Sophistication and segregation in school choice

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Abstract

We take school admission mechanisms to the lab to find out whether the manipulable Boston mechanism disadvantages students of lower cognitive ability and whether this leads to ability segregation across schools. Results suggest this is the case: lower ability participants receive a lower average payoff and are overrepresented in the worst school. Under the strategy-proof Deferred Acceptance mechanism, payoff differences between high and low ability participants tend to disappear, and distributions by ability across schools are harmonized. Hence, we find support for the argument that a move to strategy-proof mechanisms would "level the playing field". Since the Boston mechanism achieves higher ex-ante efficiency with respect to Deferred Acceptance, we document empirically the potential tradeoff between equality and efficiency in the choice of school admission mechanisms.

Keywords: laboratory experiment, school choice, strategy-proofness, cognitive ability, mechanism design.

JEL codes: C78, C91, D82, I24.

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1 Introduction

The paper studies experimentally how different allocation mechanisms influence inequality, efficiency and ability segregation across schools.

Protecting applicants who do not strategize well is one of the main arguments of those who advocate in favor of strategy-proof mechanisms in school choice—e.g., Deferred Acceptance (DA)—and against manipulable ones—e.g., Boston (BOS). Pathak and Sönmez [2008] show that, in a world where some players are always sincere and others sophisticated, DA levels the playing field, while BOS favor sophisticated students.[1] An underlying hypothesis of these arguments is that being bad at strategizing correlates with belonging to an already disadvantaged group, so that BOS would selectively discriminate the weakest students.[2] In particular, we consider the hypothesis that students of lower cognitive ability are less able to identify optimal strategies under BOS and fare worse under this mechanism compared to peers of higher ability, resulting in ability segregation across schools.

Whilst manipulable mechanisms may have these adverse distributive effects, BOS dominates DA in terms of ex-ante efficiency when priority rankings at schools are weak [Abdulkadiroglu et al., 2009; Erdil and Ergin, 2008; Miralles, 2009]. Preference manipulation allows students to weigh the probability of being admitted at a school against the utility it provides. As a consequence, a school is more likely to admit students that appreciate it more, in cardinal terms, relative to others—an efficiency gain that strategy-proofness rules out by definition.

Our contribution is twofold. First, by matching cognitive ability and behavior in a school choice game, we investigate the leveling-the-playing-field hypothesis. Second, we test whether students are sufficiently sophisticated to reap the ex-ante efficiency gains of BOS over DA. As such, we offer a tentative estimate of the costs—i.e., efficiency losses—and benefits—i.e., protecting unsophisticated applicants—of moving from BOS to DA. Since these hypotheses

[1]The mechanism design approach to school choice has highlighted the drawbacks of manipulable mechanisms from the very beginning. See the seminal paper by [Abdulkadiroglu and Sönmez, 2003], and the characterization of equilibria under the Boston mechanism in Ergin and Sönmez [2006]. For the related domain of college admission problems, see the survey in Roth and Sotomayor [1992].

[2]For instance, in his often-cited memo to the Boston School Committee on May 25, 2005, Superintendent Payzant wrote: "the need to strategize provides an advantage to families who have the time, resources and knowledge to conduct the necessary research" and "a strategy-proof algorithm levels the playing field by diminishing the harm done to parents who do not strategize or do not strategize well".

are hard to pin down in the field, where preferences are unobservable, we run a laboratory experiment.

The context we study has 16 students applying for 16 seats equally distributed across four schools. Students are all ranked in a single priority class at every school, where ties are broken according to a centralized lottery. We measure participants' cognitive ability using a 36 questions, non-verbal Raven test.[3] After that, they play ten school allocation games, always under the same mechanism—i.e., either BOS or DA— and under two different preference environments. In each game, participants submit an application list by ranking the four schools. In all conditions, preferences are uncorrelated with cognitive ability and with priority rankings at schools, so that the distribution of participants by ability should be the same in equilibrium in every school—i.e., ability segregation cannot emerge in the absence of systematic differences in strategic behavior.

Manipulation of preferences typically takes the form of placing relatively underdemanded schools higher in one's lists with respect to their true rank. For instance, the West Zone Parents Group in Boston advised parents [see, among others, Pathak and Sönmez, 2008]:

> One school choice strategy is to find a school you like that is undersubscribed and put it as a top choice, OR, find a school that you like that is popular and put it as a first choice and find a school that is less popular for a safe second choice.

The first advised strategy is to manipulate the first choice by listing a relatively less demanded school (*skipping-the-top*). The second advised strategy is to reveal truthfully the most preferred choice and manipulate the second choice to make it safer (*skipping-the-middle*). In equilibrium under BOS, students use skipping-the-middle strategies in our first preference environment, and a majority of students uses skipping-the-top strategies in our second preference environment.

Because appropriate manipulation takes these simple forms in our design, we can clearly identify students that fail at strategizing. These are made worse off in both environments. In the first, they end up in the worst school whenever rejected at their first choice. In the second, they give up the opportunity to obtain decent and relatively safe seats to compete for others they have little chance to get. Students that fail to strategize are disproportionally represented

[3] Because priorities are determined randomly, and cautionary motives are known to be an important driver of behavior in school choice [e.g. He, 2014], we also elicit risk preferences.

in the worst school. When these unsophisticated players have lower cognitive ability, ability segregation emerges under BOS. However, BOS dominates in ex-ante efficiency if a sufficient number of players strategize appropriately.

Results can be summarized as follows. We find strong support for the leveling-the-playing-field hypothesis. Under BOS low ability subjects earn significantly lower payoffs than high ability ones under both preference environments. Differences are smaller and (mostly) not significant under DA. Low ability students report truthfully more often than high ability ones under BOS. This is not the only mistake they are more prone to. They also report truthfully less often under DA, and tend to be more over-cautious. More generally, high ability subjects' strategies are more responsive to both the mechanism and the preference environment. Low ability subjects are found at particular disadvantage when required to manipulate their second listed school. We argue this is due to the higher strategic complexity of this type of manipulation.

As a consequence, the distribution by ability at schools is harmonized under DA; substantial ability segregation emerges under BOS, where low ability students are over-represented at the worst school. In the preference environment where subjects should skip the middle, the other schools admit up to 45 percent more high ability students with respect to the worst school.

Overall, average payoffs are close to equilibrium ones under DA. Because players fall short of the equilibrium benchmark under BOS, they earn lower payoffs than in equilibrium. Nevertheless, participants are able to reap part of the ex-ante efficiency gains through manipulation: BOS earns significantly higher average payoffs with respect to DA in both preference environments. Those gains are mostly concentrated in the hands of high ability subjects. Thus, our results highlight a substantial tradeoff between efficiency and equality in school choice mechanisms.

Starting from Chen and Sönmez [2006], a growing literature has addressed school choice with the use of laboratory experiments, exploiting the advantage of controlling students' preferences by design [Calsamiglia et al., 2010; Chen et al., 2015; Chen and Kesten, 2012; Klijn et al., 2013; Pais and Pintér, 2008]. These papers are mostly interested in comparing truth-telling rates, and identifying the rules of thumb used under different mechanisms. Featherstone and Niederle [2014] are closer to our work, as they try to ascertain how close to equilibrium students can get under BOS. First, they show subjects cannot play equilibrium under BOS when this requires manipulation—mostly because of failures at skipping-the-middle. Second, they demonstrate truth-telling is often played under BOS in the special case where it can be implemented as an ordinal Bayes Nash equilibrium. They conclude that, in those cases, BOS may resolve the conflict between equality and efficiency.

Outside the lab, the data in Abdulkadiroğlu et al. [2005] include some hints that DA would protect unsophisticated parents, but cannot provide direct evidence.[4] Despite this, the paper testifies to the strength of the argument in the policy process. More recently, a number of papers have addressed the empirical difficulty of not observing students' preferences. Using data from Barcelona, Calsamiglia and Güell [2014] find that the 'safety' of a school is one of the main determinants of listing it first. This fact and the presence of naive applicants induces important inequalities in how school choice affects different households. He [2014] studies a school allocation system in Beijing which is extremely similar to the one we implement. He finds that safe strategies are played too often, but finds no evidence that wealthier or more-educated parents are better at strategizing. His data suggest that switching to DA would imply a utility loss for most parents. While these carefully designed field studies are essential for policy guidance, we believe our experimental study nicely complements them by providing evidence which, admittedly, has lower external validity, but, on the other hand, is more direct and relies on much weaker assumptions in the analysis.

The paper is organized as follows. Section 2 introduces the school choice environments. Section 3 presents the experimental design and procedures. Hypotheses are found in Section 4, and results follow in Section 5. Section 6 concludes.

2 The school choice problem

Consider 4 schools $s \in S = \{A, B, C, D\}$, with 4 seats each. Competing for these seats are 16 students $i \in I$, 4 of each type $t_i \in T = \{1, 2, 3, 4\}$. Eventually, each student i is admitted to a school s and receives a payoff $p_i(s, t_i) = p(s, t_i)$ that depends on both the school s and her own type t_i.

We apply to this general set-up two different matching algorithms and two different preference environments. Students are informed about payoffs and the rules of the game. We assume players are risk neutral, and discuss the role of risk aversion separately. To derive equilibrium predictions, we will analyse the game under the assumption of complete information.

[4] In particular, many students list below the first choice schools that are in fact unavailable after the first round of the mechanism.

2.1 Mechanisms

To match students and schools we consider BOS—the *Immediate Acceptance Mechanism* also known as the Boston mechanism—and DA—the *Deferred Acceptance Mechanism* also known as the Gale-Shapley Mechanism. Under each of them, students are required to report a ranking of schools $\succ_i$, i.e. a strict linear order on S. To break ties among applicants, we apply a centralized lottery that draws a different number l_i between 1 and 16 for each student, where each of the 16! lottery draws is equally likely. The mechanisms proceed as described below.

BOS*: the Immediate Acceptance Mechanism*

ROUND 1. Each student applies at the school that she ranked first. If there are at most 4 students applying at a school, they are admitted. If there are more than 4 students applying, the school admits the 4 applicants with the lowest lottery number.

ROUND $k > 1$. Each student who has not yet been admitted, applies at the school that she ranked at the k^{th} position. The school admits applicants in the order of their lottery numbers until either it has admitted 4 students in total (including previous rounds) or until there are no more applicants who have ranked the school in k^{th} position.

Since there are as many seats as students, each student has been admitted to some school when the algorithm terminates after at most 4 rounds.

DA*: the Deferred Acceptance Mechanism*

ROUND 1. Each student applies at the school that she ranked first. The school preliminarily accepts applicants in the order of their lottery numbers until either it has accepted 4 students or until there are no more applicants. Any remaining applicants are rejected by that school.

ROUND $k > 1$. Each student who was preliminarily accepted at some school in the previous round, applies again at that school. Any student who was in the previous round rejected at some school that she ranked m^{th} on her list, now applies at the the school she ranked at the $(m+1)^{th}$ position. The school preliminarily accepts applicants in the order of their lottery numbers until either it has accepted 4 students or until there are no more applicants. Any remaining applicants are rejected by that school.

Since there are as many seats as students, and each school only rejects applicants once it has no available seats left, we reach a point where each student is preliminarily accepted. At this point, the mechanism terminates and acceptance becomes final.

2.2 Preference environment 1

Payoffs for preference environment 1 (henceforth P1) are given in the left panel of Table 1. Students agree that D is the worst school, and the associated payoff is zero. They also agree in ranking C third, but type 3 students earn a higher payoff than others at that school. Type 2 students prefer B to A, while all other students prefer A to B. Students of type 1 earn a higher payoff than others at A.

Under DA, truth-telling is dominant. Hence, if players play accordingly, types 1,3 and 4 report $A \succ_i B \succ_i C \succ_i D$ while students of type 2 report $B \succ_i A \succ_i C \succ_i D$.

Under BOS, players have incentives to strategize. The following result characterizes the equilibria of the game.

Proposition 1. *(Equilibrium under* BOS-P1*) In every pure strategy Nash equilibrium of the game induced by* BOS-P1*:*

- *11 students report* $A \succ_i C \succ_i B, D$*: all type* 1 *and 7 out of the 8 type* 3 *and* 4
- *5 students reports* $B \succ_i C \succ_i A, D$*: all type* 2 *and 1 out of the 8 type* 3 *and* 4

The proof of this result, as well as all other proofs, can be found in Appendix A. Under an equilibrium strategy profile, if a student is rejected both at her first choice and at school C, then the only remaining seats in round 3 are seats at school D, so that it does not matter whether she ranks D third or fourth. Thus, equilibrium under BOS-P1 is essentially unique, in the sense that it is unique up to redundant strategies and the identity of the one player of type 3 or 4 applying at B.

The intuition for the equilibrium is as follows. Since there are at least four students that like schools A and B best, these schools are filled in the first round. Moreover, since the payoff at D is zero, everyone rejected at A or B in round one should apply at C in the second round. Calculations show C is never ranked first, and establish who ranks A or B first.

For the experiment, we expect participants to differ in their ability to strategize. In particular, let us consider the case where half of all students are naive, and always report truthfully, while the other half are sophisticated, and play a best response to the reports of naive and other sophisticated students. Let

TABLE 1: PAYOFFS IN P1 (LEFT PANEL) AND P2 (RIGHT PANEL)

$p(s, t_i)$	School A	School B	School C	School D	School A	School B	School C	School D
Type 1	20	10	6	0	20	11	7	0
Type 2	16	17	6	0	16	15	7	0
Type 3	16	10	8	0	16	11	11	0
Type 4	16	10	6	0	16	11	7	0

Notes: each cell represents the payoff a student of type t_i obtains when admitted at school s in the relevant preference environment.

us further assume that players' sophistication is uncorrelated with their type, so that there are two naive and two sophisticated students of each type.

Proposition 2. *(Pseudo-Equilibrium under* BOS-P1 *with naive players) In every pure strategy pseudo-equilibrium of the game induced by* BOS-P1, *sophisticated players' reports are as follows:*

- *all 6 students of type* 1, 3 *and* 4 *report* $A \succ_i C \succ_i B, D$
- *all 2 students of type* 2 *report* $B \succ_i C \succ_i A, D$

In other words, the only relevant difference between the reports of naive and sophisticated players lies in their second choices: the latter report C, while the former report truthfully. Compared to equilibrium (Proposition 1), no student of type 3 or 4 applies at B in the first round. For the naive, this follows from the assumption of truthful reporting. For the sophisticated, they know that there will be fewer applicants at C in the second round compared to equilibrium, and are therefore willing to take more risk in the first round by applying at A

2.3 Preference environment 2

Payoffs in preference environment 2 (henceforth P2) are given in the right panel of Table 1. All students agree that A is better than B, and students of type 1 earn a higher payoff than others at A. All students also agree that C is better than D. Students of types 1, 2, and 4 prefer B to C, and type 2 earns a higher payoffs at B compared to others. Students of type 3 earn a higher payoff at C compared to others, and are indifferent between B and C.

Under DA, if players play according to their dominant strategy, types 1,2 and 4 report $A \succ_i B \succ_i C \succ_i D$, while students of type 3 report either $A \succ_i B \succ_i C \succ_i D$ or $A \succ_i C \succ_i B \succ_i D$.

The following result characterizes the equilibria of the game under BOS.

