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How to Avoid Black Markets for Appointments With Online Booking Systems*

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Abstract

Allocating appointment slots is presented as a new application for market design. We consider online booking systems that are commonly used by public authorities to allocate appointments for driver's licenses, visa interviews, 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 system. The alternative system collects applications for slots for a certain time period and then randomly allocates slots to applicants. We investigate the two systems under conditions of low and high demand for slots. The theory predicts and lab experiments confirm that scalpers profitably book and sell slots under the current system with high demand, but that they are not active in the proposed new system under both demand conditions.

Keywords: Market design, online booking system, first come first served, scalping
JEL classification: C92, D47

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1 Introduction

Allocation problems where money is not used to coordinate demand and supply have gained the attention of economists in recent decades. Many such markets do not function properly when left to themselves and are therefore regulated and designed by public authorities. Well-known examples are procedures to allocate seats at schools and universities. School seats are not auctioned off to the highest bidders; instead meritocratic and social criteria govern the admissions procedures. A related allocation problem is the scheduling of appointments at public offices. Appointments are provided for free and are necessary to access many essential public services, such as obtaining a driver's license, obtaining a visa, or renewing a passport. Lately, many authorities have introduced online booking systems which allow appointment seekers to book appointments 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) appointment 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, the scalpers use a software to track the system and book slots immediately after they appear. Thus, the firms have a technological advantage regarding the speed of booking slots compared to appointment seekers. Black markets for appointment slots been observed for many online booking systems. This means that the political objective of providing equal access to the public service, independent of income, may be violated. [1] Moreover, it has been argued that firms acting as intermediaries profit undeservedly from public services.

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, and then sell them. The sale is possible due to the re-appearance of canceled appointments in the system: scalpers first cancel their appointment under the fake name, and then immediately book it under the name of their customer. This re-booking of canceled slots bypasses the barrier imposed by the ID verification of the booking system. A typical side effect of the scalper's activities is that fake bookings are sometimes not canceled and lead to no-shows.

A number of prominent cases have surfaced recently where appointment slots at public offices were sold in the market. For example, time slots for appointments at the US consulate in Chennai, India, have been offered at considerable prices.[2] The introduction of an online booking system for appointments with the the Irish Naturalisation and Immigration Service Center in Dublin also led to scalping and a collapse of the system.[3] Up to US $500 were paid to scalpers to get an

[1] We do not make the normative claim that equal access has to be implemented by offering the service for free. In fact, some countries offer priority services against payment (see, for example, differential fees for visas in China: http://www.visaforchina.org/CBR_EN/upload/Attach/mrbj/281944.pdf; last accessed on April 7, 2019).

[2] See https://timesofindia.indiatimes.com/city/hyderabad/US-consulate-to-check-visa-scalping/articleshow/34333.cms. Last accessed on March 4, 2019.

[3] See https://www.irishtimes.com/news/social-affairs/bots-used-to-block-immigrants-in-ireland-from-making-

appointment at the German consulates in Beirut, Tehran, and Shanghai.[4] An increase in the demand for appointments played a crucial role in 2014 in Beirut where many Syrian refugees tried to get a visa to join family members or to study in Germany. The German consulates observed that open slots were almost immediately taken. Moreover, despite all slots being fully booked, there was a high proportion of no-shows for the booked appointments. In response to this, the German Foreign Office implemented a number of temporary fixes, such as delaying the re-opening of slots after their cancellation, increasing the number of slots, outsourcing the services to private firms, and allocating some slots via email. However, these measures have not resolved the vulnerability of the online system, and scalpers are still active.[5]

Similar problems have been documented for appointments to obtain a driver's license at the Department of Motor Vehicles in some states in the US.[6] The startup YoGov offers such appointments for money. In spite of public criticism of YoGov and the government starting investigations, YoGov has extended the range of its services by also offering appointments for TSA Pre-Check enrollment and passport renewals.[7] A related instance of scalping was observed in Berlin where appointment slots at public offices are allocated online. These time slots were offered for money on a private website.[8]

Appointments at public hospitals in China can be booked online to avoid long queues. The patient buys a registration ticket to see a particular doctor through a mobile app or online.[9] The price of the ticket is fixed and depends on the type of doctor the patient needs to see. Scalpers sell these registration tickets for appointments at prestigious hospitals for up to 50 times their face value.[10] Thus, scalping can also be profitable when people have to pay for appointments if the price does not adjust to equate demand and supply.

Online booking systems are also used by private firms, and scalpers can profit if firms try to

visa-appointments-1.3620957. Last accessed on March 4, 2019,

[4]See "Ein Termin in der deutschen Botschaft? Das kostet!" in: Spiegel Online, July 6, 2015. 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.

[5]The website of the German consulate in Beirut displays the following message: "Caution: Many applicants informed us that several local 'Visa Service Agencies' claim to be able to organise an appointment for payment. However, these agencies only send falsified e-mail-confirmations of appointments, or demand horrendous prices of several hundreds of Euros for proper bookings. In the interest of all applicants these agencies should not be used. This Embassy does NOT work with private offices for arranging appointments, even if they claim it." (Last accessed on March 2, 2019.) Outsourcing and other fixes are mentioned in "Privatsache Visavergabe" in: Die tageszeitung (taz), October 18, 2017.

[6]See https://www.sfchronicle.com/bayarea/article/DMV-investigates-startup-that-has-disrupted-13064509.php. Last accessed on April 5, 2019.

[7]See https://yogov.org/services. Last accessed on March 4, 2019.

[8]See "Für kostenlose Termine zahlen" in: Süddeutsche Zeitung, July 27, 2015. Policymakers have tried to take legal action, but without success. They finally increased the supply of slots and threatened the founders of the website, a start-up firm run by university students, which temporarily stopped the sale of time slots.

[9]See https://www.scmp.com/news/china/society/article/1928186/ticket-scalpers-selling-hospital-appointments-beijing-police. Last accessed on April 5, 2019.

[10]See http://www.chinadaily.com.cn/china/2016-01/28/content_23281382.htm or https://www.theatlantic.com/china/archive/2013/05/it-isnt-getting-any-easier-to-get-a-doctors-appointment-in-china/276400/. Last accessed on March 4, 2019.

provide a service for free. For instance, Apple offers free appointments to all its customers in Apple stores (so-called Genius bar appointments) which are part of the warranty service. Scalping in the context of Genius bar appointments was recently documented in China.[11] Apple made an attempt to complicate the booking and introduced identity verification, but the main issue, namely the relevance of speed for obtaining a slot in the first-come-first-served system, has not yet been resolved.

The examples show how widespread first-come-first-served online booking systems and scalping have become in recent years. In this paper, we ask how market design can be used to eliminate the profitability of scalping by intermediaries and how this affects the efficiency of the assignment. 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 derive the equilibrium of the system. The model captures the essential properties of the examples presented above. We demonstrate that in equilibrium intermediaries can profitably book and sell slots to appointment seekers under reasonable parameters of the first-come-first-serve system.

We propose an alternative system that collects applications in real time, and randomly allocates the slots among all applicants ('deferred' system). The system works as follows: Applications are collected over a certain time period, e.g., for one day. In the evening, all open slots are allocated to the appointment seekers. Thus, the allocation of slots is deferred, not immediate as in the first-come-first-served system.[12] In the case of excess demand, a lottery decides who gets a slot. If a slot is canceled, this slot is added to the supply of slots for the next allocation period, e.g., the following day. Thus, the scalper cannot transfer the slot from the fake name to the customer.

The deferred 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 re-bookings. Note that both effects are necessary for the success of the deferred system. If under an alternative system a scalper would have the advantage of speed but cannot transfer the identity of slots, the scalper could still profitably operate in the market if seekers foresee that they cannot receive slots by themselves, and therefore ask the scalper to book slots on their behalf. If the scalper does not have the advantage of speed but bookings do not require identification, the scalper can flood the market with fake applications in the deferred system, is virtually guaranteed to receive all slots under fake names, and sell them on a secondary market to the seekers.

We show that under reasonable parameter restrictions, the scalper does not enter the market in the equilibrium of the deferred system. The intuition for this result is that, keeping the booking

[11] https://www.businessinsider.com/apple-genius-bar-appointments-scalped-2013-7?r=US&IR=T. Last accessed on April 5, 2019.

[12] This fact is key for the equilibrium strategies of the scalper. Note that in the deferred system the scalper can still potentially book all slots by submitting thousands of fake applications, but due to the impossibility of transferring these slots to the names of the customers, the scalper cannot generate any income from flooding the market with fake applications.

behavior of the scalper fixed, a seeker has the same probability of getting a slot from buying a slot and from applying directly. Thus if price for the scalper's service is positive, seekers will always prefer to apply directly. One additional advantage of the deferred system is that the market designer can observe the demand for slots unlike in the immediate system, and can adjust the supply if possible.

Based on a parameterized version of the model, we conducted a set of lab experiments. The evidence from the experiments is important because the predicted effects of the assignment system on the incentives of scalpers to enter the market are not trivial. Furthermore, the actual behavior of appointment seekers is crucial for the possibility of the scalpers to operate under each of the systems. Due to a within-subjects design, the experiments allow us to observe the effect of a change in the booking system from immediate to deferred and of changes in the demand for appointments.

Overall, 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. This mirrors the observation from US and German consulates but also from the Department of Motor Vehicles and Chinese hospitals, that black markets develop when there is excess demand for slots.

Furthermore, theory and experiments show that the proposed deferred system does not allow the scalping firms to make profits. We observe that both with low and high demand, the proportion of scalpers entering the market is below 20% in the final round of the deferred system, and they do not make positive profits. As predicted, the welfare of appointment seekers is higher in treatments with the deferred system than in the immediate system independent of demand conditions. There is one systematic deviation from the equilibrium predictions that we observe in the lab, namely that seekers are more reluctant to buy from scalpers than predicted: even if the price is below the seekers' valuation and buying the service of a scalper is the only way to get the slot, seekers often decide against buying and thereby forgo profits. We interpret this as an attempt of seekers to discourage the scalpers from setting high prices or from entering the market in later rounds.

Related literature. The current system of scheduling appointments rewards speed and therefore privileges firms that use special software to book open slots. This feature relates our contribution to a literature on the design of financial markets. The importance of speed in high-frequency trading has led to enormous investments in fast data connections around the world. To end this high frequency trading arms race, Budish et al. (2015) have proposed implementing frequent batch auctions. Our proposal is similar in that we suggest using lotteries among applicants at discrete time intervals. However, in our case, the success of the deferred system is driven not only by eliminating the importance of speed but also by preventing the transfer of slots booked under fake names to the names of the scalpers' customers.

Speed is also decisive for sniping in online auctions. While scalpers have an advantage over other players by minimizing the booking time after a slot is made available, automated sniping aims at minimizing the time distance of the bid to the exogenous deadline. Sniping can be addressed by endogenous or unknown times of closing the auction (Roth and Ockenfels, 2002; Ockenfels and Roth, 2006; Ariely et al., 2005; Malaga et al., 2010). Note that scalping cannot be resolved by keeping the exact time of the release of new slots unknown. The monitoring of booking websites by the software of the scalper always guarantees a faster access to the newly available slots such that unknown release times of slots can even benefits scalpers. On the other hand, our proposed solution of discrete time intervals in which appointments are allocated is less useful in the context of online auctions. A discretization of the time at which bids are collected would move the auction closer to a sealed-bid format.

Our paper also relates to the literature on the sale and re-sale of tickets for sports events, concerts, popular restaurants, etc. When there is substantial excess demand at the prices charged by the seller, a secondary market can develop in which prices exceed the original prices by a large margin. In markets for sporting events, new marketing tools of the organizers have blurred the difference between primary and secondary markets (for a survey see Courty, 2017). 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.[13] Random allocations of tickets are used, for instance for the soccer World Cup final, for Wimbledon, and for baseball matches by some teams of the MBL. Ticket seekers enter a lottery where the winners get the opportunity to purchase a small number of tickets. Chakravarty and Kaplan (2013) show that under some assumptions lotteries are the optimal allocation rule. The allocation of tickets through a lottery resembles the deferred system that we propose. Our analysis therefore sheds light on the design of ticket allocations schemes using lotteries when price discrimination is considered inappropriate.

There is a large literature on the effects of resale possibilities after auctions. For example, Hafalir and Krishna (2008) have studied the efficiency effects of resale after asymmetric auctions while Garratt et al. (2009) demonstrate the possibility of collusion in auctions when resale is possible. In contrast to our application of appointment slots at public offices, these papers deal with contexts where there are no restrictions on monetary transfers.

