Chinese College Admissions and School Choice Reforms: An Experimental Study*

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Abstract

Within the last decade, many Chinese provinces have transitioned from a 'sequential' to a 'parallel' college admissions mechanisms. Inspired by this natural experiment, we evaluate the sequential (immediate acceptance), parallel, and deferred acceptance mechanisms in the laboratory, treating each mechanism as a special case in a nested parametric family of mechanisms. We find that participants are most likely to reveal their preferences truthfully under the deferred acceptance mechanism, followed by the parallel and then the immediate acceptance mechanisms. While stability comparisons also follow the same order, efficiency comparisons vary across environments. These results confirm systematic changes in properties as the parameter of "tentativeness" varies and helps explain the recent reforms in Chinese college admissions and school choice.

Keywords: college admissions, school choice, immediate acceptance mechanism, Chinese parallel mechanism, deferred acceptance, experiment

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1 Introduction

School choice has been one of the most important and widely-debated education policies in the past two decades (Hoxby 2003), with game theory playing a major role in the adoption of school choice mechanisms. Some school districts have reexamined their school choice mechanisms after game theoretic analysis (Abdulkadiroğlu and Sönmez 2003, Ergin and Sönmez 2006) and experimental evidence (Chen and Sönmez 2006) indicated that one of the most popular school choice mechanisms, the Boston mechanism, is vulnerable to strategic manipulation and thus might not result in socially desirable assignments. Following intensive policy discussions, in 2003, New York City public schools decided to replace its allocation mechanism with a version of the student-proposing deferred acceptance (DA) mechanism (Gale and Shapley 1962, Abdulkadiroğlu, Pathak and Roth 2005b). Similarly, in 2005, the Boston Public School Committee voted to replace the existing Boston school choice mechanism with the deferred acceptance mechanism (Abdulkadiroğlu, Pathak, Roth and Sönmez 2005a).

Despite serious concerns regarding potential manipulation, the Boston mechanism remains a widely-used assignment tool and is the subject of a strand of literature that revisits the mechanism in various settings for both school choice[1] and college admissions[2]. In this paper, we strive to shed light on the sources of these different points of view regarding the Boston mechanism and its comparison to DA in light of the recent college admissions reforms in China where the Boston mechanism used to be the predominant assignment mechanism until the last decade. A mechanism that we believe could provide key insights is one pioneered in Hunan for college admissions and in Shanghai for high school admissions,[3] and later adopted by most of the provinces in China for college admissions.

Since 1952, China has implemented centralized college admissions, which is among the most intensively discussed public policies in the past thirty years. In the recent years more than 10 million high school seniors annually compete for approximately 6 million seats at various universities.

[1]In stylized models, Abdulkadiroğlu, Che and Yasuda (2011) and Miralles (2009) emphasize possible ex ante welfare advantages of the Boston mechanism relative to DA. Featherstone and Niederle (2008) and Fetherstone and Niederle (2008) confirm these predictions in the laboratory. Troyan (2012) shows that these findings are sensitive to the assumptions on the priority structure. Kojima and Ünver (2010) offer axiomatic characterizations of the Boston mechanism, whereas Kesten (2011) shows that, contrary to DA, the Boston mechanism is immune to manipulation attempts by schools through concealing capacity. Dur (2015) and Dur, Hammond and Morrill (2016) propose modifications to the Boston mechanism to reduce its gaming and increase its stability aspects.

[2]As we discuss below, the Boston mechanism used to be the only mechanism for college admissions in China. The current Chinese college admissions mechanisms not only differ in their matching algorithm but also in the timing of preference submission by students. Recent empirical and experimental studies such as Wu and Zhong (2014), Lien, Zheng and Zhong (2016), and Jiang (2016) find that if students submit preferences before taking the exam, the measurement error in the exam can be corrected via the Boston mechanism, which leads to matchings that are stable with regard to students' aptitudes.

[3]This mechanism was adopted in Shanghai for high school admissions in 2003, `http://edu.sina.com.cn/l/2003-05-15/42912.html`, retrieved on April 6, 2016.

The Chinese college admissions (CCA) mechanisms are centralized matching processes via standardized tests called *gaokao*, with each province implementing an independent matching process. These matching mechanisms fall into two classes: sequential and parallel. The sequential mechanism is a priority matching mechanism, executed sequentially across tiers in decreasing prestige. In the sequential mechanism, each college belongs to a tier. Within each tier, the Boston (or immediate acceptance) mechanism is used. When assignments in the first tier are finalized, the assignment process in the second tier starts, and so on. A common complaint about the sequential mechanism is that "a good score in the college entrance exam is worth less than a good strategy in the ranking of colleges" (Nie 2007).

To mitigate the problem of high-scoring students remaining unassigned and reduce the pressure about how to form preference rankings under the sequential mechanism, the parallel mechanism has been adopted by a majority of the provinces as an alternative to the sequential (or immediate acceptance) mechanism. In the parallel mechanism, students are provided with choice-bands in which they can place several "parallel" colleges. For example, a student's first choice-band can contain three colleges, A, B, and C (in decreasing desirability). Colleges process student applications by choice-bands, where no student loses his score advantage for any school he lists within the same choice-band until he is rejected from all schools in that choice-band. In China, this mechanism is widely believed to improve allocation outcomes and has been adopted by many provinces. We call the entire class of parallel mechanisms the *Chinese parallel mechanisms*. The intuitive appeal of the parallel mechanism over its predecessor, the immediate acceptance mechanism, comes from the fact that it allows students to entertain both risky and safe options in their preferences at the same time. For example, in the example given (with a band size of three), a students is given "three shots" , one of which can be used for a more desirable but risky option and another for a less desirable but safe option.

While variants of the parallel mechanisms, each of which differs in the pre-determined sizes of its choice-bands, have been implemented in different provinces, to our knowledge, they have not been studied before. In particular, we ask: when the band size varies, how do manipulation incentives, allocation efficiency, and stability change? We investigate this question experimentally in this paper and theoretically in a companion paper (Chen and Kesten forthcoming).

We first formulate a parametric family of *application-rejection* mechanisms where each member is characterized by some positive number $e \in \{1, 2, \dots, \infty\}$ of parallel and periodic choice-band sizes that allow the application and rejection process to continue before assignments are made permanent. As parameter e increases, we go from the familiar immediate acceptance mechanism ($e = 1$) to the Chinese parallel mechanisms ($e \in [2, \infty)$), and from those to deferred acceptance mechanism ($e = \infty$). In Chen and Kesten (forthcoming) we show that members of this family become "more manipulable" (in the sense of Pathak and Sönmez (2013)) as e decreases. Further, when $e' = ke$ for some integer k, any stable equilibrium of member of the family indexed by e is also a stable equilibrium of the member indexed by e' but not vice versa. Specifically, this implies that the deferred acceptance (hereafter shortened as *DA*) mechanism is more stable than the parallel mechanism which is more stable than the the immediate acceptance (hereafter shortened as *IA*) mechanism. On the welfare side, there is no clear theoretical comparison among the members of the family.

As the DA mechanism is the only member of the application-rejection family of mechanisms with a focal dominant strategy and other members often have multiple equilibria, it is important to investigate the coordination issue. Furthermore, a tradition of lab experiments show that participant behavior in the lab can diverge from what is expected by equilibrium prediction (Crawford, Costa-Gomes and Iriberri 2013). For these reasons, empirical evaluations of the performance of these mechanisms in controlled laboratory settings can be useful to inform policymakers in school choice and college admissions reforms. To this end we evaluate three prominent members of this family – the IA, the simplest parallel, and the DA mechanisms – in two environments in the laboratory.

In both environments, we find that participants are most likely to reveal their preferences truthfully under the DA, followed by the parallel and then the IA mechanisms. Consistent with theory, the DA mechanism achieves a significantly higher proportion of stable outcomes than the parallel mechanism, which is more stable than the IA mechanism. However, the efficiency comparison is sensitive to the environment. While theory is silent on equilibrium selection, we find that stable Nash equilibrium outcomes are more likely to arise than the unstable ones. To our knowledge, our paper presents the first experimental evaluation of the Chinese parallel mechanism relative to the IA and the DA mechanisms, as well as equilibrium selection in school choice mechanisms.

The rest of this paper is organized as follows. Section 2 formally introduces the school choice problem and the parametric family of mechanisms. Section 3 describes the experimental design. Section 4 summarizes the results of the experiments. Section 5 concludes.

2 School choice problem

A school choice problem (Abdulkadiroğlu and Sönmez 2003) is comprised of a number of students each of whom is to be assigned a seat at one of a number of schools. Further, each school has a maximum capacity, and the total number of seats in the schools is no less than the number of students. We denote the set of students by $I = \{i_1, i_2, \ldots, i_n\}$, where $n \geq 2$. A generic element in I is denoted by i. Likewise, we denote the set of schools by $S = \{s_1, s_2, \ldots, s_m\} \cup \{\emptyset\}$, where $m \geq 2$ and $\emptyset$ denotes a student's outside option, or the so-called null school. A generic element in S is denoted by s. Each school has a number of available seats. Let q_s be the number of available seats at school s, or the **quota** of s. For each school, there is a strict priority order of all students, and each student has strict preferences over all schools. The priority orders are determined according to state or local laws as well as certain criteria of school districts.

A **school choice problem** consists of a collection of priority orders and a preference profile. A **matching** μ is a list of assignments such that each student is assigned to one school and the number of students assigned to a particular school does not exceed the quota of that school. A matching μ is **non-wasteful** if no student prefers a school with unfilled quota to his assignment. A matching μ is **Pareto efficient** if there is no other matching which makes all students at least as well off and at least one student better off.

A closely related problem to the school choice problem is the *college admissions problem* (Gale and Shapley 1962). In the college admissions problem, schools have preferences over students whereas in a school choice problem, schools are merely objects to be consumed. A key concept in college admissions is "stability," i.e., there is no unmatched student-school pair (i, s) such that student i prefers school s to his assignment, and school s either has not filled its quota or prefers student i to at least one student who is assigned to it. The natural counterpart of stability in our context is defined by Balinski and Sönmez (1999). The **priority of student i for school s is violated** at a given matching μ (or alternatively, student i justifiably envies student j for school s) if i would rather be assigned to s to which some student j who has lower $s-$priority than i, is assigned. A matching is **stable** if it is non-wasteful and no student's priority for any school is violated.