Proposition 3. *(Equilibrium under* BOS-P2*) In every pure strategy Nash equilibrium of the game induced by* BOS-P2*:*

- *all students of type* 1 *and three of type* 4 *report* $A \succ_i C, B, D$
- *all students of type* 2 *and one of type* 4 *report* $B \succ_i C, A, D$
- *all students of type* 3 *report* $C \succ_i A, B, D$
- *some students of type* 1*,* 2*, and* 4 *rank* C *second.*

Under these strategy profiles, the only remaining seats in round two are seats at school D, so that it does not matter to an individual student how she ranks schools beyond the reported first choice. However, if no student of type 1, 2, or 4 ranks C second, a student of type 3 would deviate and apply at A - which in turn would induce everyone else to rank C second, so that a type 3 student would no longer be willing to apply at A.

A majority of students – types 2, 3 and to a minor extent 4 – opt for a safe first choice. In particular, these students rank first the school for which they have a stronger preference relative to others.

If we again consider a population that is equally divided into naive and sophisticated students, the following obtains.

Proposition 4. *(Pseudo-Equilibrium under* BOS-P2 *with naive players) In every pseudo-equilibrium of the game induced by* BOS-P2*,*

- *sophsticated players of type* 1 *and* 3 *report* $A \succ_i C \succ_i B, D$*,*
- *sophsticated players of type* 2 *and* 4 *report* $B \succ_i C \succ_i A, D$*.*

Compared to equilibrium, the presence of naive players makes admission at school A more competitive and, thus, school B more attractive for type 4. Moreover, naive students of type 1, 2 and 4 will not apply at C in the second round, making C a safe fall-back option for type 3 who is therefore willing to take more risk in the first round by applying at A. In general, since there are seats available at C in the second round, sophisticated students all list it second.

3 Experimental design and procedures

Each session consisted of a test of cognitive ability, a risk elicitation task, and ten rounds of the school allocation game. In the latter, experimental subjects played the role of students. An English version of the experimental instructions, control questionnaires, and screenshots for all the tasks are available in Appendix B.

3.1 Cognitive ability and risk aversion

Each session started with a computerized version of Raven's Progressive Matrices test. The Raven test is a leading non-verbal measure of analytic intelligence [Carpenter et al., 1990; Gray and Thompson, 2004], and Raven test scores are associated with the degree of sophistication in the beauty contest [Gill and Prowse, 2015], with the performance in Bayesian updating [Charness et al., 2011], and with more accurate beliefs [Burks et al., 2009]. Each question of the test asks to identify the missing element that completes a visual pattern from a list of candidates.[5] The Standard Progressive Matrices version of the Raven test consists of 60 questions split into 5 blocks of increasing difficulty, labeled A-E, with 12 questions in each. We used blocks C, D and E, for a total of 36 questions. We gave the subjects 5 minutes to complete each of blocks C and D, and 8 minutes to complete block E. Within each block, subjects could move back and forth between the questions, eventually skipping some, and changing their previous answers. Participants received 0.1 ECU for each correct answer.

After the Raven test, subjects played the bomb risk elicitation task (BRET) developed by Crosetto and Filippin [2013]. For that, subjects have to decide how many out of 100 boxes to collect, one of which contains a bomb.[6] The bomb is placed randomly among the boxes, and subjects are unaware of where their bomb is located. If a subject does not collect the bomb, he receives 0.1 ECU for each collected box. He receives zero if he collects the bomb. The number of boxes collected maps into the degree of risk aversion: the more boxes a subjects collects the less risk averse (or the more risk loving) he is, where collecting 50 boxes corresponds to risk neutrality. We choose this task because it is easy to explain and intuitive to perform, features that are particularly de-

[5]See Appendix B for an example.

[6]Boxes are collected sequentially: the player needs to press a 'Stop' button to end the collection of boxes. See Appendix B for a screenshot of the decision screen.

sirable in a design that is rather demanding in cognitive terms.

3.2 Treatments

The school allocation game accords with the environment described in Section 2. Sixteen students, four for each preference type, are allocated to four schools, according to their submitted lists and a random priority ordering. The treatment variables are the allocation mechanism and the preference environment. The allocation mechanism can be either DA or BOS, the preference environment P1 or P2, resulting in four treatments. In each session subjects play five consecutive rounds of the school choice game under each of the two preference environments, for a total of ten rounds, always under the same allocation mechanism. That is, we vary the allocation mechanism *between* subjects, and the preference environment *within* subjects. We vary the order of P1 and P2 across sessions to control for order effects.

We classify each subject as either of high cognitive ability or of low cognitive ability according to whether his test score is in the top or bottom half of the distribution of scores in his session.[7] Since we want preference types to be balanced with respect to cognitive ability, we assign two high and two low subjects to each type. Subject to this constraint, a new preference type is assigned randomly to each player in every new round.

A random lottery generates a priority ordering in each round. After all sixteen subjects have submitted their lists, the allocation is computed according to the relevant mechanism. Subjects are informed of their assigned school, their lottery number, and their payoff in ECU in that round.

3.3 Experimental procedures

The computerized experiment was run at the WZB-TU Experimental Lab in Berlin, in autumn 2015, and involved 192 subjects, distributed over 12 experimental sessions. Sessions took on average 75 minutes. The computerized program was developed using Z-tree [Fischbacher, 2007]. Table 2 summarizes sessions' details. Each subject participated only in one session.

All sessions followed an identical procedure. Subjects were randomly assigned to cubicles in the lab. Instructions were read aloud before each task. To ensure everybody understood the tasks, we conducted a control questionnaire

[7] We break ties using the amount of time used to complete the Raven test. If ties still remain we break them at random.

TABLE 2: SESSIONS

Session No.	Date	Participants	Mechanism	Environment order
1	September 2015	16	BOS	P1-P2
2	September 2015	16	BOS	P1-P2
3	September 2015	16	BOS	P1-P2
4	September 2015	16	DA	P1-P2
5	September 2015	16	DA	P1-P2
6	September 2015	16	DA	P1-P2
7	September 2015	16	BOS	P2-P1
8	September 2015	16	BOS	P2-P1
9	September 2015	16	BOS	P2-P1
10	September 2015	16	DA	P2-P1
11	September 2015	16	DA	P2-P1
12	September 2015	16	DA	P2-P1

Notes: Mechanism indicates whether BOS or DA were implemented. Environment order indicates whether the five rounds of preference environment 1 were run before (P1-P2) or after (P2-P1) preference environment 2.

before the BRET and the school choice game. For the school choice game, this included finding the allocation in a simple school choice problem, given the submitted lists and the priority ordering. The tasks would only start after every subject had correctly completed the questionnaire. To get subjects used to the decision environment, we run a trial round of BRET where no ECU could be earned, before the payoff-relevant one.

At the end of the school choice game, subjects were asked to fill in a questionnaire. We gathered qualitative information about their strategies, and their opinions regarding school choice. We also collected data on whether they had faced the Raven or a similar test before, and on whether they were used to playing mind puzzles.

Subjects were told they would have been paid according to the ECU earned in the Raven test, in the BRET and in one round of the school choice game selected at random by the computer. The corresponding rounds were paid according to the exchange rate: $1\text{ECU} = .70€$. Subjects could earn between 0 and 14 Euros from the school choice game, between 0 and 2.60 Euros from the Raven test, and between 0 and 7.00 Euros from the BRET. The average payment, including 5 Euros of show-up fee, was 16.20 Euros.

4 Hypotheses

As a convention, we label *Safe-Naive* (SN) the strategy where the first choice is manipulated by swapping the order of the first and second preferred school. *Skipping-The-Middle* (STM) lists the most preferred school first, and the third preferred school second. In *Skipping-The-Top* (STT) both the first and the second choice are manipulated by listing the second preferred school first, and the third preferred school second.

As shown in section 2, for BOS-P1 equilibrium predicts that in the first round there are 11 applicants at school A and 5 applicants at school B. All students list C second. All but one student play STM. In BOS-P2, equilibrium predicts that in the first round there are 7 applicants at school A, 5 applicants at school B and 4 applicants at school C. A majority of players uses SN or STT. All reports are truthful under DA-P1 and DA-P2. Hypothesis 1 posits that comparative statics qualitatively match equilibrium predictions.

Hypothesis 1. *The fraction of truthful reports is lower under* BOS *than under* DA*, in both* P1 *and* P2*. The converse holds for STM in* P1*, and for SN and STT in* P2*.*

The ex-ante expected payoff in equilibrium—i.e., before types and lottery numbers are drawn—is between 9.9 and 9.95 in BOS-P1, equal to 9.33 in DA-P1, equal to 10.87 in BOS-P2, and at most 9.58 in DA-P2.[8] BOS increases expected payoff relative to DA by 6.1% − 6.6% in P1 and by at least 13.5% in P2. The intuition for this is that efficiency increases when a student of a certain type is assigned to the school where he earns a higher payoff relative to students of other types. Strategizing works in this direction, because students gain priority at the school they rank higher relative to others. We hypothesize BOS dominates DA in ex-ante efficiency terms.

Hypothesis 2. *Subjects' average payoff is higher under BOS than under DA in both preference environments.*

We expect subjects with a lower Raven score (Low) to be less able to identify optimal strategies than subjects with a higher Raven score (High).[9] In principle, this could be due to either random errors or systematic biases (or

[8]The expected payoff in BOS-P1 depends on the selected equilibrium, i.e. on the identity of the fifth applicant at B. The expected payoff in DA-P2 depends on the report of students of type 3, who are indifferent between B and C.

[9]Considering that cognitive ability is to a large extent genetically inherited [see, e.g. Plomin, 1999], and for the sake of simplicity, we consider parents and children as a single decision maker that applies at schools and attend the school she is assigned to.

both). As discussed in Section 2, we follow Pathak and Sönmez [2008] and hypothesize Low subjects are naive, i.e., they are biased towards truthful reporting. According to Propositions 2 and 4, High subjects would best respond to naive Low subjects by playing STM in BOS-P1, STM or STT in BOS-P2.

Hypothesis 3. *Low subjects are more likely than High subjects to report truthfully under* BOS*. High subjects are more likely than Low subjects to play STM in* BOS-P2*, STT and STM in* BOS-P2*.*

We note that the second part of Hypothesis 3 may also be true when High subjects play an equilibrium strategy (see Propositions 1 – 3). This descends from the fact that appropriate strategizing can take only few simple forms in our context, which is one of the main advantages of our design. On the other hand, this implies we cannot test for beliefs on the strategic ability of other subjects.[10]

A bias towards truth-telling puts Low subjects at a disadvantage under BOS. When Low subjects are naive and High subjects best respond to them, the expected payoff of a Low subject is XXX in BOS-P1 and YYY in BOS-P2, the expected payoff of a High subject is XXX in BOS-P1 and YYY in BOS-P2. Since truth-telling is a dominant strategy in DA, DA should level the playing field.

Hypothesis 4. *The average payoff for High subjects is larger than for Low subjects in* BOS-P1 *and* BOS-P2*. Average payoffs for Low and High subjects do not differ in* DA-P1 *and* DA-P2*.*

Finally, all subjects agree that D is the worst school. Under BOS, if Low subjects are less able to strategize well , they are less able to avoid being assigned to D. For instance, in the extreme scenario where Low subjects are naive and High subjects best respond to them, under BOS-P1 in expected terms schools A and B are balanced, school C admits only High, school D only Low subjects. Under BOS-P2, school A admits more Low, school C more High, school B only High and school D only Low subjects. Under DA, if Low subjects are naive, all schools should be balanced. Moreover, any departure from truth-telling in the ranking of the first three schools does not translate

[10]Nevertheless, behavior of High subjects when they best respond to naive Low subjects is not identical to that in equilibrium, providing us some clues on their awareness of the strategic ability of the others. Most notably, when High subjects best respond to naive Low subjects, they rank C second in BOS-P2, while their second choice is irrelevant in equilibrium. For subjects of type 3 and 4 the first listed school differs as well.

Table 3: Seat allocation dynamics

		DA-P1	BOS-P1	DA-P2	BOS-P2
School A	round 1	94%	100%	100%	100%
	round 2	100%	–	–	–
School B	round 1	85%	100%	42%	93%
	round 2	100%	–	100%	100%
School C	round 1	12%	16%	25%	36%
	round 2	20%	74%	47%	72%
School D	round 1	0%	1%	1%	2%
	round 2	1%	3%	3%	3%

Notes: the table shows the (cumulative) percentage of seats of each school that are allocated in the first two rounds of the allocation procedure in the different treatments.

into a higher probability of being assigned to D. Thus, even under more general assumptions on the strategic behavior of Low subjects, as long as they rank D last, they are not assigned to D with a higher probability than High subjects under DA.

Hypothesis 5. *Low subjects are over-represented at school* D *under BOS, but not under DA.*

5 Results

Table 3 provides an aggregate glimpse of the allocation process. It shows in which round seats at the different schools are assigned to their final match. School A is always filled in the first round.[11] The same holds for School B, except for DA-P2. Three out of four seats at school C are no longer available after round 2 under BOS. More than one third of them are already assigned in round 1 in BOS-P2.

Around 75 percent of reports are truthful under DA-P1 and DA-P2. The same figure is 51 percent under BOS-P1 and BOS-P2. School C is ranked second 27 (23) percent of the time under BOS-P1 (BOS-P2), only 6 (8) percent under DA-P1 (DA-P2). Manipulation of the first listed school account for between 14 and 21 percent of the strategies used under DA-P1, DA-P2, and BOS-

[11]First round matches are temporary in DA. However, rejected students have on average lower lottery numbers, and it is hard for them to win a seat that was assigned to someone else, especially at over-demanded schools.

TABLE 4: ACROSS TREATMENT DIFFERENCES

	Sample	Truthful		SN		STT		STM		Exp. Payoff	
		Z	P-val	Z	P-val	Z	P-val	Z	P-val	Z	P-val
DA vs BOS	P1	**2.91**	**.00**	-.80	.42	**-2.76**	**.01**	**-2.88**	**.00**	-1.92	.05
	P2	**2.81**	**.00**	**-2.54**	**.03**	**-2.73**	**.01**	**-2.19**	**.03**	**-2.41**	**.02**
P1 vs P2	DA	1.16	.25	-1.58	.11	-1.94	.05	0.315	.75		
	BOS	-.11	.92	**-2.20**	**.03**	**-2.20**	**.03**	**2.20**	**.03**		

Notes: the table reports for each of the listed variables: the Wilkoxon rank-sum test, and corresponding P-value, on the difference between DA and BOS within each preference environment; the Wilkoxon signed-rank test for the differences between P1 and P2, within each mechanism. A positive statistic means a higher value for DA (P1). The statistic is computed using one observation per session. Expected payoff is computed using a recombinant strategies procedure with 1000 recombinations for each subject in each period, and an identical number of tie breakers. Bold indicates significance at the .05 level.

P1. The figure is 42 percent in BOS-P2. Non-parametric tests on differences across treatments are shown in Table 4. Every test is based on one observation per session. We find evidence that significantly fewer truthful lists are submitted in BOS with respect to DA. Under BOS-P1, subject use STM and STT significantly more relative to DA-P1. Under BOS-P2 they also employ significantly more SN strategies relative to DA-P2. When comparing P1 to P2, there are no significant differences under DA, while P2 induces more SN and STT, and less STM strategies than P1 under BOS. Thus, while players fall short of the theoretical benchmark, all treatments shift behavior in the direction predicted by equilibrium, supporting Hypothesis 1.

