Parallel Markets in School Choice*

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Abstract

When applying to schools, students often submit applications to distinct school systems that operate independently, which leads to waste and distortions of stability due to miscoordination. To alleviate this issue, Manjunath and Turhan (2016) introduce the Iterative Deferred Acceptance mechanism (IDA). We design an experiment to compare the performance of this mechanism under parallel markets (DecDA2) to the classic Deferred Acceptance mechanism with both divided (DecDA) and unified markets (DA). Consistent with the theory, we find that both stability and efficiency are highest under DA, intermediate under DecDA2, and lowest under DecDA. While IDA is not strategic-proof, we show theoretically that strategic reporting can only lead to improved efficiency for all market participants. The experimental results are consistent with this prediction. Our findings cast doubt on whether strategy-proofness should be perceived as a universal constraint to market mechanisms.

Keywords: Matching markets, deferred acceptance, information acquisition, game theory, lab experiment

JEL classification: C92, D47

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1 Introduction

In many school districts, schools are split into groups that compete for the same set of prospective students. In the US, public schools, charter schools, private schools, and voucher programs run independent admission processes, and most families participate in the admission processes of multiple school groups.[1] This decentralization is not specific to the US. In Germany, for instance, kindergartens are typically managed by independent associations with separate admission processes. In Brazil, centralized college admissions are run separately for public and private universities. In India, there are two types of technical colleges—the Indian Institute of Technologies (IITs) and non-IIT Centrally Funded Technical Institutes (CFITs)—which ran independent centralized admission processes before 2015 without any cooperation between the two matching authorities (Baswana et al., 2019).

It is straightforward to see that parallel admission processes lead to inefficiencies. Some students might be assigned multiple seats while others remain unassigned. The lack of coordination between different authorities causes some school seats to be wasted.[2] To reduce the number of wasted seats, it is common practice for schools with vacant seats to have open enrollment after the main round of admissions. This is, however, generally an uncoordinated and chaotic process, where parents apply to individual schools in search of a seat for their unmatched child. This way of matching students to schools is inconvenient and does not always eliminate waste. Even when it solves the issue of wasted seats, it violates students' priorities and, in turn, the stability of the final allocation.[3]

To achieve a stable allocation for the overall market, the first best solution is to unify all schools under the same umbrella and use the *student-proposing deferred acceptance*

[1] We will refer to these school groups as *different authorities* that manage their admission processes.

[2] See the related discussion in New Orleans: https://www.nola.com/news/education/article_0e350fbe-7ef9-5da6-9fd2-edeefa2af285.html (last accessed on June 22, 2020).

[3] In school choice markets, match stability has become the primary concern for policymakers over the last two decades, as it implies a crucial fairness criterion. In school choice settings, Balinski and Sönmez (1999) decompose stability into individual rationality, non-wastefulness, and fairness. Note that stability guarantees that no seat is wasted. According to the fairness criterion, a student should not be denied at a school if another student with low priority was offered a seat according to the school's ranking.

mechanism (DA).[4] In practice, however, full integration is often impossible. In Indian technical college admissions, for instance, policymakers rejected the unified admissions process to IITs and CFITs in a single centralized market and instead suggested that both IITs and CFITs run their own admissions algorithms (Baswana et al., 2019).

When integration is impossible, Manjunath and Turhan (2016) propose an *iterative deferred acceptance mechanism* (IDA) that produces a stable matching for the overall market. The IDA algorithm works as follows. Each authority applies DA for its respective schools. A student who is matched to a school in more than one authority accepts her most preferred among them and turns down the rest. If there are wasted seats, each authority then computes a re-match by applying DA to the updated student preferences.[5] The re-match may still have wasted seats so that the process may be repeated. If it is repeated enough times, the resulting matching will be stable. While iterating may be costly, as it involves additional inputs from students, Manjunath and Turhan (2016) show that there are significant gains from even the first few iterations.[6]

The main goal of this paper is to use laboratory experiments to compare the performance of DA run separately in each authority and the IDA procedure. This has wide practical relevance for several reasons. First, similar mechanisms are already being used in the field. For instance, in India, a group of computer scientists and operation researchers has worked with policymakers to develop a new matching procedure for admission to Indian technical colleges. The design team proposed a semi-centralized procedure in which a certain degree of coordination between IITs and CFITs is established to solve inefficiencies. Their proposal is a variant of IDA, and Baswana et al. (2019) make an explicit connection between the two:

[4] DA was first introduced by Gale and Shapley (1962) in the context of many-to-one college admissions. It was adapted to the school choice environment by Abdulkadiroğlu and Sönmez (2003). DA produces a stable matching preferred to any other stable matching by every student. As a direct mechanism, it is strategy-proof. Hence, students are expected to report their true rankings over schools.

[5] If a student *accepts* a seat in an authority, her submitted preferences over schools in this authority are truncated by deleting every school that is ranked below the accepted school. Suppose a student *rejects* a seat in a given authority; her submitted preferences over schools in this authority are truncated by deleting the school. In that case, she turned down, and all the schools ranked below it.

[6] When iterated only a few times, the resulting matching is individually rational and fair but might be wasteful. Each additional iteration leads to Pareto improvement. Iterating this process yields a non-wasteful matching.

"In fact, each of our iterations resembles the iterations of Manjunath and Turhan (2016), who find fast convergence when there are two parallel school systems drawing upon the same set of candidates."

Second, in many countries, the markets are split between private and public schools and universities (for instance, the US, Sweden, and Turkey (Andersson et al., 2018)), and run their admissions sequentially, one after the other. Also, in Germany, different associations manage chains of kindergartens within each city. While attempts to centralize the admission processes might fail due to various concerns, IDA might be a first step to reducing the efficiency of parallel admissions without requiring complete centralization. An experimental test of IDA can serve the function of highlighting the benefit of this procedure over other alternatives before its implementation in the field, similar to how the experiments of Chen and Sönmez (2006) convinced policymakers to favor DA over the immediate acceptance mechanism in Boston and New York City (Abdulkadiroğlu et al., 2005a,b).

Finally, the insights of our test go beyond IDA and are directly related to gradual matching mechanisms that are used in overlapping matching markets, for instance, in French college admissions until reform in 2018 (Haeringer and Iehlé, 2021).

Thus, we use experiments as a testbed for a new, highly relevant mechanism. We consider markets with two authorities, each conducting an independent admission process. In the first treatment, each authority runs DA separately, and in case of admission to both authorities, students choose which school to attend (DecDA). This treatment represents the current practice of independent admissions. The second treatment implements the IDA procedure with two iterations (DecDA2): after students that are assigned a seat in both school groups choose their preferred school, their lists are truncated, and DA is run again.[7] As a baseline comparison, we also run DA on the whole market (DA),

[7]We use DecDA2 (i.e., IDA with two iterations) in the experiments for the sake of speed and simplicity. We also keep in mind that, in practice, just a few iterations are sufficient for IDA to converge to a stable outcome, as is evident by the joint admission procedure of the technical universities in India (Baswana et al., 2019). The authors report that it takes three or four iterations for their version of IDA to reach a stable outcome. For the markets we used in the experiment, the Nash equilibria in undominated strategies of the game induced by DecDA2 and IDA are the same (see Remark 3 in the Appendix for details). Moreover, because IDA is (weakly) more efficient than DecDA2 at every preference profile,

as if the school groups managed to reach an agreement on the unified admission process.

Unlike DA, IDA is not strategy-proof. Strategy-proofness is a highly desirable property for a school choice mechanism, as it levels the playing field (Pathak and Sönmez, 2008) and simplifies the school choice game for the participants. It was the main reason for multiple school choice reforms in which the non-strategy-proof Boston mechanism was abandoned in favor of DA[8] (Featherstone and Niederle, 2016). Thus, the practical applicability of IDA might be hampered by its manipulability. It turns out that, under IDA, whenever strategic students play undominated strategies, they never gain at the expense of sincere students. That is, formally speaking, we show that IDA is harmless when manipulating students to play undominated strategies (see Theorem A.1 in the Appendix). These considerations raise whether the lack of strategy-proofness of IDA is costly in practice and further motivates our experimental test.

We study three markets that differ in the source of improvement of DecDA2 relative to DecDA and its potential to reach the full efficiency benchmark of DA. One source of improvement is mechanical because it does not require strategic sophistication, while the second depends on the ability of participants to optimally manipulate their reported preferences. The markets are as follows:

- **Market RI ("Repetition improvement")**: This market has a unique stable match due to a high correlation of school priorities. Schools in both authorities desire the same students, which leads to high inefficiency. One iteration of DA restores efficiency completely in theory. The advantage of DecDA2 is mechanical and does not require strategic play, as DecDA2 is strategy-proof in this market.
- **Market SI ("Strategic improvement")**: This market has four stable matches, and there is no waste in DecDA due to relatively uncorrelated school priorities.

this strictly holds for some problems (see Proposition A.2), DecDA2 gives a lower bound concerning efficiency.

[8]Former Boston Public School (BPS) superintendent Thomas Payzent explained why BPS switched from manipulable Boston mechanism to non-manipulable deferred acceptance mechanism as follows: "A strategy-proof algorithm 'levels the playing field' by diminishing the harm done to parents who do not strategize or do not strategize well." As Featherstone and Niederle (2016) argues, this highlights the assumption in the school choice literature that if truth-telling is not a dominant strategy, parents might try to submit preferences untruthfully.

There is no mechanical advantage of DecDA2 relative to DecDA. The improvement is only possible through strategic play. All students have incentives to truncate their preferences.

- **Market BOTH**: This market has two stable matches. It has both features: a mechanical advantage of DecDA2 that does not rely on strategic behavior and an additional benefit from optimal manipulation.

