicity, we model the possibility of cancellations and rebookings by having the scalper book the slots after he knows the demand of seekers (including their IDs). This modeling assumption makes cancellations and rebookings unnecessary since the scalper knows which seekers are buying from him in a given period. At the same time, unlike in the real world when seekers observe that there is no

¹²This does not preclude a situation of excess demand. However, seekers who do not get a slot directly or through the scalper cannot be observed.

¹³Note that even if the canceled slots are freed up with a delay, a policy that has been adopted by the German consulates to deter scalping, the scalper will be faster than the seekers in booking them once they appear in the system. Moreover, the scalper knows for sure that the slot will be offered at some point, early enough for rebooking, since otherwise the canceled slot is wasted.

possibility of getting a slot except through the scalper, under our modeling assumption appointment seekers need to decide whether to buy before observing the scalper's actions. Hence, they have to anticipate that the scalper will book all the slots.¹⁴

After the scalper has made his bookings, all remaining slots are assigned to the direct applicants if there are enough slots available. Otherwise, the remaining slots are randomly assigned to them. More formally, the assignment is determined as follows: if the number of buyers is smaller than or equal to the number of slots secured by the scalper, i.e., $n_b \leq s$, each buyer will get a slot for sure and $(s - n_b)$ slots lead to no-shows; otherwise (if $n_b > s$), s slots are randomly distributed to n_b buyers such that each gets a slot with probability s/n_b . The residual supply of $m - n_s$ slots is distributed randomly among the direct applicants. Thus, each direct applicant gets a slot with a probability of $(m - n_s)/n_d$. Any remaining open slots are freely disposed of.

PROPOSITION 1 (Equilibrium in the Immediate System): *Let p^* be the price that maximizes the profit of the scalper $\Pi(p)$. In the immediate booking system, there exists a symmetric equilibrium where on the equilibrium path the following occurs.¹⁵*

- (i) *If $\Pi(p^*) \geq 0$, the scalper enters the market, sets price p^* , and makes m applications. Moreover, each seeker follows the symmetric strategy in which a type above p^* buys the service from the scalper, and a type below p^* applies directly and receives a slot with zero probability.*
- (ii) *If $\Pi(p^*) < 0$, the scalper does not enter the market, and all seekers apply directly.*

In the equilibrium of the immediate system, the scalper enters the market if the entry cost is not too high. If the scalper enters, he will book all slots. Then, the only possibility for seekers to get a slot is to buy it from the scalper.

Example.—Consider a market with 20 seekers competing for 15 slots. The valuations of the seekers are uniformly distributed on the interval $[10,100]$. The entry cost is 100. In equilibrium, the scalper enters the market with the profit-maximizing price of 51 where prices are restricted to be integers. All seekers with valuations above 51 buy his service. The scalper books all 15 slots with an expected profit of 454. The expected number of slots sold is 10.9, which implies that, on average, 4.1 slots remain unassigned, leading to no-shows despite excess demand.

While the overall welfare of the booking system is not our main interest, we can distinguish three effects of scalping on welfare in the immediate system. (i) The entry cost for the scalper creates a deadweight loss. (ii) If there are more seekers

¹⁴When the order of moves is reversed (i.e., the scalper books first, and the seekers then observe the remaining slots and decide whether to buy), it is equally straightforward for a scalper to make a profit. This does not require scalpers to be able to cancel and rebook slots under different names, as shown by the example in Section IIIC.

¹⁵The scalper's profit is given as

$$\Pi(p) = \begin{cases} \sum_{k=0}^m \binom{n}{k} F^{n-k}(p) (1 - F(p))^k pk - c & \text{if } m \geq n, \\ \sum_{k=0}^m \binom{n}{k} F^{n-k}(p) (1 - F(p))^k pk + \sum_{k=m+1}^n \binom{n}{k} F^{n-k}(p) (1 - F(p))^k pm - c & \text{if } m < n. \end{cases}$$

than slots, the presence of the scalper may improve the allocative efficiency. The reason is that without the scalper, the slots are allocated randomly to seekers, irrespective of their valuation. If the scalper is active, only seekers with a high valuation will obtain slots. (iii) The price charged by the scalper creates inefficiencies due to slots being wasted if there are fewer seekers with a valuation above the price than available slots.

B. Batch Booking System

We propose the **batch booking system** as an alternative to the immediate system. Under the batch system, the central authority collects and pools applications with IDs during a certain *time interval*. At the end of the interval, the m slots are allocated randomly to the applicants. The number of applications is not constrained by the supply of slots, since the allocation of slots takes place after the period of collecting applications. The batch system eliminates the importance of speed, since the random allocation gives every applicant the same chance independent of when she applied within the given time interval. Thus, the scalper has no technological advantage relative to the seeker, except that he can submit Q applications, while seekers can submit only one. All canceled slots are allocated in the next or later batches.

Although the allocation of slots in the batch system takes place over a time interval, modeling the dimension of time would complicate the analysis with little additional insight. For simplicity, we model the batch system as a static assignment. The assignment by the batch system is determined in one of the following two cases:

(i) The total number of applications does not exceed the number of slots, i.e., $n_d + n_s \leq m$. The scalper obtains a slot for each of his applications, $n_s = s \leq m$. Also, each direct applicant gets a slot. If $n_b \leq n_s$, n_b slots go to the buyers, and the remaining slots of the scalper ($n_s - n_b$) are assigned to fake IDs and lead to no-shows. If $n_b > n_s$, the s slots are assigned to the buyers whose applications were submitted by the scalper. Thus, each buyer gets a slot with probability n_s/n_b .