Result 1. DA *induces higher rates of truth-telling relative to* BOS. BOS-P1 *induces more STM,* BOS-P2 *more SN and STT strategies.*

Payoffs earned in the experiment depend to a large extent on the random priorities, and on the strategies used in that particular period by the other subjects in the session. To compare the payoffs across treatments and subjects we use a recombinant estimation technique similar to the one employed by Chen and Sönmez [2006]. The procedure works as follows. Start by picking the strategy of the first subject in the first period, and match it with fifteen strategies drawn at random among those used in the first period in all sessions of the same treatment, under the constraint that there are four players for each type in the resulting virtual game. Given these sixteen strategies, seats are assigned based on a new random priority ordering. Repeat n times, always rematching the same strategy, and create n random samples, each with its own priority ordering, and corresponding allocation. Implement this procedure for all subjects and all periods. We choose $n = 1000$. Because subjects' strategies are not statistically independent within a session—the game is repeated—we

TABLE 5: LPM ESTIMATES OF EQUATION (1)

	Dep. Var.: Expected payoff					
		P1			P2	
	(1)	(2)	(3)	(4)	(5)	(6)
BOS	0.391***	0.427***	0.126	0.305***	0.332***	0.206***
	(0.133)	(0.0969)	(0.138)	(0.0949)	(0.0827)	(0.0719)
High	0.550***	0.508***	0.209	0.444***	0.448***	0.323**
	(0.153)	(0.157)	(0.135)	(0.0758)	(0.103)	(0.148)
BOS*High			0.596**			0.249
			(0.235)			(0.165)
age		0.0225	0.0193		0.000899	-0.000463
		(0.0172)	(0.0183)		(0.0199)	(0.0197)
female		-0.408**	-0.402***		-0.0251	-0.0224
		(0.159)	(0.151)		(0.107)	(0.103)
period		0.0128	0.0128		0.0251	0.0251
		(0.0334)	(0.0335)		(0.0305)	(0.0305)
2.mydistrict		1.117***	1.120***		-0.200	-0.198
		(0.380)	(0.379)		(0.267)	(0.268)
3.mydistrict		-1.052***	-1.050***		0.0774	0.0774
		(0.114)	(0.115)		(0.217)	(0.218)
4.mydistrict		-1.715***	-1.716***		-1.033***	-1.036***
		(0.177)	(0.178)		(0.293)	(0.293)
order		0.143	0.136		-0.0383	-0.0412
		(0.153)	(0.160)		(0.155)	(0.160)
choicebret		0.0160**	0.0153**		0.0106**	0.0103**
		(0.00639)	(0.00616)		(0.00526)	(0.00522)
_cons	8.916***	8.082***	8.342***	9.415***	9.056***	9.165***
	(0.0665)	(0.579)	(0.637)	(0.0675)	(0.612)	(0.618)
Obs. (groups)	960 (12)	960 (12)	960 (12)	960 (12)	960 (12)	960 (12)

Notes: the dependent variable is computed using recombinant strategies procedure with 500 recombinations for each subject in each period, and an identical number of tie breakers. In parentheses we report robust standard errors, clustered at the session level. *,**,***: statistically significant at the 10%, 5% and 1% level, respectively.

cannot run parametric tests on the average payoffs earned across recombinations (as done by Chen and Sönmez [2006]). In the following, we consider each individual average payoff over recombinations as the expected payoff of the corresponding subject in that period.[12]

The empirical average expected payoff is 9.20 under DA-P1, 9.63 under BOS-P1, 9.58 under DA-P2, and 9.94 under BOS-P2. In equilibrium, the corresponding figures would be (approximately, see Section 4) 9.33, 9.9, 9.58 and 10.87. Subjects are close to equilibrium payoffs under DA, less so under BOS. The last columns in Table 4 show the efficiency gains of BOS over DA are significant in P2, but not in P1.[13] A parametric approach to the same question is taken in Table 5, where we also try to account for the multiple factors that may influence one's expected payoff through regression analysis. The dependent variable is the expected payoff obtained from the recombinant estimation technique. All models are random-effects panel regressions, where standard errors are clustered at the session level. Models (4) and (5) confirm our previous findings for P2. Models (1) and (2) detect a significant efficiency gain also in BOS-P1 relative to DA-P1.[14]

Result 2. BOS *dominates* DA *in ex-ante efficiency, confirming Hypothesis 2.*

We turn to the comparison of High and Low subjects. Figure 1 reports the distribution of Raven scores and its median.[15] For the analysis, we choose to split the overall sample between High and Low subjects, rather than keep using the classification adopted to allocate them within each session, because we observe some differences in the thresholds across sessions. Nevertheless we use on the whole sample the same criterion adopted within each session: we break ties in the partial ordering induced by Raven scores using the amount of time used to complete the test, where faster subjects receive a higher rank. If ties survive to this procedure, we break them at random. The median happens to be at a Raven score of 30, where all of the 18 minutes given are used to complete the test. Subjects that do strictly better than that are classified as High, others are classified as Low. Figure 2 reports the distribution of choices in the risk elicitation task. We overimpose the kernel densities for Low and

[12]While we think this approach is most correct, we note that all of our results hold when we use the raw payoffs obtained in the experiment.

[13]Note the P-value for P1 is precisely .05.

[14]As it should be expected, in (4) and (5) lower risk aversion/higher risk propensity is associated with higher payoffs.

[15]We do not observe ceiling effects, something that might be a concern given that we use the Standard version of Raven progressive matrices.

FIGURE 1: DISTRIBUTION OF RAVEN SCORES

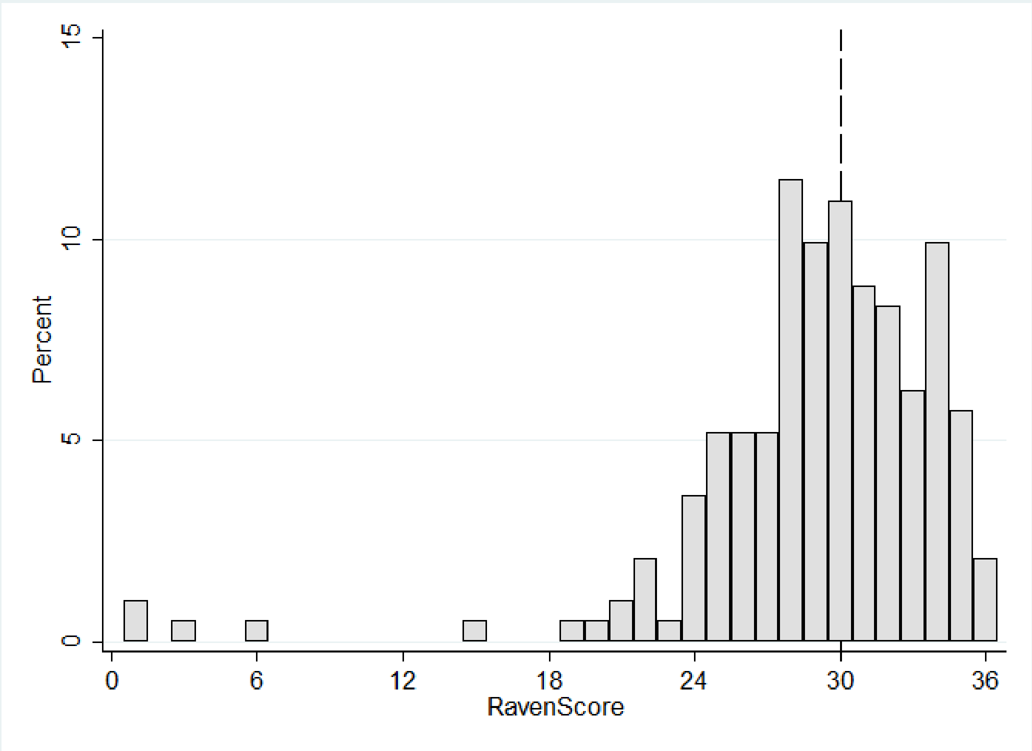


FIGURE 2: DISTRIBUTION OF RISK TASK CHOICES

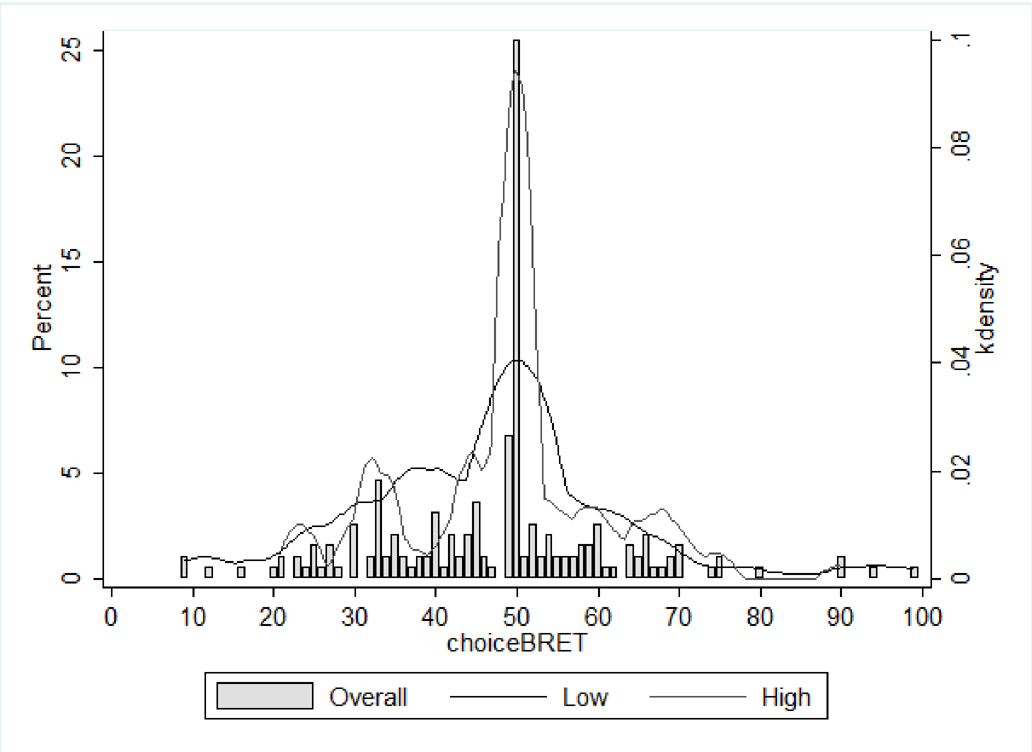


FIGURE 3: PLAYERS' STRATEGIES - P1

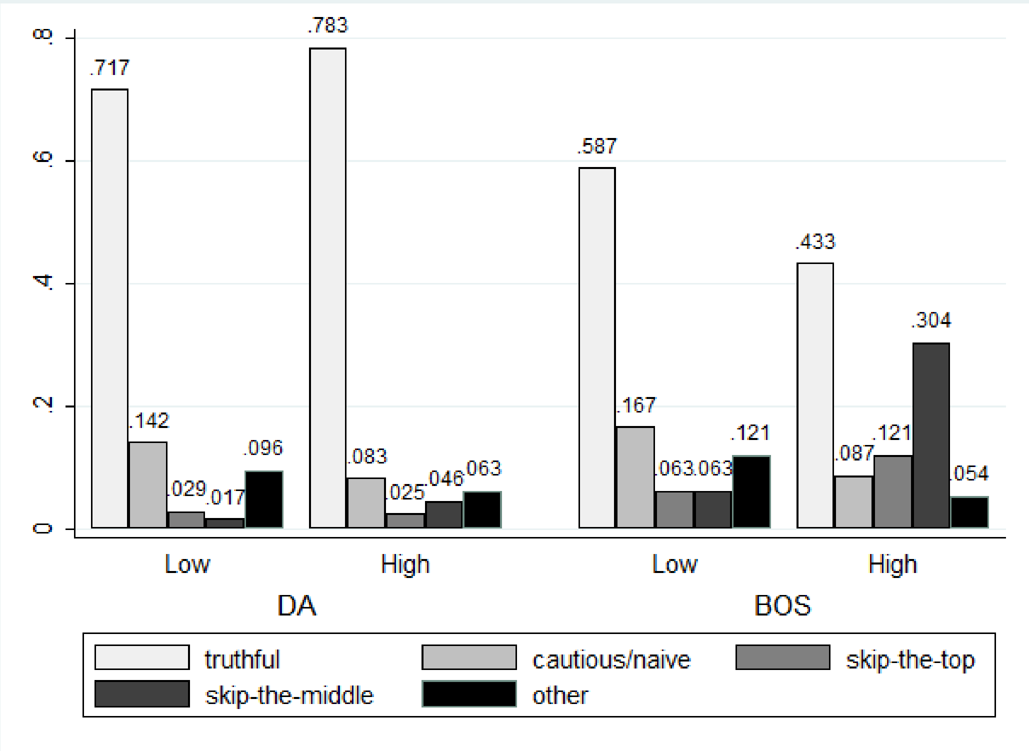


FIGURE 4: PLAYERS' STRATEGIES - P2

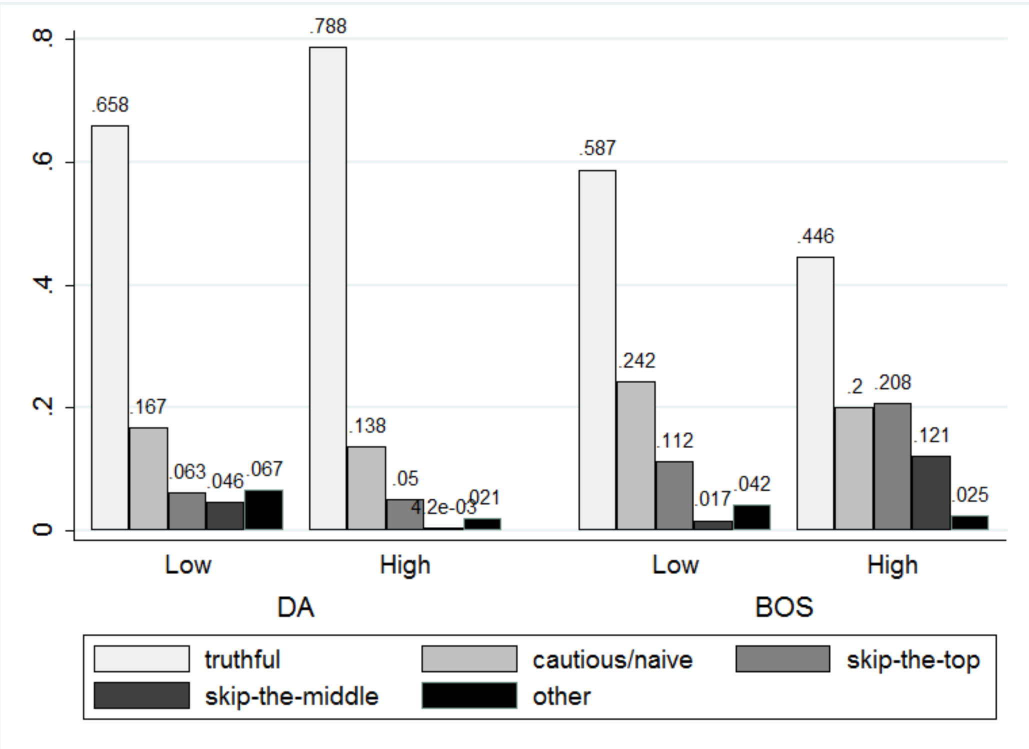


TABLE 6: DIFFERENCES IN STRATEGIES

		Truth	SN	STT	STM	Other
High vs Low	DA-P1	.063	-.059	-.005	.029	-.028
		(.072)	(.046)	(.015)	(.017)	(.026)
	BOS-P1	**-.188**	**-.071**	.057	**.244**	-.043
		(.039)	**(.036)**	(.045)	**(.041)**	(.034)
	DA-P2	**.126**	-.032	-.014	**-.040**	**-.040**
		(.048)	(.024)	(.025)	**(.008)**	**(.014)**
	BOS-P2	**-.171**	-.027	**.097**	**.106**	-.006
		(.050)	(.031)	**(.040)**	**(.026)**	(.011)
BOS-P1 vs DA-P1	Low	**-.104**	.015	.035	.046	.007
		(.040)	(.039)	(.025)	(.033)	(.035)
	High	**-.354**	.004	**.097**	**.261**	-.007
		(.057)	(.031)	**(.030)**	**(.039)**	(.028)
BOS-P2 vs DA-P2	Low	-.049	.059	.049	-.030	-.029
		(.055)	(.040)	(.027)	(.010)	(.017)
	High	**-.345**	**.064**	**.116**	**.146**	.004
		(.058)	**(.026)**	**(.043)**	**(.027)**	(.017)

Notes: each cell in the table can be interpreted as the estimated difference in the probability of using each strategy. Estimates come from a multinomial logit model. The top panel shows the difference between High and Low subjects within each treatment. The bottom panels show the difference between DA and BOS for Low and High subjects. Robust standard errors in parentheses. Bold indicates significance at the .05 level.