A **school choice mechanism**, or simply a mechanism φ, is a systematic procedure that chooses a matching for each problem. A mechanism is Pareto efficient (stable) if it always selects Pareto efficient (stable) matchings. A mechanism φ is **strategy-proof** if it is a dominant strategy for each student to truthfully report his preferences.

We next describe a family of mechanisms that are central to our study. The immediate acceptance mechanism, which is referred as the *sequential* mechanism in the context of Chinese college admissions, was the prevalent college admissions mechanism in China in the 1980s and 1990s. By 2015, while it was still used in 2 provinces, variants of the parallel mechanisms have been adopted by 28 provinces to replace the IA mechanism (see the online appendix of Chen and Kesten forthcoming for a historical account of the Chinese college admissions). We next provide a parametric algorithm to describe a general class of mechanisms that nest the IA, the Chinese parallel and the DA mechanisms.

Given student preferences, school priorities, and school quotas, we begin by outlining a parametric *application-rejection algorithm* that indexes each member of the family by a periodic[4]

[4]In China, many provinces implement asymmetric versions of this algorithm where the size of the choice-band also varies across rounds. For the purpose of the present paper it suffices to restrict attention to the symmetric class which readily embeds the three mechanisms we test in the lab. See Chen and Kesten (forthcoming) for a description and analysis of the larger asymmetric class of mechanisms.

choice-band size e representing the number of choices tentatively on hold:

Round t $=0$**:**

- Each student applies to his first choice. Each school x considers its applicants. Those students with the highest $x-$priority are tentatively assigned to school x up to its quota. The rest are rejected.

In general,

- Each rejected student, who is yet to apply to his e-th choice school, applies to his next choice. If a student has been rejected from all his first e choices, then he remains unassigned in this round and does not make any applications until the next round. Each school x considers its applicants. Those students with highest $x-$priority are tentatively assigned to school x up to its quota. The rest of the applicants are rejected.
- The round terminates whenever each student is either assigned to a school or is unassigned in this round, i.e., he has been rejected by all his first e choice schools. At this point, all tentative assignments become final and the quota of each school is reduced by the number of students permanently assigned to it.

In general,
Round t ≥ 1**:**

- Each unassigned student from the previous round applies to his $te+1$-st choice school. Each school x considers its applicants. Those students with the highest $x-$priority are tentatively assigned to school x up to its quota. The rest of the applicants are rejected.

In general,

- Each rejected student, who is yet to apply to his $te+e$-th choice school, applies to his next choice. If a student has been rejected from all his first $te+e$ choices, then he remains unassigned in this round and does not make any applications until the next round. Each school x considers its applicants. Those students with the highest $x-$priority are tentatively assigned to school x up to its quota. The rest of the applicants are rejected.

- The round terminates whenever each student is either assigned to a school or is unassigned in this round, i.e., he has been rejected by all his first $te + e$ choice schools. At this point, all tentative assignments become final and the quota of each school is reduced by the number of students permanently assigned to it.

The algorithm terminates when each student has been assigned to a school. At this point, all the tentative assignments become final. The mechanism that chooses the outcome of the above algorithm for a given problem is called the *application-rejection mechanism* (e), denoted by φ^e. This family of mechanisms nests the IA and DA mechanisms as extreme cases, the Chinese parallel mechanisms as intermediate cases (Chen and Kesten forthcoming). Specifically, the *application-rejection mechanism* (e) is equivalent to the IA mechanism when $e = 1$, the Chinese parallel mechanisms when $2 \leq e < \infty$, and the DA mechanism when $e = \infty$.

Within the family of application-rejection mechanisms, i.e., $e \in \{1, 2, \ldots, \infty\}$, the IA is the only Pareto efficient mechanism, whereas the DA is the only stable and strategy-proof mechanism. In Chen and Kesten (forthcoming), we show that while a lower e number leads to a "more manipulable" (in the sense of Pathak and Sönmez (2013)) mechanism, it does not necessarily lead to a "less stable" mechanism. Only when $e' = ke$ for some integer k, any stable equilibrium of member of the family indexed by e is also a stable equilibrium of the member indexed by e' but not vice versa. This latter result however implies that the IA mechanism is less stable than any other member of the family, showing that all the successors of the IA mechanism in China are theoretically more stable. In the next section we test these predictions.

3 Experimental Design

We design our experiment to compare the performance of the IA ($e = 1$), the simplest version of the parallel (PA, $e = 2$) and the DA ($e = \infty$) mechanisms based on the theoretical characterization of the family of application-rejection mechanisms in Chen and Kesten (forthcoming). We choose the complete information environment to test the theoretical predictions, especially those on Nash equilibrium outcomes, as the corresponding theoretical framework is in complete information.

A 3(mechanisms) $\times$ 2(environments) factorial design is implemented to evaluate the performance of the three mechanisms, {IA, PA, DA}, in two different environments, a simple 4-school environment and a more complex 6-school environment. We use a more general priority structure than that in Chinese college admissions, so that our results might be applicable in both the school choice and the college admissions contexts.[5]

[5]In a follow-up study, we test the same set of mechanisms in the college admissions context where colleges have

3.1 The 4-School Environment

The first environment, which we call the **4-school environment**, has four students, $i \in \{1, 2, 3, 4\}$, and four schools, $s \in \{a, b, c, d\}$. Each school has one slot, which is allocated to one participant. We choose the parameters of this environment to satisfy several criteria: (1) no one lives in the district of her top or bottom choices; (2) the first choice accommodation index, i.e., the proportion of first choices an environment can accommodate, is 1/2; (3) there is a small number of Nash equilibrium outcomes, which reduces the complexity of the games.

The payoffs for each student are presented in Table 1. The square brackets, **[ ]**, indicate the resident of each school district, who has higher priority in that school than other applicants. Payoffs range from 16 points for a first-choice school to 5 points for a last-choice school. Each student resides in her second-choice school.

Table 1: Payoff Table for the 4-School Environment

	a	b	c	d
Payoff to Type 1	[**11**]	7	5	16
Payoff to Type 2	5	[**11**]	7	16
Payoff to Type 3	7	16	[**11**]	5
Payoff to Type 4	5	16	7	[**11**]

For each session in the 4-school environment, there are 12 participants of four different types. Participants are randomly assigned types at the beginning of each session. At the beginning of each period, they are randomly re-matched into groups of four, each of which contains one of each of the four different types. Four schools are available for each group. In each period, each participant ranks the schools. After all participants have submitted their rankings, the server allocates the schools in each group and informs each person of his school allocation and respective payoff. The experiment consists of 20 periods to facilitate learning. Furthermore, we change the priority queue every five periods ("*block*") to investigate whether participant strategies are conditional on their priority.[6]

For each of the 4 different queues, we compute the Nash equilibrium outcomes under the IA and parallel mechanisms (which are the same) as well as under the DA. For all four blocks, the IA and parallel mechanisms each have a unique Nash equilibrium outcome, where each student is assigned to her district school. This college/student-optimal matching, $\mu^{C/S}$, is Pareto inefficient,

identical priorities (Chen, Jiang and Kesten 2015).

[6]The priority queues for each five-period block are 1-2-3-4, 4-1-2-3, 3-4-1-2 and 2-3-4-1, respectively. Appendix B has detailed experimental instructions.

with the sum of ranks of 8 and an aggregate payoff of 44:

$$\mu^{C/S} = \binom{1 \quad 2 \quad 3 \quad 4}{a \quad b \quad c \quad d}$$

For all four blocks, the matching $\mu^{C/S}$ is also a Nash equilibrium outcome under the DA. However, the DA has exactly one more Nash equilibrium outcome for all four cases, which is the following Pareto efficient matching μ^*, with the sum of ranks of 6 and an aggregate payoff of 54:

$$\mu^* = \binom{1 \quad 2 \quad 3 \quad 4}{a \quad d \quad c \quad b}.$$

The Nash equilibrium profile that sustains outcome μ^* is the following (asterisks are arbitrary): $P_1 = (a, *, *, *)$, $P_2 = (d, b, *, *)$, $P_3 = (c, *, *, *)$, and $P_4 = (b, d, *, *)$. This is an equilibrium profile regardless of the priority order.[7] Note that, in this equilibrium profile, types 1 and 3 misrepresent their first choices by reporting their district school as their first choices, while types 2 and 4 report their true top choices.[8]

We now analyze participant incentives to reveal their true preferences in this environment. We observe that, in blocks 1 and 3, while truth-telling is a Nash equilibrium strategy under the parallel mechanism, it is not a Nash equilibrium under the IA mechanism. Furthermore, under truth-telling, the parallel and the DA mechanisms yield the same Pareto inefficient outcome. A theoretical finding (Corollary 2) in Chen and Kesten (forthcoming) implies that, if truth-telling is a Nash equilibrium under the IA mechanism, then it is also a Nash equilibrium under the parallel mechanism, but the converse is not necessarily true. Blocks 1 and 3 are examples of the latter.

Table 2: Truthtelling and Nash Equilibrium Outcomes in the 4-School Environment

	Truthful Preference Revelation			Nash Equilibrium Outcomes		
	IA	PA	DA	IA	PA	DA
Block 1 (periods 1-5)	not NE	NE	dominant strategy			
Block 2 (periods 6-10)	not NE	not NE	dominant strategy	$\mu^{C/S}$	$\mu^{C/S}$	$\{\mu^{C/S}, \mu^*\}$
Block 3 (periods 11-15)	not NE	NE	dominant strategy			
Block 4 (periods 16-20)	not NE	not NE	dominant strategy			

In comparison, for blocks 2 and 4, truth-telling is not a Nash equilibrium strategy under either the parallel or IA mechanism. Under truthtelling, the IA, the parallel and the DA mechanisms

[7] This is a Nash equilibrium because, for example, if student 1 (or 3) submits a profile where she lists school d (resp. b) as her first choice, then she may kick out student 2 (resp. 4) in the first step but 2 (resp. 4) would then apply to b (resp. d) and kick out 4 (resp. 2) who would in turn apply to d (resp. b) and kick out 1 (resp. 3). Hence student 1 (or 3), even though she may have higher priority than 2 (resp. 4), she cannot secure a seat at b (resp. d) under DA.