(ii) The total number of applications exceeds the number of slots, i.e., $n_d + n_s > m$. The m slots are randomly allocated to applicants with real or fake IDs. Each buyer, fake ID, and direct applicant get a slot with probability $m/(n_d + n_s)$.

In the immediate system, the scalper can secure up to m slots for the buyers, which allows him to preempt the direct applicants completely. By contrast, in the batch system the scalper cannot secure slots for the buyers with certainty. While he is almost certain to get the full supply of slots by submitting a large number of applications with both fake and real IDs, he cannot transfer slots with fake IDs to the buyers because canceled slots are reallocated only in the next period where the scalper would again face competition from seekers who apply directly. Thus, submitting more applications than n_b reduces the likelihood that he can get slots for his clients, while submitting fewer applications than n_b reduces his profit. We conclude that the scalper makes n_b applications when observing n_b (≥ 0) buyers.

Another characteristic of the batch system is that given such optimal behavior of the scalper, a seeker has the same probability of getting a slot from buying as from

applying directly.¹⁶ Thus, since buying a slot is costly for the seeker, she always prefers to apply directly. The main properties of the batch system are summarized in Proposition 2.

PROPOSITION 2 (Equilibrium in the Batch System): *In the batch booking system, there exists a symmetric equilibrium where the scalper does not enter the market on the equilibrium path.*

In particular, the scalper not being active is a unique equilibrium outcome if $R < c$, where R is an upper bound of the expected revenue, defined as follows:

$$R = \sum_{k=1}^n \binom{n}{k} \left(\frac{2n-k-1}{2n-1} \right)^{2n-k-1} \left(\frac{k}{2n-1} \right)^k \frac{\max\{n-1, m\}}{n} k\bar{v}.$$

Just as in the immediate system, the order of moves is not crucial for this result. In the batch system, the seekers and the scalper essentially move simultaneously.

The condition of uniqueness of the equilibrium outcome is rather mild and likely to be satisfied in many settings. Online Appendix Figure A.1 presents the graph of the function R depending on n for $\bar{v} = 1$. The revenues of the scalper never exceed 0.55. Thus, whenever the entry cost of the scalper is higher than 55 percent of the highest valuation, not entering the market is the unique equilibrium outcome.

When $R > c$, there may exist another equilibrium under the batch system in which the scalper enters the market by threatening to flood the market with applications in the case of zero buyers. We describe it in Proposition 3 in the online Appendix. The risk posed by this equilibrium to the authority fighting scalping is limited, since only a few seekers with high valuations buy from the scalper while most seekers receive a slot through direct applications. This is in contrast to the equilibrium under the immediate system where seekers can only get a slot through the scalper if he is active. Moreover, we believe that it is difficult for the scalper's threat to flood the market to be effective. Since all applications are accepted in the batch system, the seekers can always apply for slots, and even if they do not get a slot in one batch, they can try again in the next. Thus, they cannot observe the scalper's activity. This is in contrast with the immediate system where the seekers observe that no slots can be booked, and therefore seek the scalper's service.

Example.—Consider again a market with 20 seekers competing for 15 slots, the valuations of the seekers uniformly distributed on the interval $[10, 100]$, and the entry cost of 100. The unique equilibrium outcome prescribes that the scalper does not enter the market. To see this, note that the condition for a unique equilibrium is satisfied with $c = 100 > 0.55 \cdot 100 = 0.55\bar{v}$.

¹⁶See Lemma 4 in the online Appendix for the scalper's behavior. To see the equal probabilities of a seeker, say, for the excess demand case ($m < n$), let \hat{n}_b and \hat{n}_d be the number of buyers among the other seekers. If she applies directly, the probability is $m/((\hat{n}_d + 1) + \hat{n}_b)$; if she buys, it is $m/(\hat{n}_d + (\hat{n}_b + 1))$. See Lemma 5 in the online Appendix for a complete analysis.

II. Experiment

We conducted an experiment that serves as a testbed of the proposed batch system. We also study the immediate system to understand the conditions under which scalpers can profitably enter the market. The experiment allows us to compare the observed strategies and outcomes to the equilibrium predictions in a tightly controlled environment.

A. Treatments and Procedures

There are four slots to be allocated in every round, $m = 4$. Of the five seekers in each market, three are active in every round, while the other two are active in only half of the rounds, thus $n = 3$ or $n = 5$ depending on the round. This design allows us to vary the demand for slots between rounds.

At the beginning of each round, every participant is informed about her valuation v for a slot, drawn from the uniform distribution over the interval between 50 and 100. Each participant has an ID, which is assigned anew in every round to ensure anonymity of the feedback across rounds. The ID allows us to identify seekers and assign slots to them. Every seeker can receive at most one slot per round. There is one scalper in every round who can enter the market. The scalper has a value of zero for the slots, but he can book slots and sell them to the seekers.

The slots are allocated through either the immediate or the batch system. Each round consists of two steps. Step 1 is the same for both booking systems while step 2 differs between them.

