Biometric Responses to Unjustified and Justified-Envy in School Choice Allocations*

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Abstract

Among strategy-proof school choice mechanisms, the two most prominent, Deferred Acceptance and Top Trading Cycles, offer a trade-off between eliminating justified-envy and Pareto efficiency, respectively. We introduce a novel, biometric approach to measure welfare under each property. Using an experimental design that randomly varies whether subjects learn about others' assignments in a school choice game, we measure discontentment through galvanic skin response when subjects experience envy with and without justification. We find increased arousal associated with receiving subsequently lower-ranked allocations, i.e., the (unjustified) envy of the allocation(s) of others. Additionally, we note additional arousal when that envy is justified, but that result requires an explicit message to accentuate the justification to subjects. Eye-tracking data confirm that subjects do not notice the property of justified-envy without prompting.

JEL classification: C90, D47, D82, D87, I24

Keywords: experiment, eye-tracking, galvanic skin response, justified-envy, matching, school choice

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1 Introduction

School choice mechanisms affect the placement and educational outcomes of many students around the world. These matching mechanisms may be a vehicle for providing access to high-quality schools to disadvantaged populations. In designing practical markets for matching students to schools, institutions have relied on theoretical properties for efficiency, fairness, and strategy proofness to advocate for the subjective value of certain mechanisms over others. The classical "Boston" Mechanism (a.k.a. "Immediate Acceptance," IA) was replaced in Boston, Chicago and greater New England, as matching theorists and experimentalists favored and directly influenced the adoption of the Deferred Acceptance (DA) mechanism because of its strategy-proofness property, meaning it provides (weak) incentives for respondents to reveal their preferences truthfully (Abdulkadiroğlu et al., 2005; Chen and Sönmez, 2006; Pathak and Sönmez, 2013).

Deferred Acceptance is currently the predominantly-used school choice mechanism because of another property, the elimination of justified-envy. Justified-envy occurs when one student i observes another student j at a school s they prefer (causing envy) and student j is not preferred to i by the desired school (making the envy justified), and also unstable. While the property is desirable all-else-equal, it comes with trade-offs. Indeed, it is well-known that no mechanism can generate Pareto efficient outcomes and simultaneously eliminate justified-envy in equilibrium (Abdulkadiroğlu and Sönmez, 2003). Another mechanism, the Top Trading Cyles (TTC) mechanism can achieve Pareto efficient outcomes in equilibrium but cannot satisfy the elimination of justified-envy. These two mechanisms are the main choices for strategy-proof mechanism design in the school choice environment.

The choice between these two mechanisms may be viewed as a classic trade-off of fairness and efficiency, with no clear answer. Justified-envy is a very specific form of fairness, and unlike equality, it is not simple to describe or well-known to most populations. In fact, Morrill (2013, 2015a,b) shows that the TTC can achieve many other notions of fairness in equilibrium assignments.

Thus it is an open question whether people actually identify and value the elimination of justified-envy, or alternatively, feel and react differently about justified-envy compared to (unjustified) envy. Our paper provides the first experiment to test this question. We use biometric measures to compare subjects who receive identical payoffs, one in the presence of justified-envy and one in the presence of envy without justification. Using a random-assignment design, we vary whether subjects learn the payoffs of others, allowing the possibility subjects notice their justified-envy.

We use biometric measures in our experiment because they provide involuntary measures of a subject's (potential) negative affect which can be interpreted as a measure of welfare. We correlate emotional reactions to subject earnings to determine whether the loss in aggregate welfare due to an inefficient mechanism is offset by the gain in welfare in imposing a fairness concern. An alternative approach might use an incentivized BDM mechanism instead to measure subjects' willingness-to-pay to avoid situations resulting in justified-envy. However, this approach is problematic. There is evidence that most subjects are unable to play dominant strategies in dominant strategy elicitation mechanisms, even when the value of preferences is induced and trivial (Cason and Plott, 2014; Danz et al., 2022; Brown et al., 2024). It is unlikely that in an environment like ours where values are more intangible that subject responses will improve. Further, subjects that misreport values on a BDM may also have difficulty responding to other dominant strategy mechanisms. This could lead to an identification problem for elicited values obtained by the BDM on willingness to use other dominant strategy mechanisms. Indeed, Basteck and Mantovani (2018) find that individuals who score higher on intelligence tasks are more likely to respond truthfully in the strategy-proof DA mechanism. There are likely unobserved correlations between responses (and hence outcomes) on dominant strategy mechanisms.

Our experiment induces a particular four-player game and valuation structure under two school choice mechanisms, the Top Trading Cycles (TTC) and Deferred Acceptance (DA). The valuation structures are specifically chosen so that two players receive their third choice under either mechanism in the focal equilibrium. The other two players receive their first choice under TTC and second choice under DA. In the TTC equilibrium outcome one of the players who did not receive their first choice experiences justified-envy while the other does not. We exogenously vary (at the subject level) whether a subject observes the assignments of the other subjects in their group at the conclusion of the game, opening the possibility for subjects to experience justified-envy, depending on their assignment.

Our results find the comparative statics of theory and previous experimental results hold well (see Section 2 for literature review). The TTC mechanism achieves Pareto efficient outcomes in 45.9% of observations compared to only 11.1% under the DA. The DA eliminates justified-envy in 88.9% of observations compared to 43.2% in the TTC. Equilibrium assignments are achieved in 45.9% and 77.8% of cases in the TTC and DA mechanisms, respectively.

Equilibrium assignments in TTC allow us to directly test whether the presence of justified-envy differentially impacts subjects with identical earnings by capturing biometric responses for the players that did not receive their first choice. We document a differential emotional arousal response among subjects who experience any kind of envy in the school choice game—specifically, for every rank a subject's assignment drops below their most preferred subjects experience an additional 0.055–0.070μS peak arousal measured in galvanic skin response,[1] consistent with higher levels of arousal resulting from negative evaluations associated with envy; i.e. knowledge that another subject has an item they prefer to their allocation.[2] We then similarly show that when subjects are informed about others' assignments and primed on their specific condition of justified-envy, an unstable matching imposes 0.190-0.198μS greater peak arousal measured in galvanic skin response, all else equal.

In a further examination of the perceptions of outcomes, we find a self-attribution effect (i.e., Heider, 2013; Jones and Davis, 1965; Kelley, 1973) where subjects with higher earnings are more likely to credit their own ability for their performance, while subjects with lower earnings are more likely to blame the mechanisms. Interestingly, subjects that experience justified-envy and are informed of the condition are no more likely to attribute their

[1]Skin conductance is not consciously controlled. Instead, it is autonomously regulated by sympathetic activity, which influences human behavior, cognition, and emotions at a subconscious level. The amount of sweat glands varies across the human body, being highest in hand and foot regions. The response of the skin and muscle tissue to external and internal stimuli, as bio-electrical phenomena, can be captured with a device that measures changes in electrical conductance that is typically measured in units of electric conductance known as microSiemens (μS).

[2]The well adopted Circumplex model of affect suggests that while both positively and negatively valenced emotions can induce arousal, negative affective states are associated with higher arousal than positive affective states (Russell, 1980). This model has found consistent support in the empirical literature (Gatti et al., 2018; Lang, 2014; Kreibig, 2010; Jones and Troen, 2007; Posner et al., 2005; Haag et al., 2004; Sinha et al., 1992; Ekman et al., 1983).

assignment to the mechanism.