We run experiments between subjects in the mechanism dimension and within-subjects on the market dimension. We test whether subjects distinguish environments from the perspective of the most relevant behavioral aspect: incentives for strategic play. Overall, our results strongly align with the theory. DecDA2 significantly improves stability and efficiency relative to DecDA in all markets. The highest improvement is observed in the market RI, where it does not require strategic play. However, we observe significantly lower truthful reporting rates among subjects with incentives to play strategically than subjects with truthful weakly dominant strategy. This translates into higher efficiency for groups with more strategic players under DecDA2 in markets SI and BOTH, as predicted by the theory. Contrary to the predictions, however, the improvement from DecDA2 is lower than theoretically predicted, and as a result, efficiency is lower than in DA. Thus, our results are twofold: In markets when DecDA2 improves the efficiency without relying on the strategic play, the improvements are the highest, while when there are incentives to manipulate, only some subjects understand them even as they still manage to improve significantly over DecDA.

Our paper provides direct guidance for market designers who face an exogenous constraint of parallel admissions. The practical implementation of the iterated parallel DA procedure does not require much cooperation between authorities, as the admission processes remain independent to a large extent, with only slight technological integration. Additional iterations can have a high effect on the efficiency of overall allocations, and the concerns of deviations from strategy-proofness are secondary in this context. While decentralization will always lead to some efficiency loss relative to a fully centralized market, DeDA2 with iterations provides a cheap and simple second-best solution.

Besides practical relevance, our experiments raise a doubt whether the absence of strategy proofness should be a universal concern. Ours is among the first experimental papers to show that a mechanism might be desirable despite not being strategy-proof. This message also emerges in several other new papers (see for instance, Cerrone et al., 2022 and Cho et al., 2021). Our paper also contributes to the relatively new and still scarce experimental literature on the ability of participants to manipulate optimally. Featherstone and Niederle (2016) focus on strategies in the Immediate acceptance mechanism, while Castillo and Dianat (2016) study the firm-proposing deferred acceptance mechanism. The latter is closely related to our paper, as optimal manipulations are surprisingly similar to those in our context and essentially boil down to optimal truncation.

2 Literature Review

The school choice literature, starting with Balinski and Sönmez (1999) and Abdulkadiroğlu and Sönmez (2003), has assumed that there is a single clearinghouse that allocates all of the available seats. Manjunath and Turhan (2016) introduce a school choice model in which groups of schools within a single district-run their admission processes independently of one another. The authors study the problem of re-matching students to take advantage of empty seats. They propose an iterative way for each school group to independently match and re-match students to its schools using DA. They show that every iteration leads to Pareto improvement and reduces waste while respecting priorities. Turhan (2019) examines the effects of partition structures of schools on students' welfare and on the incentives students face under the mechanism introduced by Manjunath and Turhan (2016).

Our paper directly relates to the experimental literature on school choice, originating with the seminal paper of Chen and Sönmez (2006). The authors show that strategy-proof mechanisms induce higher truthful reporting rates than the Boston mechanism. This finding was replicated in many subsequent experiments (see, for instance, Basteck and Mantovani (2018), Braun et al. (2014), Chen and Kesten (2015)). This empirical finding helped to convince policymakers to abandon the Boston mechanism in favor of the strategy-proof DA in some school choice districts. DA, however, might also not be strategy-proof if the list is exogenously constrained, and experimental evidence of

(Calsamiglia et al., 2010) supports this prediction. Strategy-proofness, moreover, is not a guarantee of truthful behavior. Several experimental papers show that the truth-telling rates in the strategy-proof environment are sensitive to irrelevant information. (Pais and Pintér (2008), Guillen and Hakimov (2017)). Even learning and strategic advice have only limited effects (Ding and Schotter (2019), Guillen and Hakimov (2018), Bó and Hakimov (2020)). These findings find support in recent empirical studies that identify suboptimal reporting in matching markets (see Hassidim et al. (2020), Rees-Jones (2017), Rees-Jones and Skowronek (2018)). Moreover, non-strategy-proof mechanisms can lead to significantly different levels of truthful reporting, depending on how easily optimal manipulations Dur et al. (2019). Thus, strategy-proofness per se is not a guarantee of the desired allocations, which implies that empirical testing of mechanisms and the degree to which participants understand them is important to ensure the success of mechanisms in the field.

Our paper is also directly related to theoretical work on gradual matching mechanisms. Haeringer and Iehlé (2021) study gradual matching and its implementation in French college admissions. They analyze multi-period matching mechanisms that allow students to participate again, possibly by submitting new rank-ordered lists over the schools that have seats remaining. They also study matching markets where students participate in distinct matching markets such as public and private schools. In such overlapping matching markets with wasted seats, they study the preference updating rules used in the IDA mechanism of Manjunath and Turhan (2016). Haeringer and Iehlé (2021) refer to it as the MT rule and show that the MT rule is strongly regular, which is a condition needed to obtain monotone sequential mechanisms in their framework. Our paper provides an experimental test of a real-world gradual matching mechanism and opens the door to further experimental tests of related mechanisms.

Our paper compares the strategy-proof DA to a non-strategy proof mechanism, where the manipulations are similar to the receiving side manipulations in a two-sided matching setup. The experimental literature on two-sided markets typically find a high degree of deviation from the predicted behavior, with the proposing side manipulating despite strategy-proofness and the receiving side under-truncating (see Echenique et al. (2016), Pais et al. (2011)). Strategic manipulations by the receiving side are also the focus of

Castillo and Dianat (2016), who investigate the use of truncation strategies under DA. They found that the frequencies of truncation strategies are not sensitive to the expected payoff gain but are sensitive to the inherent risk. For more details on related experiments, we refer to recent surveys of Hakimov and Kübler (2020) and Pan (2020).

Finally, several recent papers test DA against a non-strategy proof mechanism, and the comparison results do not always favor DA. Klijn et al. (2019), Bó and Hakimov (2020) and Hakimov and Raghavan (2020) compare DA to a dynamic version of DA, where participants apply to schools one by one. Even though the dynamic DA is not strategy-proof, it leads to a higher truthful play and stability rate. Cho et al. (2021) compare DA to the stable improvement cycle and the choice-augmented deferred acceptance mechanism, both of which restore efficiency under weak priorities but are not strategy-proof. The authors find no difference in truthful reporting between treatments and show that the stable improvement cycle improves efficiency over DA, as predicted. (Cerrone et al., 2022) compare DA to the efficiency-adjusted deferred acceptance mechanism and find higher rates of truthful reporting in the latter, despite it being not strategy-proof.

3 Theoretical Analysis

There is a finite set of students $I = \{i_1, ..., i_n\}$ and a finite set of schools $S = \{s_1, ..., s_m\}$. Schools are partitioned into two sets (authorities) S^1 and S^2, i.e., $S^1 \cap S^2 = \emptyset$ and $S^1 \cup S^2 = S$. Each student $i \in I$ has strict preferences P_i over $S \cup \{\emptyset\}$, where $\emptyset$ denotes remaining unmatched, i.e., the outside option. We write P_i^k for student i's preferences over $S^k \cup \{\emptyset\}$. Let $\mathcal{P}$ and $\mathcal{P}^k$ be the set of all strict preferences over $S \cup \{\emptyset\}$ and $S^k \cup \{\emptyset\}$, respectively. A school $s \in S$ is **acceptable** to student i if $s \; P_i \; \emptyset$; otherwise, it is **unacceptable.**

Schools have a capacity profile $q = (q_s)_{s \in S}$, where q_s is the capacity of school s. Each school s has a strict priority ordering $\succ_s$ over S. We write $\succ = (\succ_s)_{s \in S}$ for the schools' priority profiles. For $S' \subset S$, we write $q_{S'}$ and $\succ_{S'}$ for the capacity and priority profiles of the schools in S'. We refer to $(I, S, q, \succ)$ and $\left(I, S^k, q_{S^k}, \succ_{S^k}\right)$ as the **market** and the **submarket**.

A **matching** μ is an assignment of students and schools where no student receives more than one school, and no school admits more students than its capacity. For each student and school $k \in I \cup S$, we write μ_k to denote the assignment of k under matching μ. A matching μ is **individually rational** if, for each student i, $\mu_i \; R_i \; \emptyset$. A matching μ is **non-wasteful** if there is no student-school pair (i, s) such that $s \; P_i \; \mu_i$ and $|\mu_s| < q_s$. Matching μ is **fair** if, for each student-school pair (i, s) with $s \; P_i \; \mu_i$, $j \succ_s i$ for each $j \in \mu_s$. Matching μ is **stable** if it is individually rational, non-wasteful, and fair. A **mechanism** is a systematic procedure that assigns a matching for each problem.

3.1 Mechanisms and the Induced Games

We consider three mechanisms: DA, DecDA, and DecDA2. We describe each, as well as the game each induces, below.

3.1.1 DA

DA is a direct mechanism, and it runs as follows. Given a preference profile P,

Step 1. Each student applies to his most-preferred acceptable school. Each school tentatively accepts the top priority applicants and rejects the rest up to its quota.

In general,

Step k. Each rejected student in the previous step applies to the most-preferred acceptable school that has not rejected him. Up to its quota, each school tentatively accepts the top priority students among the current step applicants and the tentatively accepted ones and rejects the rest.

The algorithm terminates whenever each student is tentatively accepted or has gotten a rejection from all of his acceptable schools.

DA induces a game among students where each submits preferences $P \in \mathcal{P}$. It is well known that truthful reporting is a weakly dominant strategy for students under DA, which is a property known as **strategy-proofness.**

3.1.2 DecDA

DecDA is an indirect mechanism that works as follows. Each student i submits a pair of preferences $(P_i^1, P_i^2) \in \mathcal{P}^1 \times \mathcal{P}^2$. Based on these submitted preferences, DA is run within each submarket $(I, S^1, q_{S^1}, \succ_{S^1})$ and $(I, S^2, q_{S^2}, \succ_{S^2})$. Note that a student may receive multiple school seats from different submarkets. A student receiving multiple seats rejects either of them, and the final DecDA outcome is reached.