High subjects. A larger number of High subjects are risk neutral relative to Low subjects. We do not detect a significant correlation between Raven scores and risk attitudes.[16]

Figures 3 and 4 show the distribution of strategies used by High and Low subjects in each treatment. The truth-telling rate of High subjects is higher than that of Low subjects under DA, and lower under BOS, in both P1 and P2. High subjects seem to respond to the treatments as expected: STM is played by around one third of them in BOS-P1, and SN snd STT are used to a relevant extent only in BOS-P2. Low subjects seem to adjust their strategies only marginally to the different treatments.

We run a multinomial logit on the strategies used to assess the effect that being High or Low has in different treatments. We estimate the marginal effects and test for the significance of differences in marginal effects. Results are

[16]Spearman's rho = .037, P-val= .61.

TABLE 7: DIFFERENCES BETWEEN HIGH AND LOW

Treatment	Truthful		SN		STT		STM		Exp. Payoff	
	Z	P-val	Z	P-val	Z	P-val	Z	P-val	Z	P-val
DA-P1	0.84	.40	-1.36	.17	-0.31	.75	1.26	.21	0.94	.35
BOS-P1	-1.78	.07	-1.15	.25	1.15	.25	**2.20**	**.03**	**2.20**	**.03**
DA-P2	**2.20**	**.03**	-1.36	.17	-0.31	.75	**-2.20**	**.03**	1.78	.07
BOS-P2	-1.78	.07	-1.36	.17	**1.99**	**.04**	**1.99**	**.04**	**2.20**	**.03**

Notes: the table reports, for each of the listed variables, the Wilkoxon signed-rank test, and the corresponding P-value, on the difference between High and Low subjects within each treatment. A positive statistic means a higher value for High subjects. The statistic is computed using one observation per session. Expected payoff is computed using a recombinant strategies procedure with 1000 recombinations for each subject in each period, and an identical number of tie breakers. Bold indicates significance at the .05 level.

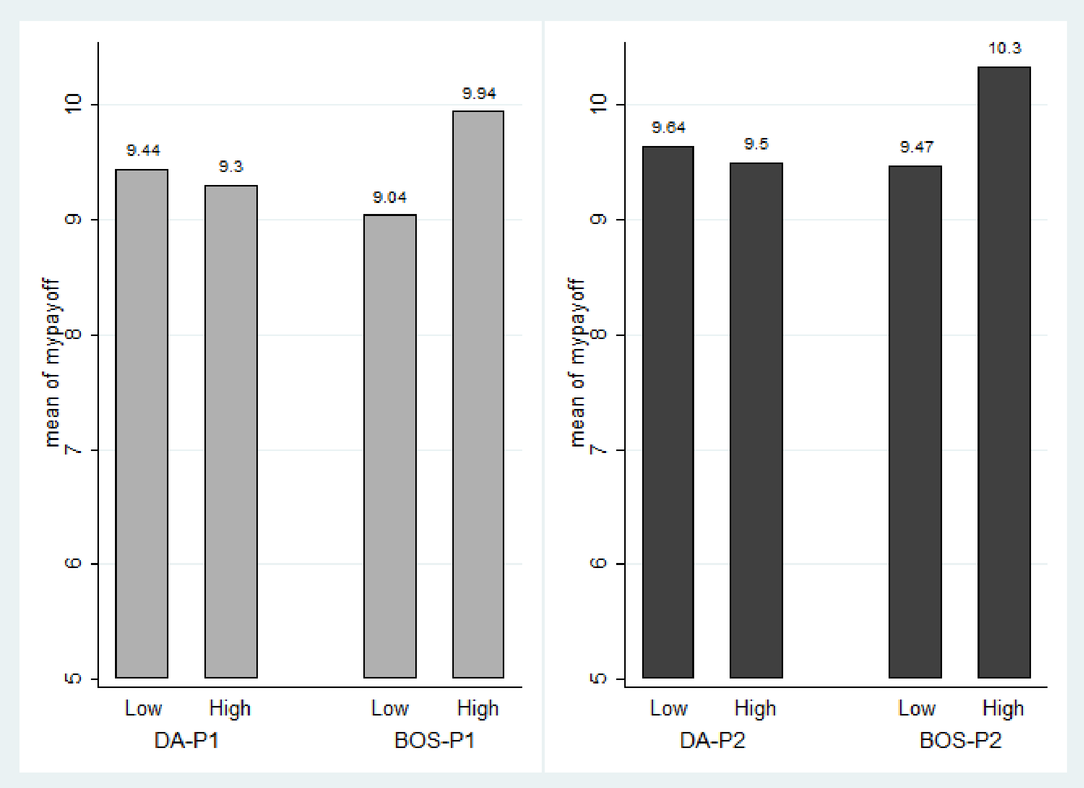
reported in Table 6. The top panel reports differences between High and Low subjects in each treatment. The bottom panels report the difference between DA and BOS, in each preference environment, for Low and High subjects separately. Each cell can be interpreted as a difference in the probability of using the strategy of the corresponding column. Bold differences are significant at the 5 percent level. For instance, the probability of being truthful in DA-P2 is 12.6 percentage points higher for a High subject, and this difference is significant. Or, High subjects reduce their truth-telling rate by 34.5 points between DA-P2 and BOS-P2.

The only significant response of Low subjects to the treatment is a reduction of truthful reports when moving from DA to BOS. This reduction is larger for High subjects (35-34 versus 5-10 percent). In each environment, High subjects increase their use of the 'correct' strategies in BOS, while Low subjects don't. As a consequence, High subjects end up playing significantly more STM and less truth-telling and SN relative to Low subjects under BOS − P1, and significantly more STT and STM and less truth-telling under BOS-P2. They are also significantly more truth-telling under DA-P2.

Table 7 presents the same comparisons, though using non-parametric methods. Since we base the tests on one observation per session, the observations for Low and High subjects are matched, and we adopt the Wilkoxon signed-rank (WSR) test. Despite the fact that the tests have relatively low power in this case, results are similar to those outlined before.

Result 3. *Compared to High subjects, Low subjects are significantly more likely to report truthfully in* BOS*. They are significantly less likely to use STM in* BOS-P1*, STM and STT in* BOS-P2*.*

FIGURE 5: LOW AND HIGH SUBJECTS' PAYOFFS



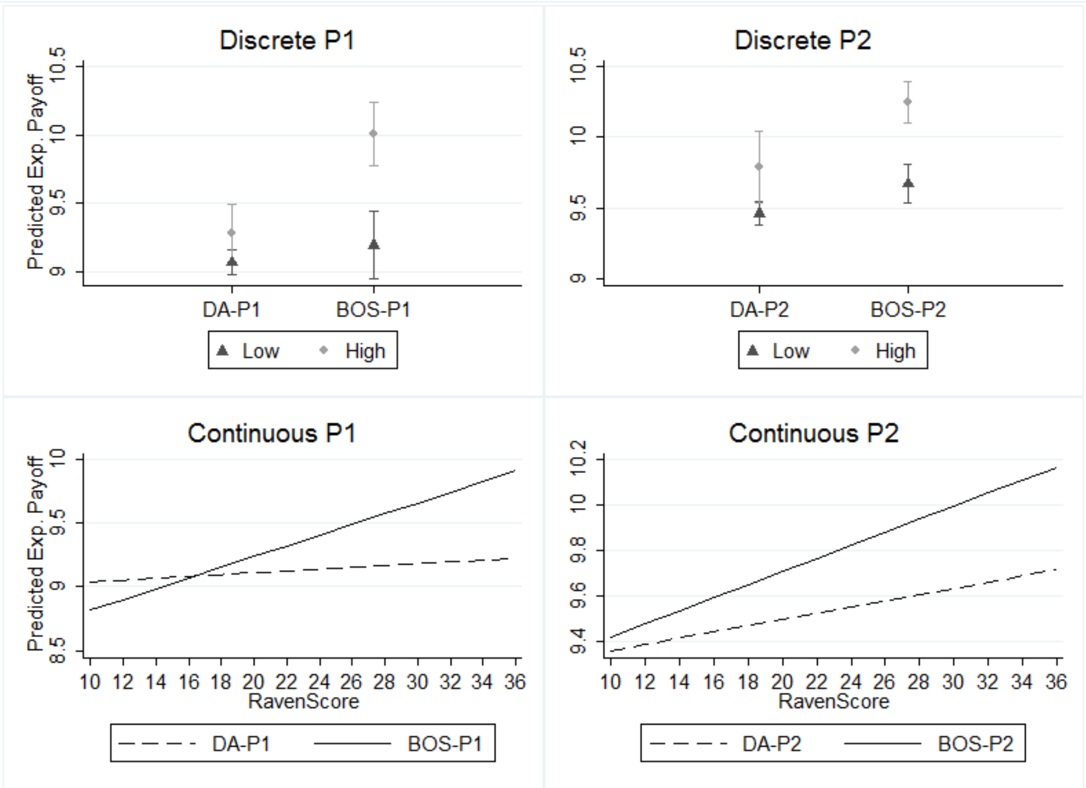
Notes: average payoffs computed for top (High) and bottom (Low) half of the distribution of Raven scores.

Result 3 is in line with Hypotheses 3. Low subjects do not simply suffer from a truth-telling bias. Indeed, they also manipulate too often when they should report truthfully, as in DA-P2, while in BOS-P1 they appear overcautious. Low subjects seem to have a particularly hard time manipulating their second listed school. This is arguably due to the higher strategic complexity of this operation relative to manipulating the first listed school. For the latter, reasoning on capacities and others' first listed schools can be sufficient. In order to manipulate the second listed school, one also needs to simulate the first round of the mechanism and its consequences on available seats.

Average payoffs for all treatments are shown in Figure 5. Low and High subjects earn similar amounts under DA, while High subjects outperform Low ones under BOS. Since these payoffs depend on a number of random factors, we test for differences between Low and High subjects using the expected payoffs obtained through the recombinant strategies technique. A WSR test finds High subjects earn significantly more than Low ones in BOS and not in DA, under both preference environments (Table 7).[17]

[17]Figures 9 and 10 in Appendix C report the average payoff of each strategy for each subject

FIGURE 6: MARGINAL EFFECTS



Notes: average payoffs computed for top (High) and bottom (Low) half of the distribution of Raven scores.

Models (3) and (6) in Table 5 also investigate differences between Low and High subjects, respectively in P1 and P2. The corresponding marginal effects for the interaction between mechanism and cognitive ability are reported in the top panels of Figure 6. The difference in the expected payoff of Low and High subjects increases in BOS relative to DA, and High subjects earn significantly higher expected payoffs than Low ones in BOS, under both preference environments. In DA-P1 Low and High subjects have similar expected payoffs. In P2 High subjects outperform Low ones also in DA. Similarly, the bottom panels of Figure 6 show the linear relation between Raven score and predicted expected payoff for each treatment. They are obtained from models similar to (3) and (6), except they estimate the interaction between the mechanism and the (continuous) Raven scores, rather than the dummy High/Low.[18] The predicted expected payoff increases more steeply with the Raven score under BOS. Indeed the marginal effect of one more Raven point—i.e., the slope of the depicted lines—is significantly different from zero only under

type.

[18]See the full estimates in Appendix C

TABLE 8: NUMBER OF HIGH SUBJECTS PER SCHOOL

	DA-P1	BOS-P1	DA-P2	BOS-P2
School A	2.11	2.11	2.09	1.92
School B	1.97	1.91	2.00	2.05
School C	1.91	2.37	1.94	2.29
School D	2.01	1.63	1.95	1.72

Notes: the table shows the expected average number of High subjects admitted at each school, given the strategies, in case axactly half of the subjects were High. The average is computed using a recombinant strategies procedure with 1000 recombinations for each subject in each period, and an identical number of tie breakers. The average is weighted to account for the different proportions of High subjects in different treatments.

BOS in both preference environments.

Overall, we show BOS induce larger inequalities between Low and High subjects. DA tends to equalize their payoffs.[19] Thus, our results are in line with Hypothesis 4, and strongly support the leveling-the-playing-field hypothesis.

Result 4. *High subjects earn higher payoffs than Low ones under* BOS*. Payoff differences are reduced under* DA*.*

Table 8 shows how many High and Low subjects one is expected to find at each school. We use the allocations obtained from the recombinant strategies procedure to retrieve the average number of High subjects admitted at each school.[20] If the strategies did not differ across groups, all cells should be equal to two. Spreads from this value are small under DA. Ability segregation emerges under BOS. In particular, Low subjects are under-represented at school C and over-represented at school D. In BOS-P1 there are 45 percent more High subjects in school C, and 30 percent more in school A, with respect to school D. In BOS-P2 there are 33 percent more High subjects in school C, and 20 percent more in school B, with respect to school D. [21]

[19]In model (6), but not in the other estimates, we find Low subjects earn less than High ones also in DA-P2. On top of being statistically less robust as a result, one could argue that strategy-induced inequalities are easy to fix under DA, where straightforward advice can be given to parents.

[20]While our classification procedure does not guarantee this, in the experiment there were exactly the same number of High and Low subjects in each treatment.