The remainder of the paper is organized as follows. Section 2 categorizes the relevant literature. Section 3 characterizes the simplified and stylized school choice game that we will study in both a theoretical setting and its experimental application, including predictions. Section 4 provides results and section 5 concludes.

2 Related Literature

Chen and Sönmez (2006) provide the first experimental study comparing the three school choice mechanisms, TTC, DA, and IA in an incomplete information setting. They find that DA outperforms TTC in truthful preference revelation, despite the strategy-proofness of both mechanisms. Furthermore, they show that TTC does not outperform DA in efficiency, although theoretically TTC is efficient whereas DA is not. Among the three mechanisms, IA performs the worst in terms of truthful preference revelation and efficiency.

While a stability comparison is not presented in Chen and Sönmez (2006), using the same experimental setting, Calsamiglia et al. (2010) find that the DA is more stable than TTC, which in turn is weakly more stable than IA. Chen et al. (2016) compare the performance of the three mechanisms using the same design as Chen and Sönmez (2006) under a complete information setting. They find that the TTC outperforms DA, which in turn outperforms IA in truth-telling. Consistent with theory, the TTC outperforms both DA and IA in efficiency, whereas DA and IA generate similar efficiency levels. In terms of stability, the DA outperforms TTC and IA by a large margin, whereas IA and TTC achieve the same level of stability. Pais and Pintér (2008) find results that are consistent with theory – the TTC mechanism outperforms both IA and DA mechanisms in terms of efficiency and it is slightly more successful than DA regarding the proportion of truthful preference revelation, whereas manipulation is stronger under the Boston mechanism. Pais and Pintér (2008) find that under the IA and DA mechanisms the amount of information has a significant effect on the average efficiency achieved by participants, while under the TTC mechanism the average efficiency does not depend on the implemented information setting. In comparing stability between the DA and TTC, Pais and Pintér (2008) find that DA is more successful than the TTC mechanism which is in accordance with theory. We examine the extent to which different mechanisms achieve equilibrium assignments by providing subjects with feedback about their assignments only after all reports are finalized. Stephenson (2022) finds all three mechanisms achieve more equilibrium assignments under real-time feedback than discrete feedback. See Table 1 in that paper for an exhaustive list of school choice experiments.

Basteck and Mantovani (2018) study the DA and IA mechanisms in an environment where subjects have common knowledge on the induced values of others and priorities of schools are determined according to a centralized lottery. In their design, there is large consensus on the rank-order preference of schools, but intensities may slightly differ across subject types. They find that subjects that score higher on the Raven's Progressive Matrices task manipulate the IA better by engaging in non-truthful strategies. This difference leads to a greater representation of lower-scoring subjects at the worst schools under the IA mechanism. In contrast, the strategy-proofness of the DA prompts high-scoring subjects to report truthfully more often, however they are not more likely to be placed in more favorable schools.

Other studies also examine preferences over allocative otucomes by complementing experiments with eye-tracking data. Jiang et al. (2016) examine eye movements while subjects make choices in simple three-person distribution experiments and characterize choices in terms of three different types of social preferences: efficiency, maxi-min and minimize envy. Their findings suggest that distributional choices are consistent with the choice rule implied by eye movements. Fischbacher et al. (2022) extend the use of eye-tracking and apply it as a communication device by providing (real-time) eye-tracking information of one participant to another. They find that untrained observers can judge the prosociality of decision-makers from their eye-tracked gaze alone, but only if there are no strategic incentives to be chosen for a future interaction. Our study attempts to shed light on the perception of school choice boards and some theorists that justified-envy is a sound fairness criterion in matching students to schools. Specifically, we test whether unjustified and justified-envy produce different emotional reactions holding earnings (quality of schools) constant.

Using biometrics, our study sheds light on the perception and repercussions of envy; both justified and unjustified. Griffin et al. (2012) rely on skin conductance measures to isolate the positive effects of cognitive-behavioral therapy on subjects diagnosed with posttraumatic stress disorder (PTSD). They find successful cognitive-behavioral treatment of PTSD is associated with a quantifiable reduction in physiological responding to loud tones as captured by Galvanic Skin Response (GSR) magnitude. Joffily et al. (2014) study emotions in a voluntary contribution mechanism with punishment by complementing their study with GSR measures and survey responses to capture the valence of emotions. Upon learning about others' contributions, they find free-riders are less aroused than subjects who learn that others contributed less than them. Free riding is associated with reports of positive valence on the perception of outcomes, while subjects that learned they contributed more than others report on average a more negative emotional state.

3 School Choice Mechanisms and the Experiment

In a school choice problem, there is a finite number of students and schools. Each student has a strict preference over all schools, whereas each school has a maximum capacity and a strict priority ordering of all students. School priorities are imposed by the school district based on state and local laws, and a random lottery. The outcome of a school choice problem is referred to as a matching (μ), which is an assignment of seats to students such that each student is assigned one seat and no school assigns more seats than its capacity. The three relevant measures for comparing the performance of school choice mechanisms are efficiency, justified-envy and strategy-proofness.

Definition 1 (efficiency) *A matching is Pareto efficient if there is no matching which assigns each student a weakly better school and at least one student a strictly better school.*

Definition 2 (justified-envy) *A matching μ is said to eliminate justified-envy if there is no student-school pair (i, s) such that: (i) student i prefers school s to her assignment under μ, and (ii) student i has a higher priority at school s than some other student j who is assigned a seat at school s under μ.*

Definition 3 (strategy-proofness) *A mechanism is strategy-proof if reporting preferences truthfully is a weakly dominant strategy.*

Our experiment concerns two mechanisms, Deferred Acceptance (DA) and Top Trading Cycles (TTC). Both are strategy-proof. The equilibrium implemented by the DA satisfies justified-envy while the equilibrium implemented by the TTC satisfies efficiency. No mechanism can satisfy both (Abdulkadiroğlu and Sönmez, 2003). A generalized description of both matching algorithms follows.

3.1 Deferred Acceptance

DA asks applicants to submit a rank order list of schools. Together with the pre-announced capacity of each school, DA uses pre-defined rules and a random lottery to determine school priority rankings over students and consists of the following rounds:

Round 1: Every student applies to her first choice. Each school rejects the lowest ranked students in excess of its capacity and temporarily holds the others.

Round 2: Every student who is rejected in Round 1 applies to the second choice on her list. Each school pools together new applicants and those on hold from Round 1. It then rejects the lowest ranked students in excess of its capacity. Those who are not rejected are temporarily held.

Generally, in Round ($k \geq 3$): Every student who is rejected in Round $k-1$ applies to the next highest choice on her list. Each school pools together new applicants and those on hold from Round $k-1$. It then rejects the lowest ranked students in excess of its capacity. Those who are not rejected are temporarily held. The process terminates after any Round k in which no rejections are issued. Each school is then matched with those students whom it is currently holding.

3.2 Top Trading Cycles

TTC asks applicants to submit rank order lists of schools. For each school, a priority ordering of students is determined. TTC assigns students to schools following the process below:

Round 1: Each school points to its highest priority student and each student points to her most preferred school according to her reported preferences. Since there are a finite number of schools and students, the directed graph will have at least one cycle. Students who are part of a cycle are assigned to the school they point to. Participants, as well as their assignments, are removed from the system.