DecDA induces a sequential-move game among students. Note that it is always optimal for students to choose their preferred schools in the last step. Therefore, students do not strategize in the school-selection stage. Hence, students only decide on their preference submissions. Moreover, because DA is used within each submarket, it is weakly dominant for students to be truthful in their preference submissions.

Remark 1. Because of its school-selection stage, DecDA is not a direct mechanism. However, as described above, this stage is automatic in that students always choose their preferred alternatives. Hence, it has nothing to do with the mechanism, implying that DecDA can be considered a direct mechanism, where students only report their preferences in each submarket. This and the fact that truthful reporting is a weakly dominant preference submission strategy make DecDA strategy-proof.

3.1.3 DecDA2

DecDA2 is another indirect mechanism that works as follows. Same as in DecDA, each student i submits a pair of preferences $(P_i^1, P_i^2) \in \mathcal{P}^1 \times \mathcal{P}^2$, and the DA outcome is calculated within each submarket. The second-stage preferences are obtained depending on these DA outcomes in the submarkets. If a student receives no seat, then his preferences remain the same. If a student i receives only one seat, say from school $s \in S^k$, then P_i^k is truncated below s as follows: If we write $P_i'^k$ for the truncated preferences, then for each $s', s'' \in S^k$, $s'' \; P_i'^k \; s'$ if and only if $s'' \; P_i^k \; s'$ and $s' \; P_i'^k \; \emptyset$ if and only if $s' \; P_i^k \; s$ or $s' = s$. We keep student i's preferences over the other submarket, which does not include school s, the same. On the other hand, if a student i receives multiple seats, say from schools $s \in S^1$ and $s' \in S^2$, and accepts s (hence, rejects s'), then $P_i'^1$ is obtained as the same as above. On the other hand, P_i^2 is similarly truncated with the twist that only the schools that are strictly better than s' remain acceptable (i.e., school s' becomes unacceptable under the truncated preferences). We then repeat DA within each submarket for the truncated preferences. A student receiving multiple seats rejects either of them, and the final DecDA2 outcome is reached.

DecDA2 induces a sequential-move game. As in DecDA, it is always optimal for students to choose their preferred schools in the last step. Therefore, students do not strategize in the last school-selection stage. They may be strategic in school selection right after the first DA outcome. However, we show that each student can always obtain a weakly better school by only strategizing at the preference submission stage (see Proposition A.1 and Remark 2 in the Appendix). Therefore, without loss of generality, we assume that students only decide on their preference submissions under DecDA2.

4 Experimental Design

In the experiment, there are four students $\{1, 2, 3, 4\}$ and four schools $\{A, B, C, D\}$, each of which has one seat.[9] The treatments make use of three different markets and three different matching procedures, leading to a 3×3 experimental design, with the markets implemented within-subjects and the matching mechanisms implemented between-subjects. The between-subjects variation on the mechanism direction is typical for matching literature (see for instance, Chen and Sönmez (2006), Calsamiglia et al. (2010)), as explaining a mechanism requires a lot of time, and explaining more than one mechanism would be time-consuming for participants. The within-subject dimension with respect to markets is driven by the practical consideration of experimental costs, and test subjects' understanding of the the mechanism under different market conditions. Two of the matching mechanisms are decentralized in the sense that the set of schools is partitioned into two authorities, $\{A, B\}$ and $\{C, D\}$.

A market specifies how each student $i \in \{1, 2, 3, 4\}$ ranks the four schools and how each school $j \in \{A, B, C, D\}$ ranks the four students. The three markets we use are reported in Table 1. The subjects' payoffs in the experiment are such that getting into a first-choice school pays 20 euros, getting into a second-choice school pays 15 euros,

[9] We opted for the smallest possible market to make the game as simple as possible. The market is of a similar size to Pais and Pintér (2008) and Featherstone and Niederle (2016). The small market makes finding the optimal manipulations in DecDA2 easier than in reality and biases our results towards more manipulations, thus against the main message of no harm of manipulability for practice in this context.

Market "Repetition improvement"(RI):

School priorities:	A	B	C	D
	2	1	1	2
	1	2	2	1
	3	4	3	4
	4	3	4	3

Student preferences:	1	2	3	4
	D	C	A	C
	C	A	C	A
	A	D	D	B
	B	B	B	D

Market "Strategic improvement"(SI):

School priorities:	A	B	C	D
	1	2	3	4
	4	3	2	1
	3	4	1	2
	2	1	4	3

Student preferences:	1	2	3	4
	D	C	B	A
	C	D	A	B
	A	B	C	D
	B	A	D	C

Market "BOTH":

School priorities:	A	B	C	D
	1	2	3	1
	3	1	1	3
	4	3	2	4
	2	4	4	2

Student preferences:	1	2	3	4
	D	D	B	B
	B	C	D	A
	A	B	C	D
	C	A	A	C

Table 1: **Markets used in the experiment**

getting into a third-choice school pays 10 euros, and getting into a fourth-choice school pays 5 euros. Remaining unmatched yields a payoff of zero.

The three matching procedures we use are DA, DecDA, and DecDA2. Comparing the allocations between the three matching procedures is the paper's main interest. The DecDA represents the typical status quo in the markets with two authorities that do not agree to unify. The DA in a unified market represents the "*first best solution,*" which is not feasible given the constraint of the separate admission processes between the authorities. We use the DA in a unified market as a benchmark. The DecDA2 is a recommended "*second best*" procedure that should theoretically improve on DecDA.

The three markets that we chose differ regarding the incentives students face in DecDA2; the only procedure we consider is not strategy-proof. This also means that DecDA2 has a different potential to recover losses in efficiency and stability due to decentralization. Our predictions on efficiency, stability and individual strategies are summarized in the next subsection and discussed more in the Appendix.

4.1 Predictions

Stability

We base our predictions on Nash Equilibria in undominated strategies.[10] We consider stability and the reach of the student-optimal stable match (SOSM) separately. Overall, while SOSM is always reached under DA, we predict weakly less stability and SOSM under DecDA2 and even less stability under DecDA (Table 2). We summarize these predictions below; the technical details can be found in the Appendix.

In DA, the student-optimal stable match (SOSM) is reached if every student submits a weakly dominant strategy.[11] We, therefore, predict full stability under DA, with SOSM being achieved 100% of the time.

In DecDA2, SOSM is the unique NE outcome in undominated strategies in markets RI and SI. In market BOTH, however, both stable and non-stable outcomes are achievable

[10] Note that if every student has a weakly dominant strategy, the equilibrium outcome in undominated strategies is unique.

[11] While it is a weakly dominant strategy for every student to fully reveal his preferences under DA, some of the students have other weakly dominant strategies, as we show in the Appendix.

	Overall stability	SOSM
RI	DA=DecDA2>DecDA	DA=DecDA2>DecDA
SI	DA=DecDA2=DecDA	DA= DecDA2>DecDA
BOTH	DA≥DecDA2=DecDA	DA≥DecDA2≥DecDA

Table 2: **Predictions on stability.** Stability is predicted to be weakly highest in DA, second-highest in DecDA2, and lowest in DecDA.

in equilibrium under DecDA2; we, therefore, predict weakly smaller levels of stability and SOSM outcomes compared to DA.

In DecDA, in market RI, student 3 remains unassigned under DecDA regardless of which combination of weakly dominant strategies is played; we, therefore, predict smaller levels of stability and fewer SOSM outcomes in DecDA than DecDA2. In market SI, the unique equilibrium outcome is the school optimal stable match (COSM) under DecDA, and thus we predict equal levels of stability and fewer SOSM outcomes relative to DecDA2. Student 4 might be unassigned under DecDA in undominated equilibria in market BOTH. Thus, both non-stable and stable (COSM and SOSM) matches can be reached. We, therefore, predict similar levels of stability under DecDA compared to DecDA2 but weakly fewer SOSM outcomes.

Efficiency

The predictions on efficiency (sum of payoffs) are summarized in Table 3.

	DA	DecDA2	DecDA
RI	70	70	Between 40 and 50
SI	80	80	40
BOTH	70	Between 40 and 70	Between 40 and 55

Table 3: **Predictions on efficiency (sum of payoffs).** Efficiency is predicted to be weakly highest in DA, second-highest in DecDA2, and lowest in DecDA.

Overall, we predict the highest levels of efficiency under DA, where SOSM is expected to be reached. Because SOSM can also be reached under DecDA2—uniquely in markets RI and SI—the SOSM sum of payoffs is always an upper bound on the predicted sum of payoffs under DecDA2. Because SOSM is never an equilibrium outcome under DecDA, the upper bound is strictly smaller than DecDA2, while the lower bound is weakly smaller. Overall, the table suggests a clear efficiency ranking, with the highest levels predicted under DA, the second-highest under DecDA2, and the smallest under DecDA.

Truthfulness

We predict that subjects are completely truthful[12] under DA and DecDA, both of which are strategy-proof. While DecDA2 is not strategy-proof in general, truthfulness is also a dominant strategy under DecDA2 in market RI; we therefore also expect subjects to be truthful in this treatment.

	Truthfulness
RI	DA=DecDA=DecDA2
SI	DA=DecDA>DecDA2
BOTH	DA=DecDA≥DecDA2

Table 4: **Predictions on truthfulness.** Less truthfulness is predicted under DecDA2 in markets SI and BOTH than the other treatments.

Under DecDA2, no student has a weakly dominant strategy in market SI, and every undominated equilibrium involves one or more students manipulating their reports. The optimal manipulations are a truncation of the reported lists above the college-optimal stable match, a third-ranked school of every student. We, therefore, predict less truthfulness under DecDA2 than under the other mechanisms in market SI. While truthful revelation can be sustained in equilibrium under DecDA2 in market BOTH, many equilibria are not truthful. We, therefore, predict no more truthfulness in the market BOTH under DecDA2 than under the other two mechanisms.