[21]Under DA and BOS-P1, High subjects are over-represented in school A. Since Low subjects use safe strategies more often when these are suboptimal, they end up under-represented at their preferred school. The 'safe bias' is found to be a major source of losses in empirical studies [Calsamiglia et al., 2015; He, 2014]. In the experiment it is the main departure from

Table 9: Differences in probability of assignment at each school

		School A	School B	School C	School D
High vs Low	DA-P1	.006	-.001	-.036	.030
		(.055)	(.056)	(.036)	(.016)
	BOS-P1	.001	-.011	**.102**	**-.091**
		(.042)	(.046)	**(.032)**	**(.042)**
	DA-P2	-.027	-.003	.020	.009
		(.046)	(.058)	(.048)	(.032)
	BOS-P2	-.006	.011	.076	**-.080**
		(.028)	(.046)	(.048)	**(.021)**
BOS-P1 vs DA-P1	Low	.006	.005	**-.077**	**.066**
		(.034)	(.040)	**(0.24)**	**(.022)**
	High	.001	-.005	**.060**	**-.056**
		(.036)	(.021)	**(.025)**	**(.024)**
BOS-P2 vs DA-P2	Low	-.008	-.002	-.031	**.041**
		(.028)	(.039)	(.031)	**(.019)**
	High	.011	.012	.025	**-.048**
		(.027)	(.034)	(.038)	**(.022)**

Notes: each cell in the table can be interpreted as the estimated difference in the probability of being admitted at each school. Estimates come from a multinomial logit model. The top panel shows the difference between High and Low subjects within each treatment. The bottom panels show the difference between DA and BOS for Low and High subjects. Robust standard errors in parentheses. Bold indicates significance at the .05 level.

Table 9 reports the difference in the probability that High and Low subjects have of being admitted at each school, and the corresponding tests of significance, based on the marginal effects obtained from a multinomial logit model. We find no significant differences between High and Low subjects in the probability of being assigned at any school under DA-P1 and DA-P2. When moving from DA to BOS, Low subjects become significantly more likely to be assigned to School D (second and third panel), and are significantly more likely to be admitted there than High subjects (first panel).

Result 5. *Low subjects are over-represented at school D and under-represented at school C under* BOS.

Thus, BOS induce segregation by ability, confirming Hypothesis 5.

truth-telling under DA, and the main suboptimal strategy other than truth-telling under BOS, used around one in six cases when it should not be played in equilibrium.

6 Conclusions

School choice is a politically sensitive issue. Because education distributes opportunities, fairness and equality concerns play a central role, and it is of paramount importance to identify the winners and losers that changes to the allocation mechanism can make. Our contribution helps achieving this information, and assessing to which extent does Deferred Acceptance level the playing field.

We show that students of lower cognitive ability are worse off with respect to high ability ones under the Boston mechanism, because they fail to manipulate appropriately. This results in ability segregation under the Boston mechanism. Despite the fact that such segregation can emerge only due to different strategic behaviors, and not, as it is the case in most field context, to priority criteria or to correlation between preferences and ability, schools other than the worst admit up to 45 percent more participants of high cognitive ability relative to the worst school. While our game does not explicitly include peer-effects, one should keep them in mind in interpreting this result. The quality of a school is determined to a significant extent by the quality of its students [e.g, Henderson et al., 1978], and if worse schools are filled with students of low cognitive ability this would further decrease their performance [see also Calsamiglia et al., 2015; Cantillon, 2013], and depress the educational prospects of the already disadvantaged.

While these results support the choice of strategy-proof mechanisms, we also show Boston achieve higher ex-ante efficiency over Deferred Acceptance. Despite participants, including high ability ones, are not perfect strategizers, every school admits more students that value it relatively more under Boston. Thus, overall, our results highlight an important tradeoff between equality and efficiency in the choice between school allocation mechanisms. They also pave the way to future investigations of methods that try to resolve this tradeoff, either through the choice of appropriate alternative mechanisms, or by reducing the strategic ability gap between applicants.

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A Proofs

Proof of Proposition 1. We will show that in Preference Environment 1, there is an essentially unique equilibrium where 11 students report $A \succ_i C \succ_i B, D$ and

5 report $B \succ_i C \succ_i A, D$. We begin by showing that this profile is an equilibrium and establish uniqueness only afterwards.

Consider students of type $1, 3$ and 4 who apply at A in the first round. They are admitted at A with probability $^{11}/_{4}$. If they are rejected at A, their conditional probability of acceptance at C is between $^{4}/_{7}$ and $^{4}/_{8}$ as there are 7 applicants who were rejected at A (and have the same conditional probability of acceptance at C) and another applicant who was rejected in a less competitive lottery at B (and therefore has a lower conditional probability of acceptance at C).

For type 1, this corresponds to an expected payoff of more than

$$\frac{4}{11}p(1,A) + \frac{7}{11}\frac{4}{8}p(1,C) \approx 9.18.$$

If she deviates and applies at B in the first round, she should again rank C second, as A will be filled in round 1. If she is rejected at B, she will compete with at least 7 other applicants at C in the second round, so that her expected payoff when submitting $B \succ_i C \succ_i A, D$ is at most [22]

$$\frac{4}{6}p(1,B) + \frac{2}{6}\frac{4}{8}p(1,C) = \frac{20}{3} + 1 \approx 7.66 < 9.18.$$

If she applies at C or D directly in the first round, she will be accepted and her payoff will be even lower. Hence, there is no profitable deviation for type 1.

A type 3 who applies at A, receives an expected payoff of more than

$$\frac{4}{11}p(3,A) + \frac{7}{11}\frac{4}{8}p(3,C) \approx 8.36.$$

If she deviates and applies at B in the first round, her expected payoff is at most

$$\frac{4}{6}p(3,B) + \frac{2}{6}\frac{4}{8}p(3,C) = \frac{20}{3} + \frac{4}{3} = 8 < 8.36.$$

If she applies at C or D directly in the first round, she will be accepted and her payoff will be even lower. Hence, there is no profitable deviation for type 3 who applies at A.

A type 4 who applies at A, receives an expected payoff of more than

$$\frac{4}{11}p(4,A) + \frac{7}{11}\frac{4}{8}p(4,C) \approx 7.73.$$

[22]Since she in the first round, she was rejected in the less competitive lottery at B, her conditional probability of acceptance at C is strictly less than $^{4}/_{8}$ but in order to check that there is no profitable deviation, taking $^{4}/_{8}$ as an upper bound suffices.

If she deviates and applies at B in the first round, her expected payoff is at most

$$\frac{4}{6}p(4,B)+\frac{2}{6}\frac{4}{8}p(4,C)=\frac{20}{3}+1\approx 7.66<7.73$$

If she applies at C or D directly in the first round, she will be accepted and her payoff will be even lower. Hence, there is no profitable deviation for type 4.

A student of type 2 applies at B and is admitted with with probability $4/5$. Hence, her expected payoff is above $4/5\,p(2,B)=13.6$. Deviating and applying at A in the first round would yield less than

$$\frac{4}{12}p(2,A)+(1-\frac{4}{12}p(2,C)=\frac{1}{3}16+\frac{2}{3}8=10.66<13.6$$

while applying at C (or even D) in the first round yields at most $p(2,C)=6$. Hence, there is no profitable deviation.

A student of type 3 or 4 who applies at B receives an expected payoff higher than $4/5\,p(3,B)=8$, since there is a positive probability that if rejected at B, she will be admitted at C. Deviating and applying at A yields an expected payoff of at most $4/12(p(3,A)+p(3,C)+p(3,D))=8$. Similarly, deviating and applying at C in the first round yields $p(4,C)<p(3,C)=8$ as she will be admitted with probability 1. Hence, there is no profitable deviation.

This establishes the strategy profile as equilibrium. Next, we show that no other (pure strategy) equilibrium exists. For that, let us denote the number of applicants at A in the first round as #A and the number of applicants at B and C as #B and #C.

Claim 1. *In any equilibrium,* $\#A,\#B\geqslant 4$.

Proof of Claim: Immediate. Otherwise, if there were less than 4 applicants at A, some type 1,3 or 4 could switch and apply at A, to be accepted with probbaility one and secure the highest possible payoff. If there were less than 4 applicants at B, some type 2 would switch. ♢

Claim 2. *In any equilibrium,* $\#A\geqslant\#B$.

Proof of Claim: Assume otherwise, i.e. $\#A<\#B$ in equilibrium. Then, any type 1, 3 or 4 who applies at B in the first round would switch and apply at A instead. As we are in equilibrium, there can be no type 1, 3 or 4 applying at B in the first round. Then $\#B\leqslant 4$, so that $\#A<4$, in contradiction to Claim 1. ♢

Claim 3. *In any equilibrium, types 1, 2, an 4 apply at* A *or* B *in the first round.*

Proof of Claim: Assume otherwise, i.e. consider a type 1, 2 or 4 who applies at C. She will either get into C or into D, as A and B are filled in the first round. Hence, her payoff is at most $p(1,C) = p(2,C) = p(4,C) = 6$. If $\#A \leqslant 9$, then a switch to A yields an expected payoff no lower than $\frac{4}{9+1}p(4,A) = 6.4$ – a profitable deviation. If on the other hand $\#B \leqslant 5$, a switch to B yields at least $\frac{4}{5+1}p(4,A) = 6.66$ – a profitable deviation. Then the only situation were some type 1, 2 or 4 applies at C would have $\#A = 10$, $\#B = 6$ – a contradiction to $\#C \geqslant 1$. ◊

Claim 4. *In any equilibrium, types 3 apply at* A *or* B *in the first round.*

Proof of Claim: Assume otherwise, i.e. consider some type 3 who applies at C. Since no type 1, 2 or 4 applies at C, she is accepted and receives a payoff of $p(3,C) = 8$. If $\#A \leqslant 7$, then a switch to $A \succ_i C \succ_i B, D$ yields an expected payoff no lower than $\frac{4}{7+1}p(3,A) = 8$. As she would be accepted at C with positive probability in round 2, this constitutes a profitable deviation. If $\#B \leqslant 4$, then a switch to $B \succ_i C \succ_i A, D$ yields an expected payoff no lower than $\frac{4}{4+1}p(3,B) = 8$. As she would be accepted at C with positive probability in round 2, this constitutes a profitable deviation. Hence, we have $\#A \geqslant 8$, $\#B \geqslant 5$, so that $\#C \leqslant 3$.

If $\#A \leqslant 8$, then a switch to $A \succ_i C \succ_i B, D$ leaves at least two available seats at C in round 2 and hence yields an expected payoff no lower than $\frac{4}{8+1}p(3,A) + \frac{5}{9}\frac{2}{6}p(3,C) = 8.59$ – a profitable deviation. Hence, we have $\#A \geqslant 9$, $\#B \geqslant 5$, so that $\#C \leqslant 2$.

If $\#A \leqslant 9$, then a switch to $A \succ_i C \succ_i B, D$ leaves at least three available seats at C in round 2 and hence yields an expected payoff no lower than $\frac{4}{9+1}p(3,A) + \frac{6}{10}\frac{3}{7}p(3,C) = 8.46$ – a profitable deviation. Hence, we have $\#A \geqslant 10$, $\#B \geqslant 5$, so that $\#C \leqslant 1$.

Finally, if $\#A \leqslant 10$, then a switch to $A \succ_i C \succ_i B, D$ leaves four available seats at C in round 2 and hence yields an expected payoff no lower than $\frac{4}{10+1}p(3,A) + \frac{7}{11}\frac{4}{8}p(3,C) = 8.36$ – a profitable deviation. Hence, we have $\#A \geqslant 11$, $\#B \geqslant 5$, so that $\#C = 0$. ◊

Since C is available in round 2 by Claim 3 and 4, while A and B are full, we know that every student submits either $A \succ_i C \succ_i B, D$ or $B \succ_i C \succ_i A, D$. It remains to quantify and identify the number of applicants at each school.

Claim 5. *In any equilibrium,* $\#A \leqslant 11$, $\#B \geqslant 5$

Proof of Claim: Assume otherwise, i.e. $\#A = 12$, $\#B = 4$. If any type 3 applies at A, she would deviate and apply B, as we saw when we established our equilibrium candidate with $\#A = 11$, $\#B = 5$ as an equilibrium. If all 4 applicants at B are of type 2, they receive $\frac{4}{12}p(2,A) + \frac{8}{12}\frac{4}{8}p(2,C) = 7.33$ and would prefer to switch and apply at B, where they get no less than $\frac{4}{5}p(2,B) = 13.6$. ◊

Claim 6. *In any equilibrium,* $\#A \geqslant 11$, $\#B \leqslant 5$

Proof of Claim: Assume otherwise, i.e. $\#A \leqslant 10$, $\#B \geqslant 6$. But then any type 1,3 or 4 applying at B would switch and apply at A as we saw when we established our equilibrium candidate with $\#A = 11$, $\#B = 5$ as an equilibrium. This leaves us with only types 2's applying at B – a contradiction to $\#B \geqslant 6$. ◊

Finally, observe that no type 1 would apply at B in equilibrium. There they receive at most $\frac{4}{5}p(1,B) + \frac{1}{5}\frac{1}{8}p(4,C) = 8.6$ while a switch to A would yield at least $\frac{4}{12}p(1,A) + \frac{8}{12}\frac{4}{8}p(1,C) = 8.66$. Similarly, no type 2 would apply at A in equilibrium. There she would receive at most $\frac{4}{11}p(2,A) + \frac{7}{11}\frac{4}{7}p(2,C) = 8$ while a switch to B would yield more than $\frac{4}{6}p(2,B) = 11.33$. □

Proof of Proposition 2. By assumption on the naive, there are 6 students of type 1, 3 and 4 who report $A \succ_i B \succ_i C \succ_i D$ and 2 of type 2 who report $B \succ_i A \succ_i C \succ_i D$. We claim, that a strategy profile where the 6 sophisticated students of type 1, 3 and 4 report $A \succ_i C \succ_i B, D$ while 2 sophisticated of type 2 report $B \succ_i C \succ_i A, D$ is an equilibrium for the sophisticated students, if we take the reports of naive students as given.

Note that A will be filled in round one as there are at least 4 applications by naive students alone. Moreover, in any equilibrium B will be filled in the first round – otherwise a sophisticated player would switch and apply at B. Then, all sophisticated should in equilibrium rank C second, as it is the best school that has seats available at this point.

The only question that remains, is how many students will apply at A and at B in the first round. Suppose $\#A = 12$, $\#B = 4$, with only types 2 applying at B. A type 2, who applies at B in our candidate profile, is admitted at B and earns her maximal possible payoff - any deviation makes her strictly worse off.

If a sophisticated player looses in the first round at A the number of applicants at C in round 2 can be between 2 (if on other sophisticated student was rejected at A) and 6 (if 5 others were rejected). The probability that one other sophisticated student is rejected at A (and 4 other accepted) is

$$\frac{7 \cdot 4 \cdot 3 \cdot 2 \cdot 1}{11 \cdot 10 \cdot 9 \cdot 8 \cdot 7} \cdot 5 = \frac{1}{66}.$$

The probability that two other sophisticated students are rejected is

$$\frac{7\cdot 6\cdot 4\cdot 3\cdot 2}{11\cdot 10\cdot 9\cdot 8\cdot 7}\cdot\frac{5\cdot 4}{2}=\frac{2}{11}.$$

The probability that three other sophisticated students are rejected is

$$\frac{7\cdot 6\cdot 5\cdot 4\cdot 3}{11\cdot 10\cdot 9\cdot 8\cdot 7}\cdot\frac{5\cdot 4}{2}=\frac{5}{11}.$$

The probability that four other sophisticated students are rejected is

$$\frac{7\cdot 6\cdot 5\cdot 4\cdot 4}{11\cdot 10\cdot 9\cdot 8\cdot 7}\cdot 5=\frac{10}{33}.$$

The probability that five other sophisticated students are rejected is

$$\frac{7\cdot 6\cdot 5\cdot 4\cdot 3}{11\cdot 10\cdot 9\cdot 8\cdot 7}=\frac{1}{22}.$$

Then the conditional probability of acceptance at C (after rejection at A) is

$$\frac{1}{66}+\frac{2}{11}+\frac{5}{11}+\frac{10}{33}\frac{4}{5}+\frac{1}{22}\frac{4}{6}=\frac{61}{66}$$

and the expected payoff for a sophisticated student of type 1, or 4 applying at A is at least

$$\frac{4}{12}p(4,A)+\frac{8}{12}\frac{61}{66}p(4,C)=9.0303,$$

and the expected payoff for a student of type 3 is

$$\frac{3}{12}p(4,A)+\frac{8}{12}\frac{61}{66}p(3,C)=10.26.$$

If i of type 1, 3 or 4 switches and applies at B, there will again be between 2 and 6 applicants at C in round two, depending on the number of rejected sophisticated types at A. The probability that 4 sophisticated students are rejected at A (and 1 other accepted) is, as above, equal to $\frac{10}{33}$. The probability that 5 sophisticated are rejected is also equal $\frac{1}{22}$. We will use these probabilities to derive lower bound on the probability that a student who switched to B ends up at D - this will yield an upper bound on the expected payoff and show that the deviation is not profitable.