Fairness and equity concerns limit the use of auctions for the assignment of vehicle licenses in China. The number of licenses is restricted to combat air pollution and traffic congestion in big cities. While some authorities auction off the plates, other cities use lottery-based allocation systems. Lately, systems have been proposed that strike a compromise between auctions and lotteries, such as auctions where the designer restricts possible bids, as studied by Liao and Holt (2013), or hybrid allocation systems combining the elements of lotteries and auctions. Rong et al. (2015) and Huang and Wen (2019) investigate the efficiency and equity properties of the hybrid mechanism relative to an auction while Li (2017) compares the welfare properties of auctions and

[13] How auctions can be used for ticket sales to reduce arbitrage profits is studied by Bhave and Budish (2017). "Purple pricing," based on a Dutch auction with a compensation for those who paid more than the final price, was devised by the game theorists Sandeep Baliga and Jeff Ely for ticket sales of sporting events at Northwestern University.

lotteries in the Chinese license plates market. Our focus differs in that we search for a mechanism that is immune to scalping and that does not rely on any monetary transfers.

When there is no possibility of monetary transfers such as buying and selling, the assignment of appointment slots becomes an indivisible resource or house allocation problem studied in the matching literature (Shapley and Scarf, 1974; Hylland and Zeckhauser, 1979; Sönmez and Ünver, 2011). In terms of the existing matching literature, it is not possible to compare the properties of the immediate and the deferred system for allocating appointment slots. The two systems differ only in how the priorities are determined in the serial dictatorship mechanism, a mechanism where agents are assigned slots in the order of their priorities. To see this, note that in the immediate system priorities are determined by the speed of booking a slot, which is exogenous to the model. On the other hand, the deferred system first pools applicants and then uses a lottery to determine priorities; it is a random serial dictatorship mechanism (e.g., Abdulkadiroğlu and Sönmez, 1998). The existing house allocation model is not appropriate to compare the immediate and the deferred system. We present a model which differentiates between the two systems with respect to the profitability of scalping.

This study is part of the experimental matching literature that uses the lab as a testbed for house allocation mechanisms. Chen and Sönmez (2002) run experiments comparing Abdulkadiroğlu and Sönmez (1999)'s top trading cycles (TTC) to the random serial dictatorship (RSD), while Guillen and Kesten (2012) compare TTC with a version of the deferred acceptance mechanism. Hugh-Jones et al. (2014) investigate the probabilistic serial mechanism and compare it with RSD. A school choice problem is a house allocation problem with heterogeneous priorities (Abdulkadiroğlu and Sönmez, 2003). We refrain from citing the vast experimental literature on school choice, but refer to the survey of Hakimov and Kübler (2019).

Experimental studies on the effects of intermediaries on market outcomes have been conducted by Cason (2000) regarding the effect of the presence of dealers in financial asset markets, Yavas et al. (2001) on bargaining in the real-estate market, and Drugov et al. (2014) who considers the role of intermediaries for corruption. Unlike these papers, we vary the profitability of the intermediary in order to investigate that intermediary's decision to enter the market or not.

2 The Model

We build a simple model of appointment allocation in the presence of scalpers. We focus on how different design choices can reduce the profitability of scalping.

There are n **(appointment) seekers**, indexed by $i \in \{1, \dots, n\}$, who need visas from a central authority. The central authority has to meet the seekers face-to-face to issue the visas, and thus m (appointment) slots are provided. However, the m slots offered can be obtained by any agent, not only the seekers. We represent non-appointment-seeking agents by one firm, called the **scalper**.[14]

A **booking system** operated by a central authority is a procedure to allocate m slots to applicants without monetary transfers. A system accepts applications with IDs of applicants. A seeker can submit at most one application for a slot with her ID. We assume that the scalper can costlessly create 'fake' IDs that do not refer to any existing appointment seekers. 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 $[\underline{v}, \overline{v}]$ according to the commonly known distribution function F where $\underline{v} > 0$. We 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 $c > 0$. If the scalper decides to enter the market, he can submit as many applications to the booking system as he wants up to Q. Thus Q represents the capacity constraint of the scalper to create fake applications. For analytical simplicity, we assume that Q is sufficiently large so that $Q > m$. 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 or not. 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 what system is in place.

Each seeker i's payoff is formulated as follows.

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

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

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

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

Under any system, a seeker can either apply directly for a slot 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,

[14] We refer to the scalper by the male personal pronoun and to a seeker by the female personal pronoun.

- n_d be the number of direct applicants,
- a be the number of applications by the scalper where $a \leq Q$,
- s be the number of slots secured by the scalper where $s \leq a$.

The likelihood that the scalper can get 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 $t = 0$, the booking system, the supply of slots, and the number of seekers are revealed and are observable for the scalper and the seekers; seekers learn their valuations privately.
- In $t = 1$, the scalper chooses whether to enter the market or not, which is observable. If he enters, the scalper sets the price for a slot which 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 decide whether to buy a slot from the scalper or apply for slots directly to the booking system. The number of buyers is observable for the scalper but not for the other seekers.
- In $t = 3$, if the scalper has entered the market, he chooses the number a of applications 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 the market, all seekers apply for slots directly, thus $n_d = n$ and $a = 0$.
- In $t = 4$, the booking system is run and payoffs are realized.

2.1 Immediate booking system

The **immediate system** models a first-come-first-served online booking system. In the immediate 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. We assume that the scalper has a technological advantage over the seekers in the sense that he can preempt them from booking slots once they become available in the system. The scalper can secure himself any number of slots up to the total supply of slots in the system, $0 \leq a = s \leq m$. Importantly, the scalper can transfer these slots to seekers who must pay for his service. This assumption captures a situation where the scalper can fill all available slots with fake IDs. Once a seeker buys the service, he can replace a fake ID with the ID of this seeker. This is possible by canceling the slot with the fake ID and then

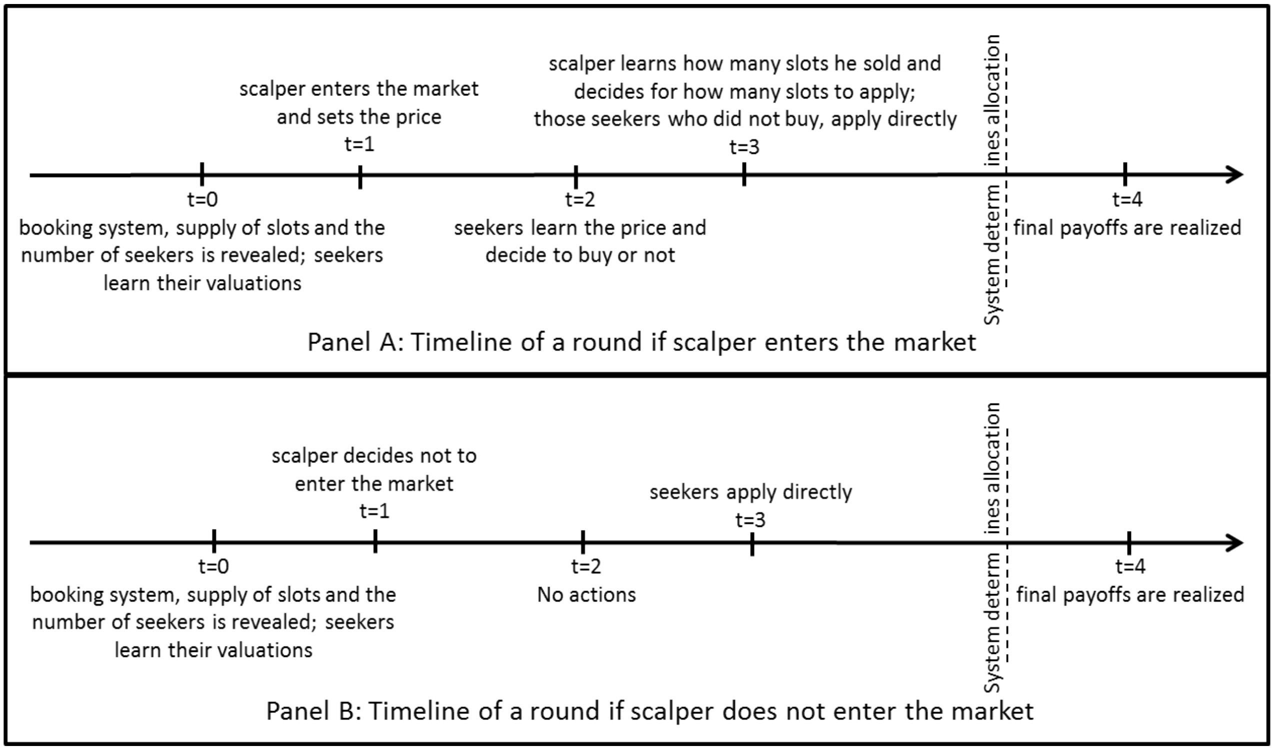

Figure 1: The timeline of the game in the experiments

immediately re-booking it under the name of the seeker.[15] For the sake of simplicity, we model this process by allowing the scalper to book the slots before the seekers, and by allowing all the slots assigned to the scalper to be transferred to the buyers automatically. The remaining slots are assigned to direct applicants if there are enough slots available for all seekers who apply directly. Otherwise, the remaining slots are randomly assigned to the direct applicants. More formally, the assignment is determined as follows.

The total number of applications to the system cannot exceed the number of slots, i.e., $n_d + a \leq m$.[16] The scalper obtains a slot for each of his applications, $0 \leq a = s \leq m$. 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 $(s - a)$ 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 $\frac{s}{n_b}$. Each direct applicant gets a slot. Any remaining open slots are freely disposed.

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 applications, denoted by $\alpha(p, n_b)$, for each combination of price p and number of buyers n_b. Every seeker observes the scalper's decision regarding entry

[15]Note that even if the canceled slots are freed up with a delay, a policy that has been adopted by consulates to deter scalping, the scalper will be faster than the seekers in booking it once it appears in the system. Moreover the scalper knows for sure that the slot will be offered at some point, early enough for re-booking, since otherwise the canceled slot is wasted.

[16]This does not preclude a situation of excess demand. However, those seekers who want to obtain a slot directly or through the scalper but are not successful are not observed by the system.

and price, and then decides whether to buy from the scalper or to apply for a slot directly. That is, a seeker i's strategy with valuation v is $\beta_i(p; v) \in \{\text{buy, direct application}\}$.

Proposition 1. *Under the immediate booking system, we have a Bayesian Nash equilibrium where on the equilibrium path,*[17] *letting p^* be the price that maximizes the profit of the scalper $\pi(p)$,*[18] *the following occurs:*

1. If $\pi(p^*) \geq 0$, the scalper enters the market, sets price p^*, and makes m applications. If $\pi(p^*) < 0$, he does not enter the market.

2. Each seeker follows the symmetric strategy in which a type above p^* buys the service from the scalper, and a type below p^* applies for slots directly.[19]

The proof of the proposition can be found in Appendix A.1.

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

While the overall welfare of the booking system is not our main interest, we can distinguish three different effects of scalping on welfare in the immediate system: (i) The entry cost c for the scalper creates a deadweight loss. (ii) If there are more appointment seekers than slots, the presence of the scalper may improve the allocative efficiency. The reason is that without the scalper, slots are allocated randomly to seekers, irrespective of their value for it. If the scalper is active, only seekers with a high value for a slot will obtain one. This ensures that on average those who obtain a slot if the scalper is active have a higher value for it than if the scalper were not active. (iii) The price charged by the scalper creates inefficiencies if there are fewer seekers with a value above the price than slots available.

In terms of the distribution of welfare, it is not clear that the improved allocative efficiency with scalping benefits the appointment seekers. The reason is that the scalper appropriates some portion of the efficiency gains by charging a price to the buyers.

2.2 Deferred booking system

We propose the **deferred booking system** as an alternative to the immediate system. Under the deferred system, the central authority collects and pools applications with IDs during some *time interval*. Only at the end of the interval are the m slots allocated to the applicants. The number of

[17] For each $p \in \mathcal{P}$ off the equilibrium path, the scalper 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 for slots directly. Actually, the equilibrium with any beliefs off the equilibrium path is a weakly perfect Bayesian equilibrium. Here, we use Bayesian Nash equilibrium so that we do not need to add a belief system with more heavy notation. The reason is that the scalper sets the price before learning how many seekers want to buy from him. The booking decision by the scalper is unaffected by his beliefs about the valuations of the bidders.