4.2 Implementation

Four sessions were run with each mechanism, with 24 subjects per session. The 24 subjects in each session were grouped into two matching groups of 12 so that the 12

[12] In our analysis of the data, following conventions in the experimental literature, we treat any weakly dominant strategy in DA as equivalent to truthfulness.

subjects within a matching group were randomly re-matched with each other every period (but not the subjects in the other matching groups) as the experiment proceeded. The re-matching was done to avoid reputation effects due to learning opponents' strategies.

At the beginning of the experiment, printed instructions were given to the participants (see the Appendix). Participants were informed that the experiment was about the study of decision-making and that their payoff depended on their own decisions and the decisions of the other participants. The instructions were identical for all treatment participants, explaining in detail the experimental setting. Clarifying questions were answered in private. Instructions included a step-by-step solution of an allocation example.

Each subject made decisions throughout 27 periods. In DA treatment, subjects submitted a rank-order list of a maximum of all four schools. In DecDA and DecDA2 treatments, subjects had two submit two rank-order lists of a maximum of two schools, separately to each authority. All subjects in the same session faced the same matching mechanism in all periods and were presented with different markets in the same order. This order was also fixed across mechanisms so that for each session of DecDA, there was a session each of DA and DecDA2 with the same sequence of markets.[13] This leads to four different order sequences in the experiment.

For each of the four order sequences, markets were fixed in three-period blocks, so that the first three periods were played with one market, the next three periods with a different market, and the last three periods with the remaining market.[14] Each order sequence, therefore, consisted of three 3-tuples of blocks, where the first 3-tuple represents the first nine periods, the second 3-tuple the following nine periods, and the last 3-tuple the last nine periods of the order sequence. The allocation of the three markets across each 3-tuple of blocks was randomly determined. We randomized at the 3-tuple (instead of 9-tuple) level to allow for learning effects within markets and simplify participants' environment. The order sequences used in the experiment are reported in Table 5.

The participants knew the preferences of all other participants and the priorities of

[13]This is to keep possible order effects the same across treatments.

[14]Different markets have different strategic properties, and we designed the block order to allow for learning within the market.

Order	Sessions
SI, RI, BOTH, RI, BOTH, SI, RI, SI, BOTH	Sess. 1 (DecDA), Sess. 2 (DecDA2), Sess. 5 (DA)
RI, SI, BOTH, RI, SI, BOTH, SI, RI, BOTH	Sess. 3 (DecDA), Sess. 4 (DecDA2), Sess. 8 (DA)
BOTH, SI, RI, RI, BOTH, SI, SI, RI, BOTH	Sess. 6 (DecDA), Sess. 7 (DecDA2), Sess. 9 (DA)
BOTH, SI, RI, BOTH, SI, RI, RI, BOTH, SI	Sess. 10 (DecDA), Sess. 11 (DecDA2), Sess. 12 (DA)

Table 5: **The order of markets.** Each number in the right column represents a three-period block. "Sess." stands for session. For instance, in Session 1, Market SI was played in periods 1-3, Market RI in periods 4-6, Market BOTH in periods 7-9, and so on.

schools in each round. We opted for complete information environments for two reasons. First, we wanted to provide subjects with enough information to manipulate reports optimally under DecDA2. Castillo and Dianat (2016) tested for optimal manipulation strategies in the context of firm-proposing deferred acceptance, and we followed their design choice, which also used complete information. Second, in practice, students have a good understanding of the popularity of schools and their priority at different schools, which is an essential factor in deciding on application strategies. We opted for complete information to capture this assumption.[15]

5 Results

Our focus is on testing whether DecDA2 leads to improved allocations relative to DecDA, using the results of DA (in which there are no constraints of decentralization) as the benchmark limit for improvement. We first present the across-market results on efficiency and stability. Next, we shed light on these results by presenting subjects' strategies, focusing on truth-telling and equilibrium behavior.

Our main results regarding stability and efficiency involve pairwise comparisons of treatments. We report the results of OLS regressions and the results of nonparametric two-sample Mann-Whitney U (MWU) tests.

The regressions we use are as follows:

[15]Note that treatment differences between mechanisms were found to be robust to information structure in Pais and Pintér (2008) and Chen et al. (2016b).

$$Y_n = \beta_{DA} DA_n + \beta_{DecDA2} DecDA2_n + \epsilon_n \quad (1)$$

Y_n is the outcome of interest, while DA_n and $DecDA2_n$ are indicator variables for the mechanisms. DecDA is used as a baseline, and standard errors are clustered at the level of matching groups.

For each market, we report the P-value for a test of the null hypothesis that $\beta_{DA} = 0$ for comparisons between DA and DecDA and that on $\beta_{DecDA2} = 0$ for comparisons between DecDA2 and DecDA. For comparisons between DA and DecDA2, we report the P-value on the test of difference of β_{DA} and β_{DecDA2}. The full regression results, as well as the robustness checks controlling for the order in which the markets were presented, can be found in Appendix C.[16] Our main results are unaffected by order effects.

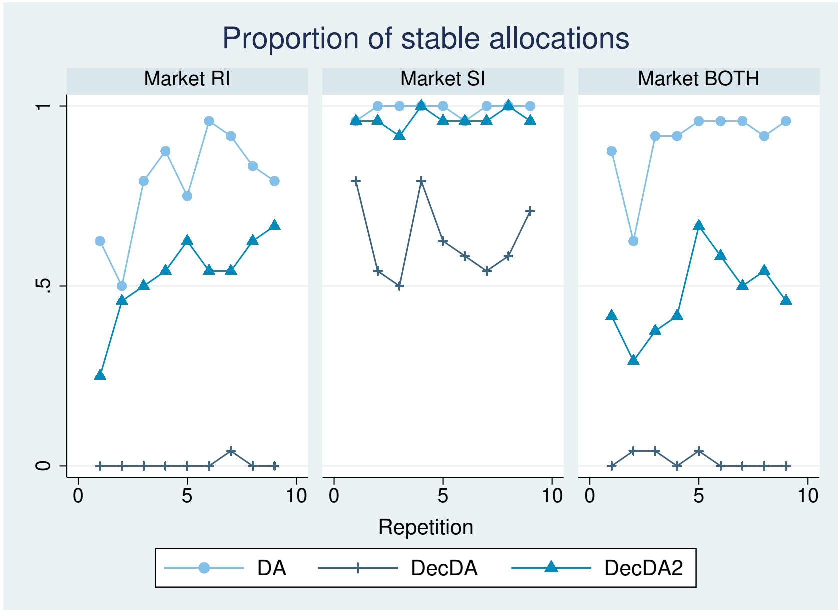
In the MWU tests, an observation is a matching group. Recall that our experiment included 12 sessions with two matching groups per session, leading to 24 independent observations. Sessions were equally split across mechanisms, and subjects participated in all three markets in each session. This gives us eight observations per mechanism when making a pairwise comparison for each market. The outcome of interest is averaged for the matching group holding fixed the market and the mechanism.

The majority of our main results on stability and efficiency (26 of 27 pairwise comparisons) are unaffected by whether OLS or nonparametric tests are used and significant at a 1% level.

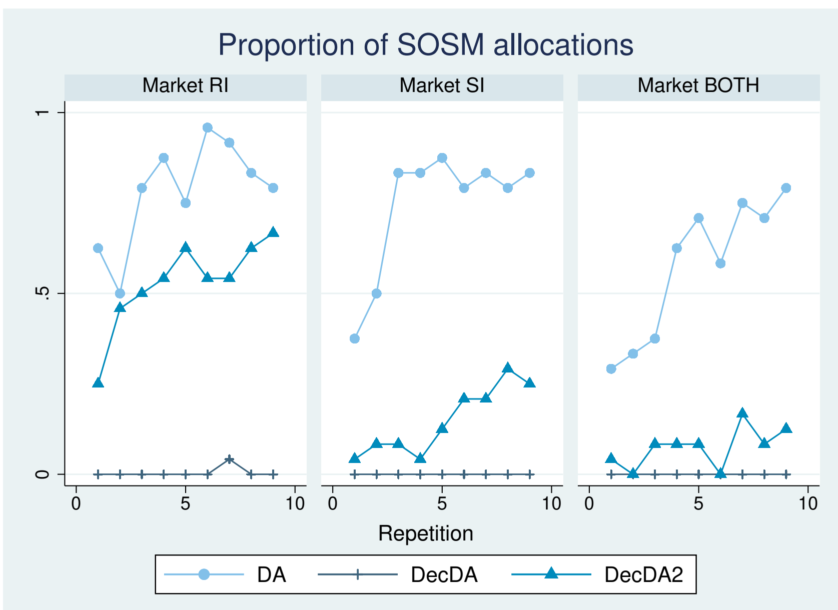
5.1 Stability

Figure 1a presents the proportion of stable allocations in each treatment (i.e., market and allocation mechanism). Overall, we find a clear ranking of the matching procedures, with DA leading to the highest stability, DecDA to the lowest, and DecDA2 falls in between. All pairwise differences are significant with $p < 0.01$ regardless of whether OLS

[16] In the regression results on stability and efficiency, an observation is a group-level outcome (e.g., whether or not the group reached a stable outcome). In the regression results on truthfulness, an observation is a subject-level outcome (whether or not the subject reported truthfully).



(a) Overall stability.



(b) SOSM allocations.

Figure 1: **Stability by treatment.** As predicted, stability is highest in DA, second-highest in DecDA2, and lowest in DecDA. The difference in SOSM allocations between DA and DecDA2 is larger in markets where reaching SOSM relies on strategic play than in market RI.

or MWU tests are used, except the difference between DecDA2 and DA in market SI ($p < 0.05$ with OLS; $p = 0.0754$ with MWU).

While the empirical relation of stability rankings is clear and does not depend on the market, note that the relations predicted by the theory were market-dependent. The two major deviations from the theory are:

1. While DecDA2 was predicted to reach full stability in markets RI and SI, realized stability levels are lower under DecDA2 than under DA. Note that misrepresentation of reported preferences is not required to reach full stability under DecDA2 in these markets.