Round 2: The remaining applicants point to their most preferred school that still has open seats. Each school points to their highest priority student among those that remain unassigned. Since there are a finite number of schools and students, the directed graph will have at least one cycle. Students who are part of a cycle are assigned to the school they point to.

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3.3 The Experimental Game

Our experiment featured a 4-player game with four students and four schools. Each student had unique and strict preferences over schools that can be expressed in monetary terms (Table 1). School priorities were fixed over the four students (Table 2) with each school having a capacity of one.

Table 1: Student Preferences over Schools for the 4-person game

Utility of Assignment				
	School A	School B	School C	School D
Player 1	$20	$14	$7	$0
Player 2	$20	$14	$0	$7
Player 3	$14	$20	$7	$0
Player 4	$14	$20	$0	$7

Table 2: School Priorities

Priority Ranking				
	School A	**School B**	**School C**	**School D**
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3

Both the DA and TTC mechanisms implement a game where truth-telling is a (weakly) dominant strategy Nash Equilibria. Under the DA mechanism, the following assignment of students to schools occurs when all players play dominant (i.e., truthful) strategies,

$$\mu = \begin{Bmatrix} 1 & 2 & 3 & 4 \\ \\ C & B & A & D \end{Bmatrix}. \tag{1}$$

In the focal equilibrium assignment of DA, μ, Player 1 is assigned to School C, Player 2 is assigned to School B, Player 3 is assigned to School A and Player 4 is assigned to School D.[3] Under the TTC mechanism, a different assignment of students to schools occurs when all players play dominant (i.e., truthful) strategies,

$$\mu' = \begin{Bmatrix} 1 & 2 & 3 & 4 \\ \\ C & A & B & D \end{Bmatrix}. \tag{2}$$

In this matching, μ', Players 1 and 4 are assigned to the same options as in matching μ, but Players 2 and 3 are assigned to strictly better options. While matching μ' Pareto dominates μ, it does not eliminate justified-envy. Player 4 prefers School A over School D, and has a higher priority at School A than Player 2.

3.4 Experimental Design and Procedures

The experiment implemented the game described in Section 3.3 in a 2×2 between-subject design. Subjects experienced the two aforementioned mechanisms {DA, TTC} under FULL feedback where they learned the assignments of all other players after the game concluded, or PARTIAL feedback, where they only learned their own assignment. In the FULL feedback condition, subjects also receive a message with their relative rank at a more desirable option if they are not assigned to their most preferred option. In the PARTIAL feedback condition, subjects are informed of their assignment only, with no knowledge of others' assignments. Mechanism assignment was randomly assigned at the session level, but feedback

[3]Player 4 is bossy in DA and decides whether players 2 and 3 are assigned to their first or second choice.

was randomly assigned at the individual level.

Subject emotional arousal was measured using Galvanic Skin Response (GSR) and visual attention was assessed using eye-tracking. GSR data were analyzed for two separate screens during the feedback stage. On the first screen, which lasted 30 seconds, subjects were informed of their assignment. If a subject was randomly assigned to the FULL treatment, the subject also observed the assignments of other group members. Immediately after, on a second screen, subjects received a message that was designed to accentuate justified-envy when present. The structure of the message can be found in the Appendix. If a subject was assigned to treatment PARTIAL, he was never informed about the assignments of other group members. Instead the subject received a neutral message saying "This concludes the stage of this game."[4] GSR data were collected using Shimmer3 units at a sampling rate of 128 Hz (i.e. 128 observations per second).

Before the experiment began, the instructions were read aloud and any questions were answered privately. Given the relatively complex nature of matching mechanisms, we allowed subjects to read instructions again at their own pace if they wished to do so. After subjects finished reading instructions, a quiz was administered to ensure comprehension. Questions were intended to check that subjects understood (i) option capacities, (ii) how to read payoff and priority ranking tables, and (iii) solving a simple allocation problem given others' reports. Instructions and the comprehension quiz are available as Supplemental Materials.

Subjects were randomly assigned to groups of four and each subject was randomly assigned to one of four preference types (1, 2, 3 or 4). Subjects played four unpaid "practice" rounds of similar school choice games so they could become familiar with the decision environment and the nature of the matching mechanisms. In each practice round, subjects were randomly matched, and faced a new set of preference profiles and priorities; all differed from those shown in Tables 1 and 2. The overall structure of preferences and priorities were constant across experimental sessions and treatments. Before starting the incentivized one-shot game, subjects were informed that their earnings depend on the outcome of the following round. This round featured the game described in Section 3.3 and was the sole basis for (differential) payoffs for subjects.

[4]Example screens for subjects assigned to different conditions can also be found as Supplemental Materials.

After the school choice game, subjects answered an open-ended question on how they played the game, other questions on their perception of a mechanism's manipulability, and completed a shortened version of the Raven's Progressive Matrices task (Raven, 2000); survey questions are available as Supplemental Materials.

A total of 24 sessions which contained 46 groups for 184 participants took place at the Human Behavior Lab at Texas A&M University during 2021. Of these groups, 9 participated in the DA sessions and 37 in the TTC sessions. The TTC group was intentionally oversampled to generate more groups that experienced justified-envy. Subjects were randomly assigned to feedback treatments using a block design at the session level, ensuring balanced sample sizes between treatments. Sessions lasted approximately one hour and subjects earned $24.14 (sd=$6.342) on average including a $10 participation payment.

3.5 Predictions

Section 3.3 provides equilibrium predictions under dominant strategy play in the experiment for both the TTC and DA mechanisms. In equilibrium, the TTC should lead to an outcome that is efficient but creates justified-envy. Conversely, assignments under the DA should have no justified-envy but they are not efficient. While it is exceedingly unlikely that every subject group will resemble equilibrium predictions exactly, we predict, consistent with previous literature (e.g., Chen and Sönmez, 2006) that comparative statics will hold.

Prediction 1 *Comparative statics of equilibrium predictions will hold, that is,*

1. *The TTC treatment will produce more efficient assignments than the DA.*

2. *The DA will produce fewer assignments with justified-envy than the TTC.*

Biometric response literature consistently points out that more negative evaluations of stimuli are associated with increased arousal (Russell, 1980; Gatti et al., 2018; Lang, 2014; Kreibig, 2010; Jones and Troen, 2007; Posner et al., 2005; Haag et al., 2004; Sinha et al., 1992; Ekman et al., 1983). To this end, we expect subjects that receive lower ranked choices in the school choice game to exhibit higher arousal.

Prediction 2 *Subjects will exhibit higher GSR magnitudes with each subsequently lower ranked choice.*

Finally, we focus on the differential effect of justified-envy. Only Player 4s in a group will possibly incur justified envy. While an allocation with justified-envy is endogenous to the group of players and allocation mechanism, the observation of others' allocations is exogeneously generated through randomization. A subject must be assigned to the FULL treatment to be able to observe others' allocations and realize their envy is justified.