In Step 1.—At the beginning of each round the participants are informed of the booking system that is in place as well as of the number of active seekers in the round (three or five). Each seeker's valuation for a slot is drawn randomly from the interval $[50, 100]$. Each seeker is informed of her own valuation, but the scalper does not know the valuations. The scalper decides whether to enter the market. Entering the market entails a fixed cost of 150 points for the scalper, $c = 150$. If the scalper enters, he sets the price p that is paid by the seeker if the scalper provides a slot. The scalper has a choice between the following prices: 15, 20, 25, . . . , 75, 80, or 85. Each seeker decides whether she wants to pay for the scalper's service at the price or whether she wants to apply directly, i.e., without the scalper.

Step 2.—Differs between the two booking systems.

Immediate System: In step 2, when the scalper enters the market, he learns how many seekers have bought his service. He can book as many slots as he wants for free. If the scalper sold a slot to a seeker in step 1, the system assigns him a slot for the ID of this seeker.

Batch System: In step 2, if the scalper is active in the market (that is, he entered the market in step 1 at a cost of 150 points), the scalper learns how many seekers bought his service. He can then submit as many applications for slots as he wants

for free. The scalper enters the IDs of the seekers who decided to apply through him in step 1.¹⁷

We implemented a 2×2 within-subjects design by varying the demand and the booking system. Before each block of five rounds, the booking system (immediate or batch) and the demand for appointments (three or five seekers) are announced. Both dimensions remain constant for five rounds. We refer to the treatments with the immediate booking system with five and three seekers as Im5 and Im3, and the treatments with the batch booking system with five and three seekers as Batch5 and Batch3. The five-round block design allows the scalper to develop a reputation, and the seekers to adjust to the behavior of the scalper and of the other seekers. By changing the ID of the seekers in every round, we attempt to capture the situation where new seekers enter the market in every round while the scalper remains active in multiple periods. Overall, each session of the experiment consisted of 40 independent decisions, i.e., 40 rounds.

Online Appendix Table C.1 presents the order of treatments by rounds. Each treatment was implemented twice, such that we can look at mature behavior in the second block of five rounds after subjects have already experienced all four treatments. The order of the treatments was chosen so as to first allow scalpers to make a profit in the immediate system with five seekers (see the equilibrium predictions below). Then, the treatments follow where the scalper should make no profit by entering the market. This allows us to study our main research question, namely whether a change in the booking system from immediate to batch will reduce the amount of scalping.

Payoffs.—Each seeker has an endowment of 220 points at the beginning of each five-round block. Within the course of the five rounds of a block, points are added to and deducted from this endowment. If active, a seeker earns her valuation minus the price if she receives a slot through the scalper. If the seeker receives a slot without the scalper, she simply earns her valuation without paying anything. If the seeker does not receive a slot, either with or without the scalper, her payoff is zero in this round, and her endowment is unchanged. Every seeker who is not active in a block of five rounds with low demand receives the equilibrium payoff of the active seekers in this round. This limits potential differences between subjects that are due to income effects.

The scalper has an endowment of 750 points at the beginning of each five-round block, and points are added and deducted to this endowment over the course of the five rounds. If the scalper enters the market, he pays 150 points, and he receives the price times the number of slots sold. Note that the 750-point endowment allows the scalper to enter the market in every round, even if he does not sell any slots. Thus, we chose a budget that does not constrain the scalper's choices. If the scalper decides not to enter the market in one of the rounds, his endowment is unchanged in this round.

¹⁷The details of the immediate and batch system implemented in the experiments can be found in online Appendix Section C.2.

After every round, all participants received feedback about the allocation of slots: a slot can be vacant, allocated to a seeker directly, allocated to a seeker through the scalper, or allocated to a fake ID.

At the end of the experiment, one block was randomly drawn and the final earnings of this block were paid out in euros. The exchange rate was 1 point = 2 cents. The experiment lasted, on average, around 100 minutes, and the average payoff was EUR 14.73, including a show-up fee of EUR 5.

The experimental sessions were run at the WZB TU lab at the Technical University Berlin. We recruited subjects from our pool with the help of ORSEE by Greiner (2015). The experiments were programmed in z-Tree (Fischbacher 2007). We conducted 10 sessions, with 24 subjects each. Thus, we end up with 40 independent matching groups. The data from the experiment and the replication code are available in Hakimov et al. (2021).

At the beginning of the experiment, printed instructions were given to the subjects (see online Appendix Section C). Participants were informed that the experiment was about the study of decision-making, and their payoff depended on their decisions and the decisions of other participants. The instructions explained the details of the experiment and were identical for all subjects. Questions were asked and answered in private. After reading the instructions, all subjects participated in a quiz to make sure they understood the main features of the experiment.

B. Predictions

The four treatments differ with respect to the predicted entry of the scalper, the predicted price of a slot, and the number of slots sold. This results in different profits for the scalper and payoffs for the seekers.¹⁸ The only treatment where the equilibrium predicts positive expected profits for the scalper is Im5, where the scalper chooses the profit-maximizing price of 60, leading to less than four slots being allocated in equilibrium. In Im3, the scalper can at most break even in equilibrium due to the lower demand. He charges a price of 50 to guarantee that all three seekers are willing to buy a slot which just covers the entry cost of 150. In Batch3 and Batch5, the scalper does not enter the market in equilibrium.

We use the stage-game predictions, although subjects play the game for five rounds changing the ID numbers of the seekers between rounds to capture that scalpers are longer-lived than seekers. The repetition can generate multiple equilibria, but playing the stage game Nash equilibrium in every round is a Nash equilibrium of the repeated game.