[8] Note that types 1 and 3's manipulation benefits types 2 and 4, thus it does not violate truthtelling as a weakly dominant strategy, since type 1 (resp. 3) is indifferent between truthtelling and lying. If type 1 (resp. 3) reverts to truthtelling, she will then cause a rejection chain which gives everyone their district school, including herself. Therefore, she is not better off by deviating from the efficient but unstable Nash equilibrium strategy.

each yield different outcomes. While the outcome under the parallel mechanism is Pareto efficient, those under the DA is not. Table 2 summarizes our analysis on truthtelling and Nash equilibrium outcomes.

3.2 The 6-School Environment

While the 4-school environment is designed to compare the mechanisms in a simple context, we now test the mechanisms in a more complex environment where student preferences are generated by school proximity and quality.

In this **6-school environment**, each group consists of six students, $i \in \{1, 2, \ldots, 6\}$, and six schools $s \in \{a, b, \ldots, f\}$. Each school has one slot. Following Chen and Sönmez (2006), each student's ranking of the schools is generated by a utility function, which depends on school quality, school proximity and a random factor. There are two types of students: for notation purposes, odd labelled students are gifted in sciences while even labelled students are gifted in the arts. Schools *a* and *b* are higher quality schools, while *c-f* are lower quality schools. School *a* is stronger in the arts and *b* is stronger in sciences: *a* is a first tier school in the arts and second tier in sciences, while *b* is a second tier school in the arts and first tier in sciences; *c-f* are each third tier in both arts and sciences. The utility function of each student has three components:

$$u^i(s) = u^i_p(s) + u^i_q(s) + u^i_r(s), \tag{1}$$

where the first component, $u^i_p(s)$, represents the proximity utility for student i for school s. We designate this as 10 if student i lives within the walk zone of School s and 0 otherwise. The second component, $u^i_q(s)$, represents the quality utility for student i at school s. For odd labelled students, $u^i_q(a) = 20$, $u^i_q(b) = 40$, and $u^i_q(s) = 10$ for $s = c - f$. For even labelled students, $u^i_q(a) = 40$, $u^i_q(b) = 20$, and $u^i_q(s) = 10$ for $s = c - f$. Finally, the third component, $u^i_r(s)$, represents a random utility (uniform in the range 0-40) which indicates diversity in tastes. Based on this utility function, we randomly generate 20 environments. We choose an environment which again satisfies several criteria: (1) no one lives within the district of her top or bottom choices; and (2) the first choice accommodation index is 1/3, a more competitive scenario than the 4-school environment.

We use Equation (1) to generate payoffs. We then normalize the payoffs such that the payoff from the first to last choice schools spans {16, 13, 11, 9, 7, 5}, the same payoff range as in the 4-school environment. The normalized payoff table is reported in Table 3.

For each session in the 6-school environment, we include 18 participants of six different types. Participants are randomly assigned types at the beginning of each session. The experiment consists of 30 periods, with random re-matching into three groups of six in each period. Again, we change the priority queue every five periods.

Table 3: Payoff Table for the 6-School Environment

	a	b	c	d	e	f
Payoff to Type 1	[**9**]	16	11	13	7	5
Payoff to Type 2	16	[**11**]	5	13	9	7
Payoff to Type 3	9	16	[**7**]	11	5	13
Payoff to Type 4	16	7	9	[**13**]	5	11
Payoff to Type 5	16	13	11	7	[**9**]	5
Payoff to Type 6	16	13	11	5	7	[**9**]

Compared with the 4-school environment, the 6-school environment has a much larger set of Nash equilibrium outcomes. Furthermore, there are more equilibrium strategy profiles under the parallel than under the IA mechanism. We examine the 6 different priority queues and compute the Nash equilibrium outcomes under both mechanisms, which are the same. The list of Nash equilibrium outcomes for each block is included in Appendix A.

Lastly, we present the efficiency analysis for the 6-school environment. The allocations that maximizes the sum of payoffs are the following ones, each leading to the sum of ranks of 13 with an aggregate payoff of 78.

$\mu_1^* = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ b & d & f & a & e & c \end{pmatrix}$ or $\mu_2^* = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ b & a & f & d & e & c \end{pmatrix}$.

In comparison, the No Choice benchmark, where each student is assigned to her district school, generates the sum of ranks of 22 with an aggregate payoff of 58.

3.3 Experimental Procedures

In each experimental session, each participant is randomly assigned an ID number and is seated in front of a terminal in the laboratory. The experimenter then reads the instructions aloud. Subjects have the opportunity to ask questions, which are answered in public. Subjects are then given 10 minutes to read the instructions at their own pace and to finish the review questions. After everyone finishes the review questions, the experimenter distributes the answers and goes over the answers in public. Afterwards, participants go through 20 (respectively 30) periods of a school choice experiment in the 4-school (respectively 6-school) environment. At the end of the experiment, each participant fills out a demographics and strategy survey on the computer. Each participant is paid in private at the end of the experiment. The experiment is programmed in z-Tree (Fischbacher 2007).

Table 4 summarizes the features of the experimental sessions. For each mechanism in each environment, we conduct four independent sessions between May 2009 and April 2012 at the Be-

Table 4: Features of Experimental Sessions

Treatment	Mechanism	Environment	# Subjects $\times$ # sessions	Total # of subjects
IA_4	IA	4-school	12×4	48
PA_4	PA	4-school	12×4	48
DA_4	DA	4-school	12×4	48
IA_6	IA	6-school	18×4	72
PA_6	PA	6-school	18×4	72
DA_6	DA	6-school	18×4	72

havioral and Experimental Economics Lab at the University of Michigan.[9] The subjects are students from the University of Michigan. This gives us a total of 24 independent sessions and 360 participants (354 unique subjects).[10] Each 4-school session consists of 20 periods. These sessions last approximately 60 minutes. In comparison, each 6-school session consists of 30 periods. These sessions last approximately 90 minutes. The first 20-30 minutes in each session are used for instructions. The conversion rate is \$1 = 20 points for all treatments. Each subject also receives a participation fee of \$5, and up to \$3.5 for answering the Review Questions correctly. The average earning (including participation fee) is \$19.08 for the 4-school treatments, and \$25.42 for the 6-school treatments. Experimental instructions are included in Appendix B. The data are available from the authors upon request.

4 Experimental Results

In examining our experimental results, we first explore individual behavior and equilibrium selection, and then report our aggregate performance measures, including first choice accommodation, efficiency and stability of the three mechanisms. We also investigate the sensitivity of our results to environment changes.

In presenting the results, we introduce several shorthand notations. First, let $x > y$ denote that a measure under mechanism x is greater than the corresponding measure under mechanism y at the 5% significance level or less. Second, let $x \geq y$ denote that a measure under mechanism x is greater than the corresponding measure under mechanism y, but the comparison is not statistically significant at the 5% level.

[9] All IA and DA sessions were conducted between May 2009 and July 2010. However, we found a z-Tree coding error for the IA_6 treatment during our data analysis. Thus, four additional sessions were conducted in July 2011 for this treatment, to replace the corresponding sessions. Sessions for the parallel mechanism were conducted in March and April 2012.

[10] Despite our explicit announcement in the advertisement that subjects should not participate in the experiment more than once and our screening before each session, six subjects participated twice. We compare their behavior between their inexperienced and experienced sessions and do not find significant difference.

4.1 Individual Behavior

We first examine the extent to which individuals reveal their preferences truthfully, and the pattern of any preference manipulation under each of the three mechanisms. Theorem 1 in Chen and Kesten (forthcoming) suggests that the parallel mechanism is less manipulable than the IA mechanism. Furthermore, under the DA mechanism, truthtelling is a weakly dominant strategy. This leads to our first hypothesis.

Hypothesis 1 (Truthtelling) *(a) There will be a higher proportion of truthtelling under the parallel than under the IA mechanism. (b) Under the DA mechanism, participants will be more likely to reveal their preferences truthfully than under the IA mechanism. (c) Under the DA mechanism, participants will be more likely to reveal their preferences truthfully than under the parallel mechanism.*

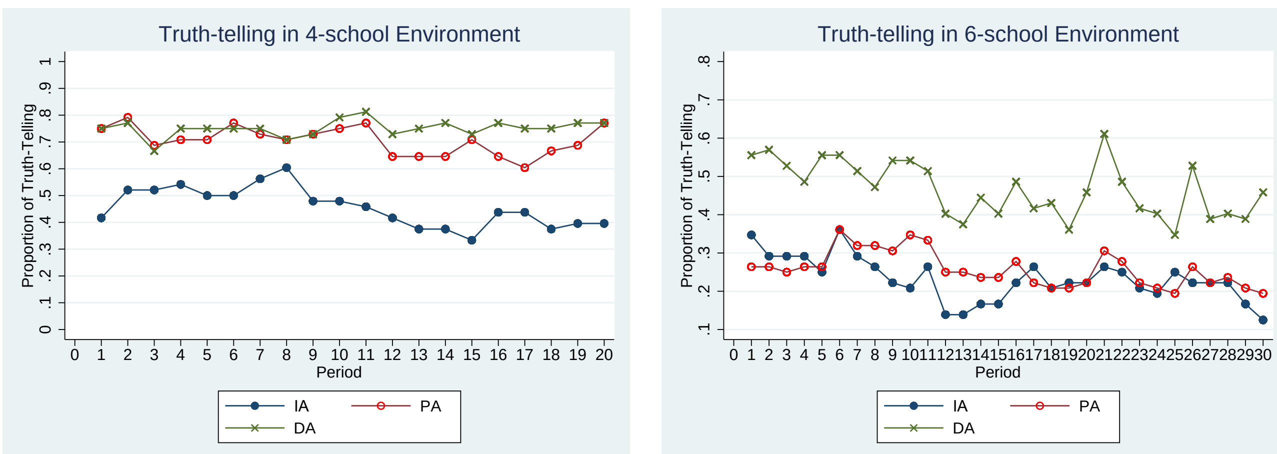

Figure 1: Proportion of Truth-Telling in Each Environment

Figure 1 presents the proportion of truthtelling in the 4- and 6-school environments under each mechanism. Note that, under the IA and parallel mechanisms, truthful preference revelation requires that the entire reported ranking is identical to a participant's true preference ranking.[11] However, under the DA mechanism, truthful preference revelation requires that the reported ranking be identical to the true preference ranking from the first choice through the participant's district school, while the remaining rankings, from the district school to the last choice, are irrelevant. While the DA mechanism has a robustly higher proportion of truthtelling than the IA mechanism, we find that the parallel mechanism has more truthtelling behavior than the IA mechanism.