Prediction 3 *Holding preference ranks constant, subjects who experience justified-envy will exhibit increased arousal in the FULL but not in the PARTIAL treatment. That is, subjects that receive identical assignments under justified-envy will exhibit higher GSR response in the FULL treatment.*

4 Results

Result 1 *Theoretically predicted comparative statics hold. That is,*

1. *The TTC mechanism achieves more efficient assignments than DA.*

2. *The DA mechanism achieves more assignments without justified-envy than TTC.*

Table 3 examines group-level outcomes of whether the two mechanisms achieved equilibrium assignments, full efficiency, and eliminated justified-envy. The TTC achieves full efficiency and never eliminates justified-envy in equilibrium. The DA, in its focal equilibrium,[5] should eliminate justified-envy but not reach full efficiency. Consistent with Prediction 1, the comparative statics of theory hold. The elimination of justified-envy is achieved in all but 1 DA group (88.9%) and about half of the TTC groups (43.2%) (Fisher exact test, $p \approx 0.023$

[5]While reporting truthfully is a weakly dominant strategy in DA and TTC, there are other non-truthful strategies that are in the set of equilibrium strategies. In our set-up, for both the DA and TTC, equilibrium strategies for players 2 and 3 can be summarized as reporting truthfully the top two choices. In both mechanisms, equilibrium strategies for players 1 and 4 involve reporting the third preferred choice ahead of the fourth. Such strategy profiles make Player 4 bossy in DA since this role decides whether players 2 and 3 obtain their first or second choice. Hence, equilibrium strategies in DA can sometimes generate efficient outcomes and not eliminate justified-envy.

Table 3: Group-level Outcomes of Deferred Acceptance (DA) and Top Trading Cycles (TTC) Mechanisms

	Groups	Equilibrium Assignments	Full Efficiency	Elimination of Justified-Envy
DA	9	7 (77.8%)	1 (11.1%)	8 (88.9%)
TTC	37	17 (45.9%)	17 (45.9%)	16 (43.2%)
Total	46	24 (52.2%)	18 (39.1%)	24 (52.2%)

two-tailed; $p \approx 0.016$ one-tailed). In contrast, only 1 (11.1%) DA group is fully efficient compared to nearly half (45.9%) the TTC groups (Fisher exact test, $p \approx 0.069$ two-tailed; $p \approx 0.057$ one-tailed). Mean group payoffs are also \$1.58 higher per person under the TTC compared to DA (\$11.64 vs. \$10.06; Wilcoxon rank-sum test, $p \approx 0.086$ two-tailed; $p \approx 0.043$ one-tailed).[6]

We examine the robustness of Result 1 in a linear probability model. This specification controls for possible session-level correlations between groups as well as the number of subjects in the FULL treatment who received additional feedback at random.[7] We report regression results in Table 4. TTC is 32 probability points less likely to achieve an equilibrium outcome. Consistent with Prediction 1, TTC is 35 probability points more likely to achieve an efficient outcome; DA is 46 probability points more likely to achieve an outcome that eliminates justified-envy.

Having confirmed the theoretical comparative statics of our experiment, we next turn to how subjects physiologically react (if at all) to envy and specifically justified-envy.

Result 2 *Higher levels of arousal in galvanic skin response is associated with being assigned to lower ranked choices.*

Over all results, only four distinct allocative assignments were realized, whether equilibria or not. Table 5 characterizes all four and their frequency in the experiment. Allocations

[6]Due to our intentional oversampling of the TTC mechanism (see Section 3.4), our power to detect a difference between these treatments is limited. However, all three of our three predictions are unidirectional. While a one-tailed test is technically more appropriate in statistics, we report both one- and two-tailed tests to avoid confusion, leaving it to the reader to decide the appropriate significance level. While this distinction is usually trivial, the Fisher exact test is unusual in that it is an exact test based on an inherently asymmetric distribution, so the one-tailed and two-tailed p-value cannot be directly derived from each other. Nonetheless we follow this convention in reporting throughout our analysis even with symmetric tests.

[7]Subjects assigned to the FULL treatment received additional feedback over the four practice rounds. While this assignment was done randomly and exogenous to other treatments, it is possible that subjects assigned to treatment FULL may act differently.

Table 4: Linear probability model of theoretical properties on mechanism and number of FULL treated subjects in group

	(1) Equilibrium assignments	(2) Full efficiency	(3) Elimination of Justified-Envy
TTC mechanism	-0.318**	0.348**	-0.456***
	(0.147)	(0.140)	(0.146)
# of FULL treated subjects	-0.091	-0.091	0.091
	(0.131)	(0.113)	(0.091)
Constant	0.960***	0.293	0.707***
	(0.298)	(0.257)	(0.220)
Observations	46	46	46
Sessions	24	24	24

p-values (two-tailed): $***p < 0.01$, $**p < 0.05$, $*p < 0.10$

Notes: All three regression models use cluster-robust standard errors at the session level.

μ (see equation (1)) and μ' (see equation (2)) are the dominant-strategy equilibria of the DA and TTC mechanisms, respectively. The other two allocations, ν and ν', provide useful analogues as they only differ from those allocations in that players 1 and 4 now receive their least preferred alternative. Under μ' and ν' Player 4 also experiences justified-envy despite having the identical assignment to allocations μ and ν, respectively.

Table 5: Allocative Outcomes Observed in the Experiment

Matching Allocation	Assignment (Player-School)	Payoffs	Observances Per Group of 4
μ	1-C, 2-B, 3-A, 4-D	$(7, 14, 14, 7)$	20 (43.4%)
μ'	1-C, 2-A, 3-B, 4-D*	$(7, 20, 20, 7)$	18 (39.1%)
ν	1-D, 2-B, 3-A, 4-C	$(0, 14, 14, 0)$	4 (8.70%)
ν'	1-D, 2-A, 3-B, 4-C*	$(0, 20, 20, 0)$	4 (8.70%)

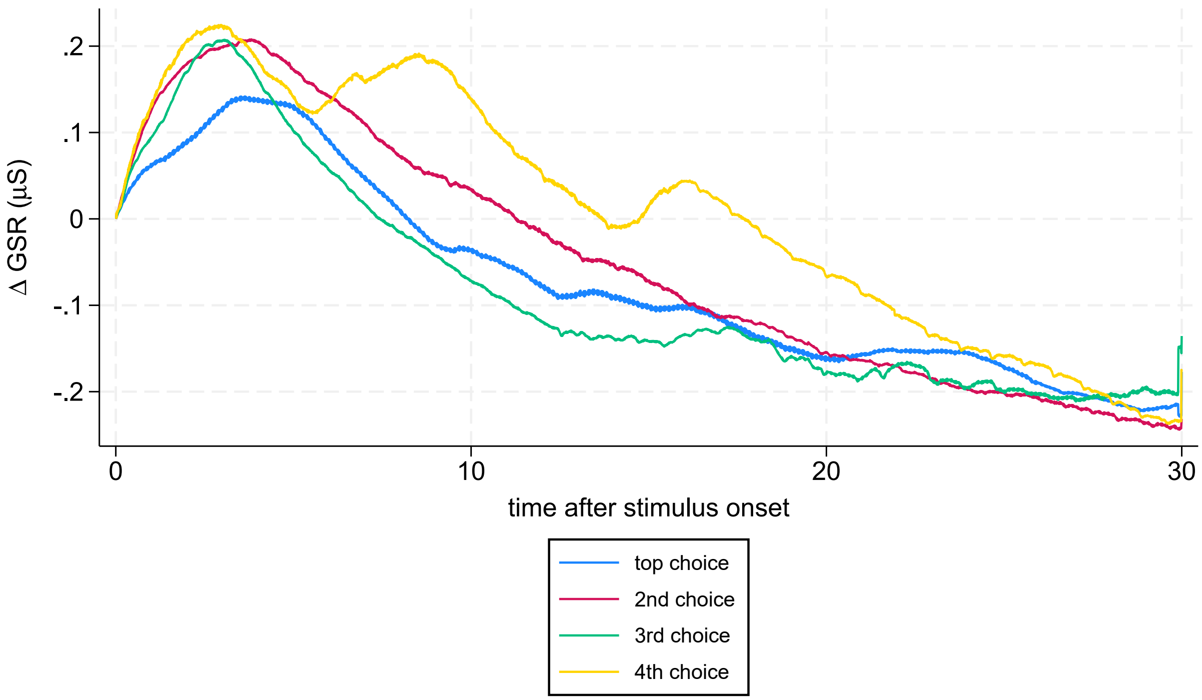
* Player 4 has justified-envy toward Player 2.