2. In market SI, we predicted full stability under DecDA but realized stability is lower than DA and DecDA2. The prediction is based on participants playing dominant strategies in DecDA, just like in DA.

Figure 1b presents the proportion of student-optimal stable match (SOSM) allocations in each treatment. Again, we observe a clear ranking of the matching procedures, with DA leading to the highest proportion of SOSM, DecDA2 the second-highest, and DecDA the lowest. All of the pairwise differences are significant with $p < 0.01$ regardless of whether OLS or MWU tests are used. While SOSM is essentially never reached under DecDA, as predicted, the level of SOSM under DecDA2 is lower than predicted in markets RI and SI. In market SI, the prediction of equal levels of SOSM under DA and DecDA2 is based on the strategic play of participants in DecDA2, and we observe a significant deviation from this prediction. Note that the difference SOSM levels across DA and DecDA2 are larger in market SI than in market RI ($p < 0.01$), where the prediction of equal levels of SOSM is based on truthful reporting. These results suggest that participants only partially use strategic play. [17]

We summarize our results as follows:

[17] To test this hypothesis, we regress a dummy variable for a SOSM outcome against dummy variables for treatments DA and DecDA2, dummy variables for markets SI and BOTH, and interactions between the treatments and markets, using DecDA in market RI as a baseline: $SOSM_n = \beta_{DA}DA_n + \beta_{DecDA2}DecDA2_n + \beta_{SI}SI_n + \beta_{BOTH}BOTH_n + \beta_{DA\times SI}DA_n \cdot SI_n + \beta_{DA\times BOTH}DA_n \cdot BOTH_n + \beta_{DecDA2\times SI}DecDA2_n \cdot SI_n + \beta_{DecDA2\times BOTH}DecDA2_n \cdot BOTH_n + \alpha + \epsilon_n$. The null hypothesis is that $\beta_{DA} - \beta_{DecDA2}$ is equal to $(\beta_{DA} + \beta_{DA\times SI}\beta_{DecDA2} + \beta_{DecDA2\times SI})$.

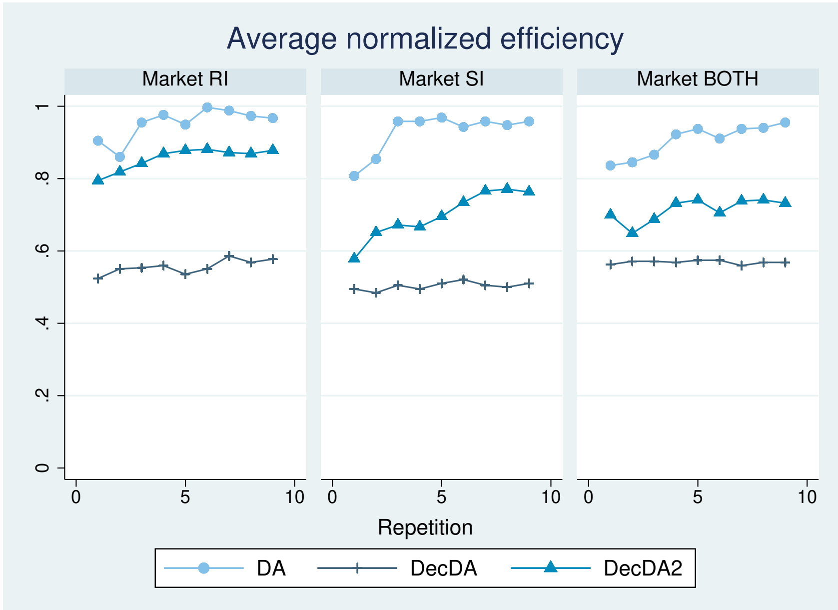


Figure 2: **Average efficiency (normalized by the SOSM level) by treatment.** As predicted, efficiency is highest in DA, second-highest in DecDA2, and lowest in DecDA. The difference between DA and DecDA2 is larger in markets where reaching SOSM relies on strategic play than in market RI.

Result 1 (Stability): The proportion of stable allocations and student-optimal stable matches is the highest in DA, the second-highest in DecDA2, and the lowest in DecDA in all markets, with all differences being significant.

5.2 Efficiency

Figure 2 presents the normalized efficiency levels by treatments. Normalized efficiency is calculated by dividing the realized sum of payoffs of the group by the sum of payoffs in the student-optimal stable match. There is a clear efficiency ranking in all markets, with all differences statistically significant with $p < 0.01$ regardless of whether OLS or MWU tests are used. DecDA leads to the lowest efficiency in all markets, DA leads to the highest efficiency, and DecDA2 attains an intermediate level.

Of primary interest is how efficiency is restored in DecDA2 relative to DecDA. While

DecDA2 leads to significantly higher efficiency than DecDA, the improvement is not substantial enough to reach the DA level and completely overcome the inefficiency of dividing the market into separate authorities. The normalized efficiency levels of DecDA2 and DA are the closest in market RI, where the improvement results from the elimination of empty seats and does not require strategic play from the participants. The improvement of DecDA2 over DecDA is smaller but still highly significant in markets SI and BOTH, where it requires strategic play. We highlight our results as follows:

Result 2 (Efficiency): Efficiency is the highest in DA, the second-highest in DecDA2, and the lowest in DecDA in all markets, with all differences being significant.

Thus, using stability and efficiency as evaluation criteria produces similar mechanism rankings. While DA implemented in the centralized market is the best alternative, in the presence of a constraint for having different authorities, DecDA2 leads to significant improvements over DecDA in all markets we consider. Note that these improvements put different demands on strategic behavior, depending on the market. The next section analyzes subjects' strategies to shed light on the main treatment effects.

5.3 Individual Behavior

Figure 3 shows the percentages of truthful strategies in all treatments.[18] Recall that we predicted reports to be fully truthful under DA and DecDA in all markets, as well as under DecDA2 in market RI. Overall, subjects are far from fully truthful when this is predicted. On average, the participants report truthfully in 59.7% of rounds in DA, with 65.3% in the last block. This is in line with typical rates of truthful reporting documented in the literature (see Hakimov and Kübler, 2020).

In market SI, where we predicted higher rates of truthfulness under DA and DecDA than under DecDA2, the results are in line with our predictions (highest $P < 0.05$ for

[18] We define a strategy as truthful if the report completely reveals the student's preferences or represents a dominant strategy, and the choice of school in case of assignments in both of the authorities corresponds to true preferences. Note that only 38 out of 2,749 choices between schools assigned in different authorities violated the participants' true preferences.

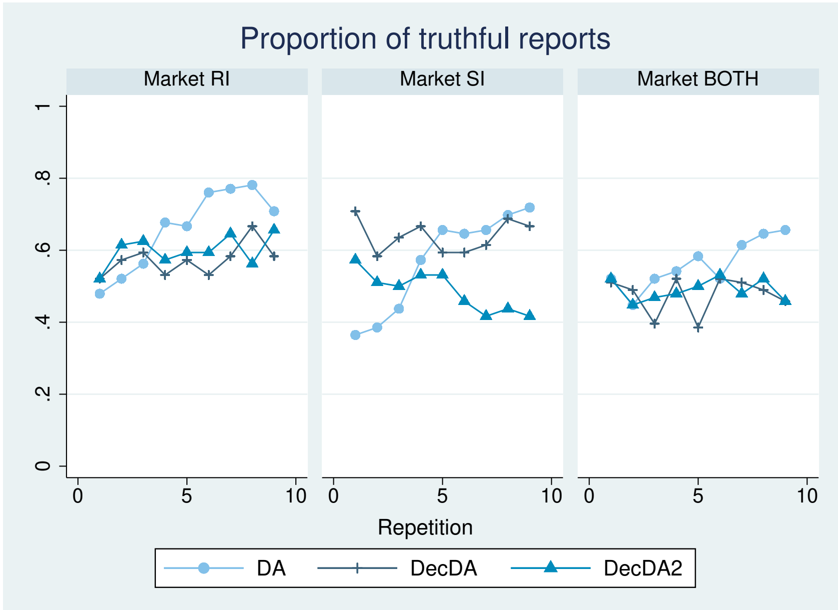


Figure 3: **Truthfulness by treatment.** In line with our predictions, a lower rate of truthfulness is observed under DecDA2 than the other mechanisms in market SI.

both pairwise comparisons regardless of whether OLS or MWU tests are used).[19]

In markets RI and BOTH, we find a higher rate of truthfulness under DA than under DecDA ($P < 0.01$ for both markets with both OLS and MWU) and DecDA2 ($P < 0.05$ for both markets with OLS; $P < 0.1$ for both markets with MWU), and similar rates of truthfulness under DecDA and DecDA2 ($P > 0.1$ for both markets and tests). Overall, the results on truthfulness only partially align with our predictions.

We now explore in more detail whether the lack of strategy-proofness of DecDA2 leads to a lower rate of truthful reporting and whether participants understand the incentives to truncate their reported lists. We take an explorative approach and construct two variables that might influence participants' propensity to report truthfully:

1. The variable "Incentives to lie" equals one if the student has incentives to manipulate her reports in a market. More precisely, the dummy equals one if the student

[19]The difference between DA and DecDA is not significant with OLS and significant with $P < 0.01$ with MWU. Note that this difference disappears with learning.

misreports her preferences in one of the undominated equilibrium strategies. This is true for all students in market SI and students 2 and 3 in market BOTH under DecDA2. The variable aims to disentangle the effect of DecDA2 as a mechanism from the effect of incentives to manipulate the reports under DecDA2.

2. The variable "Unassigned in equilibrium" is equal to 1 if the subject is not assigned in at least one of the market's equilibrium outcomes. This is true for students 3 and 4 in market RI in DecDA and student 4 in market BOTH under DecDA and DecDA2. Intuitively, being unassigned might push subjects to experiment with reports, as they have nothing to lose.