Assume that $l_i = 16$, i.e. assume that i draws the lowest lottery number. Then she is rejected at B (where she is one out of now 5 applicants) and will also be rejected at C whenever there are 5 or 6 applicants in round two, i.e.

whenever 4 or 5 sophisticated types have been rejected at A.

Assume that $l_i = 15$. Then she will be rejected at B if all other applicants have lottery numbers between 1 and 14, i.e. with probability $\frac{14\cdot 13\cdot 12\cdot 11}{15\cdot 14\cdot 13\cdot 12} = \frac{11}{15}$. Note that if she is rejected, one of the 7 students rejected at A has lottery number 16. If then there are 5 applicants at C, she will be rejected if none of the 4 rejected sophisticated types that where rejected at A has lottery number 16. If then there are 6 applicants at C, she will be rejected if none of the 5 rejected sophisticated types that where rejected at A has lottery number 16.

Combining all cases, we get a lower bound on the probability that i ends up at D of

$$\frac{1}{16}\left(\frac{10}{33}+\frac{1}{22}\right)+\frac{1}{16}\left(\frac{11}{15}\left(\frac{3}{7}\frac{10}{33}+\frac{2}{7}\frac{1}{22}\right)\right)=\frac{23}{1056}+\frac{11}{1680}.$$

This yields an upper bound on the expected payoff of types 1 and 4 of

$$\frac{4}{5}p(4,B)+\left(\frac{1}{5}-\frac{23}{1056}-\frac{11}{1680}\right)p(4,C)=9.0300.$$

A type 3 who would switch to B would get at most

$$\frac{4}{5}p(3,B)+\left(\frac{1}{5}-\frac{23}{1056}-\frac{11}{1680}\right)p(3,C)=9.37.$$

Hence, for any i of type 1, 3 or 4, switching to B lowers her expected payoff.

In the same way, for any other profile where $\#A < 12$, and $\#B > 4$, sophisticated students of type 1, 3 and 4 would deviate and apply at A. The only thing left to show, is that there cannot be an equilibrium where $\#A = 12$, and $\#B = 4$ and some type 2 applies at A. There, she would earn $\frac{4}{12}16+\frac{8}{12}\frac{61}{66}6 = 9.0303$ (as we calculated for type 4 above), while a switch to B would earn her at least $\frac{4}{5}p(2,B) = 13.6$. This completes the proof.

□

Proof of Proposition 3. We claim that a profile where all type 1 and one of type 4 report $A \succ_i B, C, D$, all type 2 and three of type 4 report $B \succ_i A, C, D$ and all type 3 report $C \succ_i A, B, D$ can be an equilibrium - and that no other profile can.

First, to check that the profile constitutes an equilibrium, consider students of type 1 and 4 who apply at A in the first round. They are admitted at A with probability $4/7$. If they are rejected at A, they are admitted at D.

For a student of type 1 or 4, this corresponds to an expected payoff of at least $\frac{4}{7}\cdot p(4,A) \approx 9.14$. If she deviates and applies at B in the first round, her expected payoff is $\frac{4}{6} \cdot 11 \approx 7.33$. If she applies at C, her expected payoff is $\frac{4}{5} \cdot 7 = 5.6$. Hence, there is no profitable deviation.

A student of type 2 or 4 who applies at B is admitted with with probability $4/5$ and otherwise ends up at D. Hence, her expected payoff is at least $4/5 \cdot p(4, B) = 8.8$. Deviating and applying at A in the first round would yield $1/2 \cdot 16 = 8$, while applying at C in the first round yields $4/5 \cdot 7 = 5.6$. Hence, there is no profitable deviation.

A student of type 3 who applies at C is admitted and receives a payoff of $p(3, C) = 11$. If all others rank C second, deviating and applying at A yields an expected payoff of at most $\frac{1}{2} \cdot p(3, A) + \frac{1}{2}\frac{1}{4} \cdot p(3, C) = 10.75$. Similarly, deviating and applying at B in the first round yields at most $4/6 \cdot p(3, B) + \frac{2}{6}\frac{1}{5} \cdot (3, C) = 8.1$. Hence, there is no profitable deviation, if sufficiently many students rank C second.

Next, we show that there are no other equilibrium profiles.

Claim 1. *In any equilibrium,* $\#A \geqslant 4$.

Proof of Claim: Immediate. Otherwise, if there were less than 4 applicants at A, some type 1,3 or 4 could switch and apply at A, to be accepted with probbaility one and secure the highest possible payoff. $\lozenge$

Claim 2. *In any equilibrium,* $\#B \geqslant 4$.

Proof of Claim: Assume otherwise. Then any student could switch to B and secure an expected payoff of 15 or 11 respectively. Since no one is willing to do this in equilibrium, we know that the sum over expected payoffs must be at least $4 \cdot 15 + 12 \cdot 11 = 192$. But the highest possible sum over deterministic payoffs is $4 \cdot 20 + 4 \cdot 15 + 4 \cdot 11 = 184$ – a contradiction. $\lozenge$

Claim 3. *In any equilibrium,* $\#A \geqslant \#B$.

Proof of Claim: Assume otherwise, i.e. $\#A < \#B$ in equilibrium. Then any type 1, 3 or 4 who applies at B in the first round would switch and apply at A instead. Hence, as we are in equilibrium, there can be no type 1, 3 or 4 applying at B. Then $\#B \leqslant 4$, so that $\#A < 4$, in contradiction to Claim 1. $\lozenge$

Claim 4. *In any equilibrium, types 1, 2, an 4 apply at* A *or* B *in the first round.*

Proof of Claim: Assume otherwise, i.e. consider a type 1, 2 or 4 who applies at C. She will either get into C or into D, as A and B are filled in the first round. Hence, her payoff is at most $p(1, C) = p(2, C) = p(4, C) = 7$. If $\#A \leqslant 8$, then a switch to A yields an expected payoff no lower than $\frac{4}{8+1} p(4, A) \approx 7.11$ – a profitable deviation. If on the other hand $\#B \leqslant 5$, a switch to B yields at least $\frac{4}{5+1}p(4,B) \approx 7.33$ – a profitable deviation. Then the only situation were some type 1, 2 or 4 applies at C would have $\#A = 9$, $\#B = 6$ and $\#C = 1$. In such an equilibrium, everybody would apply at C in the second round. But then, a student of type 3 who applies at A would receive at most $\frac{4}{9}p(3,A) + \frac{5}{9}\frac{3}{5}p(3,C) \approx 10.77$ and would be willing to switch to C where she receives $p(3,C) = 11$ for sure. In the same way, she would deviate when initially she applied at B, where the expected payoff would be at most $\frac{4}{6}p(3,B) + \frac{2}{6}\frac{3}{7}p(3,C) \approx 8.9$. ♢

Claim 5. *In any equilibrium, at least 7 students apply at* A *in the first round.*

Proof of Claim: By Claim 4 and Claim 3, we know that $A \geqslant 6$. Towards a contradiction, assume $\#A = 6$, so that $\#B = 6$ as well. Since no-one would apply at D in the first round, we know that $\#C = 4$ (with all types three applying at C). Then there has to be some student of type 1 or 4 who applies at B, and whose expected payoff is $\frac{4}{6} \cdot 11 \approx 7.33$. A switch to A would yield at least $\frac{4}{7} \cdot 16 \approx 9.14$. ♢

Claim 6. *In any equilibrium, no students of type* 3 *apply at* B *in the first round.*

Proof of Claim: Assume otherwise, so that $\#C < 4$. If $\#B > 4$, every student ranks C second and no type 3 is willing to apply at B instead of C as she risks to be assigned to D. Hence (by Claim 2) we know that $\#B = 4$. But then, some type 2 applies at A where there are at least 9 applicants and she receives at most $\frac{4}{9} \cdot 16 + \frac{5}{9} \cdot 7 = 11$, whereas if she switched and applied at B, she would receive at least $\frac{4}{5} \cdot 15 = 12$. ♢

Claim 7. *In any equilibrium, all students of type* 3 *apply at* C *in the first round.*

Proof of Claim: Assume otherwise, so that $\#C < 4$. Then in the second round, there are available seats at C but not at A or B. Hence, every student that applies at A will rank C second. Moreover, if $\#B > 4$, every student applying at B will also rank C second.

If $\#C = 3$ there is one available seat at C in round two, so a student of type 3 who applies at A in the first, will receive at most $\frac{4}{7} \cdot 16 + \frac{3}{7}\frac{1}{3} \cdot 11 = 10.71$ and would instead prefer to apply at C to receive $p(3,C) = 11$ for sure.

If $\#C = 2$ there are two available seat at C in round two. If moreover $\#A = \#B = 7$ a student of type 3 who applies at A in the first, will receive at most $\frac{4}{7} \cdot 16 + \frac{3}{7}\frac{2}{6} \cdot 11 \approx 10.71$. If on the other hand $\#A \geqslant 8$, she receives at most $\frac{4}{8}16 + \frac{4}{8}\frac{2}{4}11 = 10.75$ when applying at A. In either case, she would deviate and apply at C.

If $\#C = 1$ there are three available seat at C in round two. If $\#A \geqslant 9$, a type 3 applying at A receives at most $\frac{4}{9}16 + \frac{5}{9}\frac{3}{5} \cdot 11 \approx 10.78$ and would deviate to apply at C. If on the other hand $\#A = 8$ and $\#B = 7$, any type 1 or 4 applying at B would switch and apply at A: at B they earn at most $\frac{4}{7} \cdot 11 + \frac{3}{7}\frac{3}{7} \cdot 7 \approx 7.57$, if they switch, they earn at least $\frac{4}{9}16 + \frac{5}{9}\frac{3}{7}7 \approx 8.78$.

If $\#C = 0$ there are four available seat at C in round two. If $\#A \geqslant 10$, a type 3 applying at A receives at most $\frac{4}{10}16 + \frac{6}{10}\frac{4}{6} \cdot 11 = 10.8$ and would deviate to apply at C. If $\#A \leqslant 9$ and $\#B \geqslant 7$, any type 1 or 4 applying at B would switch and apply at A: at B they earn at most $\frac{4}{7} \cdot 11 + \frac{3}{7}\frac{4}{8} \cdot 7 = 7.79$, while if they switch, they earn at least $\frac{4}{10} \cdot 16 + \frac{6}{10}\frac{4}{8} \cdot 7 = 8.5$. ◊

Claim 8. *In any equilibrium, 7 students apply at A in the first round.*

Proof of Claim: We already know that $A \geqslant 7$. Towards a contradiction, assume $\#A \geqslant 8$, so that $\#B = 4$. Then there has to be some student of type 2 or 4 who applies at A, and whose expected payoff is at most $\frac{4}{8}16 = 8$. A switch to B would yield at least $\frac{4}{5} \cdot 11 = 8.8$. ◊

Hence we now know that $\#A = 7$, $\#B = 5$ and $\#C = 4$. It remains to show that all type 1 apply at A and all type 2 apply at B. Towards a contradiction, assume there is a type 1 who applies at B. There she receives $\frac{4}{5} \cdot 11 = 8.8$ If she switches and applies A, she would receive $\frac{4}{8}20 = 10$. Similarly, assume there is a type 2 who applies at A. There she receives $\frac{4}{7}16 \approx 9.1$ If she switches and applies B, she would receive $\frac{4}{6}15 = 10$.

□

Proof of Proposition 4. By assumption on the naive, there are 6 students who report $A \succ_i B \succ_i C \succ_i D$ and 2 students who report $A \succ_i B, C \succ_i D$. We claim, that a strategy profile where the 4 sophisticated students of type 1 and 4 report $A \succ_i C \succ_i B, D$ and 4 sophisticated of type 2 and 4 report $B \succ_i C \succ_i A, D$ is the unique equilibrium for the sophisticated students, if we take the reports of naive students as given.

Note that A will be filled in round one as there are at least 8 applicants by naive students alone.

Claim 1. *There is no equilibrium with $\#A = 8$.*

Proof of Claim: Assume $\#A = 8$, so that all sophisticated types apply at B or C. If $\#B \leqslant 5$, any type 1, 2, 4 who applies at C would switch and apply at B instead, as $\frac{4}{6} \cdot 11 > 7$. However, for $\#B \geqslant 6$, no type 1 would apply at B or C, as a switch to A yields at least $\frac{4}{9} \cdot 20 + \frac{5}{9}\frac{2}{4} \cdot 7 \approx 10.83$ while applying at B yields at most $\frac{4}{6} \cdot 11 + \frac{2}{6} \cdot 7 \approx 9.33$ and applying at C yields 7 – a contradiction. ◊

Claim 2. *There is no equilibrium with $\#A = 9$.*

Proof of Claim: Assume #A $= 9$. If #B $\leqslant 5$, any type 1, 2, 4 who applies at C would switch and apply at B instead, as $\frac{4}{6} \cdot 11 > 7$. However, for #B $\geqslant 6$, no type 1 would apply at B or C, as a switch to A yields at least $\frac{4}{10} \cdot 20 + \frac{6}{10}\frac{2}{4} \cdot 7 = 10.1$ while applying at B yields at most $\frac{4}{6} \cdot 11 + \frac{2}{6} \cdot 7 \approx 9.33$ and applying at C yields 7 – a contradiction. ♢

Claim 3. *There is no equilibrium with* #A $= 10$.

Proof of Claim: Assume #A $= 10$. If #B $=$ #C $= 3$, any type 1, 2, 4 who applies at C would switch and apply at B instead, as $11 > 7$. If #B $= 5$, #C $= 1$, and both naive students of type 3 rank C second, no type 1 or 3 would apply at B where they earn less than $\frac{4}{5} \cdot 11 + \frac{1}{5} \cdot 7 = 10.2$ and instead apply at A where they receive

$$\begin{aligned} \frac{4}{11} \cdot 20 + \frac{7}{11} \Bigg(\frac{3}{5} \left(\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{3}{7} \right) + \frac{3}{4} \left(\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{4}{7} \cdot 4 \right) \\ + 1 \left(1 - \frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{3}{7} - \frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{4}{7} \cdot 4 \right) \Bigg) 7 \\ = \frac{80}{11} + \frac{49}{11} \left(\frac{92}{105} \right) \approx 11.2 \end{aligned}$$

or, in case of type 3,

$$\frac{4}{11} 16 + \frac{7}{11} \left(\frac{92}{105} \right) 11 \approx 11.95.$$

If #B > 5 or if less than two naives rank C second, this only increases the incentives to switch to A. Hence, any equilibrium with #A $= 10$ would have #B $= 4$ and #C $= 2$.