[11]The only exception is when a participant's district school is her top choice. In this case, truthful preference revelation entails stating the top choice. However, by design, this case never arises in our experiment, as no one's district school is her first choice.

Result 1 (Truthtelling) *: In both environments, the proportion of truthful preference revelation under the DA mechanism is significantly higher than that under the IA mechanism over all periods, whereas it is significantly (weakly) higher than that under the parallel mechanism in the 6-school (4-school) environment. The proportion of truthful preference revelation under the parallel mechanism is significantly (weakly) higher than that under the IA mechanism in the 4-school (6-school) environment.*

Table 5: Proportions of Truthful Preference Revelation and Misrepresentations

	Truthful Preference Revelation			District School Bias		
All Periods	Proportion	H_a	p-value	Proportion	H_a	p-value
IA_4	0.456	IA < PA:	$p = 0.014$	0.478	IA > PA:	$p = 0.014$
PA_4	0.706	PA < DA:	$p = 0.200$	0.147	PA > DA:	$p = 0.100$
DA_4	0.751	IA < DA:	$p = 0.014$	0.107	IA > DA:	$p = 0.014$
IA_6	0.232	IA < PA:	$p = 0.271$	0.549	IA > PA:	$p = 0.343$
PA_6	0.258	PA < DA:	$p = 0.014$	0.526	PA > DA:	$p = 0.014$
DA_6	0.468	IA < DA:	$p = 0.014$	0.144	IA > DA:	$p = 0.014$

SUPPORT: Table 5 presents the proportion of truthful preference revelation, as well as the proportion of district school bias, a prevalent form of misrepresentation, for each treatment. P-values are computed from one-sided permutation tests, treating each session as an observation. ∎

By Result 1, we reject the null in favor of Hypothesis 1(a) that the parallel mechanism is less manipulable than the IA mechanism at the 5% level in the 4-school environment. Furthermore, we reject the null in favor of Hypothesis 1(b) that the DA mechanism is less manipulable than the IA mechanism. Lastly, we reject the null in favor of Hypothesis 1(c) that the DA mechanism is less manipulable than the parallel mechanism in the 6-school environment. The result is similar for inexperienced participants (first period). While the ranking of truthtelling between the IA and the DA mechanisms is consistent with Chen and Sönmez (2006), manipulability of the parallel mechanism is reported for the first time. Even though truthtelling is not a dominant strategy under the parallel mechanism, the extent of manipulation is significantly less under the parallel mechanism than under the IA mechanism in our simple 4-school environment. The same ranking holds in the more complex 6-school environment but it is only significant at the 10% level.

While we do not observe 100% truthtelling under the DA mechanism, it is less manipulable than the IA mechanism in both environments and the parallel mechanism in the 6-school environment. Furthermore, we observe that the proportion of truthtelling under the DA mechanism is significantly higher in the 4-school environment than in the 6-school environment ($p = 0.014$, one-sided permutation test). We interpret this as due to the relative simplicity of the environment.

Note that subjects are *not* told that truthtelling is a dominant strategy under the DA mechanism in the experimental instructions (Appendix B). Following the convention in the experimental mechanism design literature, we describe each algorithm without prompting the subjects to behave in one way or another. Thus, results in this section summarize participant behavior without prompting from the experimenter. In practice, however, the market designer can educate the students when truthtelling is a dominant strategy. In fact, the Boston Public Schools, after switching to the DA mechanism, advise the students to "list your school choices in your true order of preference" and that "there is no need to "strategize."[12] If parents follow the advice, we expect the DA mechanism to achieve close to 100% truthtelling in practice, further enlarging the gap between the DA and the other mechanisms reported in Result 1.

Table 6: Probit: Truthful Preference Revelation

	Dependent Variable: Truthtelling					
Environments:	4-School Environment			6-School Environment		
Specifications:	(1)	(2)	(3)	(4)	(5)	(6)
Mechanisms:	IA	PA	DA	IA	PA	DA
Lottery Position	-0.128***	-0.074***	-0.013	-0.098***	-0.045***	-0.028***
	(0.027)	(0.013)	(0.018)	(0.010)	(0.008)	(0.005)
Period	-0.009**	-0.004	0.002	-0.004	-0.003***	-0.005**
	(0.004)	(0.003)	(0.003)	(0.003)	(0.000)	(0.002)
Log Likelihood	-619.97	-564.42	-538.00	-986.75	-1194.58	-1475.81
Observations	960	960	960	2160	2160	2160

Notes:

1. Robust standard errors are adjusted for clustering at the session level.
2. Coefficients are probability derivatives.
3. Significant at the: ** 5 percent level; *** 1 percent level.

To investigate factors affecting truthtelling, we present six probit specifications in Table 6. The dependent variable is a dummy variable indicating whether a participant reveals her preferences truthfully. The independent variables include lottery position (1 being the best, and 6 being the worst), and a period variable to capture any effects of learning. In the 4-school environment (specifications 1-3), participants are 12.8 (resp. 7.4) percentage points less likely to tell the truth under the IA (resp. PA) mechanism for a one-position increase in the lottery position, while such an effect is absent under the DA mechanism, where truthtelling is a dominant strategy. We also observe a small but significant effect of learning to manipulate under the IA mechanism. In comparison, in the 6-school environment (specifications 4-6), we observe a similar lottery position effect on

[12]Source: `http://www.bostonpublicschools.org/files/introbps_13_english.pdf`, retrieved on December 12, 2013.

truthtelling, but for all three mechanisms. The 2.8-percentage-point marginal effect of lottery position on truthtelling under the DA mechanism indicates that some participants might not understand the incentives in the DA mechanism in the 6-school environment, consistent with the significantly lower level of truthtelling in this environment compared to the 4-school environment (Figure 1). Again, we observe a small but significant effects of learning on preference manipulation under the parallel and DA mechanisms.

A main critique of the IA mechanism is centered around the fact that the mechanism puts a lot of pressure on manipulation of first choices. The parallel mechanism alleviates this pressure. We now examine the likelihood that participants reveal their first choices truthfully under each mechanism.

Hypothesis 2 (Truthful First Choice) *A higher proportion of reported first choices will be true first choices under the parallel than under the IA mechanism.*

Result 2 (Truthful First Choice) *: The proportion of truthful first choices under the parallel mechanism is significantly higher than that under the IA mechanism in both environments.*

SUPPORT: In the 4-school (6-school) environment, the proportion of truthful first choices is 78% (55%) under the DA, 78% (48%) under the parallel, and 49% (37%) under the IA mechanism. Using each session as an observation, one-sided permutation tests for pairwise comparisons of the proportion of truthful first choices yield DA $>$ IA ($p = 0.014$), DA $\geq$ PA ($p = 0.529$), and PA $>$ IA ($p = 0.014$) for the 4-school environment. For the 6-school environment, using the same tests, we obtain DA $>$ IA ($p = 0.014$), DA $>$ PA ($p = 0.057$), and PA $>$ IA ($p = 0.029$). ■

By Result 2, we reject the null in favor of Hypothesis 2 that the parallel mechanism generates a higher proportion of truthful first choices than the IA mechanism. In particular, the parallel mechanism is virtually identical to the DA mechanism in the proportion of truthful first choices in the 4-school environment. Regardless of the environment, participants are more likely to submit true first choices under the parallel mechanism than under the IA mechanism.

We next examine our results regarding District School Bias, a prevalent form of manipulation where a participant puts her district school into a higher position than that in the true preference order. Table 5 indicates that the proportion of participants who exhibits District School Bias is significantly (weakly) higher under the IA than under the parallel mechanism in the 4-school (6-school) environment, which is then followed by the DA mechanism. This type of preference manipulation has been reported in previous experimental studies of the IA mechanism (Chen and Sönmez 2006, Calsamiglia, Haeringer and Klijn 2010, Klijn, Pais and Vorsatz 2010).

The proceeding analysis of individual behavior has implications for Nash equilibrium outcomes. Generically, there are multiple Nash equilibria in the application-rejection family of mechanisms. Thus, from both the theoretical and practical implementation perspectives, it is important to investigate which equilibrium outcomes are more likely to arise. To our knowledge, equilibrium selection in school choice mechanisms has not been studied before.

Our 4-school environment is particularly well suited to study equilibrium selection. Recall that in our 4-school environment, the student-optimal Nash equilibrium outcome, $\mu^{C/S}$, is the unique Nash equilibrium outcome under the IA and the parallel mechanisms, while there are two Nash equilibrium outcomes under the DA mechanism, $\mu^{C/S}$ and μ^*, where the latter Pareto dominates the former. Thus, it will be interesting to examine which of the two equilibrium outcomes arises more frequently under the DA mechanism. While the Pareto criterion predicts that the Pareto optimal unstable Nash equilibrium should be selected, experimental results from secure implementation suggest that the dominant strategy equilibrium, when coinciding with the Nash equilibrium, is more likely to be chosen (Cason, Saijo, Sjöström and Yamato 2006). This empirical finding is the basis for our next hypothesis.