C. Experimental Results

The main questions addressed by the experiment are whether scalping is profitable and scalpers enter the market. We also summarize the main findings regarding the seekers' choices. All results reported are significant at the 5 percent level if not

¹⁸ Online Appendix Table C.2 presents a summary of the equilibrium predictions of the stage game by treatments.

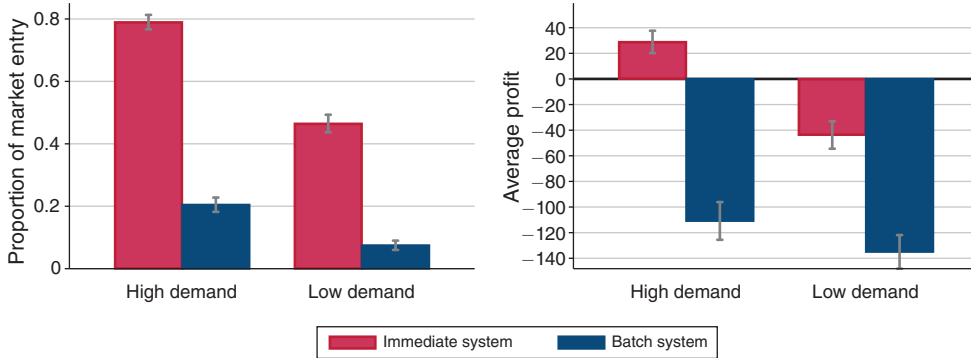


FIGURE 2. PROPORTION OF MARKET ENTRY BY SCALPERS (LEFT) AND AVERAGE PROFITS (RIGHT)

Notes: Gray bars represent 95 percent confidence intervals. High demand stands for five seekers (Im5 and Batch5) while low demand for three seekers (Im3 and Batch3). The figure is based on all decisions in the second block.

stated otherwise. For all results, we focus on the second block (i.e., the last five rounds) of each treatment.

The batch system was designed to remove the incentives of scalpers to enter the market, book slots, and sell them to the seekers. We therefore begin by investigating the entry decisions of scalpers across treatments. The left panel of Figure 2 shows the average proportions of scalpers entering the market in the second block of each treatment. The highest proportion of scalpers in the market is observed in Im5, amounting to 79 percent, on average, for the last five rounds of the treatment. This is qualitatively in line with the equilibrium prediction, according to which scalpers enter the market. In the equilibrium with low demand (Im3), the scalpers are indifferent between entering and not entering the market as the expected profit is zero. We observe, on average, 47 percent of market entry by scalpers. This proportion is significantly lower than in Im5. For the treatments with the batch system, the equilibrium predicts that scalpers do not enter the market, independent of whether demand is high or low. We find 20.5 percent of market entry by scalpers in Batch5 and 7.5 percent in Batch3 in the last five rounds of the treatment. This is significantly lower than in Im5 and Im3.¹⁹

We sum up the findings as follows.

RESULT 1 (Market Entry): *The proportion of market entry by scalpers is highest in Im5, followed by Im3, while entry is lowest in Batch5 and Batch3.*

Are the scalpers' entry decisions optimal? To answer this question, we turn to the analysis of the scalpers' profits. The right panel of Figure 2 shows the average profits conditional on entering the market for each treatment. Only treatment Im5 leads to positive average profits for the active scalpers both in theory and in the data. However, the realized profits are lower than predicted: equilibrium profits are

¹⁹ All pairwise comparisons of the proportion of market entry by scalpers in the last five rounds of each treatment show significant differences ($p < 0.01$). For the tests, we use the p -values for the coefficient of the dummy of interest in the probit regression on the dummy for entering the market. Standard errors are clustered at the level of matching groups and the sample is restricted to the treatments that are relevant to the test.

70.34 while average profits are 22.8, with 36.5 in the last round of the treatment. Similarly, in Im3 profits are lower than the predicted equilibrium profits of zero. Turning to the profits of the scalpers in the batch system, the scalpers do not enter the market in equilibrium, and thus equilibrium profits are zero. As shown by Figure 2, we observe negative profits, conditional on entering the market.

Regarding the booking decisions of scalpers, in Im5 and Im3 scalpers booked the entire supply of four slots in 91 percent and 87 percent of cases, respectively, after entering the market. This behavior is close to the equilibrium prediction of 100 percent. In Batch5 and Batch3, the scalpers do not enter the market in 89 percent and 66 percent of all cases, respectively, as predicted in equilibrium, and therefore do not make any booking decisions. Conditional on out-of-equilibrium entry in the batch system, scalpers try to block the system by submitting 10 or more applications in 33 percent and 30 percent of cases in Batch5 and Batch3, respectively. This points to the attempts of scalpers to block the market, but it is not profitable.

The main findings can be summarized as follows.

RESULT 2 (Profits and Booking Decisions of Scalpers): *Scalpers earn positive profits only in Im5. In the immediate system, in almost 90 percent of cases after equilibrium entry, the scalpers book all four slots, which is the equilibrium booking strategy. In the batch system, the majority of scalpers do not enter the market, as predicted in equilibrium, and therefore do not take any booking decisions.*

Appointment Seekers.—We next study the welfare of seekers and the total number of slots allocated to them. For detailed analyses of the seekers' behavior, we refer the reader to online Appendix Section C.5. First, we consider the seekers' decisions to buy the service from the scalper. Then, we study the welfare of appointment seekers and the total number of slots allocated.