[18] The profit of the scalper is defined in equation (3) in Appendix A.1

[19] A symmetric strategy is one that depends only on the type.

applications is not constrained by the supply of slots, since the allocation of slots takes place after a period of collecting applications. This is different from the immediate system where the application and the allocation of slots happen at the same time. Thus, under the deferred system, rejected applications are observable for the authority. The scalper has no technological advantage relative to the seeker, except that he can submit Q applications, while seekers can submit only one.[20] The deferred system as described above involves time, which would complicate its analysis. Explicitly modeling the dynamics of the system would complicate its analysis, with little additional insight. For simplicity, we define the assignment by the deferred system as a static problem capturing the essence of the above description. The assignment by the deferred system is determined in one of the following two cases.

1. The total number of applications does not exceed the number of slots, i.e., $n_d + a \leq m$. The scalper obtains a slot for each of his applications, $0 \leq a = s \leq m$. Also, each direct applicant gets a slot. If $n_b \leq s$, n_b slots go to the buyers, and the remaining slots of the scalper $s' \equiv s - n_b$ are assigned to fake IDs and lead to no-shows. If $n_b > s$, the s slots are randomly distributed to n_b buyers such that each gets a slot with probability $\frac{s}{n_b}$.

2. The total number of applications exceeds the number of slots, i.e., $n_d + a > m$. 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 $\frac{m}{n_d+a}$.

In the immediate system, the scalper can secure up to m slots, which allows him to preempt the seekers completely. By contrast, in the deferred system the scalper cannot secure the slots for the buyers for sure.[21] One of the characteristics of the deferred system is that a seeker has the same probability of getting a slot from buying or from applying directly, keeping the behavior of the scalper fixed. Thus, since buying a slot is costly for the seeker, she always prefers to apply directly.[22] Why is this the case? Note that the scalper can submit both fake IDs and the IDs of buyers. However, the only way that the scalper can sell a slot to a buyer is by putting her ID in the application. In contrast to the immediate system, he cannot re-allocate slots with fake IDs to buyers, since canceled applications are re-allocated only in the next period and not immediately. The deferred booking system is less favorable to the scalper than the immediate system, since it reduces the importance of speed, an advantage that the scalper has over the seekers. The main properties of the equilibrium are summarized in Proposition 2.

[20] The scalper having no technological advantage means that the time interval is long enough such that a seeker can submit her application directly in every allocation period if her previous application was not successful. Thus, speed is not important for a successful application.

[21] Note that the scalper is almost certain to secure the full supply of slots such that $s = m$ by submitting a large number of fake applications. However, this is not profitable since the scalper cannot sell the slots by transferring them to the seekers' IDs.

[22] The only exception is the case when she can change the strategy of the scalper by buying his service. This is only an equilibrium for specific parameter values, and the equilibrium is characterized by Proposition 3.

Proposition 2. *Under the deferred booking system, we have a Bayesian Nash equilibrium where on the equilibrium path,*[23]

1. *the scalper does not enter the market, and*
2. *every seeker applies directly.*

The proof of Proposition 2 and the details of the equilibrium can be found in Appendix A.2.

There exists another equilibrium under the deferred system. Consider the possibility that the scalper enters the market and submits Q applications if there are no buyers ($n_b = 0$). In this case the probability of the seekers to receive a slot is close to zero when Q is large enough, since the probability equals $\frac{m}{n+Q}$. If the seekers anticipate this threat, some of them can buy the service of the scalper in order to stop him from flooding the system with fake applications. Note that conditional on having a positive number of buyers, it is optimal for the scalper to submit exactly n_b applications.[24] This equilibrium is summarized in Proposition 3.

Proposition 3. *Under the deferred booking system, we have a Bayesian Nash equilibrium where on the equilibrium path, letting p^* be the price that maximizes the profit of the scalper $\pi(p)$,* the following occurs.[25]

1. When $\pi(p^*) \geq 0$, the scalper enters the market with price p^*; moreover, he makes n_b applications when observing $n_b > 0$ buyers, and makes Q applications when observing zero buyers. When $\pi(p^*) < 0$, he does not enter the market.

2. Each seeker follows a symmetric strategy with the cutoff function $\hat{v}$,[26] *i.e., a type above $\hat{v}(p^*)$ buys the service, and a type below $\hat{v}(p^*)$ applies directly. Moreover, $\hat{v}(p^*) > p^*$.*

Because we have $\hat{v}(p^*) > p^*$, the seekers only buy the service of the scalper if their valuation is sufficiently larger than the price, unlike in the immediate system where the cutoff for buying the service of the scalper is equal to p. Note also that even in the equilibrium of Proposition 3, the scalper is not active in the market for a large set of parameters. The reason is that in equilibrium the expected number of seekers who buy the slot is equal to one. Thus, $\pi(p^*) \geq 0$ holds only when the price of one slot can cover the fixed cost of participating in the market. We consider this to be unrealistic, and the parameters that we chose for the experiment therefore exclude this equilibrium. Nevertheless, Proposition 3 is useful for the analysis of the experimental results. It characterizes the continuation equilibrium of the deferred system after the scalper has made the

[23] Off the equilibrium path, in case the scalper enters the market, he sets a price in $\mathcal{P}$ and always submits n_b applications; moreover, every seeker applies directly. Like Proposition 1, the equilibrium with any beliefs off the equilibrium path is a weakly perfect Bayesian equilibrium.

[24] More precisely, the scalper is indifferent between submitting n_b and $m - n_b$when $n_b > 0$ and $n <= m$. See Claim 3 in Appendix A.2 for details.

[25] For each $p \in \mathcal{P}$ off the equilibrium path, a type above $\hat{v}(p)$ buys the service, and a type below $\hat{v}(p)$ applies directly; moreover, $\hat{v}(p) > p$. Like Propositions 1 and 2, the equilibrium with any beliefs off the equilibrium path is a weakly perfect Bayesian equilibrium. Moreover, the profit of the scalper is defined in equation (5) in Appendix A.2, which is a different function from the one in Proposition 1.

[26] The function $\hat{v}$(p) is defined in Claim 5 in Appendix A.2.

out-of-equilibrium decision to enter the market. In particular, it pins down the booking strategy of the scalper and the buying strategy of seekers.

To understand the intuition of the continuation equilibrium, first note that in the case of no buyers, the scalper is indifferent between any number of fake bookings. However, the scalper may want to flood the market with fake applications to punish the seekers for not having bought his service and to teach them that he can also block the system in future rounds. For the seekers it is collectively optimal if exactly one slot is bought from the scalper since this will break his indifference between flooding the market or not and will make him submit only this one application. In equilibrium, only seekers with high valuations want to pay to obtain a slot for sure, thereby providing a benefit to other seekers.

Notice that the deferred system can be extended to accommodate the preferences of seekers over slots and to reward long waiting times. When different time slots have a different value for the appointment seekers, the system can be adjusted such that seekers submit a rank-order list of time slots. A mechanism such as serial dictatorship with a lottery determining the priority could then be used to determine the allocation. In periods of very high demand, it can be the case that some seekers are not picked by the lottery for a large number of periods. One way to reward waiting times would be, for instance, to provide applicants with a number of lottery draws equal to the number of periods in the waiting queue.

2.3 Alternative solutions

In this subsection we discuss potential alternative solutions to fight scalping. One possibility is to ask appointment seekers for a small payment which is refunded if an applicant shows up at her appointment. While this policy restricts the set of parameters where scalping is profitable in equilibrium in the immediate system, it does not preclude scalping when demand for slots is high. The equilibrium price for a slot under the immediate system, as specified in Proposition 1, is shifted up. To see this, note that the payment does not affect the seekers' behavior, and the scalper's revenue is the price multiplied by the number of buyers minus the payment for slots that have not been sold. Thus, the increase in price will compensate the additional cost to the scalper caused by unsold slots. In the deferred system, the type of equilibria described in Proposition 2 is not affected and thus the scalper does not enter the market. But note that the small payment for each application rules out the type of equilibria described in Proposition 3 in which the scalper threatens to flood the market with a large number of applications if there are no buyers. Thus, the introduction of an application fee does not solve the problem of scalping in the first-come-first-served system, but makes scalping even less attractive in the deferred system.

A second possible remedy is the introduction of a cancellation fee. Again, it has only a limited effect on scalping in the immediate system. A cancellation fee will increase the equilibrium price of the scalper by the expected proportion of canceled slots multiplied by the cancellation fee.

Thus, similar to a small payment for each booking, a cancellation fee can restrict the set of parameters for which entering the market is profitable for the scalper. Under the deferred system, a cancellation fee does not affect the equilibrium. This is due to the impossibility of transferring canceled slots to other applicants in the deferred system, which implies that cancellations do not occur in equilibrium. Note that these arguments are informal and go beyond our model. It is possible that profitable market entry of the scalper can be avoided with appropriate fees, but in order to see this and to determine the right size of a fee, a calibrated analysis of the effects of fees is required. Our proposed solution does not require the introduction of fees and is therefore simpler to implement and more straightforward.

A third alternative solution is to provide canceled slots to a physical line instead of making the slots available online. This can prevent the immediate re-booking of canceled slots by the scalper under the names of his customers. However, 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-serve system. Moreover, the scalper can still make profits in equilibrium when seekers with high valuations or those who have a high disutility from lining up buy his service to obtain a slot for a future booking period. The reason is that unlike in the deferred system, the scalper can still guarantee the seeker a slot with certainty since he is faster than the seekers.

Finally, a simple waitlist could be employed instead of the first-come first-serve system. Appointment seekers put their names on a wait list and are assigned a slot once it is their turn.[27] If an appointment seeker cancels her slot, all appointment seekers on the wait list are moved upwards. This system makes it impossible for the scalper to operate, since he cannot exchange fake bookings with his clients. However, the system has a number of disadvantages, such as the uncertainty regarding the exact date and time of obtaining a slot. The waitlist system can be useful for applications where the exact time of getting a scarce resource is less relevant, but appointment seekers may have to travel a considerable distance for their appointments, which makes certainty regarding the date crucial for the success of the system. Moreover, a waitlist system can suffer from appointment seekers hoarding slots where people put their names on the list even if they do not need the appointment at the moment, expecting that this need may arise in the near future. One example is the waitlist for the apartment rentals 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 rental housing.[28]

We believe that our solution is the simplest and straightforward to implement. While the small delay (e.g., one day) before finding out whether the application for an appointment was successful

[27]It might well be that in the case of high overdemand, seekers are not immediately assigned slots in the future, e.g. because the supply is uncertain. In this case, applicants will be on the waitlist for some time and will only be assigned a slot once they have moved up on the list. For instance, German consulates currently only offer slots three months before the appointment dates.

[28]http://www.bbc.com/capital/story/20160517-this-is-one-city-where-youll-never-find-a-home. Last accessed on July 15, 2019.

can carry a cost, the costs of alternative systems seem much higher. Most importantly, unlike all alternative solutions discussed above, the deferred system, as the immediate system, features online bookings, appointments scheduled at a predetermined time with no physical lines forming, no payments, and uncertainty about receiving a slot.

3 Design of the Experiment

We conducted an experiment that serves as a testbed of the proposed deferred system. We also study the immediate system to understand the conditions under which scalpers can profitably enter the market. Finally, the experiment allows us to compare the strategies and outcomes to the equilibrium predictions.

3.1 Treatments and procedures

There are four appointment slots to be allocated in every round, thus $m = 4$. Of the five appointment seekers in each market, three are active in every round, while the other two are active only in 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 the appointment, 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, and all seekers are indifferent between all slots. There is one scalper in every round who can enter the market. The scalper does not have any valuation for the slots himself, but he can book slots and sell them to the appointment seekers.

The appointment slots are allocated through one of two different booking systems, the immediate and the deferred 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, and the scalper does not know the valuations. The scalper decides whether to be active in the market or not. Entering the market entails a fixed cost of 150 points for the scalper, $c = 150$.[29] If the scalper has entered, he sets the price p that has to be paid by the appointment seeker if the scalper provides a slot. The scalper has a choice between the following prices: 15, 20,

[29] When interpreting the setup as a repeated game between a scalper and appointment seekers, the fixed cost that the scalper incurs in every round can be interpreted as the salary of its employees and other fixed costs of running the business.