Hypothesis 3 (Equilibrium Selection) *Under the DA mechanism, the stable Nash equilibrium outcome is more likely to arise compared to the unstable Nash equilibrium outcome.*

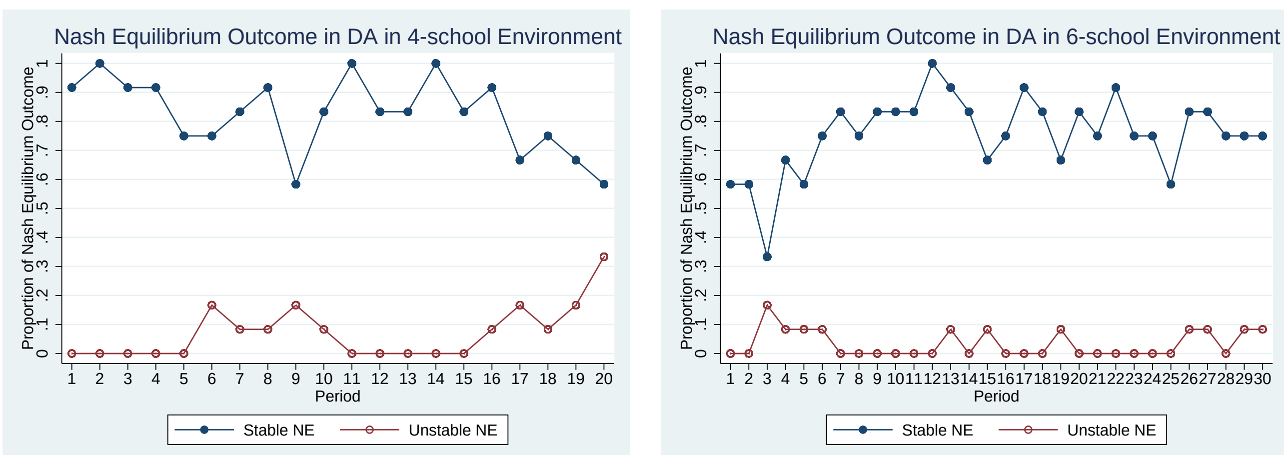

Figure 2: Proportion of Stable and Unstable Nash Equilibrium Outcomes under the DA Mechanism

Figure 2 reports the proportion of the stable and unstable equilibrium outcomes over time under the DA mechanism in the 4-school (left panel) and 6-school (right panel) environments, while Table 7 reports session-level statistics for each mechanism and pairwise comparisons between mechanisms and outcomes.

Result 3 (Equilibrium Selection under DA) *: Under the DA mechanism, the proportion of the inefficient but stable Nash equilibrium outcome (82.5%) is weakly higher than that of the efficient but unstable Nash equilibrium outcome (8.9%) in the 4-school environment.*

Table 7: Proportion of Nash Equilibrium Outcomes

4-School	IA ($\mu^{C/S}$)	PA ($\mu^{C/S}$)	DA	DA ($\mu^{C/S}$)	DA (μ^*)	H_a	p-value
Session 1	0.683	0.933	0.967	0.950	0.017	IA $\neq$ PA	0.028
Session 2	0.600	0.817	0.850	0.717	0.133	IA $<$ DA	0.014
Session 3	0.600	0.867	0.817	0.800	0.017	PA $<$ DA	0.457
Session 4	0.533	0.633	0.950	0.833	0.117	DA(μ^*) <DA($\mu^{C/S}$)	0.063
6-School	**IA**	**PA**	**DA**	**DA(Stable)**	**DA(Unstable)**	**H_a**	**p-value**
Session 1	0.011	0.122	0.822	0.811	0.011	IA $\neq$ PA	0.028
Session 2	0.011	0.267	0.778	0.778	0.000	IA $<$ DA	0.014
Session 3	0.033	0.189	0.844	0.789	0.056	PA $<$ DA	0.014
Session 4	0.078	0.222	0.711	0.644	0.067	DA(unstable)<DA(stable)	0.063

SUPPORT: The last column in Table 7 presents the p-values for permutation tests comparing the proportion of equilibrium outcomes under different mechanisms. The null of equal proportion against the H_a of DA(μ^*) $<$ DA($\mu^{C/S}$) yields $p = 0.063$ (paired permutation test, one-sided). ■

By Result 3, we reject the null in favor of Hypothesis 3 at the 10% significance level. We conjecture that the stable Nash equilibrium outcome ($\mu^{C/S}$) is observed more often despite being Pareto dominated by μ^*, because the former requires truthful preference revelation, the weakly dominant strategy adopted by about 75% of the participants under the DA mechanism, while the latter requires coordinated manipulation of top choices by players 1 and 3. However, we also note an increase of the unstable but efficient Nash equilibrium outcome, μ^*, in the last block in Figure 2 (left panel), indicating that players 1 and 3 learn to coordinate their manipulation towards the end of the game. This increase has direct implications for the efficiency comparisons in Result 5.

In comparison to the 4-school environment, the 6-school environment generates many Nash equilibrium outcomes. Because of this multitude of Nash equilibria, without strategy-proofness, on average, 3% and 20% of the outcomes are Nash equilibrium outcomes under the IA and parallel mechanisms, respectively. In contrast, 79% of the outcomes under the DA mechanism are Nash equilibrium outcomes. The proportion of this Nash equilibrium outcome follows DA $>$ IA ($p = 0.014$, one-sided permutation test), DA $>$ PA ($p = 0.014$, one-sided permutation test), and PA $>$ IA ($p = 0.014$, one-sided permutation test). If we break down the Nash equilibrium outcomes under the DA mechanism into stable and unstable equilibria, we again observe that the stable outcomes arise weakly more frequently than the unstable ones ($p = 0.063$, paired permutation test, one-sided).

In sum, Result 3 and our analysis of the 6-school data indicate that the stable Nash equilibrium outcome is more likely to arise than the unstable Nash equilibrium outcomes under the DA mechanism. To our knowledge, this is the first empirical result on equilibrium selection under the DA mechanism.

4.2 Aggregate Performance

Having presented the individual behavior and equilibrium outcomes, we now evaluate the aggregate performance of the mechanisms using three measures: the proportion of participants receiving their reported and true first choices, the efficiency achieved, and the stability under each mechanism.

In the education literature, the performance of a school choice mechanism is often evaluated through the proportion of students who receive their reported top choices. Thus, we compare the proportion of participants receiving their reported top choices, as well as the proportion who actually receive their true top choices. Corollary 5 from Chen and Kesten (forthcoming) suggests the following hypothesis.

Hypothesis 4 (First Choice Accommodation) *The proportion of participants receiving their reported top choices will be the highest under the IA mechanism, followed by the parallel mechanism, and then the DA mechanism.*

Table 8: First Choice Accommodation: Reported versus True First Choices

	Proportion Receiving *Reported* First Choice					Proportion Receiving *True* First Choice				
4-school	IA	PA	DA	H_a	p-value	IA	PA	DA	H_a	p-value
Session 1	0.596	0.217	0.138	IA > PA	0.014	0.088	0.033	0.017	IA $\neq$ PA	0.114
Session 2	0.617	0.221	0.271	IA > DA	0.014	0.113	0.063	0.121	IA $\neq$ DA	0.114
Session 3	0.583	0.158	0.192	PA > DA	0.257	0.121	0.067	0.071	PA $\neq$ DA	0.943
Session 4	0.608	0.304	0.183			0.138	0.125	0.075		
6-school	IA	PA	DA	H_a	p-value	IA	PA	DA	H_a	p-value
Session 1	0.717	0.400	0.196	IA > PA	0.014	0.217	0.157	0.109	IA $\neq$ PA	0.057
Session 2	0.665	0.344	0.270	IA > DA	0.014	0.230	0.139	0.111	IA $\neq$ DA	0.029
Session 3	0.667	0.441	0.231	PA > DA	0.014	0.178	0.157	0.085	PA $\neq$ DA	0.029
Session 4	0.706	0.398	0.241			0.202	0.181	0.120		

Table 8 reports the proportion of participants receiving their reported (left panel) and true first choices (right panel) in each session in each treatment. Note that the alternative hypotheses comparing mechanisms accommodating true first choices are two-sided, as neither the IA nor the parallel mechanism is strategy-proof. P-values of permutation tests are reported in the last column. The results are summarized below.

Result 4 (First Choice Accommodation) *: In both environments, the proportion of subjects receiving their reported first choice is significantly higher under the IA than under either the parallel* *or the DA mechanism. Furthermore, the proportion receiving their reported first choice is significantly higher under the parallel than under the DA mechanism in the 6-school environment. However, for the proportion receiving their true first choices, the IA and the parallel mechanisms are not significantly different, but each significantly outperforms the DA mechanism in the 6-school environment.*

SUPPORT: Treating each session as an observation, p-values from the corresponding permutation tests are reported in Table 8. ∎

By Result 4, we reject the null in favor of Hypothesis 4 for reported first choices. However, looking at the accommodation of true first choices, we find that reported top choices are not a good measure of performance when the incentive properties under each mechanism are different. In the 4-school environment, the three mechanisms are not significantly different from each other, while in the 6-school environment, the IA and the parallel mechanisms are not significantly different from each other, but each outperforms the DA mechanism.

We next compare the efficiency of the mechanisms in each environment. As our theoretical benchmarks are based ordinal preferences, we present a corresponding efficiency measure using ordinal ranking of assignments.[13] We define a normalized efficiency measure as

$$\text{Normalized Efficiency} = \frac{\text{maximum group rank - actual group rank}}{\text{maximum group rank - minimum group rank}}, \tag{2}$$

where the *minimum group rank* is the sum of ranks for all group members for the Pareto efficient allocation(s), which equals 6 (resp. 13) for for the 4-school (resp. 6-school) environment. Likewise, the *maximum group rank* is the sum of ranks for the worst allocation, which equals 14 (resp. 33) for the 4-school (resp. 6-school) environment. Because of this normalization, this measure always lies between zero and one, inclusive.

Figure 3 presents the normalized efficiency under each mechanism in the 4-school and 6-school environments. Session-level normalized efficiency for the first and last blocks, as well as the average efficiency over all periods, is reported in Table 9.