Figure 3 shows the average payoffs of seekers by treatments. As predicted, the batch system leads to significantly higher payoffs for seekers than the immediate system, and seekers fare worst in Im5. All pairwise comparisons of treatments with different booking systems with the same demand yield significant differences ($p < 0.01$).²⁰

Regarding absolute levels, the observed average payoffs of seekers are 55 and 73 in Batch3 and Batch5, compared to the prediction of 60 and 75 respectively. Thus, in the batch system the payoffs of the seekers are slightly below the equilibrium payoffs. In Im3 and Im5, the observed payoffs of the seekers are higher than in equilibrium, namely 30 instead of 15 in Im5 and 51 instead of 25 in Im3. These deviations from the equilibrium are due to excessive entry of scalpers in treatments with the batch system, and too little entry in the immediate system.

Summing up, Result 3 states that in line with the equilibrium predictions, a designer who cares about the utility of seekers should implement the batch system.

RESULT 3 (Payoffs of Appointment Seekers): *The average payoffs of appointment seekers are higher in the batch than in the immediate system for a given demand.*

²⁰The p -values are computed for the coefficients of the dummies of interest in an OLS regression of the seekers' payoffs; standard errors are clustered at the level of matching groups, and the sample is restricted to treatments of interest for the test.

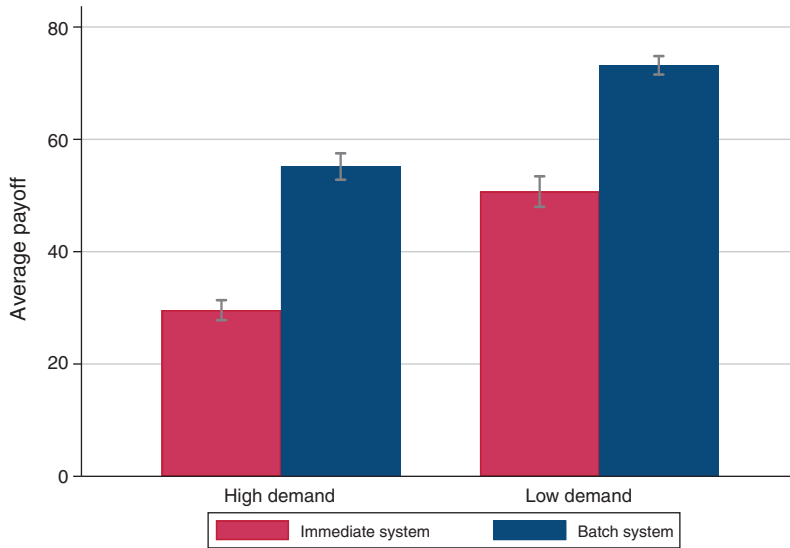


FIGURE 3. AVERAGE PAYOFFS OF SEEKERS

Notes: Gray bars represent 95 percent confidence intervals. High demand stands for five seekers (Im5 and Batch5) while low demand for three seekers (Im3 and Batch3). The figure is based on the second block.

A potential source of welfare loss are slots that are wasted due to scalping. We compare the number of slots allocated to seekers by treatments. With high demand, the proportion of slots allocated to seekers is almost identical in both booking systems at around 90 percent. With low demand, it is significantly higher in the batch system than in the immediate system. For further details on the allocation of slots, see online Appendix Section C.7.1, and for details on the valuations of the seekers who receive a slot, see Section C.7.2.

III. Practical Challenges, Alternative Solutions, and Other Markets with Scalping

In this section, we discuss design features of the batch system that are not part of the model but are important for its implementation. Moreover, we discuss alternative solutions for the problem of scalping under first-come-first-served booking systems and the applicability of the batch system to other markets with scalping.

A. Practicalities of the Batch System

The theoretical model shows that the batch system makes scalping unprofitable, and the experiments support this prediction. To make the batch system work as predicted, however, the designer has to carefully choose some additional design parameters. Our model is static and therefore agnostic about essential details that can influence the practical success of the batch system. We have abstracted from the seekers' preferences over slots, including the issue of when these preferences arise.

Length of the Time Interval of Each Batch.—The designer faces a trade-off when choosing the time interval of a batch.

- Seekers need to have enough time to apply for slots. Sufficiently long time intervals ensure that the scalper cannot book all the slots offered with certainty, e.g., because seekers do not notice that a new batch is available. Thus, sufficiently long time intervals ensure that the scalper faces competition from seekers' direct applications for every batch. For instance, long time intervals prevent the scalper from flooding the market with applications for fake IDs for one batch and using a later batch with no competition from seekers to cancel these slots booked for fake IDs and transfer them to their clients' IDs. Note that in the extreme case when the length of the interval is very short, the batch system is essentially equivalent to the immediate system.
- Seekers want to learn as soon as possible whether they received a slot, and when the appointment will take place. Short time intervals during which applications are collected guarantee this while long time intervals mean that uncertainty regarding the allocation of slots is resolved only after a considerable period of time. Moreover, long time intervals can make it impossible to reallocate canceled slots when the appointments take place before the end of the next allocation procedure. This can lead to welfare losses.

What is the right length of the time interval for a batch? The answer will depend on the context. In many cases, it seems reasonable to start with a one-day time interval. It is long enough to make regular monitoring of the system by the seekers not too costly and short enough for seekers to learn about the outcome relatively quickly and make plans.