Table 6 reports marginal effects of probit regressions where the probability of playing a truthful strategy is modeled as a function of several explanatory variables, including "Incentives to lie" and "Unassigned in equilibrium."

The model in the first column presents the results for the full sample. The variable "Incentives to lie" has a negative and significant effect on the probability of truthful reporting, showing that subjects indeed understand that truncation might be profitable for them. Notably, the effect is robust for each repetition block (second to fourth columns), and the effect increases in magnitude with experience.

Subjects unassigned in at least one market equilibrium are significantly more likely to deviate from truthful reporting, independent of incentives. While this is a deviation from predicted behavior, it would often not be a payoff relevant deviation, as subjects are unassigned. The effect of the "Unassigned in equilibrium" variable is relatively stable across repetitions.

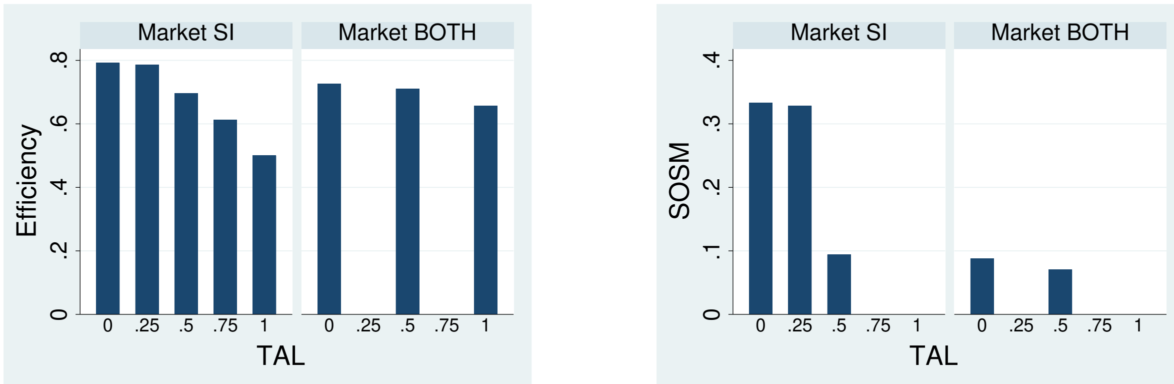
Market BOTH leads to a significantly lower rate of truthful reporting, especially with experience. The effect is small and might be driven by the presence of several equilibrium outcomes in undominated strategies in DecDA and DecDA2 (2 and 3, respectively).

The order of the markets does not have significant effects on truthful reporting.

When the entire sample is considered, DecDA2 has a weakly higher percentage of truthful reporting than DA, on average, controlling for incentives to manipulate the reports. However, the effect is driven by the first block of repetitions. In the first block (second column), both DecDA and DecDA2 have a higher rate of truthful reporting

	Truthful All (1)	Truthful First block (2)	Truthful Second block (3)	Truthful Third block (4)
DecDA	0.03	0.15***	-0.02	-0.04
	(0.02)	(0.03)	(0.03)	(0.03)
DecDA2	0.06**	0.16***	0.04	-0.03
	(0.03)	(0.03)	(0.03)	(0.04)
Market SI	-0.01	-0.03	0.02	-0.02
	(0.03)	(0.04)	(0.04)	(0.03)
Market BOTH	-0.07**	-0.05	-0.06**	-0.08**
	(0.03)	(0.04)	(0.03)	(0.03)
Order 2	-0.00	0.00	0.01	-0.01
	(0.03)	(0.03)	(0.04)	(0.04)
Order 3	-0.01	0.00	-0.01	-0.02
	(0.02)	(0.02)	(0.03)	(0.03)
Order 4	0.01	0.03	0.00	-0.01
	(0.03)	(0.03)	(0.04)	(0.03)
Incentives to lie	-0.22***	-0.16***	-0.24***	-0.26***
	(0.02)	(0.04)	(0.03)	(0.02)
Unassigned in equilibrium	-0.26***	-0.30***	-0.21***	-0.26***
	(0.02)	(0.02)	(0.04)	(0.03)
Observations	7776	2592	2592	2592

Table 6: **Determinants of truthful reporting.** Marginal effects of a probit model on truthful reporting for the whole sample, and each block of repetitions separately. DecDA and DecDA2 are dummies for the corresponding treatments. Market SI and Market BOTH are dummies for the corresponding markets. Orders 2 to 4 are dummies for orders of markets, corresponding to orders in Table 5. The values in parentheses represent standard errors clustered at the level of matching groups. *: $p < 0.1$,**: $p < 0.05$,***: $p < 0.01$.



(a) Efficiency.

(b) SOSM allocations.

Figure 4: **The relationship between individual behavior and outcomes.** In both (a) and (b), the variable on the horizontal axis is the percentage of truthful reports among those with incentives to misrepresent their preferences. As predicted, this variable has a negative relationship with both efficiency and stability, although the relationship is weaker in market BOTH, which has multiple equilibrium outcomes.

than DA, which is likely driven by the shorter length of the reported lists.[20] With experience, the significance of the treatment dummies vanishes, and the differences in truthful reporting between the three mechanisms are captured by other explanatory variables. We conclude that subjects with incentives to truncate their reports show a lower rate of truthfulness. Moreover, students at risk of being unassigned misreport their preferences despite having a weakly dominant strategy of truthful reporting, which is in line with a low probability of payoff-relevant manipulations.

We explore the relationship between individual behavior and outcomes as follows. First, we focus on markets under DecDA2 where one or more subjects has an incentive to lie, namely markets SI and BOTH. Note that all four subjects have an incentive to lie in market SI, while only two subjects have an incentive to lie in market BOTH. Second, for each matched group in these markets, we count the number of subjects with an incentive to lie that lied. We define a variable TAL (truth among those with incentives

[20]It has been reported in the literature that the longer the list that has to be submitted, the more likely subjects are to misrepresent their preferences, especially in a one-shot, i.e., inexperienced, environment (see the overview in Hakimov and Kübler, 2020).

	(1)	(2)
	Efficiency	SOSM
Market SI	-0.34***	-0.55***
	(0.06)	(0.15)
Market BOTH	-0.05**	-0.06
	(0.01)	(0.05)
Observations	432	432

Table 7: **Marginal effects of TAL on efficiency and stability in markets SI and BOTH.** The values in parentheses represent standard errors, clustered at the level of matching groups. *: $p < 0.1$,**: $p < 0.05$, ***: $p < 0.01$.

to lie) that captures the fraction of subjects in a group with an incentive to lie that reported truthfully.

Plotting the data for markets SI and BOTH separately, Figure 4 shows the relationship between TAL and efficiency (a) and the probability of reaching SOSM (b). Note that if subjects misreport optimally, SOSM is the unique equilibrium outcome in market SI, and thus efficiency is predicted to be 100%. As for market BOTH, SOSM is only one out of three equilibrium outcomes, and equilibrium efficiency can be as low as 57%. Overall, Figure 4 suggests that TAL has a negative effect on efficiency and stability, which is stronger in market SI.

Focusing on observations in markets SI and BOTH, we explore this relationship further using the following regression:

$$Y_n = \beta_{TAL}TAL_n + \beta_{BOTH}BOTH_n + \beta_{TAL\times BOTH}TAL_n \cdot BOTH_n + \alpha + \epsilon_n \qquad (2)$$

In the regression, Y_n is the group-level outcome (efficiency in the first model; a dummy variable for whether SOSM is reached in the second model), TAL_n is as defined above, and $BOTH_n$ is a dummy variable for market BOTH.

The full regression results are reported in Table 10 in the Appendix, while the marginal effects are shown in Table 7. The effect of TAL on efficiency is negative and significant in both markets SI ($p < 0.01$) and BOTH ($p < 0.05$), in line with the predictions, as strategic play is a source of efficiency gain over DecDA in these markets. The relationship between TAL and SOSM is negative in market SI ($p < 0.01$) and insignificant in market BOTH ($p = 0.25$), again highlighting the difficulty of finding optimal strategies in market BOTH. Overall, these results align with our intuition that truth-telling leads to worse outcomes for the group in treatments where incentives to lie are present.

6 Conclusion

We present the first experimental investigation of the IDA mechanism in partitioned matching markets. We investigate the performance of this mechanism and whether the absence of strategy-proofness causes preferences misreporting and worse outcomes. Our primary focus is efficiency, as partitioned markets often lead to waste. The experimental results show that efficiency is significantly higher under DecDA2 than under DecDA. Moreover, the improvement is driven by mechanical iterations and strategic behavior of students, when this is optimal, and leads to stable matches closer to the student-optimal one. The levels are, however, lower than in centralized DA. Our results strongly support switching to IDA for markets where assignments are currently split. One might argue that while improved efficiency is encouraging, the lack of strategy-proofness may hurt naive players, thus raising fairness concerns. However, the ease of recognizing and enacting manipulations may vary across manipulable mechanisms.[21] As Troyan and Morrill (2020) highlight, some mechanisms provide manipulation opportunities that are much easier for agents to identify and execute successfully than others. In their terminology, the IDA mechanism is not obviously manipulable, whereas the Boston mechanism, for example, is.[22] Moreover, the relevance of the "leveling the playing field" argument depends on the mechanism and the consequences of manipulations on the placements of other students. In the case of IDA, the "leveling the playing field" argument is not a salient concern because whenever sophisticated students play undominated strategies, they never gain

[21] Pathak and Sönmez (2013); Bonkoungou and Nesterov (2020); Decerf and Van der Linden (2020), and Chen et al. (2016a) introduce different criteria to compare mechanisms by their vulnerability to manipulation.

[22] Troyan and Morrill (2020)'s definition and behavioral characterization are inspired by the idea of obvious strategy-proofness (Li, 2017). Troyan and Morrill (2020) show which manipulations are obvious, classify manipulable mechanisms as either obviously manipulable or not obviously manipulable, and show that stable mechanisms are not obviously manipulable.

at the expense of sincere students. We prove this result theoretically in the Appendix and find empirical support for it, as efficiency increases with the higher proportion of strategic players under DecDA2 in markets SI and BOTH.