Result 5 (Efficiency) *: While the DA mechanism is significantly (weakly) more efficient than the IA (parallel) mechanisms in the 4-school environment, the IA mechanism is more efficient than the parallel mechanism, which in turn is more efficient than the DA mechanism in the 6-school environment.*

SUPPORT: Using one-sided permutation tests with each session as an observation, we find that (1) First block: $\text{IA}_6 > \text{DA}_6$ ($p = 0.029$), $\text{PA}_6 > \text{DA}_6$ ($p = 0.029$), while none of the pairwise

[13]For robustness check, we have also completed efficiency analysis based on the sum of payoffs, which yields similar results.

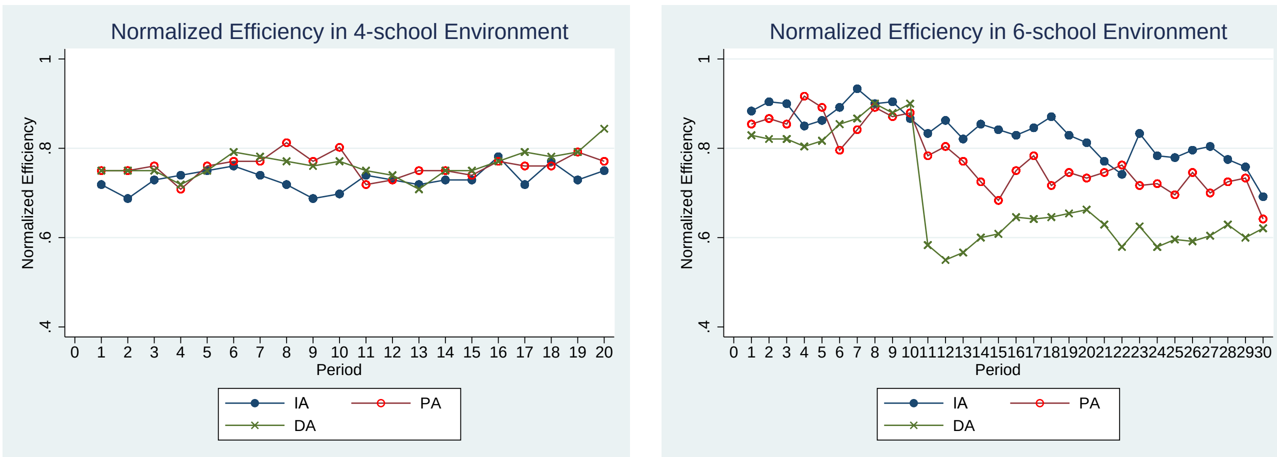

Figure 3: Normalized Efficiency in the 4- and 6-School Environments

Table 9: Normalized Efficiency: First Block, Last Block and All Periods

	First Block (periods 1-5)			Last Block			All Periods		
4-school	IA	PA	DA	IA	PA	DA	IA	PA	DA
Session 1	0.733	0.750	0.750	0.733	0.817	0.767	0.721	0.767	0.752
Session 2	0.742	0.758	0.733	0.758	0.733	0.808	0.744	0.752	0.777
Session 3	0.742	0.758	0.750	0.742	0.775	0.775	0.733	0.775	0.748
Session 4	0.683	0.717	0.742	0.767	0.758	0.833	0.727	0.746	0.777
6-school	IA	PA	DA	IA	PA	DA	IA	PA	DA
Session 1	0.870	0.887	0.800	0.773	0.753	0.567	0.849	0.805	0.676
Session 2	0.850	0.820	0.807	0.780	0.597	0.593	0.850	0.714	0.685
Session 3	0.910	0.907	0.850	0.740	0.710	0.560	0.810	0.801	0.679
Session 4	0.890	0.893	0.817	0.767	0.777	0.717	0.828	0.792	0.720

efficiency comparisons in the 4-school environment is significant.
(2) Last block: $\text{DA}_4 > \text{IA}_4$ ($p = 0.029$); $\text{IA}_6 > \text{DA}_6$ ($p = 0.014$); $\text{PA}_6 > \text{DA}_6$ ($p = 0.043$); $\text{IA}_6 \geq \text{PA}_6$ ($p = 0.057$).
(3) All periods: $\text{DA}_4 > \text{IA}_4$ ($p = 0.014$); $\text{DA}_4 \geq \text{PA}_4$ ($p = 0.071$); $\text{IA}_6 > \text{PA}_6$ ($p = 0.043$); $\text{IA}_6 > \text{DA}_6$ ($p = 0.014$); $\text{PA}_6 > \text{DA}_6$ ($p = 0.014$). ■

Result 5 is consistent with our equilibrium analysis which indicates that there is no systematic efficiency ranking within the class of the application-rejection mechanisms. It also contributes to our understanding of the empirical performance of the school choice mechanisms. First, it indicates efficiency comparison is environment sensitive. While no single mechanism is more efficient in both environments, the parallel mechanism is never the worst. Second, while a first-period pairwise efficiency comparison is not significant in either environment, separation of performance occurs with learning, so that the last block ranking is significant. Our first period results are consistent with Calsamiglia, Haeringer and Klijn (2011). Our results point to the importance of allowing subjects to learn in school choice experiments. Lastly, our finding that the DA mechanism is more efficient than the IA mechanism in the last block is driven by the rise of the unstable but efficient Nash equilibrium outcome observed in Figure 2 (left panel).

Finally, we evaluate the stability achieved under each mechanism. Corollary 3 from Chen and Kesten (forthcoming) suggests the following ranking:

Hypothesis 5 (Stability) *The DA mechanism is more stable than the parallel mechanism, which in turn is more stable than the IA mechanism.*

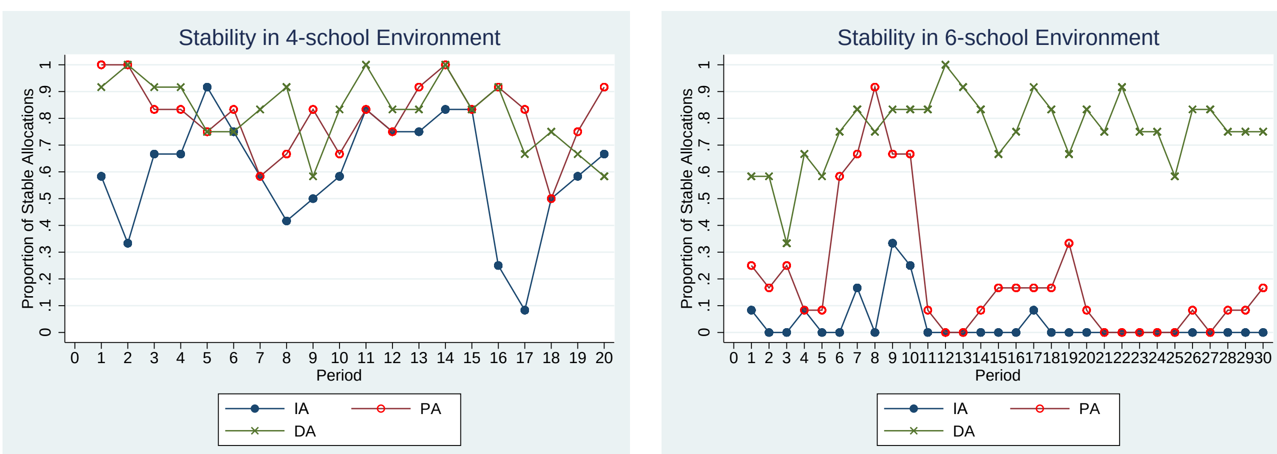

Figure 4: Proportion of Stable Allocations in the 4- and 6-School Environments

Figure 4 presents the proportion of stable allocations under each mechanism in the 4-school (left panel) and 6-school (right panel) environments. An allocation is marked as unstable if any student in a group of four (resp. six) is justifiably envious of another student in the group.

Table 10: Stability: First Block, Last Block and All Periods

	First Block (periods 1-5)			Last Block			All Periods		
4-school	IA	PA	DA	IA	PA	DA	IA	PA	DA
Session 1	0.733	1.000	1.000	0.533	0.733	0.867	0.683	0.933	0.950
Session 2	0.533	0.867	0.733	0.333	0.867	0.733	0.600	0.817	0.717
Session 3	0.800	0.867	0.933	0.400	0.867	0.600	0.600	0.867	0.800
Session 4	0.467	0.667	0.933	0.400	0.667	0.667	0.533	0.633	0.833
6-school	IA	PA	DA	IA	PA	DA	IA	PA	DA
Session 1	0.000	0.067	0.800	0.000	0.000	0.867	0.011	0.122	0.811
Session 2	0.000	0.200	0.600	0.000	0.200	0.867	0.011	0.267	0.778
Session 3	0.000	0.067	0.333	0.000	0.133	0.933	0.033	0.189	0.789
Session 4	0.133	0.333	0.467	0.000	0.000	0.467	0.078	0.222	0.644

Table 10 reports the proportion of stable allocations among all allocations in the first and last block, and averaged over all periods in each session. We summarize our stability analysis below.

Result 6 (Stability) *: The DA and the parallel mechanisms are each significantly more stable than the IA mechanism in both environments. The DA mechanism is significantly more stable than the parallel mechanism in the 6-school environment.*

SUPPORT: Table 10 reports the proportion of stable allocations among all allocations in the first and last block, and averaged over all periods in each session. Using one-sided permutation tests with each session as an observation, we find that (1) $\text{DA}_4 \geq \text{PA}_4$ ($p = 0.457$), $\text{DA}_4 > \text{IA}_4$ ($p = 0.014$), $\text{PA}_4 > \text{IA}_4$ ($p = 0.029$); (2) $\text{DA}_6 > \text{IA}_6$ ($p = 0.014$), $\text{DA}_6 > \text{PA}_6$ ($p = 0.014$), and $\text{PA}_6 > \text{IA}_6$ ($p = 0.014$). ∎

By Result 6, we reject the null in favor of Hypothesis 5. Thus, consistent with theory, in both environments, the DA and the parallel mechanisms each achieve a significantly higher proportion of stable allocations than the IA mechanism. In the 6-school environment, the DA mechanism also achieves a higher proportion of stable outcomes than the parallel mechanism. However, in the 4-school environment, the proportion of stable outcomes is indistinguishable between the DA and the parallel mechanisms. While our empirical stability ranking between the DA and IA mechanisms is consistent with Calsamiglia et al. (2010), the stability evaluation of the parallel mechanism is new.