But who would be willing to apply at C? No type 3 - if they would deviate and apply at A, they could earn 11.95 (see above). Similarly, any other type applying at C would deviate and receive at least

$$\frac{4}{11} 16 + \frac{7}{11} \left(\frac{92}{105} \right) 7 \approx 9.7 > 7.$$

Hence, there is no equilibrium with #A $= 10$. ♢

Claim 4. *There is no equilibrium with* #A $= 11$.

Proof of Claim: Assume #A $= 11$. If #B < 4, any type 1, 2, 4 who applies at C would switch and apply at B instead, as $11 > 7$. If #B $= 5$, #C $= 0$ and both naive type 3 rank C second, no type 1 or 3 would apply at B where they earn at most $\frac{4}{5}\cdot 11+\frac{1}{5}\cdot 7=10.2$ and instead apply at A where they receive

$$\begin{aligned}\frac{4}{12}20+\frac{8}{12}\Bigg(&\frac{4}{6}\left(\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{3}{7}\right)+\frac{4}{5}\left(\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{4}{7}\cdot 5\right)\\ &+1\left(1-\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{3}{7}-\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{4}{7}\cdot 5\right)\Bigg)7\\ =\frac{80}{12}+\frac{56}{12}\left(\frac{61}{66}\right)\approx 10.98\end{aligned}$$

or, in case of type 3,

$$\frac{4}{12}16+\frac{8}{12}\left(\frac{61}{66}\right)11\approx 12.1.$$

If less than two naives rank C second, this only increases the incentives to switch to A. We are left with the case $\#A=11$, $\#B=4$ and $\#C=1$, but then no one would be willing to apply at C - not even type 3, who would receive

$$\frac{4}{12}16+\frac{8}{12}\left(\frac{61}{66}\right)11\approx 12.1$$

when switching to A. ◊

Now, let us consider our candidate profile where $\#A=12$, $\#B=4$. We just saw that type 1 and 3 are wiling to apply at A (rather than switch back to B or C). To see that type 2 and 4 are willing to apply at B, check that their expected payoff is 15 and 11 respectively. If they were to switch to A, they would receive at most $\frac{4}{13}\cdot 16+\frac{9}{13}\cdot 7=9.8$ (ranking B second is even less profitable as there will be many naives at B in round 2). This establishes our candidate profile as an equilibrium.

Could there be an equilibrium with $\#A=12$, $\#B=4$ where some type 2 or 3 applies at A? No: If both naives rank C second, a type 2 or 3 at A would earn

$$\frac{4}{12}16+\frac{8}{12}\left(\frac{61}{66}\right)7\approx 9.65,$$

whereas a switch to B yields at least

$$\begin{aligned}&\frac{4}{5}11+\frac{1}{5}\underbrace{\left(1-\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{3}{7}-\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\frac{4}{7}\cdot 5\right)}_{\mathbb{P}(\leqslant 3 \text{ applicants from A at C in round two})}7\\ &=\frac{44}{5}+\frac{7}{5}\left(\frac{43}{66}\right)\approx 9.71.\end{aligned}$$

If less than two naives rank C second, applying at A yields at most $\frac{4}{12}16+\frac{8}{12}7=10$ whereas a switch to B yields at least

$$\frac{4}{5}11+\frac{1}{5}\left(1-\frac{7}{11}\frac{6}{10}\frac{5}{9}\frac{4}{8}\right)7=\frac{44}{5}+\frac{7}{5}\left(\frac{59}{66}\right)\approx 10.05.$$

Finally, could there be an equilibrium with $\#A > 12$? No. This would require that some sophisticated type 2 or 3 applies at A, but we just saw that there are not even willing to do this even when $\#A = 12$. □

B Experimental materials

Instructions

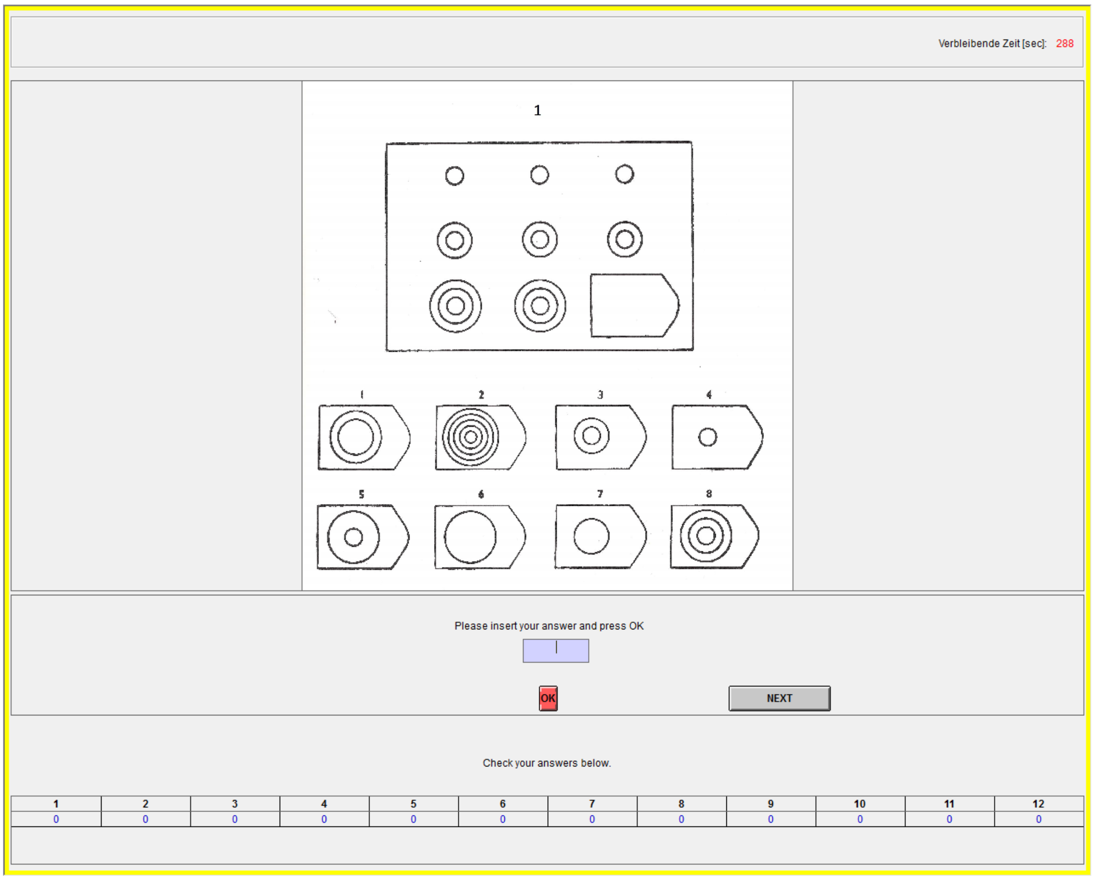
Welcome to this experiment in decision-making. You will receive 5 Euros as a show-up fee. Please, read carefully these instructions. The amount of money you earn depends on the decisions you and other participants make. In this experiment, on top of the show-up fee, you can earn between 0 and 26.30 Euro. In the experiment you will earn ECU (Experimental Currency Units). At the end of the experiment we will convert the ECU you have earned into Euro according to the rate: 1 ECU = 0.7 EURO. You will be paid your earnings privately and confidentially after the experiment. Throughout the experiment you are not allowed to communicate with other participants in any way. If you have a question please raise your hand. One of us will come to your desk to answer it.

TASK 1

On the sheet of paper on your desk you see a puzzle: a matrix with 8 graphic elements and an empty slot. There are eight possible numbered elements that could fill the empty slot. Only one is correct. Your task is to identify the element that correctly solves the puzzle. You choose the element you want by typing the corresponding number and pressing OK.

You will face 36 such puzzles, divided in three blocks of 12 puzzles each. Within each block, you can move back and forth through puzzles even without solving them, and change the answers you have given before. You have five minutes to complete blocks 1 and 2, and eight minutes to complete block 3. For each puzzle you correctly solve you earn 0.1 ECU. You will be informed about your score and earnings at the end of the experiment.

FIGURE 7: SCREENSHOT OF A QUESTION IN THE RAVEN TEST



TASK 2

On the sheet of paper on your desk you see a field composed of 100 numbered boxes. You earn 0.1 ECU for every box that is collected. Every second a box is collected, starting from the top-left corner. Once collected, the box disappears from the screen and your earnings are updated accordingly. At any moment you can see the amount earned up to that point.

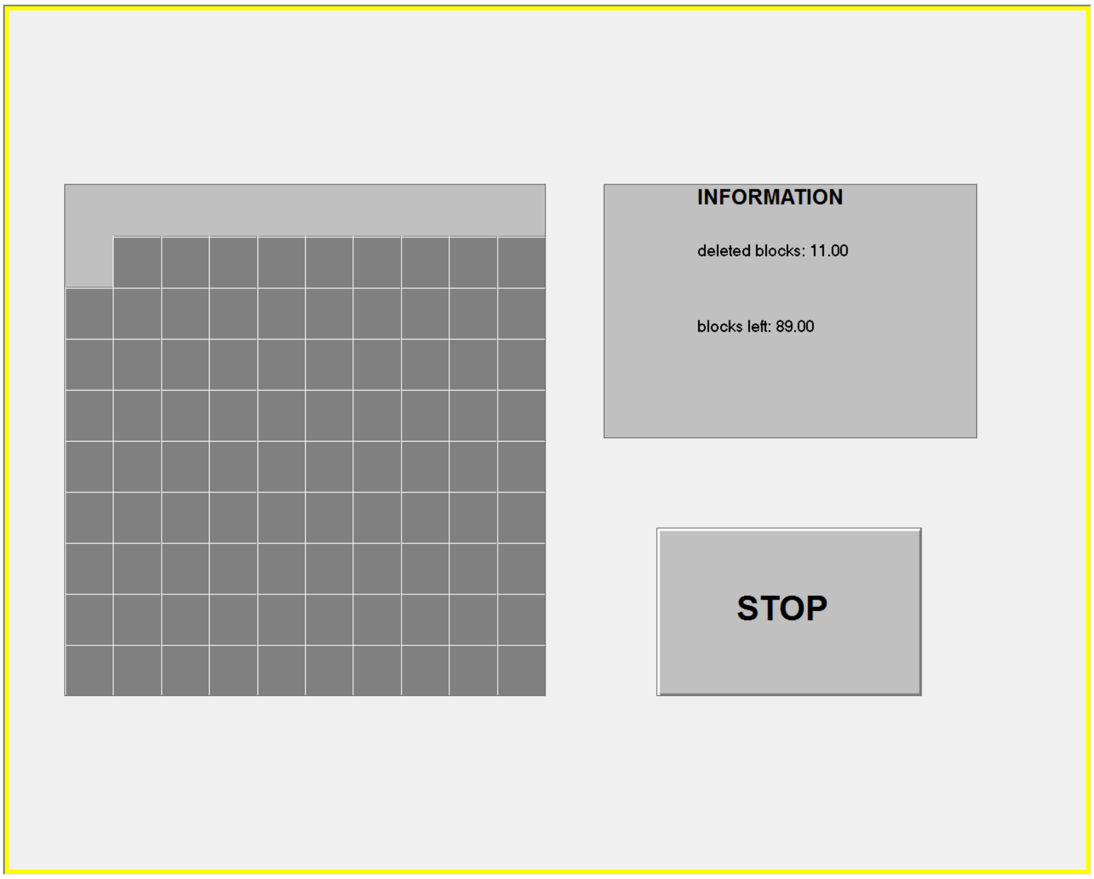
Such earnings are only potential, however, because behind one of these boxes hides a time bomb that destroys everything that has been collected.

You do not know where this time bomb lies. You only know that the time bomb can be in any place with equal probability: the computer will randomly determine the number of the box containing the time bomb. Moreover, even if you collect the time bomb, you will not know it until the end of the experiment.

Your task is to choose when to stop the collecting process. You do so by hitting 'Stop' at any time.

If you happen to have collected the box where the time bomb is located, you will earn zero. If the time bomb is located in a box that you did not collect you will earn the amount of money accumulated when hitting 'Stop'. We will start with a practice round. After that, the paying experiment starts.

FIGURE 8: SCREENSHOT OF THE BOMB RISK ELICITATION TASK



TASK 3

In this part of the experiment, we model a procedure to allocate seats at schools to students. Each student has to submit an application form to apply for a seat at a school. You and the other participants take the role of students. An assignment procedure that we will explain in detail below, decides, based on the application forms submitted by you and the other 15 participants, who receives a seat at which school.

There are 10 Rounds, in which you will apply anew for a seat at a school. All rounds are independent: where you are admitted, depends only on the application forms submitted in this round. Your chances in the current round are not influenced by your own decisions or the decisions of other participants in previous rounds. At the end of the experiment, one round is selected randomly. Your payoff for Task 3 depends on the school that you have been admitted to in that round.

Earnings: rounds 1-5
In each round, you and the remaining 15 participants apply for one of 16 seats. These are distributed over 4 schools—A, B, C, D—where each school has 4 seats. The earnings of a student admitted at a school depends on his type. There are 4 types of students—1, 2, 3, 4—with 4 students of each type. The type of a participant will be randomly drawn in each round. The earnings of a student, depending on his type and the school the he is admitted to, are summarized in the table below.

ECU for a seat at school	A	B	C	D
Type 1	20	10	6	0
Type 2	16	17	6	0
Type 3	16	10	8	0
Type 4	16	10	6	0

You can read the table as follows: in a round where you are a student of type 2 and are admitted at school C you earn 6 ECU - if this round is chosen to be paid out, this amount will be converted to Euros and paid out at the end of the experiment. In the same way, a student of type 3 that is admitted at school A receives a payoff of 16 ECU.

The payoffs above remain unchanged for the first 5 rounds. In rounds 6-10, there is different payoffs table, which you will see on the screen.

Available decisions
In each round, you have to submit an application form. To do so, you have to fill in under 'first choice', 'second choice', 'third choice' and 'fourth choice' the name of the respective school: 'A','B','C' or 'D'. This ranking determines the order with which your applications are sent to the schools, and, through the procedure outlined below, the school you are assigned to. You are free to choose the order in which you rank schools. When you are done, confirm your list by clicking 'submit'.

The assignment procedure [DA]
Once all application forms have been submitted, each student draws a lottery number from 1 to 16: each number is drawn once. Each student has the same

chances. For the assignment, students with a lower lottery number receive preferential treatment over students with a higher lottery number.

The assignment of participants to available seats works as follows:

phase 1:

- Application by students. Each student applies at the school that he ranked as first choice on his application form.

- Admission. If at most 4 students apply at a school, all of them are preliminarily accepted. If more students apply at a school than the school has seats, the school preliminarily accepts the 4 students with the lowest lottery number. Applicants that do not receive a seat are permanently rejected at the respective school.

phase 2:

- Application by students. Every student, who has been accepted preliminarily in round 1, still applies at the respective school. Every student that was rejected permanently in round 1, applies at the school that is next on his application form.