Using these four outcomes, we can examine whether subjects who experience envy exhibit higher arousal as captured by the GSR magnitude which is calculated as the difference between the signal amplitude at the peak and the onset times with the unit measurement being in microSiemens (μS).[8]

Figure 1 shows changes in galvanic skin response levels averaged across subjects by realized choice of outcome over the first 30 seconds after results are realized (i.e., the "Results

[8]Data are limited to 130 subjects due to ectopic responses and capacity constraints in Shimmer3 units.

Figure 1: Skin Conductance by Preference Rank of Received Choice (Results Stage)



Stage"). Peak response—usually in the first few seconds after results are shown—follows the reverse order of preference rank received: it is highest for subjects who receive their fourth ranked choice, then third, second and first. The duration of increased arousal is noticeably different for subjects who receive their 4th choice (increasing for nearly 15 seconds) and perhaps those who receive their 2nd (increasing for over 10 seconds), and noticeably different from similar typed counterparts that receive a slightly more preferred option.

Table 6 provides a regression model of peak response during the Results Stage (models 1 & 2), the Message Stage (models 3 & 4), and a combined model of both stages that features subject random effects (models 5 & 6). Note that the first four models cannot have random effects terms as they only provide one observation per subject. Models (1) and (5) both suggest that in the Results Stage for each subsequently lower ranking from one's most preferred outcome, subjects exhibit 0.055 μS higher level of measured galvanic skin response in the Results Stage ($p \approx 0.094$ two-tailed; $p \approx 0.047$ one-tailed). There is no similar effect in the Message Stage ($p \approx 0.577$–0.217 two-tailed; $p \approx 0.288$–0.108 one-tailed). When other controls are added the magnitude of the effect is slightly greater, 0.070 μS in models (2)

Table 6: Regression of peak GSR magnitude on preference rank of received alternative and realization of justified-envy interacted with FULL information treatment. GSR magnitude was measured for 30 seconds after subjects learned the results of the mechanism (1) & (2) and another 30 seconds after they received a message notifying them of the end of the experiment (3) & (4). A final model (5) & (6) combines observations in a panel, utilizing subject random effects. All regression models use cluster-robust standard errors at the session level.

	Results Stage		Message Stage		Combined Panel Model	
VARIABLES	(1) GSR magnitude	(2) GSR magnitude	(3) GSR magnitude	(4) GSR magnitude	(5) GSR magnitude	(6) GSR magnitude
ranks from top	0.055*	0.070*	0.016	0.033	0.055*	0.070**
(1st=0)	(0.031)	(0.036)	(0.022)	(0.026)	(0.031)	(0.036)
message					-0.055	-0.048
stage					(0.077)	(0.095)
FULL		0.001		-0.016	0.000	0.001
treatment		(0.070)		(0.051)	(0.043)	(0.070)
message×					-0.039	-0.037
ranks from top					(0.039)	(0.045)
justified-envy		-0.121		-0.239***		-0.121
		(0.103)		(0.041)		(0.103)
FULL ×		-0.004		0.194*		-0.004
justified-envy		(0.113)		(0.111)		(0.113)
message ×						-0.118
justified-envy						(0.112)
message ×						-0.017
FULL						(0.071)
message × FULL ×						0.198*
justified-envy						(0.102)
Constant	0.266***	0.260***	0.211***	0.212***	0.266***	0.260***
	(0.055)	(0.067)	(0.048)	(0.052)	(0.057)	(0.068)
Subject Random Effects?	n/a	n/a	n/a	n/a	Y	Y
Observations	130	130	130	130	260	260

p-values (two-tailed): *** p<0.01, ** p<0.05, * p<0.1

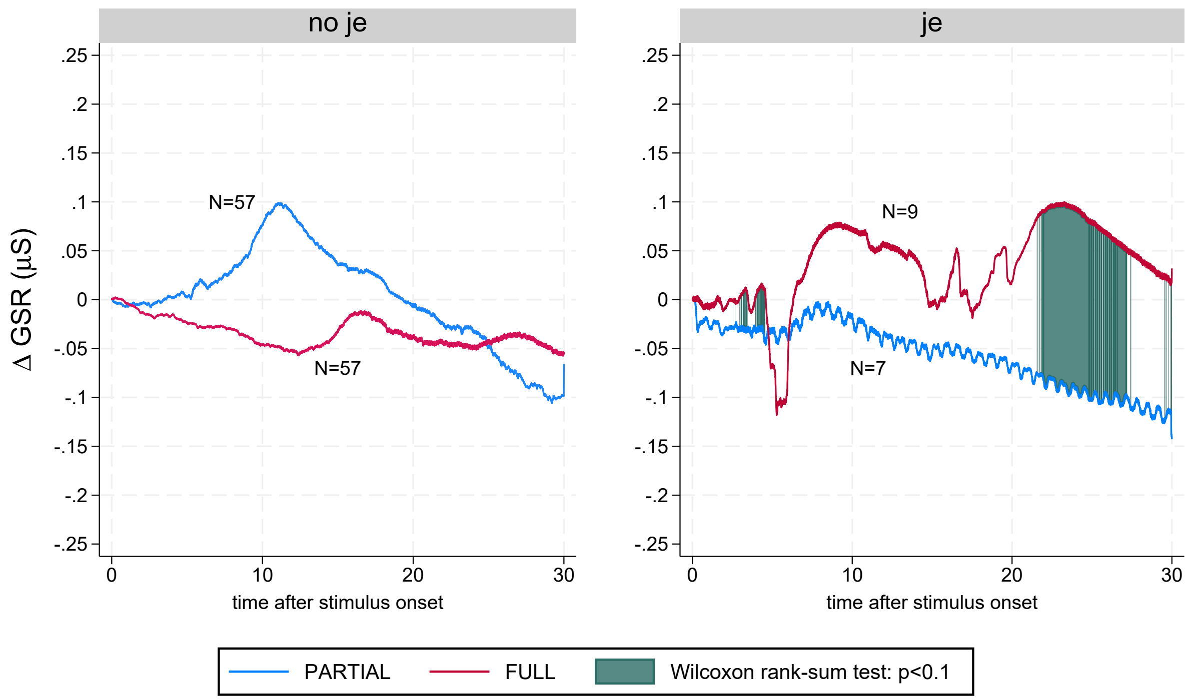
and (6). In the latter model (6) the effect reaches its highest level of significance ($p \approx 0.048$ two-tailed; $p \approx 0.024$ one-tailed).

Taken together, we interpret these results as showing that envy in the form of lower payoffs is detected in greater arousal in galvanic skin response, supporting Prediction 2.