While centralized DA would be ideal, centralization is not always possible. Our solution provides a fast partial fix in partitioned markets, which is feasible and does not require much cooperation between authorities. The cost of the procedure is lack of strategy-proofness, and it lasts for several rounds, with an additional decision being made by students between rounds. However, it still presents a significant improvement over the unstructured and often ad-hoc post-allocation scramble.

The procedure is faster with a slightly higher cooperation effort between the authorities if the students submit a full rank order list. Then, a computer splits the list and sends the corresponding lists to each authority. Once first-round assignments are completed, students' decisions regarding multiple assignments are made based on the submitted list, and the procedure is re-run automatically. Joint seat allocation at Indian technical universities is implemented in this way, and it needs three or four iterations to reach a stable outcome according to the data (Baswana et al., 2019).

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Appendix

A Theoretical Results

Let us write ψ for the Iterative Deferred Acceptance (IDA).[23] If we write σ_i for a *strategy* of a student i, then $\sigma_i = (P_i^1, P_i^2, C_i^1, .., C_i^t)$, where for each $\ell \in \{1, .., t\}$, C_i^ℓ is a choice function that maps each subset of schools to a school from this set. Note that here t is fixed, and it is equal to the maximum number of iterations that can occur (it is bounded from above). Let $\sigma = (\sigma_i)_{i \in N}$ be a *strategy profile.* For $k \in \{1, 2\}$ and $\ell \in \{1, .., t\}$, we write $\sigma_i^k(P) = P_i^k$ and $\sigma_i^\ell(C) = C_i^\ell$.

We say that C_i^ℓ *agrees with* P_i if, for each $S' \subseteq S$, $C_i^\ell(S')$ is the most preferred school among those in S'. For each student i and submarket S^k, P_i^k agrees with P_i if the restriction of P_i to S^k is the same as P_i^k. A strategy σ_i is *sincere* if, for each $k \in \{1, 2\}$ and $\ell \in \{1, .., t\}$, both $\sigma_i^k(P)$ and $\sigma_i^\ell(C)$ agree with P_i.

Proposition A.1. *Let P be a problem and σ be a strategy profile. For each agent i, there exists a strategy σ_i' such that for each $\ell \in \{1, .., t\}$, $\sigma_i'^\ell(C)$ agrees with P_i and $\psi_i(\sigma_i', \sigma_{-i}) \; R_i \; \psi_i(\sigma)$.*

Proof. Let $\psi_i(\sigma) = a$. Suppose that agent i's preferences are truncated for the last time at Step m of ψ. That is, after this step, his preferences are never truncated in ψ at σ. Let σ_i' be such that for each $k \in \{1, 2\}$, $\sigma_i'^k(P)$ is the same as these last truncated preferences in submarket k under σ_i.

As DA is used in each submarket iteratively, no student $j \neq i$ is worse off at $\psi(\sigma_i', \sigma_{-i})$. This as well as the definition of σ_i' implies that student i receives at least a weakly better school at $\psi(\sigma_i', \sigma_{-i})$, finishing the proof. $\square$

Because of Proposition A.1, we only consider strategies whose choices agree with the preferences. Therefore, we suppress the dependency of ψ on the choices from its notation.

[23] We do not include its formal definition, as it works the same as $DecDA2$ except that it keeps iterating DA until no student rejects an offer. Please see the Introduction for the verbal definition.

Remark 2. Note that Proposition A.1 is independent of the maximum number of iterations, shown by t above. Therefore, if we set $t = 2$, we obtain the same result for $DecDA2$.

The following definitions are from Afacan and Dur (2017).

Definition A.1.
i. A mechanism ψ is harmful at problem P if there exists a pair of agents i, j and P_i' such that $\psi_i(P_i', P_{-i})\ P_i\ \psi_i(P)$ and $\psi_j(P)\ P_j\ \psi_j(P_i', P_{-i})$.
ii. A mechanism ψ is weakly harmful at problem P if there exists a pair of agents i, j and P_i' such that $\psi_i(P_i', P_{-i})\ R_i\ \psi_i(P)$ and $\psi_j(P)\ P_j\ \psi_j(P_i', P_{-i})$.

A mechanism is *weakly harmless* if it is never harmful. A mechanism is *harmless* if it is never weakly harmful.

For a preferences P_i^k and school $s \in S^k$, let us write $U(P_i^k, s) = \{s' \in S^k : \ s'\ R_i\ s\}$. In what follows, for ease of notation, we write $P_i = (P_i^1, P_i^2)$ for each student i. Let us also write $P = (P_i)_{i \in I}$.

Lemma A.1. *Suppose for a problem P, agent i, and P_i', we have $\psi_i(P_i', P_{-i})\ R_i\ \psi_i(P)$. If, for some student j, $\psi_j(P)\ P_j\ \psi_j(P')$, then there exists some school s such that it becomes unacceptable under ψ at P for agent i, but not under P'.*

Proof. Let $\psi_i(P') = a$ and $\psi_i(P) = b$. By our supposition, we have $a\ R_i\ b$. Let Step m be the last step of ψ at P where agent i's preferences are truncated (this means that it is never truncated after that). Let us consider the set of acceptable student schools i by the end of Step m at P. If no school becomes unacceptable in ψ at P, but not at P', then the competition under P' ultimately becomes at least weakly less fierce than under P. This, in turn, implies that no agent is worse off at P', contradicting our supposition. □

A strategy P_i' is *dominated* if, for some P_i'', $\psi_i(P_i'', P_{-i})\ R_i\ \psi_i(P_i', P_{-i})$ for each P_{-i}, where it strictly holds for some P_{-i}. A strategy is *undominated* if it is not dominated. A mechanism ψ is *harmless in undominated strategies* if, at each problem P, agent i, and undominated strategy P_i' with $\psi_i(P_i', P_{-i})\ R_i\ \psi_i(P)$, there is no agent j with $\psi_j(P)\ P_j\ \psi_j(P_i', P_{-i})$.

Theorem A.1. *ψ is harmless in undominated strategies.*

Proof. Let P be a problem and $P' = (P'_i, P_{-i})$ where $\psi_i(P')\ R_i\ \psi_i(P)$. Suppose for some student j, $\psi_j(P)\ P_j\ \psi_j(P')$. By Lemma $A.1$, there exists some school s such that it becomes unacceptable under ψ at P, while it does not under P'. This implies that $\psi_i(P)\ P_i\ s$ yet $s\ P'_i\ \psi_i(P')$. Note that as we focus on preference misreportings (we consider sincere choices), all $s, \psi_i(P)$, and $\psi_i(P')$ are in the same submarket.

Let us now consider P''_i where the set of acceptable schools are the same as those under P'_i, with the same relative rankings except $\psi_i(P)\ P''_i\ s$. At P', as student i does not obtain school s anyhow, the competition does not increase under P'', meaning that student i does not lose by reporting P''_i at P. Moreover, as DA is used in each submarket, student i never gains by swapping $\psi_i(P)$ and s. On the other hand, for some preference submissions by the other students, he may obtain school s under P'_i whereas he obtains a better school under P''_i, (for instance, he may obtain $\psi_i(P)$ at P''_i while s under P'_i). All these show that P'_i is dominated, finishing the proof. □

Proposition A.2. *For each P and student i, $\psi_i(P)\ R_i\ DecDA2_i(P)$, and it holds strictly for some student at some problem.*

Proof. ψ works as the same $DecDA2$ until the latter reaches its outcome. Therefore, whenever $DecDA2$ terminates, each student already receives the same school under ψ. Moreover, ψ continues its DA iterations unless no student rejects an offer. No student is worse off in the later iterations, showing that each student at least weakly prefers his school under ψ to that under $DecDA2$. That is, for each P and student i, $\psi_i(P)\ R_i\ DecDA2_i(P)$.

Let us consider a problem where $I = \{i, j, k\}$ and $S^1 = \{a, b\}$ and $S^2 = \{c\}$, each with a unit quota. Suppose that the priorities are the same at all schools in the order of i, j, j. Let the preferences be such that $P_i : a, c, \emptyset$, $P_j :\ c, b, \emptyset$, and $P_k :\ b, \emptyset$.

Let μ be the $DecDA2$ outcome, and it is such that $\mu_i = a$, $\mu_j = c$, and $\mu_k = \emptyset$. On the other hand, if we write μ' for the ψ outcome, then $\mu'_i = a$, $\mu'_j = c$, and $\mu'_k = b$, completing the proof. □

B Predictions

B.1 DA

Weakly dominant strategies in market RI

- Student 1: {DCAB,DCBA,DCA,DCB,DC}
- Student 2: {CADB,CABD,CAD,CAB,CA}
- Student 3:{ACBD}
- Student 4: {CABD}

The unique outcome the weakly dominant strategies is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & A & B \end{pmatrix}$, which is the student-optimal stable outcome.

Weakly dominant strategies in market SI

- Student 1: {DCAB,DCA}
- Student 2 {CDBA,CDB}
- Student 3: {BACD,BAC}
- Student 4: {ABDC,ABD}

The unique outcome of the weakly dominant strategies is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & B & A \end{pmatrix}$, which is the student-optimal stable outcome.

Weakly dominant strategies in market BOTH

- Student 1: {DABC, DACB, DBAC, DBCA, DCAB, DCBA, DAB, DBA, DAC, DCA, DBC, DCB, DA, DB, DC, D}
- Student 2: {DCBA, DCB}

- Student 3: {BDCA, BDC}
- Student 4: {BADC}

The unique outcome under weakly dominant strategies is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & B & A \end{pmatrix}$.