25, ... 75, 80, or 85. Each seeker decides whether she wants to pay for the scalper's service at the price asked for by the scalper 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, if the scalper has entered the market in step 1 at a cost of 150 points, he can book as many slots as he wants for free. Before deciding on how many slots to book, the scalper learns how many scalpers have bought his service. If the scalper has sold a slot to a seeker in step 1, the system assigns him a slot for the ID of this seeker.[30] The scalper can also book more slots than he has sold in step 1 by entering fake IDs. The fake IDs were created by the computer if the scalper decided to book more slots than the number of buyers. The number of booked slots cannot exceed the total supply. In the experiment, slots with fake IDs are blocked and cannot be taken any more by appointment seekers. If the scalper does not book all available slots, the remaining slots are randomly distributed among appointment seekers who have applied for slots directly, without the scalper, in step 1. Appointment seekers do not have to take any decision in the second step, and can only receive or not receive a slot.

Deferred 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), he can submit as many applications for slots as he wants for free. Before deciding how many slots to book, the scalper learns how many scalpers bought his service. The scalper enters the IDs of the seekers who decided to apply through him in step 1.[31] Each ID can be entered into the system only once. The scalper can also enter fake IDs. The maximum number of applications was 10 000 000. The allocation of slots is determined randomly in the following way: all applications of the scalper and the applications of the seekers who decided to apply directly are put into an (imaginary) urn. Then, one by one, four applications are randomly drawn from the urn to fill the slots. Note that if the scalper received a slot for a fake ID, he cannot sell it to the seekers.

We implemented a 2x2 within-subjects design by varying the demand and the booking system. Before each block of five rounds, the demand for appointments (three or five active appointment-seekers) and the nature of the booking system (immediate or deferred) are announced. Both stay constant for five rounds. We implement a five-rounds block design to allow 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.

[30] This was implemented automatically in the experiment, i.e., if a seeker bought the service of the scalper, her ID was automatically used for one of the slots booked by the scalper if the scalper booked any slots. If there were more seekers who bought the service than the number of slots booked by the scalper, it was randomly determined who received a slot.

[31] Similar to the immediate system, this was automatically implemented in the experiment, i.e., if a seeker bought the service of the scalper, her ID was automatically used for one of the applications if the scalper submitted applications for slots. If there were more seekers who bought the service than the number of applications submitted by the scalper, the system randomly determined whose IDs to use.

Table 1: Characteristics and sequence of treatments

Round	Block	System	Demand (n)	Supply (m)	Treatment
1-5	1	Immediate	5	4	Im5
6-10	2	Immediate	3	4	Im3
11-15	3	Deferred	5	4	Def5
16-20	4	Deferred	3	4	Def3
21-25	5	Immediate	5	4	Im5
26-30	6	Immediate	3	4	Im3
31-35	7	Deferred	5	4	Def5
36-40	8	Deferred	3	4	Def3

Table 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 when subjects have already experienced all four treatments. The order of the treatments was chosen so as to first allow scalpers to make profits in the immediate system with five appointment 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 deferred will reduce the amount of scalping. We thereby follow the approach of Kagel and Roth (2000) where a centralized mechanism is introduced after subjects experienced a decentralized market in order to study the change in behavior due to a change in the mechanism.

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 asked by the scalper if she receives a slot through the scalper. If the seeker receives a slot without the scalper, the seeker 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 in the course of the five rounds. If the scalper enters the market, he has to pay the cost of 150 points, and he receives the price times the number of slots sold to the seekers. Note that the endowment of 750 allows the scalper to enter the market in every round, even if he does not sell any slots in any of the rounds. 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, he does not have to pay nor does he earn anything in this round, and thus his endowment is unchanged.

After every round, all participants received feedback about the allocation of slots: either a slot was vacant, or a slot was allocated to a seeker directly, or a slot was allocated to a seeker through the scalper, or the slot was allocated to a fake ID due to the scalper's fake application.

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 experimental economics 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.

At the beginning of the experiment, printed instructions were given to the subjects (see Appendix). 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 check their understanding of the main features of the experiment. The quiz was checked by the experimenter in private, and the correct answers with explanations were distributed. Any remaining questions were answered, and the experiment was started.

3.2 Predictions

The four treatments differ with respect to the predicted entry of the scalper, the predicted price for an appointment slot, and the number of slots sold. This results in different profits for the scalper and payoffs for the seekers. Table 2 presents a summary of the equilibrium predictions of the stage game by treatments.

The only treatment where the equilibrium predicts positive expected profits for the scalper is Im5. Due to the scalper's ability to book all slots in the immediate system, and given the excess demand for slots, the scalper chooses the profit-maximizing price of 60. The higher the price, the smaller the probability is that all four slots can be sold, due to the uncertainty about the realization of the seekers' valuations. Thus, in equilibrium welfare losses occur due to an inefficient allocation of slots, since the expected number of slots sold is 3.87, not four. In Im3, just like in Im5, the scalper has full control over all slots, but due to the lower demand, he can only break even in equilibrium. He charges a price of 50 to guarantee that all three seekers are willing to buy a slot from him. Due to the entry cost of 150, this is not enough to make positive profits. Thus, the scalper is indifferent between entry and no entry in Im3. Unlike in Im5, no welfare loss is predicted in equilibrium, as all slots are allocated to appointment seekers.

In Def3 and Def5, the scalper does not enter the market in equilibrium. However, if the scalper

Table 2: Equilibrium predictions

Treatment	Im5	Im3	Def5	Def3
Entry by scalper	yes	indifferent	no	no
Price after entry (p)	60	50	40	45
# of slots booked by scalper (a)	4	4	# of buyers (n_b); indiff. if n_b=0	# of buyers (n_b); indiff. if n_b=0
Expected # of slots sold	3.67	0 [3.00]	0	0
Expected profit of scalper	70.34	0 [0]	0	0
Expected payoff of seekers	14.68 (18.35)	25.00	60 (75)	75

Notes: The predictions refer to one round. The numbers for the immediate system are calculated based on proposition 1, while the numbers for the deferred system are calculated based on proposition 2. The numbers in square brackets denote the continuation equilibrium after scalpers enter the market, calculated based on proposition 3. The equilibrium payoff of seekers in Im3 is calculated given entry of the scalper in case of indifference. The numbers in parentheses refer to the normalized payoffs of appointment seekers where payoffs in Im5 and Def5 are divided by 0.8 to make them comparable to payoffs in Im3 and Def3.

has entered the market, we can describe his equilibrium strategy. In the continuation equilibrium characterized in proposition 3, there is a threshold valuation of the seekers such that the seeker will buy the service from the scalper if and only if the valuation is higher than the threshold. Note that in expectation this is true for one seeker. Thus, the scalper always experiences losses, since the entry cost cannot be covered by the price paid by one seeker only.

We use the stage game predictions although subjects play the game for five rounds, with changing ID numbers of the seekers between rounds. While we are interested in the stage game outcomes, we implemented five rounds with a partner matching 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.

4 Experimental Results

The main questions addressed by the experiment are whether scalping is profitable and scalpers enter the market accordingly, and how many slots are filled by the two systems. First, we present an analysis of the behavior and outcomes of the scalpers and then turn to the appointment seekers. All results reported are significant at the 5%-level if not stated otherwise.

4.1 Scalpers

6.1.1. Market entry

The deferred booking system was designed to remove the incentives of scalpers to book slots and sell them to the seekers. We therefore first investigate the entry decisions of scalpers across

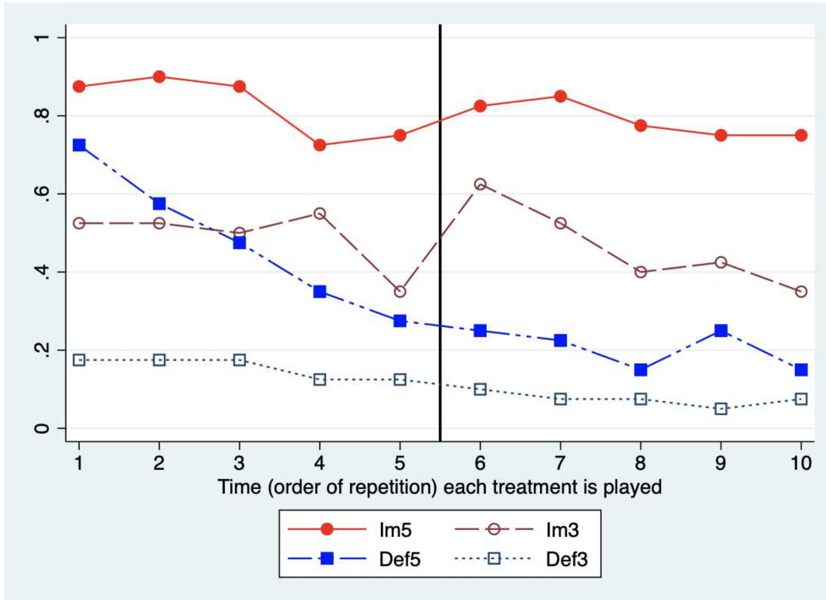

Figure 2: Proportion of scalpers entering the market

Notes: Rounds 1-5 form the first block while rounds 6-10 the second block of a given treatment. The black vertical line separates the first and the second blocks.

treatments. Figure 2 shows the average proportions of scalpers entering the market over time. The highest proportion of scalpers in the market is observed in Im5, amounting to 79% on average for the last five rounds of the treatmnet. This is qualitatively in line with the equilibrium prediction regarding Im5, where all scalpers are predicted to enter the market. In the equilibrium of Im3, the scalpers are indifferent between entering and not entering the market as the expected profit is 0. We observe, on average, 47% of scalpers deciding to enter the market in the last five rounds of the treatment. This proportion is significantly lower than in Im5. For the treatments with the deferred booking system, the equilibrium predicts that scalpers do not enter the market. We find that 20.5% of scalpers enter in Def5 and 7.5% in Def3 in the last five rounds of the treatment. This is significantly lower than in Im5 and Im3 in the last five rounds.[32]

Summing up, the scalpers are less likely to enter the market in the deferred system than in the immediate system, and in the case of low demand than in the case of excess demand.

The within-subject design allows us to study how scalpers react to changes in the booking system and how experience affects their choices. By comparing the first block of five rounds to the second block, we observe that the proportion of scalpers entering the market decreases significantly with experience in Def5 ($p<0.01$). In all other treatments the number of scalpers is not significantly different in the first five relative to the last five rounds of each treatment.[33] In Def5 market entry

[32] All pairwise comparisons of the proportion of scalpers entering the market 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 with standard errors clustered at the level of matching groups and with a sample restricted to the treatments that are of interest for the test.

[33] The p-values are $p=0.29$ for Im5, 0.68 for Im3 and 0.13 for Def3.

not only decreases between blocks (from 29 to 6 out of 40 scalpers in the first versus the last round), but the decrease sets in already within the first block. Since the first block of Def5 is preceded by Im5 and Im3 where entry is (weakly) profitable, the decline in entry within the first block of Def5 reflects the adjustment of scalpers to the deferred system where entry is unprofitable. In Def3 which follows after Def5, we do not observe a similar decrease due to the small proportion of scalpers entering the market in the initial rounds in the first place.

We summarize these findings in

Result 1 (Market entry): *In the second block of each treatment, the proportion of scalpers entering the market is highest in Im5, followed by Im3, while entry is lowest in Def5 and Def3.*

4.1.1 Profits of scalpers

Are the scalpers' entry decisions optimal? To answer this question, we turn to the analysis of the scalpers' profits. Figure 3 shows the average profits per round. Only treatment Im5 leads to positive average profits of the active scalpers both in theory and in the data from the second block. However, the realized profits are lower than predicted: equilibrium profits are 70.34 while average profits in the second block are 22.8, with 36.5 in the last round of the treatment.[34] Similarly, in Im3 profits are lower than predicted in equilibrium, since they remain negative even in the second block of the treatment.

Now, consider the profits of the scalpers in the deferred system. In equilibrium the scalpers do not enter the market, and thus the equilibrium profits are zero. We observe negative average profits of -22.7 in Def5 and of -10 in Def3 in the second block of the treatment.[35] These negative average profits are due to 20.5% of scalpers in Def5 and 7.5% in Def3 who enter the market in the second block despite its being unprofitable.[36]

The main finding can be summarized as

Result 2 (Profits of scalpers): *In the second block of each treatment, scalpers make positive profits only in Im5.*

Figure 3 also displays that profits increase in all four treatments. In Im5, the average profit increased from -26.75 in the first to 22.8 in the second block of the treatment ($p<0.01$). Note that making profits in the immediate system requires scalpers to book the entire supply of slots

[34] In round 3 of Im5, profits are especially low. Out of 35 firms who enter the market, 16 (46%) set a price higher than in equilibrium, such that all their seekers have valuations lower than the price. Even for those firms who have set a price below the valuations of some seekers, only 38% of those seekers that are supposed to buy the service actually buy it. Thus, some seekers boycott the scalper.