We suggest monitoring the system of one-day time intervals and looking for signs of scalping. If the designer observes a high volatility of the probability to obtain a slot, the time interval should be extended to give seekers a better chance of applying. However, if the probability of receiving a slot is constant between batches, the designer may shorten the interval to increase the convenience of the system for the seekers.

As a complementary measure, to make the batch system more convenient for seekers and less likely to be profitable for scalpers, the designer can provide the seekers with the option of automatic reapplications for the next batch if their previous application was unsuccessful. If a seeker opts for this, her application will remain in the system until she receives a slot. This can help to ensure that there are direct applications for every batch, thereby decreasing the opportunity for scalpers to book slots. Depending on the exact context, this could also be the default choice for all seekers. In this case, the length of the time period of each batch is not essential, since there is one set of seekers for all batches. This set would change over time with arrivals of new applicants and departures of those who received a slot. The only design choice would then be the frequency in which batches are allocated to best accommodate the seekers' needs, but this choice would not affect the profitability of scalping.

Time at Which Canceled Slots Become Available for Rebooking.—The model does not specify the exact timing of when canceled slots should reappear in the system. To avoid the potential welfare loss of slots that are not used, the designer should make the canceled slots available immediately after their cancellation in the next batch. Slots that are canceled late, namely after the last batch was allocated before the appointment, will be wasted, however. It is crucial to commit to not allocating them in the last moment, since this would reintroduce an advantage of speed and incentives for scalping.

Accommodation of Preferences over Slots.—In our theoretical analysis, we abstract from the fact that seekers might have preferences over specific slots. The immediate booking system makes it convenient to choose among slots. The batch system can also accommodate preferences if seekers submit rank-order lists of the different slots with their application. Instead of a random lottery assigning the slots, the random serial dictatorship mechanism can be employed. A lottery then determines the priority of applicants, such that the first person in the order receives her highest-ranked slot, the second in the order receives the highest-ranked slots among those that are still available, and so on.

Time Interval between the Date of the Slot and the First Possibility to Book the Slot.—One important feature of every booking system is how long in advance the slots can be booked. A short time interval between the batch being offered and the date of the slots helps those seekers who realize their demand for appointments on short notice. The benefit of a long time interval is that there are many batches in which slots can be reallocated in the case of cancellations. In our model, we assume that seekers know their demand for slots when booking becomes possible, but this is unrealistic when slots are offered very far in the future. For example, if there is excess demand for slots and slots are allocated three months in advance, this would require seekers to make long-term plans, and short-term needs could not be accommodated. Also, seekers might have an incentive to apply for a slot despite being uncertain whether they will need it. This can lead to welfare losses when such seekers frequently cancel a slot or do not show up. For these reasons, it can be useful to bundle slots arriving soon and slots arriving in the future in the batches to accommodate the different needs. Note that the choice of the time interval does not affect the potential vulnerability of the batch system for scalping but should be chosen to best accommodate the needs of the seekers in the relevant context. For instance, slots at consulates can often be booked three months in advance, since the trips for which the visa are required are usually planned in advance. On the other hand, table reservations in restaurants are often made available on short notice.

B. Alternative Solutions

One possible alternative to fight scalping is to require a booking deposit, i.e., a small payment which is refunded when an applicant shows up at her appointment. We have modeled this policy and characterize the equilibria under the two booking systems with a deposit in online Appendix Section B in Propositions 4 and 5. While this policy restricts the set of parameters where scalping is profitable in equilibrium

in the immediate system, it does not preclude scalping with an excess demand for slots. In the batch system, the scalper's non-entry is the unique equilibrium outcome for all parameter values. Thus, the introduction of a deposit does not solve the problem of scalping in the first-come-first-served system, but makes scalping even less profitable in the batch system.

A second possible remedy is the introduction of a cancellation fee. In the immediate system, when the slots are first booked under fake names and then rebooked under clients' names, the cancellation fee is incurred at the moment of rebooking. Thus, from a modeling perspective, the cancellation fee is equivalent to a deposit, and Propositions 4 and 5 hold (see online Appendix Section B). Moreover, the scalper can operate in the immediate system without making use of cancellations, as demonstrated by our experiment and the case of train tickets in India (see Section IIIC). Under the batch system, a cancellation fee does not affect the equilibrium, since there are no cancellations. This is due to the inability of the scalper to transfer canceled slots to other applicants.

A third possible solution is to provide canceled slots to seekers forming a physical line instead of making the slots available online. This can prevent the immediate rebooking of canceled slots by the scalper under the names of his customers. But note again that scalping in the immediate system does not require cancellations and rebookings, as in the Indian Taktal train ticketing scheme. Even when rebookings are necessary for profitable scalping, allowing for lines at the public office defeats the purpose of using an online booking system. Lines in front of public offices essentially create another first-come-first-served system.

Another potential solution is tighter control of the booking process itself, e.g., by introducing ex post verification of the allocation to cancel suspicious applications such as multiple applications made within a second, or by requiring pre-registration as a "verified user." These measures are often observed on sport ticket platforms. While the measures may render scalping slightly more complicated, the scalper still has the advantage of speed relative to the seekers. Thus, some seekers with a high valuation may prefer to pay the scalper and provide him with the registration information for a higher chance of getting a slot relative to applying directly (see again the example of train tickets in Section IIIC).