In sum, our experimental study has several new findings. First, we evaluate the performance of the simplest form of the parallel mechanism, and find that its manipulability, reported first-choice accommodation, efficiency and stability measures are robustly sandwiched in between the IA and the DA mechanisms. Second, compared to the one-shot implementation of previous experiments on school choice except Featherstone and Niederle (2008),[14] our experimental design with repeated

[14]Featherstone and Niederle (2008) investigate the performance of the IA and DA mechanisms under incomplete

random re-matching enables us to compare the performance of the mechanisms with experienced participants. In doing so, we find that learning separates the performance of the mechanisms in terms of efficiency. Lastly, we report equilibrium selection under the DA mechanism for the first time, which reveals that stable Nash equilibrium outcomes are more likely to arise than the unstable ones even when the latter Pareto dominates the former.

5 Conclusions

While much of the debate on school choice exclusively focused on the IA (Boston) vs. DA mechanism comparisons, in this paper we provide a new dimension to this debate by bridging these mechanisms with the parallel mechanisms used for school choice and college admissions in China, and characterize them as members of a family of application-rejection mechanisms, with the IA and the DA mechanisms being extremal members. Our theoretical analysis (Chen and Kesten *forthcoming*) indicates a systematic change in the manipulability and stability properties of this family of mechanisms as one goes from one extreme member to the other.

To test our theoretical predictions and to search for behavioral regularities where theory is silent, we conduct laboratory experiments in two environments differentiated by their complexity. In the laboratory, participants are most likely to reveal their preferences truthfully under the DA mechanism, followed by the parallel and then the IA mechanisms. Furthermore, while the DA mechanism is significantly more stable than the parallel mechanism, which is more stable than the IA mechanism, efficiency comparisons vary across environments. Whereas theory is silent about equilibrium selection, we find that stable Nash equilibrium outcomes are more likely to arise than unstable ones. In another laboratory experiment designed to study the scale effect on the performance of matching mechanisms, we find that the mechanism rankings in our paper remains robust when the number of students per match increases from 4 to 40, and then to 4,000 (Chen, Jiang, Kesten, Robin and Zhu 2016).

Our study represents the first systematic experimental investigation of the class of Chinese parallel mechanisms. The analysis yields valuable insights which enable us to treat this class of mechanisms as a parametric family, and systematically study their properties and performance. More importantly, our results have policy implications for school choice and college admissions. As the parallel mechanism is less manipulable than the IA mechanism, and its achieved efficiency is robustly sandwiched between the two extremes whose efficiency varies with the environment, it might be a less radical replacement for the IA mechanism compared to the DA mechanism.

Around the same time as the Chinese college admissions reforms, a similar (but more drastic,

information, whereas we study the family of mechanisms under complete information. While their experiment is implemented under a random re-matching protocol, they do not explicitly analyze the effects of learning.

in light of our analysis) transition took place in the United States in Boston and New York City in the context of school choice. Although economists were directly involved in the decision processes that lead to the reforms in these cities, we are not aware of any such involvement in the Chinese context. In China, college admissions is considered as “a battle that determines one’s fate: one point [difference] in the exam can determine whether you go to heaven [i.e., universities] or hell [i.e., becoming a worker]” (Yang, 2006). We suspect that such perception of extremely high stakes involved in this process and the search to reduce the element of gaming and risk-taking behavior might have been a strong driving factor in these reforms. Thus far the students and parents appear to have favorably responded to the reforms. As school choice and college admissions reforms continue in China and other parts of the world (Westkamp 2013, Braun, Dwenger, Kübler and Westkamp 2014), experimental and empirical analyses of ongoing reforms offer insights which might affect education and labor market policies.

Appendix A: Nash Equilibrium Outcomes in the 6-School Environment

We first rewrite Table 3 as a preference profile, where, for each student, the underlined school is her district school:

P_1	P_2	P_3	P_4	P_5	P_6
b	a	b	a	a	a
d	d	f	$\underline{d}$	b	b
c	$\underline{b}$	d	f	c	c
$\underline{a}$	e	a	c	$\underline{e}$	$\underline{f}$
e	f	$\underline{c}$	b	d	e
f	c	e	e	f	d

We now examine the 6 different priority queues and compute the Nash equilibrium outcomes under the IA and the parallel mechanisms, which are the same. Since the outcomes are stable, the analysis is simplified by first computing the student optimal DA outcome μ^S and the college optimal μ^C and checking if there are any stable allocations in between the two in case they are different. Note that since school e is worse for each student than his district school, student 5 always gets matched to school e in all stable matchings. An allocation below μ^C is always the same regardless of the priority order since it simply assigns each student to his district school.

Every stable matching (with respect to the given profile and the corresponding priority order) is a Nash equilibrium outcome of the DA mechanism. That is, the Nash equilibrium outcomes of the DA mechanism is a superset of the stable set. This means any Nash equilibrium we compute for the IA (or parallel) mechanism is also a Nash equilibrium of the DA mechanism. But there may be other unstable Nash equilibrium outcomes. In what follows, we present the Nash equilibrium outcomes for each block.

Block 1: $f = 1 - 2 - 3 - 4 - 5 - 6$.

There are two Nash equilibrium outcomes that are stable:

$\mu^S = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ b & a & c & d & e & f \end{pmatrix}$ and $\mu^C = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ a & b & c & d & e & f \end{pmatrix}$

There are three unstable Nash equilibrium outcomes:

$\begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ d & b & c & a & e & f \end{pmatrix}$, $\begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ c & b & a & d & e & f \end{pmatrix}$, and $\begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ a & b & f & d & e & c \end{pmatrix}$.

Block 2: $f = 6 - 1 - 2 - 3 - 4 - 5$

There are three Nash equilibrium outcomes that are stable:

$\mu^S = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ c & b & f & d & e & a \end{pmatrix}$, $\mu = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ a & b & f & d & e & c \end{pmatrix}$, and $\mu^C = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ a & b & c & d & e & f \end{pmatrix}$

There are three other unstable Nash equilibrium outcomes:

$\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{d\ \ b\ \ c\ \ a\ \ e\ \ f}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{c\ \ b\ \ a\ \ d\ \ e\ \ f}$, and $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{b\ \ a\ \ c\ \ d\ \ e\ \ f}$.

Block 3: $f = 5 - 6 - 1 - 2 - 3 - 4$
There is one stable Nash equilibrium outcome:

$\mu^S = \mu^C = \binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ c\ \ d\ \ e\ \ f}$

There are four other unstable Nash equilibrium outcomes:

$\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{d\ \ b\ \ c\ \ a\ \ e\ \ f}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{c\ \ b\ \ a\ \ d\ \ e\ \ f}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ f\ \ d\ \ e\ \ c}$, and $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{b\ \ a\ \ c\ \ d\ \ e\ \ f}$.

Block 4: $f = 4 - 5 - 6 - 1 - 2 - 3$.
There are two stable Nash equilibrium outcomes:

$\mu^S = \binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{d\ \ b\ \ c\ \ a\ \ e\ \ f}$ and $\mu^C = \binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ c\ \ d\ \ e\ \ f}$

There are three other unstable Nash equilibrium outcomes:

$\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ f\ \ d\ \ e\ \ c}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{c\ \ b\ \ a\ \ d\ \ e\ \ f}$, and $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{b\ \ a\ \ c\ \ d\ \ e\ \ f}$.

Block 5: $f = 3 - 4 - 5 - 6 - 1 - 2$.
There is one stable Nash equilibrium outcome:

$\mu^S = \mu^C = \binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ c\ \ d\ \ e\ \ f}$

There are three other unstable Nash equilibrium outcomes:

$\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{d\ \ b\ \ c\ \ a\ \ e\ \ f}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{c\ \ b\ \ a\ \ d\ \ e\ \ f}$, and $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{b\ \ a\ \ c\ \ d\ \ e\ \ f}$.

Block 6: $f = 2 - 3 - 4 - 5 - 6 - 1$
There is one stable Nash equilibrium outcome:

$\mu^S = \mu^C = \binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ c\ \ d\ \ e\ \ f}$

There are four other unstable Nash equilibrium outcomes:

$\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{d\ \ b\ \ c\ \ a\ \ e\ \ f}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{c\ \ b\ \ a\ \ d\ \ e\ \ f}$, $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{a\ \ b\ \ f\ \ d\ \ e\ \ c}$, and $\binom{1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6}{b\ \ a\ \ c\ \ d\ \ e\ \ f}$.

Appendix B: Experimental Instructions (For Online Publication)

Instructions for the PA_4 treatment (Type 1) is presented first. Instructions for the IA_4 and the DA_4 treatments are identical except for the subsection, "The allocation of schools . . .," and the work sheet for Review Question #1. Thus, only this subsection is presented. Instructions for the 6-school treatments are identical except for the number of schools and players. Hence they are omitted, but are available from the authors upon request.

B.1: Instructions for the Chinese Parallel Mechanism (PA_4, Type 1)

Instructions - Mechanism PA_4

(Please turn off your cell phone. Thank you.)

This is an experiment in the economics of decision making. In this experiment, we simulate a procedure to allocate students to schools. The procedure, payment rules, and student allocation method are described below. The amount of money you earn will depend upon the decisions you make and on the decisions other people make. Do not communicate with each other during the experiment. If you have questions at any point during the experiment, raise your hand and the experimenter will help you. At the end of the instructions, you will be asked to provide answers to a series of review questions. Once everyone has finished the review questions, we will go through the answers together.

Procedure

- There are 12 participants of four different types in this experiment. You are type 1. Your type remains the same throughout the experiment.
- You will be randomly matched into groups of four at the beginning of each period. Each group contains one of each of the four different types.
- In this experiment, four schools are available for each group. Each school has one slot. These schools differ in geographic location, specialty, and quality of instruction in each specialty. Each school slot is allocated to one participant.
- **Your payoff** amount depends on the school you are assigned to at the end of each period. Payoff amounts are outlined in the following table. These amounts reflect the desirability of the school in terms of location, specialty and quality of instruction.