[35] This difference is marginally significant. For all tests regarding Result 2, we use p-values for the coefficient of the dummy of interest in an OLS regression of the round profits of scalpers with standard errors clustered at the level of matching groups and a sample restricted to treatments that are of interest for the test.

[36] In 68 out of 137 rounds with entry in Def5, no slots were sold to appointment seekers, leading to a loss of 150 points. In only two of the 137 rounds, the scalpers were able to make a positive profit of 15 points. In Def3 no slots were sold in 35 out of 46 rounds, leading to a loss of 150 points, and there were no rounds with positive profits.

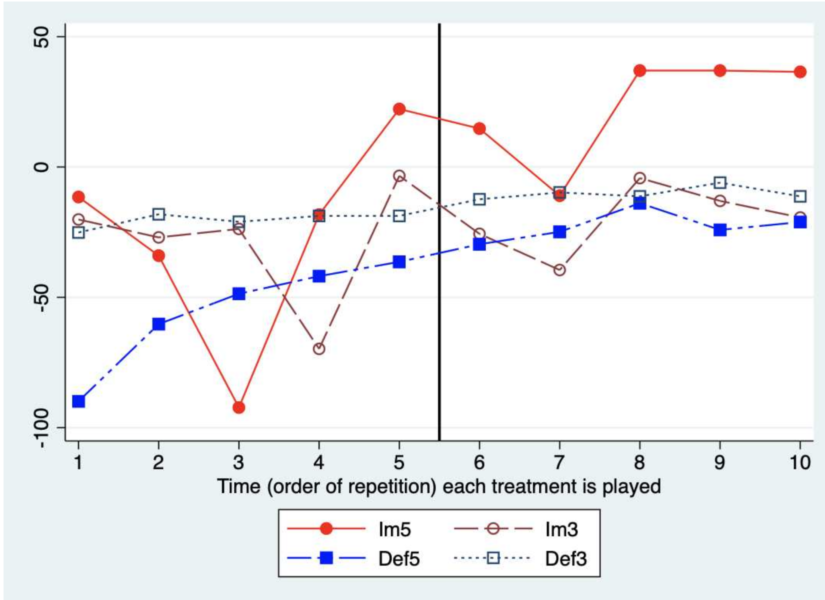

Figure 3: Average profits of scalpers

Notes: Rounds 1-5 form the first block while rounds 6-10 form the second block of a given treatment. The black vertical line separates the first and the second blocks.

in order to prevent appointment seekers from acquiring a slot directly. Appointment seekers need to anticipate this behavior when they decide whether to buy the service from the scalper in the first step of the system. It takes time for scalpers and appointment seekers to converge to this equilibrium in Im5, which explains the negative profits of the scalpers in the first five rounds of Im5. Note also that some scalpers (around 20% in the last five rounds) decided not to participate in the market after experiencing losses for several rounds in a row, which lowers average profits in Im5. In Im3 the increase in profits is smaller (from -28.8 in the first to -20.3 in the last round) and only marginally significant (p=0.09).[37] In the deferred system, profits increase especially in Def5, played before Def3, since scalpers have to learn that entering is not profitable.

4.1.2 Scalpers' booking and pricing decisions

For a complete picture of the scalpers' behavior, we analyze the prices they choose and whether they book slots in line with the equilibrium predictions.

In both treatments with the immediate system, the scalpers started out with prices above the equilibrium. In Im5 they decreased the price, leading to an average price lower than in equilibrium in the second block of the treatment. In contrast, in Im3 despite a decrease, the prices remained above the equilibrium.[38]

[37]In the immediate system, if only the profits of the firms which enter the market are considered, the increases are sharper than if all firms are considered. In Im5, the average profit increased from -32 in the first five to 29 in the last five rounds of the treatment (p<0.01). In Im3 the increase is from -59 to -44, but still statistically significant (p=0.04).

[38]In the appendix, Figure 8 shows the average prices of scalpers entering the market by rounds of a given treatment

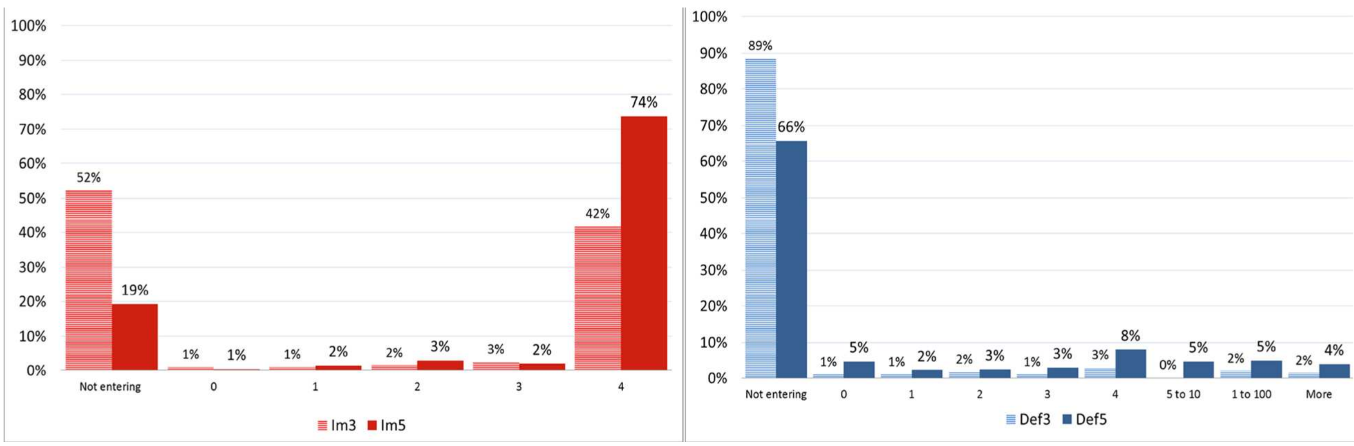

Figure 4: Number of slots booked by the scalpers.

Notes: The bars show the distribution of slots booked upon entry and of no entry for every treatment. The percentages add up to 100%. A bar indicating 1% corresponds to four decisions in the experiment.

Next, we consider the booking decisions of the scalpers. Figure 4 shows the distribution of the number of slots booked, separately for both booking systems and demand conditions. The left-hand panel of Figure 4 shows the distribution for Im3 and Im5. In 19% and 52% of the rounds, respectively, the scalpers did not enter the market. Once they entered, the scalpers booked the entire supply of four appointment slots in 87% and 92% of the cases in Im3 and Im5, respectively. This behavior is close to the equilibrium prediction of 100%. Comparing the booking decisions of the first and second block of Im3, the proportion of slots booked conditional on entering increases from 82% to 94% (two-sided Fisher exact p=0.02). In Im5 the proportion increases from 87% to 96% (two-sided Fisher exact p=0.01). Thus, we conclude that in the immediate system almost all scalpers who entered the market booked according to the equilibrium prediction.

The right-hand panel of Figure 4 shows the distribution of the number of slots booked in Def3 and Def5. The scalpers did not enter the market in 89% and 66% of rounds, respectively. Thus, the majority of choices are in line with the equilibrium prediction. Comparing the proportions of equilibrium decisions of not entering in the first five and the last five rounds of each treatment, in Def5 the proportion of equilibrium behavior increases from 52% to 78% (the difference is significant, two-sided Fisher exact p=0.02). In Def3 equilibrium choices increase from 84.5% to 92.5% (two-sided Fisher exact, $p<0.01$).

How many slots do scalpers book conditional on out-of-equilibrium entry in the deferred system? In 41% and 36% of cases in Def5 and Def3, respectively, scalpers try to block the system by submitting 10 or more applications, thus making it unlikely that appointment seekers can receive a slot directly. In 24% and 27% of cases in Def3 and Def5, respectively, scalpers book exactly four slots, which points to a failure to recognize the difference between the two systems. In general, scalpers fail to follow the continuation equilibrium of Proposition 3: in total only 33% and 22% of

and the results of statistical tests. It also displays the prices in the two treatments with the deferred mechanism, in spite of the small number of observations.

booking decisions of scalpers are in line with the continuation equilibrium prediction.

Thus, we observe an asymmetry between the two systems: in the immediate system the most frequent deviation from equilibrium behavior is not entering the market, while among those who enter, almost all scalpers book in line with equilibrium. In the deferred system, almost all scalpers take the equilibrium decision of not entering, but those who enter do not play the continuation equilibrium of Proposition 3.

The main findings on booking choices by scalpers are summarized in

Result 3 (Booking by scalpers):

(i) (Immediate system) In almost 90% of cases after equilibrium entry, the scalpers book all four slots, which is the equilibrium booking strategy.

(ii) (Deferred system) Only in 33% and 22% of booking decisions after out-of-equilibrium entry (which occurs in 34% and 11% of rounds in Def5 and Def3, respectively), is the scalpers' booking strategy in line with the continuation equilibrium.

4.2 Appointment seekers

In this section, we investigate the results from the point of view of the appointment seekers. First, we consider their decisions to buy the service from the scalper. Then, we study the welfare of appointment seekers, as well as the total number of slots allocated to them.

4.2.1 Appointment seekers' purchase decisions

In the immediate system, the appointment seekers should buy the scalper's service whenever the price is lower than their valuation. In Def3 and Def5, the optimal decision in the continuation equilibrium also depends on the price: the higher the price, the higher the valuation of the slot that is necessary to buy the service in equilibrium. Figure 5 shows the average proportion of equilibrium decisions by appointment seekers. The left part of the figure displays the proportion of equilibrium decisions when the equilibrium prescribes not buying the scalper's service. In Im3 and Im5, 95% and 94% of decisions are in line with the equilibrium. In Def3 and Def5 the proportions of equilibrium decisions when not buying is a continuation equilibrium are 72% and 85%.

The right panel of Figure 5 shows the proportions of equilibrium behavior of appointment seekers when the equilibrium prescribes buying the scalper's service. First, in all treatments the proportions are lower than in the left panel, i.e., when seekers do not buy the service in equilibrium, and these differences are significant in Im3, Im5 and Def3 (all p-values <0.01).[39] Thus, appointment

[39] For all tests regarding treatment differences in proportions of equilibrium behavior summarized in Result 4, we use p-values for the coefficient of the dummy of interest in probit regressions of the proportions of seekers taking equilibrium decisions. Standard errors are clustered at the level of matching groups, and the sample is restricted to the treatments of interest.

seekers were more likely to apply directly when they should apply directly than to buy the service of the scalper when they should buy it. In Im3 and Im5, the appointment seekers do not buy the service of the scalper despite their valuation being higher than the price of a slot in 26% and 24% of the cases, respectively. Appointment seekers may have refrained from buying a slot from the scalper because they did not expect the scalpers to book all the slots. Alternatively, it is possible that they wanted to punish the scalper for blocking the entire supply of appointments. The average forgone profit of appointment seekers who chose not to buy the scalper's service despite the price being lower than their valuation is 18 and 16 points in Im3 and Im5, respectively.

In Def3 and Def5, the continuation equilibrium predicts that seekers buy the service only when their valuation of a slot is high compared to the price. The only reason to buy the scalper's service in the deferred system is to stop the scalper from blocking the system by submitting many fake applications. We observe that appointment seekers do not buy the scalper's service in 50% to 60% of the cases where the continuation equilibrium prescribes buying it, as shown in Figure 5. It should be noted that the number of such decisions in Def5 and Def3 is relatively small, because the majority of scalpers take the equilibrium decision to stay out of the market and because in equilibrium it is predicted that only one seeker will buy from the scalper.

Overall, we observe that the proportion of equilibrium decisions of appointment seekers is higher under the immediate system than under the deferred system (p-values for comparison of Im5 and Def5, and comparison of Im3 and Def3 $<$0.01). The continuation equilibrium of Proposition 3 does not find support. We interpret this as evidence in favor of the deferred system. Even under unrealistic parameter constellations where entry of scalper is an equilibrium, our results show that this equilibrium is unlikely to occur, as it is not supported either by the equilibrium booking strategy of scalpers, nor by the equilibrium buying behavior of seekers.