- Admission. Each school preliminarily accepts the 4 applicants with the lowest lottery number. If there are less than 4 applicants, the school preliminarily accepts all applicants. Applicants that do not receive a seat are permanently rejected at the respective school.

phase 3:

- Application by students. Every student, who has been accepted preliminarily in round 2, still applies at the respective school. Every student that was rejected permanently in round 2, applies at the school that is next on his application form.

- Admission. Each school preliminarily accepts the 4 applicants with the lowest lottery number. If there are less than 4 applicants, the school preliminarily accepts all applicants. Applicants that do not receive a seat are permanently rejected at the respective school.

(. . .)

The procedure continues according to these rules. The procedure ends, once a phase is reached where every applicant is preliminarily accepted. In this moment, preliminary acceptance becomes permanent acceptance.

After every round you are informed about your lottery number and about the school where you received a seat. Then, the next round starts.

The assignment procedure [BOS]

Once all application forms have been submitted, each student draws a lottery number from 1 to 16: each number is drawn once. Each student has the same chances. For the assignment, students with a lower lottery number receive preferential treatment over students with a higher lottery number.

The assignment of participants to available seats works as follows:

phase 1:

- Application by students. Each student applies at the school that he ranked as first choice on his application form.

- Admission. If at most 4 students listed a school as first choice, all of them receive a seat at that school. If more students listed a school as first choice, than the school has seats, the seats at that school are given to the students with the lowest lottery numbers. Students, who receive a seat in phase 1 are admitted for good; for them, the assignment procedure is over. Applicants that do not receive a seat move to the next phase.

phase 2:

- Application by students. Every student, who has not been assigned a seat in phase 1, applies at the school that he ranked as second choice on his application form.

- Admission. If in the second phase there are at most as many applicants as free seats at the school, all of them receive a seat at the school. If there are more applicants than free seats, the remaining free seats are given to the students with the lowest lottery numbers. If there are no free seats left, no applicant receives a seat at the school. Students, who receive a seat in phase 2 are admitted for good; for them, the assignment procedure is over. Applicants that do not receive a seat move to the next phase.

phase 3:

- Application by students. Every student, who has not been assigned a seat in phases 1 and 2, applies at the school that he ranked as third choice on his application form.

- Admission. If in the third phase, there are at most as many applicants as free seats at the school, everyone receives a seat at the school. If there are more applicants in the third phase than free seats, the remaining free seats are given to the students with the lowest lottery number. If there are no free seats left, no applicant receives a seat at the school. Students, who receive a seat in phase 3 are admitted for good; for them, the assignment procedure is over. Applicants that do not receive a seat move to the next phase.

phase 4:
- Application by students. Every student, who has not been assigned a seat in phases 1, 2 and 3, applies at the school that he ranked as fourth choice on his application form.
- Admission. Since there are 16 applicants and 16 seats, there are as many free seats in phase 4 as applicants. Everyone receives a seat.

After every round you are informed about your lottery number and about the school where you received a seat. Then the next round starts.

Example [DA]

To illustrate the procedure described above, we consider an example. In this example, there are 8 students and 4 schools—V, W, X, Y—with 2 seats each to be assigned. Each Student draws a lottery number between 1 and 8.

student	Lottery number	First choice	Second choice	Third choice	Fourth choice
1	7	W	V	Y	X
2	5	V	W	X	Y
3	2	X	V	Y	W
4	8	V	X	Y	W
5	1	V	Y	W	X
6	3	X	W	Y	V
7	6	X	W	Y	V
8	4	V	Y	X	W

phase 1:
- Student number 1 applies at his first choice, school W. Since he is the only applicant there for two seats, he is preliminarily accepted.
- Students number 2, 4, 5 and 8 apply at school V, that has only two seats available. The students with the two lowest lottery numbers (Students number 5 and 8) are preliminarily accepted at school V. Students number 2 and 4 receive no seat in this phase.
- Students number 3, 6 and 7 apply at school X, that also has two available seats. Since there are more applicants than available seats, students with the lowest lottery numbers (student number 3 and 6) are preliminarily accepted at X. Student number 7 receives no seat in this phase.
- Students number 1, 3, 5, 6 and 8 have been preliminarily accepted. Students number 2, 4 and 7 have received no seat in this phase. The procedure moves to the next phase.

phase 2:
- Student number 2, 4 & 7 have no seat yet and apply at their second choice.
- Students number 2 and 7 apply at school W. Together with student number 1 who was preliminarily accepted there, there are now three applicants for two available seats. The school preliminarily accepts the applicants with the lowest lottery number (students number 2 and 7). Student 1, receives no seat in this phase.
- Student number 4 applies at school X. There, there are now three applicants, students number 3, 4, and 6, and only two seats. The school preliminarily accepts students number 3 and 6. Student number 4 receives no seat in this phase.
- Students number 1 and 4 have received no seat in this phase. The procedure moves to the next phase.
phase 3:
- Student number 1 applies at his second choice, school V. Together with the preliminarily accepted students number 5 and 8, there are now three applicants for two available seats. The school preliminarily accepts the applicants with the lowest lottery number, students number 5 and 8. Student 1 receives no seat in this phase.
- Student number 4 has been rejected twice and now applies at his third choice, school Y. There he is the only applicant and he is preliminarily accepted.
- Students number 1 has received no seat in this phase. The procedure moves to the next phase.
phase 4:
- Student number 1 applies at his third choice, school Y. Together with the preliminarily accepted student number 4, there are now two applicants for two available seats. The school accepts both.
- All Students have a preliminary acceptance at the end of the phase. The procedure stops; preliminary acceptances become permanent acceptances.

We arrive at the following assignment:

Student number	1	2	3	4	5	6	7	8
school	Y	W	X	Y	V	X	W	V

We start with a short quiz and an example. Then we begin with round 1.

Example [BOS]

To illustrate the procedure described above, we consider an example. In this example, there are 8 students and 4 schools—V, W, X, Y—with 2 seats each to be assigned. Each Student draws a lottery number between 1 and 8.

student	Lottery number	First choice	Second choice	Third choice	Fourth choice
1	7	W	V	Y	X
2	5	V	W	X	Y
3	2	X	V	Y	W
4	8	V	X	Y	W
5	1	V	Y	W	X
6	3	X	W	Y	V
7	6	X	W	Y	V
8	4	V	Y	X	W

phase 1:
- Student number 1 applies at his first choice, school W. Since he is the only applicant there for two seats, he is accepted.
- Students number 2, 4, 5 and 8 apply at school V, that has only 2 seats available. The students with the two lowest lottery numbers (Student number 5 and 8) are accepted at school A. Students number 2 and 4 receive no seat in this phase.
- Students number 3, 6 and 7 apply at school X, that also has two available seats. Since there are more applicants than available seats, students with the lowest lottery numbers (students number 3 and 6) are accepted at X. Student number 7 receives no seat in this phase.
- The assignment procedure ends for students number 1, 3, 5, 6, and 8, who all received a seat at a school. Students number 2, 4 and 7 have received no seat in this phase and move to the next phase.

phase 2:
- Students number 2, 4 & 7 have no seat yet and apply at their second choice.
- Students number 2 and 7 apply at school W, where there is one free seat available. This is assigned to the student with the lowest lottery number (student number 2).
- Student number 4 applies at school X. There, there are no free seats.
- Students number 4 and 7 have received no seat in this phase and move to the next phase.

phase 3:

- Students number 4 and 7 apply at their third choice school, school Y, and are admitted, as school D has two free seats available. With this, the assignment procedure ends.

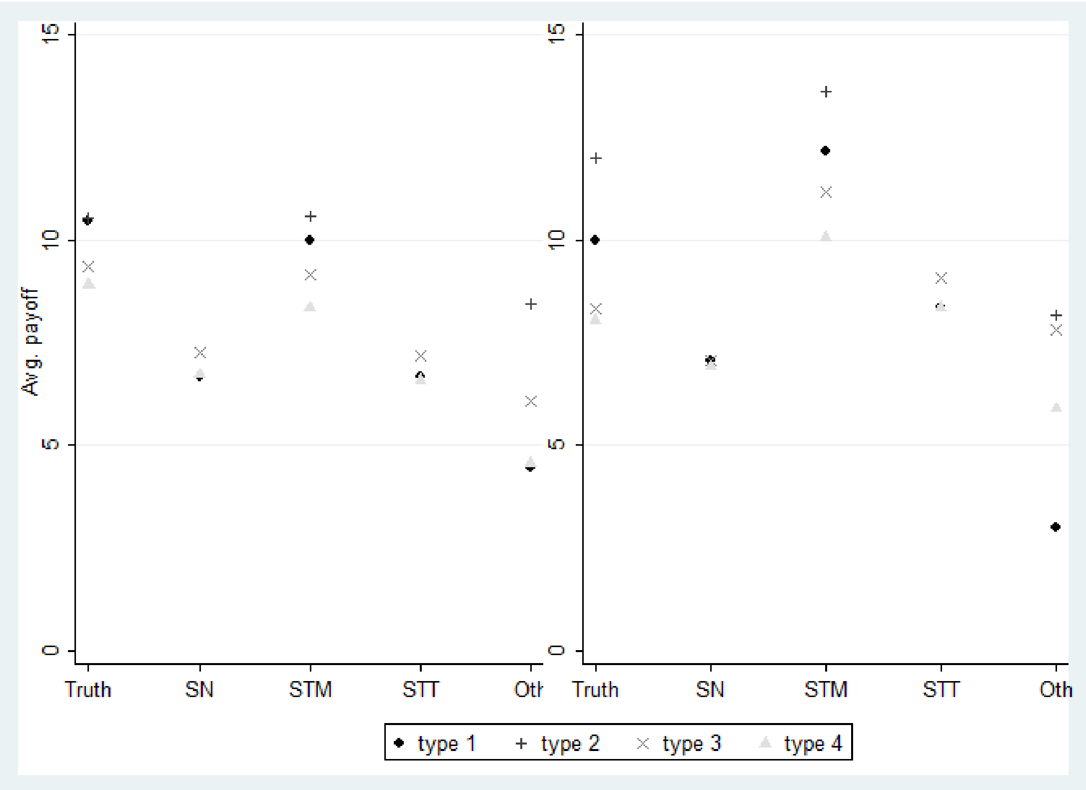
We arrive at the following assignment:

Student number	1	2	3	4	5	6	7	8
school	W	W	X	Y	V	X	Y	V

We start with a short quiz and an example. Then we begin with round 1.

C Additional figures and results

FIGURE 9: AVERAGE PAYOFF OF EACH STRATEGY, BY PLAYER TYPE - P1



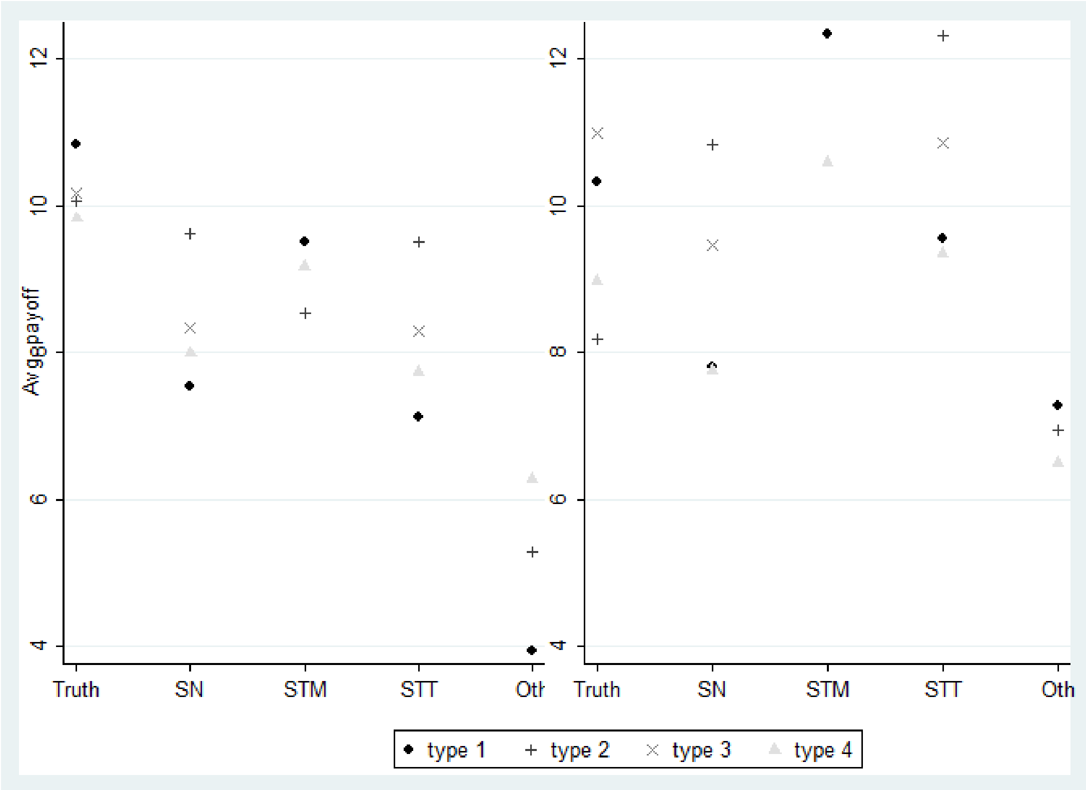
Section 2 provides detailed hypotheses on the strategies of students of different types. In particular we now how many applicants of each district we should observe at each school in the first round of the allocation process. Table 10 compares these prediction with actual data. On aggregate, comparative statics across treatments are always in the predicted direction: overall, there

TABLE 10: FIRST RANKED SCHOOLS

		DA-P1		BOS-P1		DA-P2		BOS-P2		
		School A	School B	School A	School B	School A	School B	School A	School B	School C
Type 1	Predicted	4	0	4	0	4	0	4	0	0
	Actual	3.17	0.73	3.50	0.43	3.17	0.70	3.13	.77	0.10
Type 2	Predicted	0	4	0	4	0	4	0	4	0
	Actual	0.47	3.33	0.63	3.27	2.63	1.13	1.40	2.47	0.13
Type 3	Predicted	4	0	3	1	4	0	0	0	4
	Actual	3.07	0.67	2.27	1.33	3.07	0.40	2.13	0.80	1.07
Type 4	Predicted	4	0	4	0	4	0	3	1	0
	Actual	2.97	0.83	2.13	1.77	3.20	0.57	2.77	1.00	0.17
Overall	Predicted	12	4	11	5	16	0	7	5	4
	Actual	9.68	5.60	8.53	6.80	12.07	2.80	9.43	4.04	1.47

Notes: the table shows the number of applicants of each type at every school in the first round of the allocation procedure—i.e., the number of students that rank that school first. Actual numbers are contrasted with those predicted according to Section 2.

FIGURE 10: AVERAGE PAYOFF OF EACH STRATEGY, BY PLAYER TYPE - P2



are more applicants at school A under DA than under BOS. Students who are expected t list their true first choice most often do so. Subjects of type 3 and 4 tend to over-manipulate their first choice in P1, and in particular under Boston. Students of type 3 in BOS-P2 have the hardest time strategizing correctly: they do not grab the full advantage of listing school C first and are almost as likely to list, instead, school A and school B first. This hampers BOS-P2 to fully realize its efficiency advantage over DA-P2. Similarly. too many students, in particular of type D, apply at school B first in BOS-P1, and compete for its seats with students of type 2, who have the strongest preference for that school.