Finally, a simple wait list could be employed instead of the first-come-first-served system. Seekers put their name on a wait list or in a virtual queue and are assigned a slot once it is their turn. Applicants will be on the wait list for some time and will only be assigned a slot once they have moved up on the list. Typically, the slot assignment happens shortly before the actual appointment, and not far in advance. This is due to the possibility of cancellations that need to be accommodated. If a seeker cancels her slot, all seekers on the wait list are moved upwards. This uncertainty regarding the exact date and time of obtaining a slot can be a disadvantage when seekers have to travel a considerable distance for their appointments. Moreover, a waitlist system can suffer from appointment seekers hoarding slots where people put their names on the wait list even if they do not need an appointment but expect that this need may arise in the future. Finally, it is not clear whether the scalper can make profits in equilibrium. While the speed of bookings does not matter since the waitlist is always open, the scalper could offer to shorten the waiting time for seekers by canceling

appointments with fake IDs that he put on the wait list before. We leave a rigorous analysis of waitlists for future research.²¹

Increasing the supply of slots has been suggested as another remedy for scalping. However, our model shows that scalping can be profitable without excess demand. It is enough that the number of seekers and their valuations are sufficient to cover the scalper's costs. Another problem is that the true demand is not easy to gauge in the immediate system, since applicants who do not receive a slot are not observed. It is an advantage of the batch system that the market designer can observe the entire demand for slots, and can adjust the supply if possible.

We believe that our proposed solution is simple and straightforward to implement. While the small delay (e.g., one day) before finding out the result of an application can carry a cost, the costs of alternative systems seem much higher. Most importantly, unlike all alternative solutions discussed above, the batch system, just as the immediate system, features online bookings, appointments scheduled at a predetermined time with no physical lines, and no payments.

C. Other Markets with Scalping

In this subsection, we discuss other markets that are prone to scalping. We also consider whether our solution is suitable for these markets.

Tickets for Major Sporting Events (Olympic Games, FIFA World Cup, etc.).—Sporting events and concerts have been the object of scalpers for a long time. Tickets for such events are often sold out within the first minutes of being on sale, and are offered on the black market for a higher price shortly after. Using bots to buy large numbers of tickets is profitable because prices are set below the market-clearing price.²² Artists and ticket platforms make attempts to fight scalping, e.g., by offering tickets to official fans only, but the estimated profit of the resale business is eight billion dollars per year in the United States alone.²³ Governments have even introduced anti-scalping legislation: the Better Online Tickets Sales Act, also known as the BOTS Act, was passed by the US Congress in 2016. It outlaws using bots or other technology for obtaining tickets via online systems to resell them on the secondary market. However, for the allocation of tickets for the 2018 World Cup, FIFA collected applications for tickets for each match and category, and in the case of overdemand for a specific match and price category, a lottery decided who received the tickets. Scalping was still observed, since people without a matching ticket and fan ID were allowed to enter the stadium. Without ID verification, the scalper's strategy of buying many tickets with fake IDs is successful, since he pays less than the market price and sells the tickets without any constraints later on.

²¹ An example is the waitlist for apartments in Stockholm where the waiting time has reached 20 years, and newborn children are put on the waitlist by their parents well before they need housing. See Maddy Savage, "This Is One City Where You'll Never Find a Home," *BBC*, <https://www.bbc.com/worklife/article/20160517-this-is-one-city-where-youll-never-find-a-home>, (accessed July 15, 2019).

²² For an analysis of these markets, see Courty (2017) and Leslie and Sorensen (2014). Courty (2019) studies the design of resale platforms with ID verification as a potential solution to scalping.

²³ See Adrienne Green, "Adele versus the Scalpers," *The Atlantic*, <https://www.theatlantic.com/business/archive/2015/12/adele-scalpers/421362/> (accessed December 1, 2020).

ID verifications are not costly in the case of appointments at public offices, but they can be much harder to implement for sporting events and concerts. While organizers of such events commonly state that ID verification will be used, in reality they tend to shy away from imposing it. ID checks require additional personnel at the entrance of stadiums, though this has become easier due to scanners and related technologies.²⁴ Another barrier to ID verification is the desire to fill the stadium, since this is important for the success of the event, and also for broadcast revenues. One can observe scalpers and people leaving messages on Internet forums trying to convince buyers that there will be no ID verifications required. A potential solution could be to check the IDs of a small number of people at random and to commit to refusing entry to those whose ID does not match their ticket. The effectiveness of such a system depends on many parameters, and we leave its exploration for future research.

To sum up, the evidence from large-scale sporting events demonstrates that the batch system is not successful without ID verification, which is in line with our theory.