Next, we study the determinants of the purchase decisions of appointment seekers with the help of regressions. Table 3 presents probit regressions of the dummy for buying from the scalper. The sample is restricted to all rounds in which the scalper is active in the market. Over time, there is a tendency to buy more often in Im5, and to buy less often in Def5. The coefficients for the valuation of slots and the price are significant in each treatment with the predicted sign, except for Def3. In Def3 the coefficients are only marginally significant or not significant due to the small sample size caused by many scalpers staying out of the market. The last explanatory variable shows that blocking the system (by booking all slots in the immediate system or booking at least 10 slots in the deferred system) in the previous round is correlated with more seekers buying the service from the scalper in the immediate system, but not in the deferred system. Thus, the seekers understand that the scalpers' attempts to threaten them in the deferred system are empty.

Result 4 (Purchase decisions of appointment seekers):

(i) The proportion of seekers who take equilibrium purchase decisions is higher in the immediate than in the deferred system, for both demand conditions.

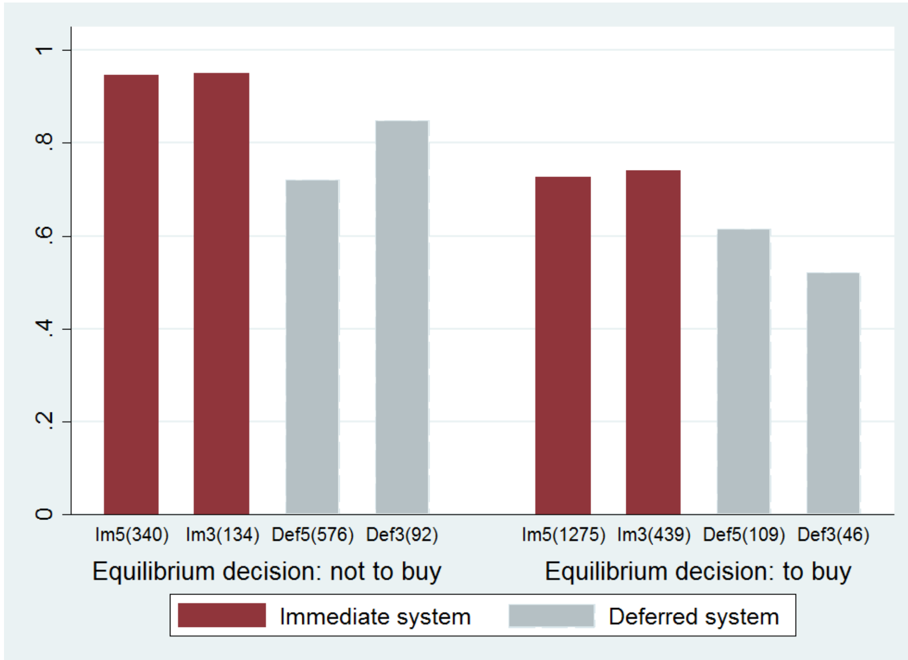

Figure 5: Proportion of equilibrium purchase decisions by appointment seekers
Notes: The numbers in brackets next to the treatments correspond to the sample size for the respective column.

Table 3: Purchase decisions of appointment seekers

re	(1) Im5	(2) Im3	(3) Def5	(4) Def3
Time played	.02**	-.00	-.02*	-.02
	(.01)	(.01)	(.01)	(.02)
Valuation for a slot	.02***	.02***	.01***	.01*
	(.00)	(.00)	(.00)	(.00)
Price of service	-.02***	-.02***	-.01***	-.00
	(.00)	(.00)	(.00)	(.00)
Scalper booked all slots (Im)	.33***	.24***	-.02	.11
or blocked in previous round (Def)	(.06)	(.08)	(.07)	(.17)
Observations	1440	510	540	117
No. of clusters	39	31	28	10
log(likelihood)	-641.35	-249.12	-293.86	-59.11

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: 'Scalper books all slots' or 'blocked in previous round' is a lagged dummy for booking all four slots in the immediate system and submitting more than 10 applications in the deferred system.

(ii) The proportion of seekers who do not buy is higher when not buying is the equilibrium decision given the scalper's price compared to when the seeker is predicted to buy in Im5, Im3, and Def3.

(iii) Appointment seekers are more likely to buy the service of the scalper the higher their valuation is in all treatments and the lower the price is in treatments Im3, Im5, and Def5.

(iv) In the immediate system, the probability of an appointment seeker buying the service is higher if the scalper booked the entire supply of slots in the previous round. This is not the case in the deferred system.

4.2.2 Payoffs of appointment seekers

We now turn to the payoffs earned by the appointment seekers as a measure of their welfare. In order to make the average payoffs of appointment seekers comparable between the treatments with different demand conditions, we normalize the payoffs a follows: In Im3 and Def3 normalized payoffs correspond to the real profits of the appointment seekers in each round of the experiment. For Im5 and Def5, only four out of five active appointment seekers can potentially earn positive payoffs in each round, and thus we normalize the realized payoffs by dividing them by 0.8. These normalized payoffs can be directly compared between all four treatments.

There are a number of effects that determine the welfare of appointment seekers. On the one hand, the presence of scalpers in the immediate system with an excess demand for slots (Im5) ensures that appointments are allocated to the seekers with the highest valuations. On the other hand, the price of the service decreases the payoffs of the appointment seekers. In the deferred system, we do not expect any scalpers to enter the market. However, if scalpers enter the market they can block the full supply of slots. In our parametrization of the game, the equilibrium payoffs of seekers are highest in the deferred system (75 points), followed by Im3 and Im5 with 25 and 18.35 points, respectively, see Table 2.

Figure 6 shows the average payoffs of appointment seekers by treatments. It emerges that as predicted the deferred system leads to significantly higher normalized payoffs for appointment seekers than the immediate system, and seekers fare worst in Im5. All pairwise comparisons of treatments with different booking systems yield significant differences in the last five rounds of each treatment ($p<0.01$) except for the payoffs in Def3 and Def5 ($p=0.18$).[40]

Regarding absolute welfare levels, the observed average normalized payoffs in the second block of each treatment are 74 and 69 in Def3 and Def5, compared to the prediction of 75. Thus, in the deferred system the payoffs of appointment seekers are slightly below the equilibrium payoffs in the second block. In Im3 and Im5, the observed payoffs of the appointment seekers are higher than

[40] For all tests leading to summarized in Result 5 we use p-values for the coefficient of the dummy of interest in an OLS regression of profits of appointment seekers with standard errors clustered at the level of matching groups and the sample restricted to treatments of interest for the test.

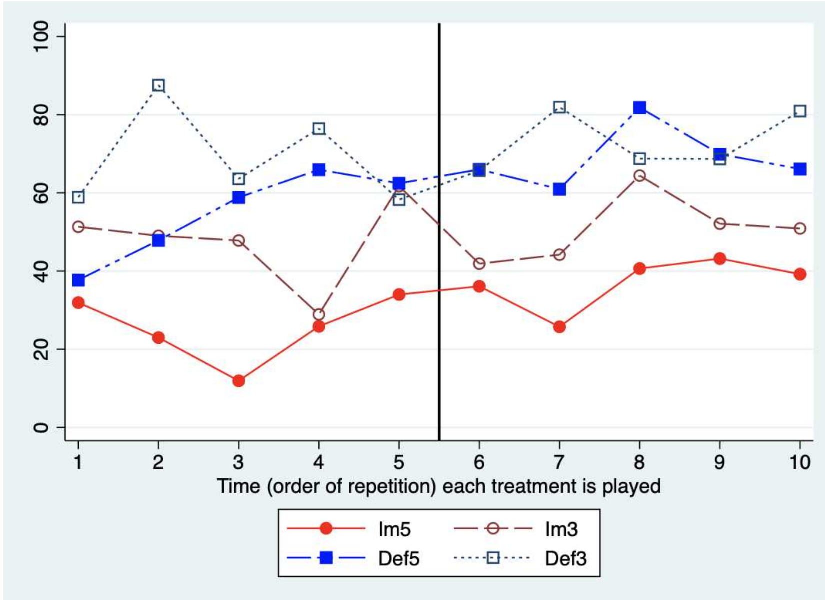

Figure 6: Average payoffs of appointment seekers

Notes: Rounds 1-5 form the first block while rounds 6-10 the second block of a given treatment. The black vertical line separates the first and second block. The payoffs of seekers in Im5 and Def5 are normalized, dividing them by .8, since by design only four out of five appointment seekers can obtain a slot, while in Im3 and Def3, all three seekers can obtain a slot.

in equilibrium, namely 37 instead of 18 in Im5 and 55 instead of 25 in Im3. The deviations from equilibrium are explained by the over-entry of scalpers in treatments with the deferred system, and by under-entry in treatments with the immediate system. Note that the under-entry of scalpers in the immediate system over-compensates the appointment seekers for the payoff lost due to their out-of-equilibrium buying decisions.

Summing up, Result 5 states that if the designer cares about the utility of appointment seekers, she should implement the deferred system:

Result 5 (Payoffs of appointment seekers): *The normalized average payoffs of appointment seekers are higher in the deferred than in the immediate system for given demand in the second block.*

As for the effect of experience, comparing the first five to the last five repetitions of each treatment, the payoffs of appointment seekers are significantly higher in the last five rounds of Im5 and Def5 ($p<0.01$ in both treatments). In Def5 this is mostly explained by significantly fewer scalpers entering the market. In Im5, it is explained by a combination of factors: the scalpers lowering the prices and the appointment seekers buying more often in line with the equilibrium. Note that in Im5, both the appointment seekers' and the scalpers' payoffs are higher in the second block than in first block. This is due to fewer fake IDs submitted in later rounds.

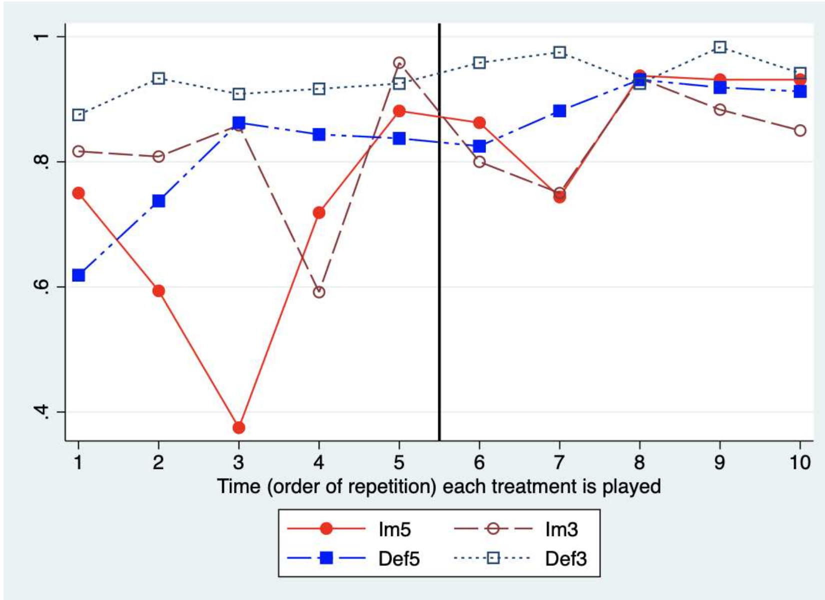

Figure 7: Proportion of slots that were allocated
Notes: Rounds 1-5 form the first block while rounds 6-10 the second block of a given treatment. The black vertical line separates the first and second block. The proportions are normalized in Im3 and Def3.

4.3 Welfare

4.3.1 Allocation of slots

Which system is preferable if the designer cares about the overall efficiency of the allocation and is indifferent as to how the profits are split between the appointment seekers and the scalpers? First, we compare the number of slots allocated to appointment seekers by treatments. Again, we normalize the proportions of slots allocated in Im3 and Def3.

Figure 7 presents the normalized proportion of slots allocated to appointment seekers by treatments. It includes both the slots which were assigned through the scalper and the slots that the appointment seekers received directly.

In the treatments with excess demand, Im5 and Def5, both systems converge to around 90% of slots being allocated. In Im5 the 10% unfilled slots are explained by some appointment seekers refusing to buy the service if the difference between the price and their valuation is low, while the unfilled slots in Def5 are due to some scalpers entering the market and blocking the system.