Result 3 *When subjects with justified-envy are primed that their envy is justified, they exhibit greater levels of arousal in galvanic skin response.*

We now look at subject response to the realization of justified-envy. Recall that in all student-to-school assignments only Player 4 may experience justified-envy, either with their 3rd most preferred (μ', the unique equilibrium allocation of the TTC) or 4th most preferred option (ν'). Because it requires the observance of others' assignments, subjects can only

Figure 2: Skin Conductance by Realization of Justified-Envy (JE) and Information Treatment (Message Stage)



learn their envy is justified in treatment FULL where such information is disclosed. Further, because subjects still may not realize their envy is justified, we explicitly tell subjects in the FULL treatment about this condition 30 seconds after results are disclosed, in what is called the "Message Stage."

Figure 2 provides a breakdown of GSR change with and without justified-envy. In general, subjects tend to experience reduced arousal during the 30 seconds of the Message Stage. Without justified-envy, a message that alerts subjects to the fact there is no justified-envy tends to lead to less arousal. In the presence of justified-envy, however, such message leads to increased arousal for a substantial duration of the stage. We conduct functional Wilcoxon rank-sum tests to examine if there are statistical differences between subjects who experience justified-envy in different feedback information treatments. Since GSR data were collected at 128 Hz, we conducted 3840 such non-parametric tests for each comparison. We take an approach based on functional data analysis, where temporal galvanic skin response data are transformed into curve functions to then conduct statistical analyses on these very functions over the entire time window of thirty seconds. Crucially, this approach ensures that all of the data are used instead of an arbitrary subset of time following stimulus onset that is summarized to discrete values. Such approaches may lead to instances where effects are subtle, but false negatives may be reported. Another advantage of this approach is that while the original data is a function of time, so are the associated statistical tests with these data. To illustrate this, a Wilcoxon rank-sum test is not a single value, but a curve function that can be expressed over time, which then allows us to examine if and when statistically significant differences in arousal may have emerged. These properties eliminate concerns over arbitrariness of window time selection found in common approaches (Sirois and Brisson, 2014). We find that differences begin to emerge upon receiving the message (Wilcoxon rank-sum tests, $p < 0.10$, two-tailed, during the first 5 seconds) and toward the end of the Message Stage (Wilcoxon rank-sum tests, $p < 0.10$, two-tailed, in the interval between 21-29 seconds). For a Player 4 subject to understand the message that accentuates justified-envy, she must attend to her own induced preferences, the assignment of Player 2, and option priorities at Option A.

Table 6 also estimates changes in galvanic skin response magnitude in both the Results and Message stages on FULL treatment interacted with justified-envy. We already know from the previous result that rank of received choice regardless of information treatment has predictive value in this stage. In the second, Message Stage, where rank of received choice has little explanatory power, we see that subjects experiencing an assignment with justified-envy and who are not informed of this condition have typically low arousal. However, a message that primes them on the occurrence of such envy, leads to a significant increase in arousal of roughly 0.194 μS higher level of measured galvanic skin response in the Message Stage compared to other subjects that do not see the message (model 4: $p \approx 0.093$ two-tailed; $p \approx 0.046$ one-tailed). The magnitude of the effect, 0.198, is similar in the combined model with subject random effects (model 6: $p \approx 0.052$ two-tailed; $p \approx 0.026$ one-tailed). It is also apparent that there is not a similar effect in the Results Stage. The estimated term, -0.004, is roughly 0 (see models (2) and (6)). That is, subjects do not appear to differentially respond to the presence of justified envy until they are alerted to it.

Thus we find evidence to support Prediction 3, but with one strong qualification. Subjects appear to exhibit increased arousal when receiving an allocation under justified envy, however, such arousal will only appear when subjects are explicitly told about this occurrence.

Comparing the magnitudes of our last two results, the estimated terms for the increased arousal of justified-envy in the Message Stage (0.190–0.198 μS) and the drop of one preference rank in the Results Stage (0.055-0.070 μS) are quite consistent across our regression models. Using model (6), we can estimate the ratio of the two terms to be roughly 2.8, that is, the increased arousal of being informed of justified-envy is a little less than the increased arousal from a subject receiving their fourth choice rather than their first (a drop of 3 ranks). This term is imprecisely estimated, however, and we provide it more as a ballpark term for discussion rather than a precise estimate.

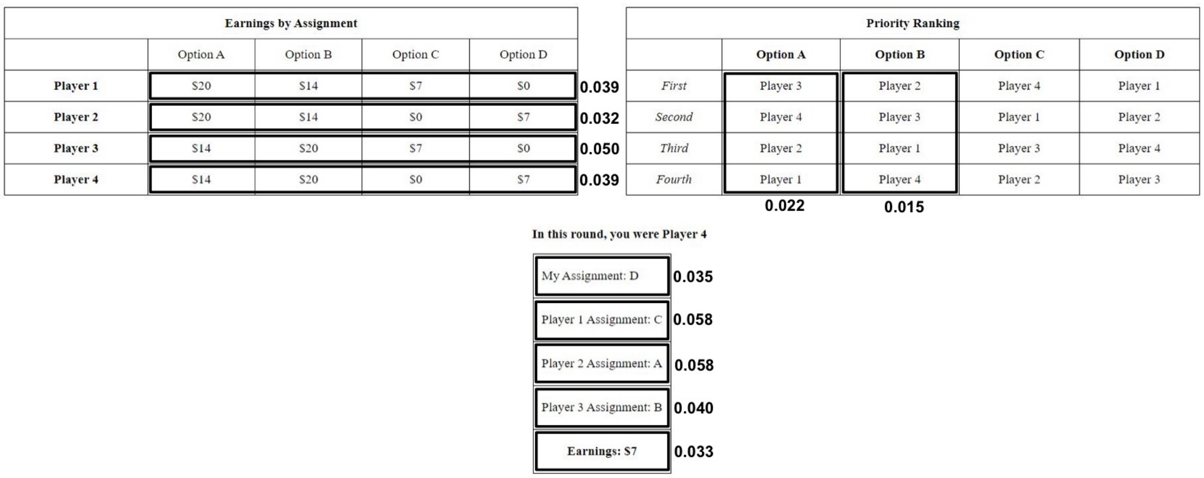
Result 4 *In the FULL treatment, subjects do not appear to notice their condition of justified-envy until prompted in the Message Stage. Once alerted, they dedicate a disproportionate amount of their visual attention towards the accentuating message and the relevant Option. No other group of subjects gives similar visual attention to these elements.*

Since the visual attention of subjects was captured using eye-tracking technology, we have data on where subjects were focusing their gaze throughout the experiment. Our interpretation of Result 3 is that subjects do not notice justified-envy until they are notified of its existence in the Message Stage. As both an important robustness check on this interpretation as well as a standalone topic of interest, we will quantify the visual attention subjects exhibit with their gaze. Specifically, we will examine their visual focus towards the priority levels of their options and earnings of other subjects both before and after they are informed of the condition of justified-envy.