Slot received at School:	A	B	C	D
Payoff to Type 1	[**11**]	7	5	16

The table is explained as follows:

You will be paid	11	points if you hold a slot of School A at the end of a period.
You will be paid	7	points if you hold a slot of School B at the end of a period.
You will be paid	5	points if you hold a slot of School C at the end of a period.
You will be paid	16	points if you hold a slot of School D at the end of a period.

- ***NOTE* different types have different payoff tables. This is a complete payoff table for each of the four types:**

	A	B	C	D
Payoff to Type 1	[**11**]	7	5	16
Payoff to Type 2	5	[**11**]	7	16
Payoff to Type 3	7	16	[**11**]	5
Payoff to Type 4	5	16	7	[**11**]

The square brackets, **[ ]**, indicate the resident of each school district, who has higher priority in that school than other applicants. We will explain this in more detail in the next section.

- In this experiment, participants are defined as belonging to the following school districts:

Participant Type 1	lives within the school district of school	A,
Participant Type 2	lives within the school district of school	B,
Participant Type 3	lives within the school district of school	C,
Participant Type 4	lives within the school district of school	D.

- The experiment consists of 20 periods. In each period, you will be randomly matched with 3 other people in the room to form a group of four, which has one of each type. Your earnings for each period depend on your choices as well as the choices of the three other people you are matched with.

- Every period, each participant will rank the schools. Note that you need to rank all four schools in order to indicate your preferences.

- After all participants have submitted their rankings, the server will allocate the schools in each group and inform each person of his/her school allocation and respective payoff. Note that your allocation in each period is independent of your allocations in the previous periods.

- Your total payoff equals the sum of your payoffs in all 20 periods. Your earnings are given in points. At the end of the experiment you will be paid based on the exchange rate,

  \$1 = 20 points.

  In addition, you will be paid \$5 for participation, and up to \$3.5 for answering the Review Questions correctly. Everyone will be paid in private and you are under no obligation to tell others how much you earn.

Allocation Method

- **The priority order for each school is separately determined as follows**:

  –

  - **High Priority Level:** Participant who lives within the school district.

  - **Low Priority Level:** Participants who do not live within the school district.

    The priority among the Low Priority Students is based on their respective position in a lottery. The lottery is changed every five periods. In the first five periods, your lottery number is the same as your type number. In each subsequent block of five periods, your lottery number increases by one per block. Specifically, the lottery number for each type in each five-period block is tabulated below:

	Type 1	Type 2	Type 3	Type 4
Periods 1-5	1	2	3	4
Periods 6-10	2	3	4	1
Periods 11-15	3	4	1	2
Periods 16-20	4	1	2	3

- **The allocation of schools is obtained as follows**:

  - An application to the first choice school is sent for each participant.

  - Throughout the allocation process, a school can hold no more applications than its capacity.

    If a school receives more applications than its capacity, then it *temporarily* retains the student with the highest priority and rejects the remaining students.

- Whenever an applicant is rejected at a school, his/her application is sent to his or her second choice.
- Whenever a school receives new applications, these applications are considered together with the retained application for that school. Among the retained and new applications, the one with the highest priority is retained *temporarily*.
- After each applicant's **first two choices** have been considered by the corresponding schools, each applicant is assigned a school that holds his or her application in that step. These students and their assignments are removed from the system. The remaining students are rejected. Assignments at the end of this step is *final*.

- Students rejected from their first two choices then apply for their third choice.
- The process repeats for the third and fourth choices.
- The allocation process ends when no more applications can be rejected.

Note that the allocation is finalized every two choices.

An Example:

We will go through a simple example to illustrate how the allocation method works. This example has the same number of students and schools as the actual decisions you will make. You will be asked to work out the allocation of this example for Review Question 1.

Feel free to refer to the experimental instructions before you answer any question. Each correct answer is worth 25 cents, and will be added to your total earnings. You can earn up to $3.5 for the Review Questions.

Students and Schools: In this example, there are four students, 1-4, and four schools, A, B, C and D.

Student ID Number: $1, 2, 3, 4$	Schools: A, B, C, D

Slots and Residents: There is one slot at each school. Residents of districts are indicated in the table below.

School	Slot	District Residents
A	☐	1
B	☐	2
C	☐	3
D	☐	4

Lottery: The lottery produces the following order.

$$\boxed{1 - 2 - 3 - 4}$$

Submitted School Rankings: The students submit the following school rankings:

	1st Choice	2nd Choice	3rd Choice	Last Choice
Student 1	D	A	C	B
Student 2	D	A	B	C
Student 3	A	B	C	D
Student 4	A	D	B	C

Priority : School priorities first depend on whether the school is a district school, and next on the lottery order:

	Resident	Non-Resident
Priority order at A:	**1**	– 2 – 3 – 4
Priority order at B:	**2**	– 1 – 3 – 4
Priority order at C:	**3**	– 1 – 2 – 4
Priority order at D:	**4**	– 1 – 2 – 3

The allocation method consists of the following steps: Please use this sheet to work out the allocation and enter it into the computer for Review Question #1.

Step 1 (temporary): Each student applies to his/her first choice. If a school receives more applications than its capacity, then it holds the application with the highest priority and rejects the remaining students.

Applicants		School		Accept	**Hold**	**Reject**
3, 4	⟶	A	⟶	N/A	☐	
	⟶	B	⟶	N/A	☐	
	⟶	C	⟶	N/A	☐	
1, 2	⟶	D	⟶	N/A	☐	

Step 2 (temporary): Each student rejected in Step 1 applies to his/her second choice. When a school receives new applications, these applications are considered together with the application on hold for that school. Among the new applications and those on hold, the one with the highest priority is temporarily on hold, while the rest are rejected.

Accepted	Held	New Applicants		School		Accept	**Hold**	**Reject**
	□		⟶	A	⟶	N/A	□	
	□		⟶	B	⟶	N/A	□	
	□		⟶	C	⟶	N/A	□	
	□		⟶	D	⟶	N/A	□	

Step 3 (**final**): Each student rejected in Step 2 applies to his/her second choice. When a school receives new applications, these applications are again considered together with the application on hold for that school. Among the new applications and those on hold, the one with the highest priority is accepted, while the rest are rejected. Since every student's top two choices have been considered, the allocation is final at this step.

Accepted	Held	New Applicants		School		**Accept**	Hold	**Reject**
	□		⟶	A	⟶	□	N/A	
	□		⟶	B	⟶	□	N/A	
	□		⟶	C	⟶	□	N/A	
	□		⟶	D	⟶	□	N/A	

Step 4 (temporary): Each student rejected in Step 3 applies to his/her third choice. If a school still has vacancy, it holds the application with the highest priority and rejects the rest. If a school is already full, it rejects all new applications.

Accepted	Held	New applicants		School		Accepted	**Hold**	**Reject**
□			⟶	A	⟶	□		
□			⟶	B	⟶	□		
□			⟶	C	⟶	□		
□			⟶	D	⟶	□		

Step 5 (**final**): Each student rejected in Step 4 applies to his/her fourth choice. If the fourth choice has a vacancy, it accepts the application. Furthermore, all applications on hold are accepted in this step.

Accepted	Held	New Applicants		School		**Accept**	Hold	Reject
□			⟶	A	⟶	□	N/A	N/A
□			⟶	B	⟶	□	N/A	N/A
□			⟶	C	⟶	□	N/A	N/A
□			⟶	D	⟶	□	N/A	N/A

The allocation ends at Step 5.

- Please enter your answer to the computer for Review Question 1.
- Afterwards, you will be asked to answer another 10 review questions. When everyone is finished with them, we will go through the answers together.

Review Questions 2 - 11

2. How many participants are there in your group each period?
3. True or false: You will be matched with the same three participants each period.
4. True or false: Participant living in a school district has higher priority than any other applicants for that school.
5. True or false: The priority for non-residents of a school district is determined by a lottery.
6. True or false: The lottery is fixed for the entire 20 periods.
7. True or false: A lottery number of 1 means that I have the highest priority among the other non-resident applicants in a school.
8. True or false: Other things being equal, a low lottery number is better than a high lottery number.
9. True or false: If you are accepted by a school of your choice, the schools ranked below are irrelevant.
10. True or false: If you are not rejected at a step, then you are accepted into that school.
11. True or false: The allocation is final at the end of each step.

You will have 5 minutes to go over the instructions at your own pace. Feel free to earn as much as you can. Are there any questions?

B.2: Instructions for the IA Mechanism (IA$_4$)

. . . . . .

- **The allocation of schools is described by the following method**:

Step 1.

–

a. An application to the first ranked school is sent for each participant.

b. Each school accepts the student with highest priority in that school. These students and their assignments are removed from the system. The remaining applications for each respective school are rejected.

Step 2.

–

a. The rejected applications are sent to his/her second choice.

b. If a school is still vacant, then it accepts the student with the highest priority and rejects he remaining applications.

Step 3.

–

a. The application of each participant who is rejected by his/her top two choices is sent to his/her third choice.

b. If a school is still vacant, then it accepts the student with the highest priority and rejects the remaining applications.

Step 4. Each remaining participant is assigned a slot at his/her last choice.

Note that the allocation is final in each step.

. . . . . .

B.3: Instructions for the Deferred Acceptance Mechanism (DA_4)

. . . . . .

The allocation of schools is described by the following method:

- An application to the first ranked school is sent for each participant.
- Throughout the allocation process, a school can hold no more applications than its capacity.

  If a school receives more applications than its capacity, then it temporarily retains the student with the highest priority and rejects the remaining students.
- Whenever an applicant is rejected at a school, his or her application is sent to the next highest ranked school.

- Whenever a school receives new applications, these applications are considered together with the retained application for that school. Among the retained and new applications, the one with the highest priority is temporarily on hold.

- The allocation is finalized when no more applications can be rejected.

  Each participant is assigned a slot at the school that holds his/her application at the end of the process.

Note that the allocation is temporary in each step until the last step.

. . . . . .

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