In the treatments with an excess supply of slots, Im3 and Def3, the deferred system leads to a higher proportion of slots allocated in the last five rounds ($p<0.01$).[41] In Im3 around 15-20% of the slots are not filled (excluding slots that are in excess of demand) due to scalpers entering the market and setting a price higher than in equilibrium, together with the seekers' tendency to refuse to buy slots if the difference between price and valuation is low. In Def3, we observe a loss

[41] Result 6 is based on the p-values of the coefficient of the treatment dummy in a probit regression of the proportion of slots allocated to visa seekers on this dummy, with standard errors clustered at the level of matching groups and the sample restricted to the treatments of interest for the test.

of around 5% of slots in the last block of the treatment, which is explained by the irrational choice of some scalpers to enter the market despite losses and to block the system with fake applications.

As for the effect of experience, the figure shows that the proportion of slots allocated is increasing in Im5 and Def5. In Im5, the appointment seekers started to buy the scalper's service after round 3 in which almost no slots were sold. They understood that the only way to get a slot was through the scalper. In Def5 the increase in the number of slots allocated is explained by the fact that scalpers stopped entering the market, and thus most slots were allocated directly.

Result 6 (Slots allocated to seekers):

(i) In the second block with high demand, the proportion of slots allocated to appointment seekers is almost identical in both systems at around 90%. It is significantly higher in the deferred system than in the immediate system in the second block with low demand.

(ii) The proportion of slots allocated to appointment seekers increases significantly from the first to the second block of Im5 and Def5.

4.3.2 Who gets a slot?

For the sake of completeness, we also show which seekers get a slot under the two booking systems. It could be argued that the allocation of slots to seekers with the highest valuation is a desirable policy objective. While we think that the contexts we have in mind for our study exclude this, it is conceivable that in other contexts, a welfare analysis should include the valuations of seekers. We therefore also analyze the allocations from this perspective.

First, we define for each seeker in each round an ordinal rank based on her valuation of a slot compared to the other seekers who are active in this round. Thus, the seeker with the highest valuation in a given round receives an ordinal rank of one, the seeker with the second highest valuation receives a rank of two, and so on.[42] Thus, in Im5 and Def5 we have ranks from one to five, and in Im3 and Def3 ranks from one to three.

Table 4 presents the average ranks based on the valuation of a slot of all seekers receiving a slot by treatments. We partition the sample with respect to the total number of seekers assigned in a round. Comparing Im5 and Def5, the average rank of assigned seekers is lower in Im5 than in Def5, that is, seekers who value the slots more highly in relative terms receive a slot in Im5 compared to Def5. The difference is not significant in rounds with one seeker receiving a slot ($p=0.17$) but is significant for rounds with two, three, and four seekers receiving a slot ($p<0.01$). As for the difference between Im3 and Def3, the difference goes in the same direction, and is significant for the rounds with one seeker being assigned ($p=0.01$). Thus, the presence of scalpers and prices has the expected effect: in the immediate system the seekers with higher evaluations receive slots, since they are more likely to pay the price of the scalpers' service.

[42] If seekers have equal valuations, they are assigned the average of two ranks. For instance, if two seekers have the highest valuation in a round, they are both assigned a rank of 1.5.

Table 4: Average ranks of seekers who received a slot

Rounds with	Im5	Im3	Def5	Def3
... one seeker receiving a slot				
Average rank of assigned seekers	1.68	1.37	2.37	1.88
Number of rounds	28	43	16	13
... two seekers receiving a slot				
Average rank of assigned seekers	2.10	1.70	3.07	1.84
Number of rounds	54	64	31	14
... three seekers receiving a slot				
Average rank of assigned seekers	2.41	2.00	3.03	2.00
Number of rounds	68	273	31	360
... four seekers receiving a slot				
Average rank of assigned seekers	2.88		3.01	
Number of rounds	224		292	

Note: The table displays the average rank based on the valuations of the seekers who obtain a slot.

Result 7 (Allocation of slots to the seekers with the highest valuations): *Seekers with relatively higher valuations are assigned slots in the immediate system compared to the deferred system.*

5 Discussion and conclusions

This paper considers a novel application for market design, namely the allocation of appointment slots with online booking systems. We study a widespread problem of such markets, namely the possibility of scalping in the frequently used first-come-first-served online booking system. We model the booking problem and the first-come-first-served system. An alternative mechanism is proposed that in theory does not allow for profitable market entry by scalpers.

We run an experiment to test whether switching to the new system renders scalping unprofitable. The experiment makes three points. First, it shows that students in the role of scalpers make profits in the immediate system when demand is high, despite the attempts of the seekers to boycott them and to not buy their service. We infer from this that the profit opportunities are straightforward to understand, explaining the presence of scalpers in first-come-first-served online booking systems around the world. Second, scalpers have at least as much power in our experiment as in real life since they can block the system in order to convince the seekers to use their service. Thus, we believe that the experimental test of the deferred system is valid. If scalping is not profitable in our experiment, it should also be unprofitable under less favorable conditions in real life. The reason is that the new mechanism ensures that this blocking strategy cannot work. For a given number of applications submitted by the scalper, every seeker has the same chance of getting a slot independent of whether she uses the service of the scalper or not. Thus, a seeker will never buy from the scalper.

Third, the experiment shows that appointment seekers understand the difference between the systems, leading to the predicted results with respect to the market entry of scalpers. This finding is meaningful, since it is not trivial either for the scalpers or for the appointment seekers to realize the shift of market power from the scalper to the seekers when moving from the immediate to the deferred system. The switch to the deferred system mostly results in a change of the purchasing behavior of the seekers who are no longer willing to buy from the scalper. We interpret the experiment as indicating that in existing assignment markets, even if the seekers continue to use the scalper's service at first, they probably learn quickly to apply for slots directly, thereby forcing the scalper out of the market.

A number of modifications of the deferred system could be introduced to make it more seeker-friendly. For example, seekers may be given the opportunity to express their preferences for particular time slots. A lottery mechanism such as the random serial dictatorship or the probabilistic serial (Bogomolnaia and Moulin, 2001) can then be used to allocate slots based on these lists. Moreover, if excess demand is severe, the system can be designed such that seekers with longer waiting times or urgent needs receive more lottery tickets. This gives them a higher probability of receiving a slot.

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. The solution also sheds light on potential ways to deal with black markets in other contexts. For instance, tickets for big sports events and concerts 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. Scalping occurs because prices are below the market-clearing price. Artists and tickets platforms make attempts to fight scalping, e.g., by offering tickets to official fans only, but the resale business profit estimates are eight billion a year in the US alone.[43] 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. A mechanism that is similar to the deferred system has been used for the allocation of tickets for the Soccer World Cup 2018, for instance. The FIFA collected applications for tickets for each match and category, and in case of overdemand for a specific match and price category, a lottery decided who received the tickets. However, scalping was still observed. To avoid scalping, the IDs of ticket holders would have to be checked at the entrance of the stadium ID checks do not impose a large cost in the case of appointments at public offices, but they can be much harder to implement for sports events and concerts. While organizers commonly state that ID verification will be in place, de facto they tend to shy away from imposing the rule. Among the reasons may be the desire to fill the stadium or the additional cost of implementing the ID

[43] See https://www.theatlantic.com/business/archive/2015/12/adele-scalpers/421362/. The webpage was accessed on April 5, 2019.

checks.[44] It can also be observed that scalpers and people leaving messages on internet forums try to convince ticket buyers that ID checks will not take place. A potential solution could be to check the IDs of a small number of randomly selected people and commit to refusing entry for 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.

A Proofs

A.1 Proof of Proposition 1: Equilibrium of the immediate system

We construct a Bayesian Nash equilibrium. To this end, we have several claims.

Claim 1. Given the entry of the scalper, for each $p \in \mathcal{P}$ and each number of buyers, $n_b \in \{0, \ldots, n\}$, the profit does not depend on seekers' types, and it is optimal for him to make $\alpha(p, n_b) = m$ applications.

Proof. We calculate the profit from making a applications where $0 \leq a \leq m$ in the following two cases. When $m < n_b$, the profit is $pa - c$. On the other hand, when $n_b \leq m$, the profit is $pa - c$ for $a \leq n_b$; $pn_b - c$ for $n_b < a \leq m$. Thus, in any case, $a = m$ is optimal. □

We focus on a Bayesian Nash equilibrium in which a seeker uses a symmetric strategy, denoted by $\beta(p; v)$, with the cutoff $\hat{v}(p)$ that takes the following form: For each $p \in \mathcal{P}$, there is some $\hat{v}(p) \in [\underline{v}, \overline{v}]$ such that

$$\beta(p; v) = \begin{cases} \text{direct application} & \text{if } v \leq \hat{v}(p), \\ \text{buying} & \text{if } v > \hat{v}(p). \end{cases}$$

To obtain simple expressions, we introduce the following notation: for each $\tilde{n} \in \mathbb{N}$, each $k \in \{1, \ldots, \tilde{n}\}$, and each $\tilde{v} \in [\underline{v}, \overline{v}]$,

$$q_{\tilde{n},k}(\tilde{v}) = \binom{\tilde{n}}{k} F^{\tilde{n}-k}(\tilde{v})(1 - F(\tilde{v}))^k.$$

Here, the value $q_{\tilde{n},k}(\tilde{v})$ is the probability that out of $\tilde{n}$ seekers, $(\tilde{n} - k)$ seekers have valuations below $\tilde{v}$ and k seekers have valuations above $\tilde{v}$.

[44] A related problem concerns scalpers booking tables in popular restaurants under fake names. The tables are offered on a website, and customers who pay for the slot learn the fake name under which the reservation was made. The restaurants often do not receive any of the fees, 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 the scalpers could still re-book the canceled slots under the real name of the customers.Under the deferred system with checking of IDs, scalping is no longer possible. On the other hand, restaurants are not necessarily concerned about the way their tables are allocated, and might even be interested in selecting clients with the highest willingness to pay for the table.

Claim 2. Given that the scalper enters the market with any price p and the number of applications $a = m$, when the cutoff is $\hat{v}(p, a) = p$, the symmetric strategy is optimal for a seeker.

Proof. Each seeker knows her own valuation v and faces $(n-1)$ other seekers. Suppose that the other seekers follow a strategy β with the cutoff function $\hat{v}$. We calculate the expected utility of type v both for the case of applying directly and for the case of buying from the scalper.

Suppose that she makes a direct application. Since all of the m slots are obtained by the scalper ($\because a = m$), she has no chance of getting a slot. Thus her utility from a direct application is zero.

Suppose next that she buys the service. Then, the number of slots available for buyers is m. Consider the event in which she faces k buyers and $(n-1-k)$ direct applicants. The probability of this event is $q_{n-1,k}(\hat{v}(p))$. Moreover, conditional on this event, when $k+1 \leq m$, she is certain to obtain a slot. On the other hand, when $k+1 \geq m+1$, she gets a slot with probability $\frac{m}{k+1}$. Thus, her expected utility from buying is

$$\text{if } n > m, \quad \left(\sum_{k=0}^{m-1} q_{n-1,k}(\hat{v}(p)) + \sum_{k=m}^{n-1} \frac{m}{k+1} q_{n-1,k}(\hat{v}(p)) \right) (v - p), \tag{1}$$

$$\text{if } n \leq m, \quad v - p. \tag{2}$$

A seeker whose type is the cutoff $\hat{v}(p)$ is indifferent between direct application and buying. Thus, the value of (1) and (2) should be equal to zero. Thus, $\hat{v}(p) = p$. □

Given the behavior of the scalper with his m applications and the behavior β of a seeker as Claims 1 and 2, the profit $\pi(p)$ of the scalper in setting price p is

$$\pi(p) = \begin{cases} \sum_{k=0}^{m} q_{n,k}(p)\, p\, k + \sum_{k=m+1}^{n} q_{n,k}(p)\, p\, m - c & \text{if } n > m, \\ \sum_{k=0}^{n} q_{n,k}(p)\, p\, k - c & \text{if } n \leq m. \end{cases} \tag{3}$$

Since the profit function is continuous on the compact set $\mathcal{P}$, there is a price, denoted by p^*, that maximizes the profit (3).

Therefore, by the above discussion, it is straightforward to see that the strategy profile described in Proposition 1 is a Bayesian Nash equilibrium.

A.2 Proofs of Propositions 2 and 3: Equilibria of the deferred system

We derive two kinds of Bayesian Nash equilibria in this subsection.

Claim 3. Suppose that the scalper enters the market with a price $p \in \mathcal{P}$ and n_b seekers buy the service. Then the profit does not depend on seekers' types, and an optimal number of applications by the scalper is

- any non-negative integer between 0 and $Q - n_d$ when $n_b = 0$;

- any integer between n_b and $m - n_d$ when $n_b > 0$ and $n \leq m$;
- n_b when $n_b > 0$ and $n > m$.