First, we study attention dispersion of subjects assigned to the role of Player 4 conditional on a two-way efficient cycle forming between players 2 and 3, that is under either the realization of matching allocations μ' or ν'. Recall, in these instances, Player 4 experiences justified-envy towards Player 2, but unjustified-envy towards Player 3. Figure 3 reports the mean proportion of gaze time allocated toward relevant Areas of Interest (AOI) over all subjects in the role of Player 4 who experience justified-envy in the FULL treatment. Note

Figure 3: The proportion of gaze time is averaged for each AOI for subjects in the FULL treatment under equilibrium allocation μ', and ν', for subjects that experience justified-envy (Player 4s). The bold rectangles represent AOIs (not visible to the subjects) and the numbers in bold correspond to the proportion of gaze time of each AOI.

(a) Results Stage

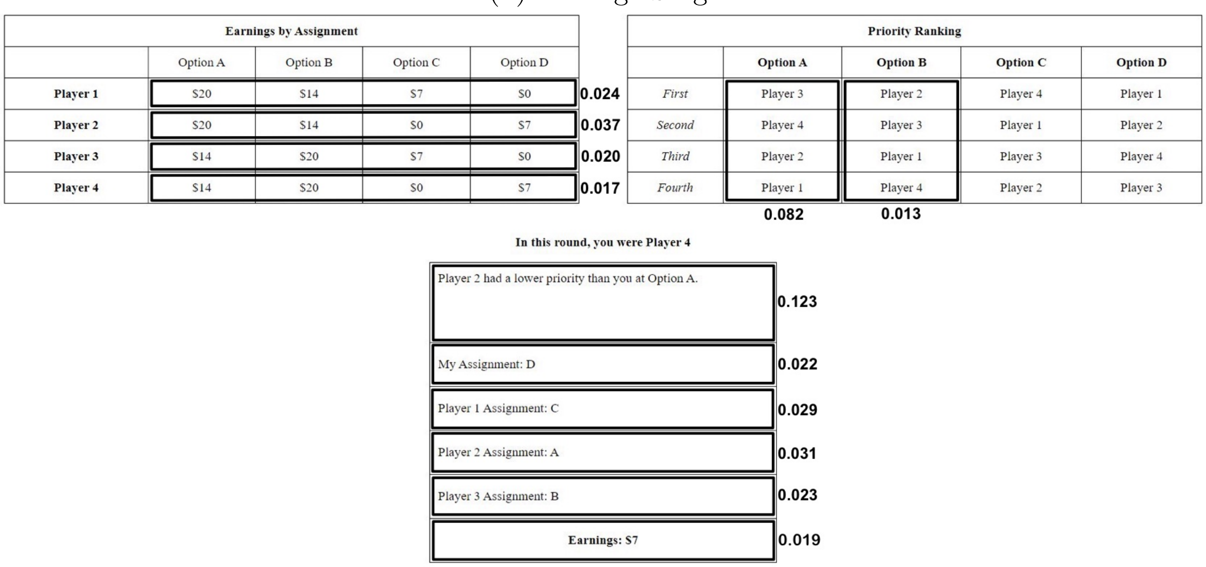


Earnings by Assignment	Option A	Option B	Option C	Option D	
Player 1	$20	$14	$7	$0	**0.039**
Player 2	$20	$14	$0	$7	**0.032**
Player 3	$14	$20	$7	$0	**0.050**
Player 4	$14	$20	$0	$7	**0.039**

Priority Ranking	Option A	Option B	Option C	Option D
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3
	0.022	**0.015**		

In this round, you were Player 4	
My Assignment: D	**0.035**
Player 1 Assignment: C	**0.058**
Player 2 Assignment: A	**0.058**
Player 3 Assignment: B	**0.040**
Earnings: $7	**0.033**

(b) Message Stage



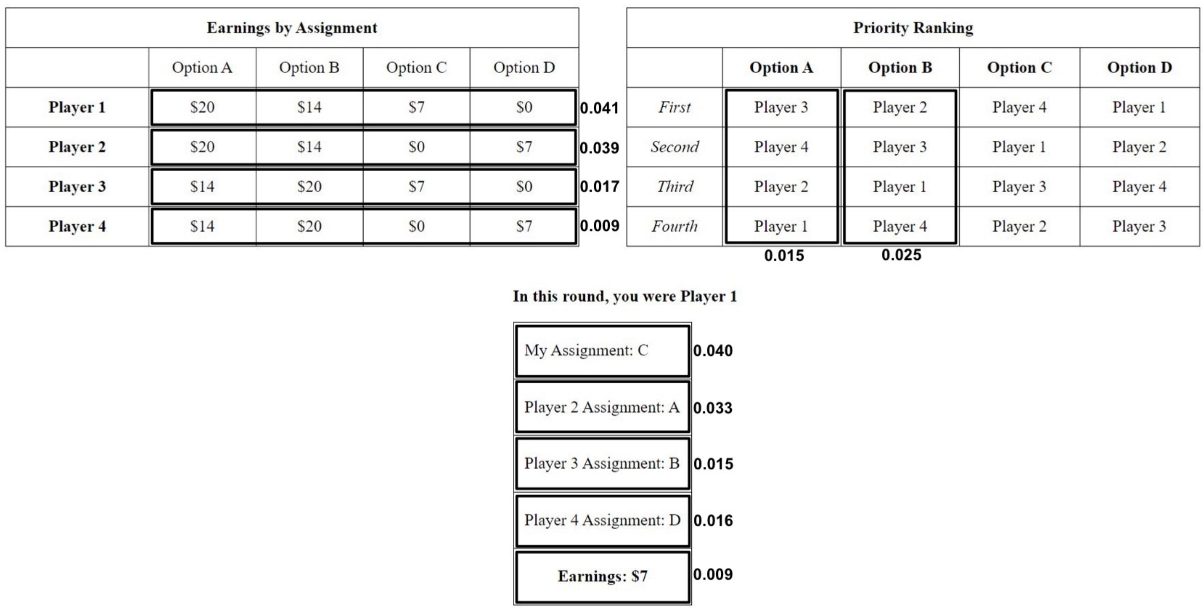
Earnings by Assignment	Option A	Option B	Option C	Option D	
Player 1	$20	$14	$7	$0	**0.024**
Player 2	$20	$14	$0	$7	**0.037**
Player 3	$14	$20	$7	$0	**0.020**
Player 4	$14	$20	$0	$7	**0.017**

Priority Ranking	Option A	Option B	Option C	Option D
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3
	0.082	**0.013**		