B.2 DecDA

Weakly dominant strategies in market RI

- Student 1: $\{(AB, DC), (A, DC), (BA, DC), (B, DC), (\emptyset, DC)\}$
- Student 2: {(AB,CD),(A,CD),(AB,C),(A,C)}
- Student 3: {(AB,CD)}
- Student 4: {(AB,CD)}

The equilibrium outcome is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & \emptyset & X \end{pmatrix}$, where $X = B$ only when student 1 does not report B as acceptable. Otherwise, $X = \emptyset$.

Weakly dominant strategies in market SI

- Student 1: {(AB,DC),(A,DC)}
- Student 2: {(BA,CD),(B,CD)}
- Student 3: {(BA,CD),(BA,C)}
- Student 4: {(AB,DC),(AB,D)}

The unique outcome at the weakly dominant strategies is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ A & B & C & D \end{pmatrix}$, which is the school-optimal stable outcome.

Weakly dominant strategies in market BOTH

- Student 1: $\{(BA, DC), (BA, D), (B, D), (\emptyset, D), (AB, DC), (A, DC), (\emptyset, DC), (A, D), (B, DC)\}$
- Student 2: {(BA,DC),(B,DC)}
- Student 3: {(BA,DC),(B,DC)}
- Student 4: {(BA,CD)}

The outcome under weakly dominant strategies is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & B & C & X \end{pmatrix}$, where $X = A$ if (and only if) both students 1 and 3 do not list school A as acceptable to the authority $\{A, B\}$. Otherwise, $X = \emptyset$.

B.3 DecDA2

Weakly dominant strategies in market RI

- Student 1: $\{(AB, DC), (A, DC), (\emptyset, DC), (BA, DC), (B, DC)\}$
- Student 2: {(AB,CD),(A,CD),(AB,C),(A,C)}
- Student 3: {(AB,CD)}
- Student 4: {(AB,CD)}

The unique outcome of the weakly dominant strategies is $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & A & B \end{pmatrix}$, which is the student-optimal stable outcome.

Market SI

No student has a weakly dominant strategy. There are nine undominated Nash equilibria, which we list below. Note that once offered a choice between schools, all students choose a better school according to the true preferences in each equilibrium strategy profile.

- All students drop their third choice:

$$\{(B, DC), (A, CD), (BA, D), (AB, C)\}$$

- All students except student 1 drop their third choices:

$$\{(AB, DC), (A, CD), (BA, D), (AB, C)\}$$

- All students except student 2 drop their third choices:

$$\{(B, DC), (BA, CD), (BA, D), (AB, C)\}$$

- All students except student 3 drop their third choices:

$$\{(B, DC), (A, CD), (BA, CD), (AB, C)\}$$

- All students except student 4 drop their third choices:

$$\{(B, DC), (A, CD), (BA, D), (AB, DC)\}$$

- Students 1 and 2 drop their third choices:

$$\{(B, DC), (A, CD), (BA, CD), (AB, DC)\}$$

- Students 1 and 3 drop their third choices:

$$\{(B, DC), (BA, CD), (BA, D), (AB, DC)\}$$

- Students 2 and 4 drop their third choices:

$$\{(AB, DC), (A, CD), (BA, CD), (AB, C)\}$$

- Students 3 and 4 drop their third choices:

$$\{(AB, DC), (BA, CD), (BA, D), (AB, C)\}$$

At the unique equilibrium outcome, each student gets his top choice: $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & B & A \end{pmatrix}$.

Market BOTH

Weakly dominant strategies of students are as follows:

- Student 1: $\{(BA, DC), (BA, D), (B, D), (\emptyset, D), (AB, DC), (A, DC), (\emptyset, DC), (A, D), (B, DC)\}$
- Student 2: no weakly dominant strategy
- Student 3: no weakly dominant strategy
- Student 4: no weakly dominant strategy

Undominated Nash Equilibria profiles are as follows:

- Student 1: Any strategy submitted to authority $\{C, D\}$ that ranks D at the top and submitted to authority $\{A, B\}$ that either ranks B as unacceptable or ranks A above B.
- Student 4: (BA, DC)
- Students 2 and 3 submit the following strategies:
  — $\{(DC, A), (BA, DC)\}$
  — $\{(DC, BA), (BA, D)\}$
  — $\{(DC, A), (B, DC)\}$
  — $\{(DC, B), (BA, D)\}$

or

- Student 1: $\{(BA, DC), (BA, D), (B, D), (\emptyset, D), (\emptyset, DC), (B, DC)\}$

- Student 4: $\{(BA, DC)\}$
- Students 2 and 3 submit following strategies:
  — $\{(DC, A), (BA, D)\}$
  — $\{(DC, BA), (BA, DC)\}$
  — $\{(DC, B), (B, DC)\}$

In the undominated Nash Equilibrium outcome

- Student 1 always receives D,
- Student 2 receives B (C) if and only if student 3 receives C (B),
- Student 4 receives $\emptyset$ if and only if student 3 receives C and ranks A as acceptable.

The Nash equilibria are as follows: $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & C & B & A \end{pmatrix}$ or $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & B & C & \emptyset \end{pmatrix}$ or $\begin{pmatrix} 1 & 2 & 3 & 4 \\ D & B & C & A \end{pmatrix}$.

Remark 3. One can easily verify that the set of undominated Nash equilibrium profiles under IDA is the same as DecDA2 in all of the markets we consider above. However, the (undominated) Nash equilibrium outcomes may be different. Under IDA, the Nash equilibria that include a wasted seat in market BOTH no longer prevails. Besides this, the rest is the same across IDA and DecDA2.

C Regression Estimates

	(1) Stability	(2) SOSM	(3) Efficiency	(4) Truthfulness
DA	0.78***	0.78***	0.40***	0.09***
	(0.05)	(0.05)	(0.02)	(0.02)
DecDA2	0.52***	0.52***	0.30***	0.03
	(0.04)	(0.04)	(0.02)	(0.03)
Constant	0.00	0.00	0.56***	0.57***
	(0.00)	(0.00)	(0.01)	(0.01)
Observations	648	648	648	2592

(a) **Market RI**

	(1) Stability	(2) SOSM	(3) Efficiency	(4) Truthfulness
DA	0.36***	0.74***	0.43***	-0.06
	(0.05)	(0.06)	(0.02)	(0.04)
DecDA2	0.33***	0.15***	0.20***	-0.15***
	(0.05)	(0.04)	(0.02)	(0.03)
Constant	0.63***	0.00	0.50***	0.63***
	(0.05)	(0.00)	(0.00)	(0.03)
Observations	648	648	648	2592

(b) **Market SI**

	(1) Stability	(2) SOSM	(3) Efficiency	(4) Truthfulness
DA	0.88***	0.57***	0.34***	0.09**
	(0.02)	(0.05)	(0.01)	(0.03)
DecDA2	0.46***	0.07***	0.15***	0.01
	(0.04)	(0.02)	(0.01)	(0.02)
Constant	0.01**	0.00	0.57***	0.47***
	(0.01)	(.)	(0.00)	(0.01)
Observations	648	648	648	2592

(c) **Market BOTH**

Table 8: **Main results.** The effects of mechanisms on stability, the likelihood of reaching a stable match, efficiency and truthfulness. DecDA is used as a baseline. The values in parentheses represent standard errors, clustered at the level of matching groups. *: $p < 0.1$,**: $p < 0.05$, ***: $p < 0.01$.

	(1) Stability	(2) SOSM	(3) Efficiency	(4) Stability	(5) SOSM	(6) Efficiency
DA	0.67***	0.70***	0.39***	0.68***	0.66***	0.38***
	(0.03)	(0.05)	(0.01)	(0.03)	(0.02)	(0.01)
DecDA2	0.44***	0.25***	0.21***	0.49***	0.23***	0.21***
	(0.02)	(0.03)	(0.01)	(0.04)	(0.03)	(0.01)
Order 2				0.02	-0.00	0.00
				(0.03)	(.)	(0.01)
Order 3				0.05	-0.00	0.01
				(0.05)	(.)	(0.01)
Order 4				0.02	0.01	0.01
				(0.04)	(0.00)	(0.01)
DA × Order 2				-0.05	0.03	-0.00
				(0.06)	(0.09)	(0.02)
DA × Order 3				0.01	0.14*	0.02
				(0.06)	(0.07)	(0.02)
DA × Order 4				0.02	-0.02	-0.01
				(0.05)	(0.11)	(0.03)
DecDA2 × Order 2				-0.07	0.00	0.01
				(0.04)	(0.06)	(0.02)
DecDA2 × Order 3				-0.05	0.10	0.01
				(0.08)	(0.07)	(0.04)
DecDA2 × Order 4				-0.08*	-0.02	-0.02
				(0.04)	(0.03)	(0.02)
Constant	0.22***	0.00	0.54***	0.19***	0.00	0.54***
	(0.02)	(0.00)	(0.00)	(0.03)	(.)	(0.00)
Observations	1944	1944	1944	1944	1944	1944

Table 9: **Order effects.** In the first three columns, we regress stability, a dummy variable for reaching a SOSM outcome, and efficiency, respectively, on DA and DecDA2 dummies, using DecDA as a baseline. In the last three columns, we control for the order in which the markets were presented and the interactions between treatment dummies and market order. The coefficients on the treatment dummies are virtually unaffected by controlling for order effects. The values in parentheses represent standard errors clustered at the level of matching groups. $p < 0.1$,**: $p < 0.05$,***: $p < 0.01$.

	(1)	(2)
	Efficiency	SOSM
TAL	-0.34***	-0.55***
	(0.06)	(0.15)
BOTH	-0.13**	-0.32**
	(0.04)	(0.10)
TAL × BOTH	0.29***	0.49**
	(0.06)	(0.15)
Constant	0.86***	0.42***
	(0.04)	(0.11)
Observations	432	432

Table 10: **The effect of TAL on efficiency and stability in markets SI and BOTH.** The values in parentheses represent standard errors, clustered at the level of matching groups. $p < 0.1$,**: $p < 0.05$,***: $p < 0.01$.