Proof. Let a be any number of applications made by the scalper. Note that $0 \leq a \leq Q$ by our assumption. Denote by $\pi(a)$ the profit of the scalper from making a applications.
Case 1: $n_b = 0$. Then, $\pi(a) = 0 - c$. Thus, an optimal number is any integer $a \in [0, Q - n_d]$.
Case 2: $n_b > 0$ and $n \leq m$. Then, note that $n_d + n_b \equiv n \leq m$ so that we have $n_b \leq m - n_d$.

$$\pi(a) = \begin{cases} pa - c & \text{if } a \in [0, n_b], \\ pn_b - c & \text{if } a \in [n_b, m - n_d], \\ p\frac{m}{a+n_d}n_b - c & \text{if } a \in [m - n_d, Q]. \end{cases}$$

Thus, an optimal number is any integer $a \in [n_b, m - n_d]$.
Case 3: $n_b > 0$ and $n > m$. Then, note that $n \equiv n_b + n_d > m$ so that we have $m - n_d < n_b$.

$$\pi(a) = \begin{cases} pa - c & \text{if } a \in [0, m - n_d], \\ p\frac{m}{a+n_d}a - c & \text{if } a \in [m - n_d, n_b], \\ p\frac{m}{a+n_d}n_b - c & \text{if } a \in [n_b, Q]. \end{cases}$$

Then, $\pi(a)$ is strictly increasing in $[0, n_b]$ and strictly decreasing in $[n_b, Q]$. Thus the unique optimal number is $a = n_b$. □

Now we turn to the behavior of seekers.

Claim 4. Given that the scalper enters the market with a price p and makes $\alpha(p, n_b) = n_b$ applications for each n_b, a direct application is optimal for a seeker with type $v \in [\underline{v}, \overline{v}]$.

Proof. Each seeker knows her valuation v and faces $(n - 1)$ other seekers. We show that it is optimal for her to make a direct application regardless of the other seekers' behavior. Let the behavior of the other seekers be given. Denote by $\hat{n}_b$ and $\hat{n}_d$ the number of buyers and direct applicants among the other seekers, respectively. Note that $\hat{n}_b + 1 + \hat{n}_d = n$.
Case 1: $n \leq m$. Then, if the seeker makes a direct application, her payoff is v. If she buys, her payoff is $v - p$. Thus, a direct application is optimal for her.
Case 2: $n > m$. If the seeker makes a direct application then her probability of getting a slot is $\frac{m}{(\hat{n}_d+1)+\hat{n}_b}$ and thus her payoff is $\frac{m}{(\hat{n}_d+1)+\hat{n}_b}v$. On the other hand, if she buys then her probability of getting a slot is $\frac{m}{\hat{n}_d+(\hat{n}_b+1)}$ and thus her utility is $\frac{m}{\hat{n}_d+(\hat{n}_b+1)}v - p$. Thus, a direct application is optimal for her. □

Proof of Proposition 2. When the scalper enters the market, the scalper's choice of n_b applications is optimal by Claim 3. Given this, under Claim 4, all seekers will make direct applications. Then, the scalper's profit is $-c$ if she enters the market; 0 if he does not. Thus, the scalper does not enter the market. In the case that he enters, any price is optimal. □

We note that as described in Proposition 3, there is another Bayesian Nash equilibrium in which the scalper enters the market. For its precise description, we need several claims. Let $\beta(p; v)$ be a symmetric strategy with the cutoff function $\hat{v}(p)$ where $\beta(p, v) =$ direct application if $v \leq \hat{v}(p)$; $\beta(p, v) =$ buying if $v > \hat{v}(p)$.

Claim 5. Suppose that the scalper enters the market with any price p and makes Q applications when observing zero buyers, and makes n_b applications when observing any positive number of buyers. Let $\mathcal{P}^{**} = \{p \in \mathcal{P} \mid \left(\min\left\{1, \frac{m}{n}\right\} - \frac{m}{n+Q}\right)\overline{v} - p \geq 0\}$. Then, the symmetric strategy is optimal with the following cutoff $\hat{v}$:

1. If $p \in \mathcal{P}^{**}$, $\hat{v}$ is a unique solution to $\left(\min\left\{1, \frac{m}{n}\right\} - \frac{m}{n+Q}\right) xF^{n-1}(x) - p = 0$.
2. If $p \notin \mathcal{P}^{**}$, $\hat{v} = \overline{v}$. Thus, all types prefer a direct application to buying.

Proof. Each seeker knows her valuation v and faces $(n-1)$ other seekers. Suppose that the other seekers follow a symmetric strategy β with the cutoff function $\hat{v}$. For simple notation, we denote $\hat{v} = \hat{v}(p)$. We calculate the expected utility of type v.

Suppose that she buys. There is then at least one buyer and thus the scalper makes n_b applications for any n_b. Therefore, similarly to the calculation in the proof of Claim 4, the probability of her getting a slot is 1 if $n \leq m$; and is $\frac{m}{n}$ otherwise. Then, her expected utility is $\min\{1, \frac{m}{n}\}v - p$.

On the other hand, suppose she makes a direct application. Then, her expected utility is

$$
\begin{aligned}
& \left(q_{n-1,0}(\hat{v})\frac{m}{(n-1)+Q+1} + \sum_{k=1}^{n-1} q_{n-1,k}(\hat{v}) \min\left\{1, \frac{m}{n}\right\}\right) v \\
= & \left(F^{n-1}(\hat{v})\frac{m}{n+Q} + (1 - F^{n-1}(v)) \min\left\{1, \frac{m}{n}\right\}\right) v.
\end{aligned}
$$

Note that when $\hat{v} < \overline{v}$, a seeker with type $\hat{v}$ is indifferent between buying and applying directly; when $\hat{v} = \overline{v}$, she prefers direct application to buying. Thus, we have

$$
\begin{aligned}
& \min\left\{1, \frac{m}{n}\right\} \hat{v} - p \leq \left(F^{n-1}(\hat{v})\frac{m}{n+Q} + (1 - F^{n-1}(v)) \min\left\{1, \frac{m}{n}\right\}\right) \hat{v} \\
\Rightarrow & \left(\min\left\{1, \frac{m}{n}\right\} - \frac{m}{n+Q}\right) \hat{v}F^{n-1}(\hat{v}) - p \leq 0. \qquad (4)
\end{aligned}
$$

Define a function $f : [\underline{v}, \overline{v}] \to \mathbb{R}$ by

$$
f(x) = \left(\min\left\{1, \frac{m}{n}\right\} - \frac{m}{n+Q}\right) xF^{n-1}(x) - p.
$$

Then, f is strictly increasing, $f(\underline{v}) = -p < 0$, and $f(\overline{v}) = \left(\min\left\{1, \frac{m}{n}\right\} - \frac{m}{n+Q}\right)\overline{v} - p$.
Case 1: $p \in \mathcal{P}^{**}$. Then, $f(\underline{v}) < 0$ and $f(\overline{v}) \geq 0$. Since a seeker with the cutoff type $\hat{v}$ is indifferent between buying and direct application, we have $f(\hat{v}) = 0$. Thus, since f is strictly increasing, there is a unique such $\hat{v}$. Moreover, as $f(\hat{v}) = 0$, we have $\left(\min\{1, \frac{m}{n}\} - \frac{m}{n+Q}\right)\hat{v}F^{n-1}(\hat{v}) - p = 0$. Thus, since $0 < (\min\{1, \frac{m}{n}\} - \frac{m}{n+Q}) < 1$, we have $\hat{v}F^{n-1}(\hat{v}) > p$. Thus, since $0 < F^{n-1}(\hat{v}) \leq 1$, we have $\hat{v} > p$.
Case 2: $p \notin \mathcal{P}^{**}$. Then, $f(\overline{v}) < 0$. Thus, for each $v \in [\underline{v}, \overline{v}]$, since f is strictly increasing, $f(v) < 0$. Thus, all types prefer a direct application to buying. Thus, the cutoff is $\hat{v} = \overline{v}$. Moreover, since $f(\hat{v}) = f(\overline{v}) < 0$, we have $\left(\min\{1, \frac{m}{n}\} - \frac{m}{n+Q}\right)\hat{v} - p = 0$. Thus, since $0 < (\min\{1, \frac{m}{n}\} - \frac{m}{n+Q}) < 1$, we have $\hat{v} > p$. □

Given the applications made by the scalper and the behavior of seekers as in Claim 3 and Claim 5, the profit $\pi(p)$ of the scalper in setting price p is

$$\pi(p) = \begin{cases} -c & \text{if } p \notin \mathcal{P}^{**}, \\ \sum_{k=1}^{m} q_{n,k}(\hat{v}(p))kp - c & \text{if } n \leq m \text{ and } p \in \mathcal{P}^{**}, \\ \sum_{k=1}^{m} q_{n,k}(\hat{v}(p))\frac{m}{(n-k)+k}kp + \sum_{k=m+1}^{n} q_{n,k}(\hat{v}(p))\frac{m}{(n-k)+k}mp & \text{if } n > m \text{ and } p \in \mathcal{P}^{**}. \end{cases} \tag{5}$$

Note that the set $\mathcal{P}^{**}$ is compact. Since $\pi(p)$ is continuous on the compact set $\mathcal{P}^{**}$, there is a price, denoted by p^{**} that maximizes π in $\mathcal{P}^{**}$. Thus, there is a price, denoted by p^*, that maximizes π in $\mathcal{P}$.

Proof of Proposition 3. Now it is straightforward to obtain Proposition 2 from Claim 3 and Claim 5 and the above discussion. □

B Additional results

B.1 Prices of scalpers

The average prices in the first five rounds of the immediate treatments are 60.5 and 61.6 in Im5 and Im3, respectively. Prices are decreasing in the treatments with the immediate system, and the decrease is significant. The p-values for the difference in prices in the first five and the last five rounds of Im5 and Im3 are 0.00 and 0.03, respectively. For all tests regarding Result 3, we use p-values for the coefficient of the dummy of interest in the OLS regression of the prices of scalpers with standard errors clustered at the level of matching groups and a sample that is restricted to scalpers who entered the market and treatments that are of interest for the test.

The average prices in the second block of the treatments are 55 and 56.7 in Im5 and Im3, respectively. In equilibrium, the price in Im5 is 60, while the price in Im3 is 50. In the deferred

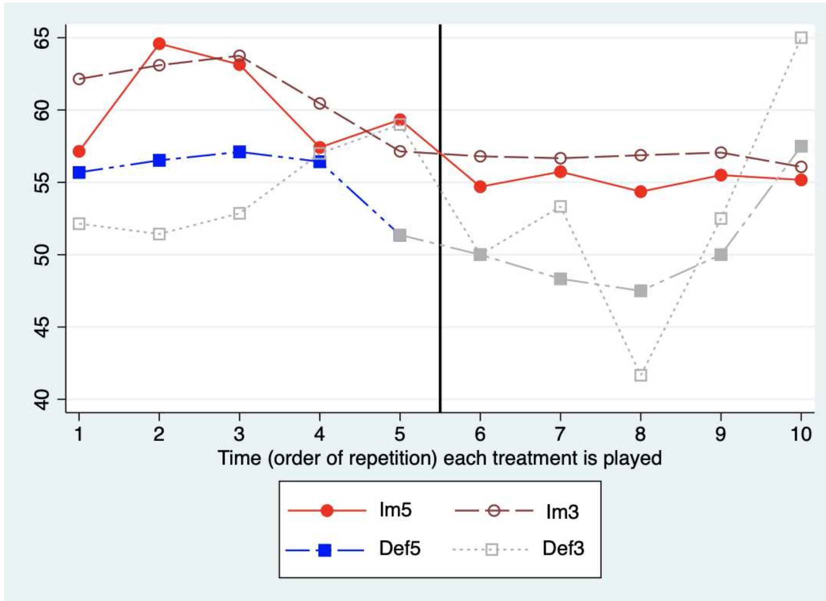

Figure 8: Prices of scalpers.

Notes: Rounds 1-5 form the first block while rounds 6-10 the second block of a given treatment. The black vertical line separates the first and the second blocks. Light gray lines stand for rounds in which less than 30% of scalpers entered the market.

system there are too few observations to have meaningful conclusions about pricing strategies of scalpers in the second block of each treatment, as less than 30% of scalpers enter the market.

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