Limited Editions of Sneakers and Other Consumer Goods.—Some producers offer limited editions of certain goods below the market-clearing price to a subset of customers. Prominent examples are sneakers and streetwear.²⁵ Some brands managed to build a fan base using these limited releases. This is the business model of Supreme, which specializes in various kinds of streetwear items and was established in New York in 1994. Supreme regularly offers new limited-edition items, leading to long queues and a secondary market that appears almost immediately after the goods have become available. The goods offered in such “drops” often become collectibles. Some of the limited-edition items are sold online, and scalpers dominate these sales.²⁶

Drops in online shops are analogous to the immediate system in that speed determines who gets the goods. Some companies, however, use preregistration and random draws for their releases. For instance, one of the most successful limited editions by Adidas, the Yeezy Boost sneakers collection in collaboration with Kanye West, used both online shops and lotteries. For some releases, Adidas also uses a virtual queue to fight scalping. Nike fights bots by allocating its limited release sneakers through its own SNKRS App, creating a short time window where customers can enter a lottery for a pair of sneakers.²⁷ These solutions are similar to the batch system. Our theory, however, casts doubt on the success of these lotteries, since bots can submit many applications and thereby ensure a high chance of getting

²⁴ At the 2018 World Cup, the tickets had a name and each spectator had to have a fan ID. At the entrance to the stadium the consistency of the documents was checked, but it was inconsequential.

²⁵ Another example is the sale of luxury bags, for instance, the Birkin Bag by Hermès. Despite being released in 1984, it is still overdemanded with a waiting time of several months. These bags can only be bought through so-called sales associates that require customers to have a long history of purchases from Hermès: see Lauren Sherman, “How the Legendary Birkin Bag Remains Dominant,” *Bloomberg*, <https://www.bloomberg.com/news/articles/2015-06-10/how-the-legendary-birkin-bag-remains-dominant> (accessed December 1, 2020).

²⁶ See Damian Fowler, “The Hype Machine: Streetwear and the Business of Scarcity,” *BBC*, <https://www.bbc.com/worklife/article/20180205-the-hype-machine-streetwear-and-the-business-of-scarcity> (accessed December 1, 2020).

²⁷ See Cam Wolf, “The War against Sneaker Bots Peaked at the End of 2018,” *GQ*, <https://www.gq.com/story/war-against-sneaker-bots> (accessed December 1, 2020).

the underpriced items. Adidas introduced additional barriers against bots, namely the restriction of one purchase per IP address and credit card, but these measures can also hurt regular customers.²⁸ Note that such technical restrictions are not feasible and not necessary for the batch system that we propose for the allocation of appointments.

Firms that offer limited-release sales could increase the supply to match demand. However, they benefit from the limited availability of their collections since it helps them to create a fan base and a certain hype around the products. Thus, the firms may be less opposed to scalping than they claim. Nevertheless, they are concerned about the perceived fairness of how the limited-release items are allocated. If fairness concerns are sufficiently important, the proposed batch system may be useful, since it is likely to be perceived as fairer than online drops flooded by bots.

Train Tickets in India.—The market for train tickets in India suffers from scalping despite ID verification. On the day before departure, Indian railways offer tickets for overdemanded trains on short notice, under the so-called Tatkal reservation scheme. This scheme was introduced to fight scalpers, and to make journeys on overdemanded routes possible without planning far ahead. The price under the Tatkal ticket system is 10 percent to 30 percent higher than the normal fare.²⁹ The supply of Tatkal tickets is lower than the demand for such tickets, and scalpers use bots to buy tickets under the names of their clients. Tickets are typically sold out within four to five seconds, such that people who want to buy a ticket without the scalper do not have a chance of obtaining one. The scalpers can book tickets under the true names of their clients since clients know that they need the help of the scalpers (so-called travel agencies) to get tickets. The service fee to the agency is often higher than the price of the ticket.³⁰ This is an example of a booking system where even without the possibility to re-book canceled slots or tickets, the advantage of speed makes scalping profitable. Officials have tried to prevent scalpers by tracking suspicious IDs and payments, with limited success. Our proposed batch system is directly applicable to this market.

Restaurant Reservations.—A related problem concerns scalpers booking tables in popular restaurants under fake names. Scalpers offer the tables on a website, and customers who pay for the reservation learn the fake name under which the reservation was made. The restaurants often do not receive any of the fees paid to the scalpers, and they run the risk of tables not being taken. Note that under the current first-come-first-served system, the checking of IDs by the restaurant would not solve the problem, since scalpers could still re-book the canceled slots with the real name of the customers. Under the proposed batch system, scalping would no longer be possible. However, restaurants are not necessarily concerned about the way their

²⁸ See Edgar Alvarez, “Adidas Tries to Make Buying Yeezys Fair but Misses the Mark,” <https://www.engadget.com/2016-04-07-adidas-yeezy-online-sales-block-ip-addresses.html> (accessed December 1, 2020).

²⁹ http://www.indianrailways.gov.in/railwayboard/uploads/directorate/traffic_comm/CC-2019/Tatkal_Scheme_02082019.pdf (accessed November 25, 2019).

³⁰ Latitha Sundaram, “Spl Software Helps Touts Book Tatkal Tickets in Secs,” *New Indian Express*, <https://www.newindianexpress.com/cities/bengaluru/2019/jun/20/spl-software-helps-touts-book-tatkal-tickets-in-secs-1992638.html> (accessed December 1, 2020).

tables are allocated, and might even have a preference for those clients with the highest willingness to pay for a table.

IV. Conclusion

This paper considers a novel application for market design, namely the allocation of appointment slots with online booking systems. With the help of a model and an experiment, we explain the presence of scalpers in first-come-first-served online booking systems around the world. We also show that the proposed batch system makes scalping unprofitable. Our paper presents a simple solution for an important problem that has surfaced recently with online booking systems. We do not claim that it is the unique solution, but it is feasible and technologically simple to implement. More broadly, we believe that taking into account the incentives of third parties, such as scalpers, to interfere with matching markets opens up novel and important research questions.

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