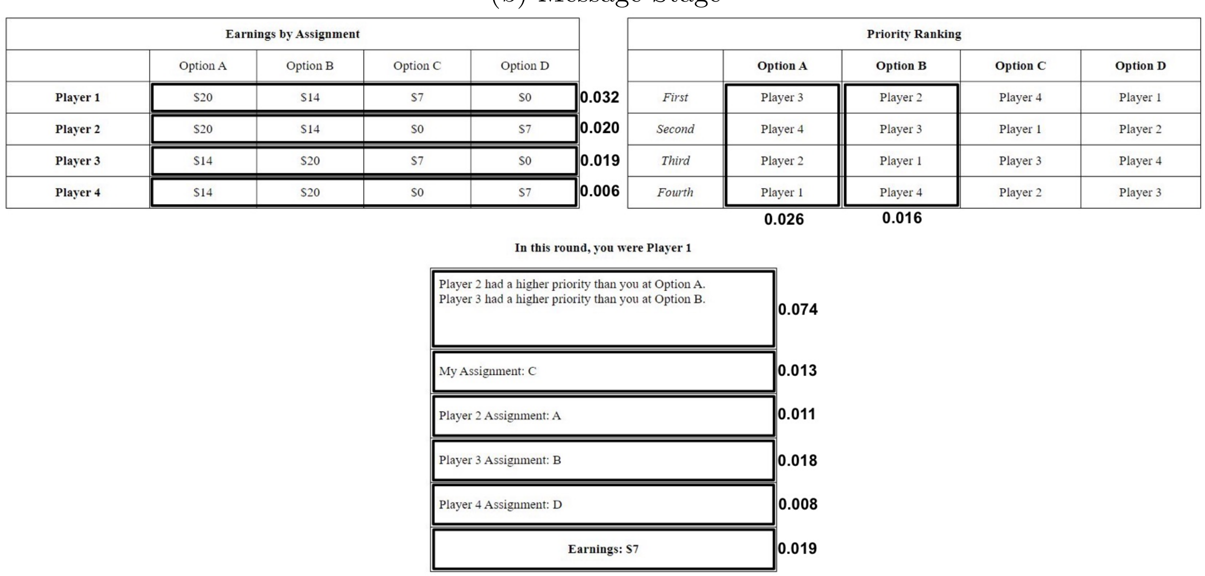
In this round, you were Player 4	
Player 2 had a lower priority than you at Option A.	**0.123**
My Assignment: D	**0.022**
Player 1 Assignment: C	**0.029**
Player 2 Assignment: A	**0.031**
Player 3 Assignment: B	**0.023**
Earnings: $7	**0.019**

Figure 4: The proportion of gaze time is averaged for each AOI for subjects in the FULL treatment under equilibrium allocation μ', or ν', for Player 1s that do not experience justified-envy. The bold rectangles represent AOIs (not visible to the subjects) and the numbers in bold correspond to the proportion of gaze time of each AOI.

(a) Results Stage



(b) Message Stage



that for all subjects these values are bounded by 1 (because they are a proportion), but may, and often do not, sum to 1 as subjects may gaze elsewhere including off-screen.

We begin our analysis in the Results Stage. These Player 4 subjects focus most (i) on their own rows and the rows of the Player who received their top choice in the Payoff table (Player 3); (ii) show no to little interest and no differential focus on priority rankings of their top 2 options; and (iii) less focus on the assignment of Player 3. Figure 4 provides the corresponding diagram for Player 1s that do not experience justified-envy under the same allocative outcomes. This figure can serve as a control to the gazes of Player 4s. Using a regression framework (see Appendix Tables A1 and A2 columns (1) for more detail), we can reject the null hypothesis of these 11 AOIs having equal mean gaze duration ($F(11, 12) = 3.84$; $p \approx 0.014$) and fixation ($F(11, 12) = 15.73$; $p \approx 0.000$). However, the differences are probably least apparent in the priority ranking table where, if anything, Player 1s appear to spend marginally more focus. In general, Player 4 subjects tend to have greater focus overall (i.e., the total of the 11 AOIs is higher) but it is most directed towards the Earnings table's bottom two rows (i.e., Player 3 and 4). Thus this difference in gaze appears to be simply due to logistic details in placement of Player 1 data vs. Player 4, not any player's reaction to justified-envy. Once Player 4s receive a message designed to accentuate justified-envy (towards Player 2) in the latter, Message Stage (Figure 3(b)), subjects assigned to the Player 4 role focus most on the earnings row of that player; (ii) spend more time overall focusing on priorities, deferentially weighted toward option A, and nominally the most time fixating on the assignment of Player 2. This pattern is not found among Player 1s who receive a message similar in content but does not note justified-envy. Using a regression framework (see Appendix Table A1 and A2 columns (2) for more detail), we can reject the null hypothesis of these 12 AOIs having equal mean gaze duration ($F(11, 12) \approx 2.74$; $p \approx 0.048$) and fixation ($F(12, 12) \approx 39.59$; $p \approx 0.00$) during the Message Stage. The pairwise differences of greatest magnitude occur in the AOIs that involve the Message and Option A (the Option that prefers Player 4 to the assigned Player 2, a situation of justified-envy). Over these two AOIs, Player 4 subjects spend 11.42 more percentage points of their gaze time ($p \approx 0.052$ two-tailed; $p \approx 0.026$ one-tailed) and 14.80 more total fixations ($p \approx 0.023$ two-tailed; $p \approx 0.012$ one-tailed). We find effects of similar magnitude and significance if we instead look at the differential changes for Player 1s and 4s between periods—the total difference-in-difference for those two AOIs is 10.70 ($p \approx 0.057$ two-tailed; $p \approx 0.028$ one-tailed) percentage points and 13.68 ($p \approx 0.021$ two-tailed; $p \approx 0.010$ one-tailed) fixations (see column (3) in Tables A1 and A2).

It should be noted that our main results on justified-envy (Result 3) involves the comparison of the randomly-assigned treatment of subjects in FULL and PARTIAL in the Player 4 role under justified-envy, not a comparison between subjects in the roles of Player 1 and 4. It is difficult to make an equivalent comparison here as the PARTIAL treatment involves 3 fewer AOIs. Perhaps due to this fact, subjects in the corresponding Player 4 role in the PARTIAL treatment spend a higher proportion of their gaze time across their 8 AOIs than similar subjects in the FULL treatment across those same AOIs. In the Results Stage, the mean time and fixation is higher for all 8 AOIs and the gaze patterns are significantly different ($F(8, 12) \approx 8.46$; $p \approx 0.000$ mean gaze proportion; $F(8, 12) \approx 38.54$; $p \approx 0.000$ fixation count). Nonetheless, we find FULL subjects who are informed of their justified-envy in the Message Stage spend a differential amount of visual focus on the Message and Option A AOIs, however, while the magnitudes are meaningful, the results are not significant (6.58 percentage points, $p \approx 0.324$ two-tailed; $p \approx 0.162$ one-tailed; 8.16 more fixations, $p \approx 0.186$ two-tailed; $p \approx 0.093$ one-tailed). The changes between periods provide mixed results (a difference in differences of 7.44 percentage points $p \approx 0.230$ two-tailed; $p \approx 0.120$ one-tailed; 9.30 more fixations, $p \approx 0.077$ two-tailed; $p \approx 0.034$ one-tailed). We interpret these results as an issue with the type of comparison between the 8 and 11 AOIs that could go away with more precision.

Other regression specifications that include additional player types and other assignments provide similar results. No other class of subjects visually attune to the Messsage and Option A AOIs to the same extent as FULL-treatment, Player 4 subjects who experienced justified-envy, and only during the Message Stage.

Two other regressions that compare to all FULL subjects show similar results (not shown). In general, full subjects experiencing justified envy, such subjects spend in total 10 percentage points more visual focus ($p \approx 0.010$–0.023 two-tailed; $p \approx 0.005$–0.012 one-tailed) and 11 more fixations ($p \approx 0.008$–0.010 two-tailed; $p \approx 0.004$–0.005 one-tailed) in the Message Stage on these two AOIs than other groups. There is no such relation in the Results Stage.

It is difficult to think of an explanation for these findings other than the most simple. Player 4 subjects were not aware of their particular situation of justified-envy in the Results Stage. After receiving a Message designed to alert them to it, subjects began to consider their particular case of justified-envy. Other subjects do not exhibit a similar pattern of visual focus which likely means this pattern is triggered by a subject considering their situation involving justified-envy.

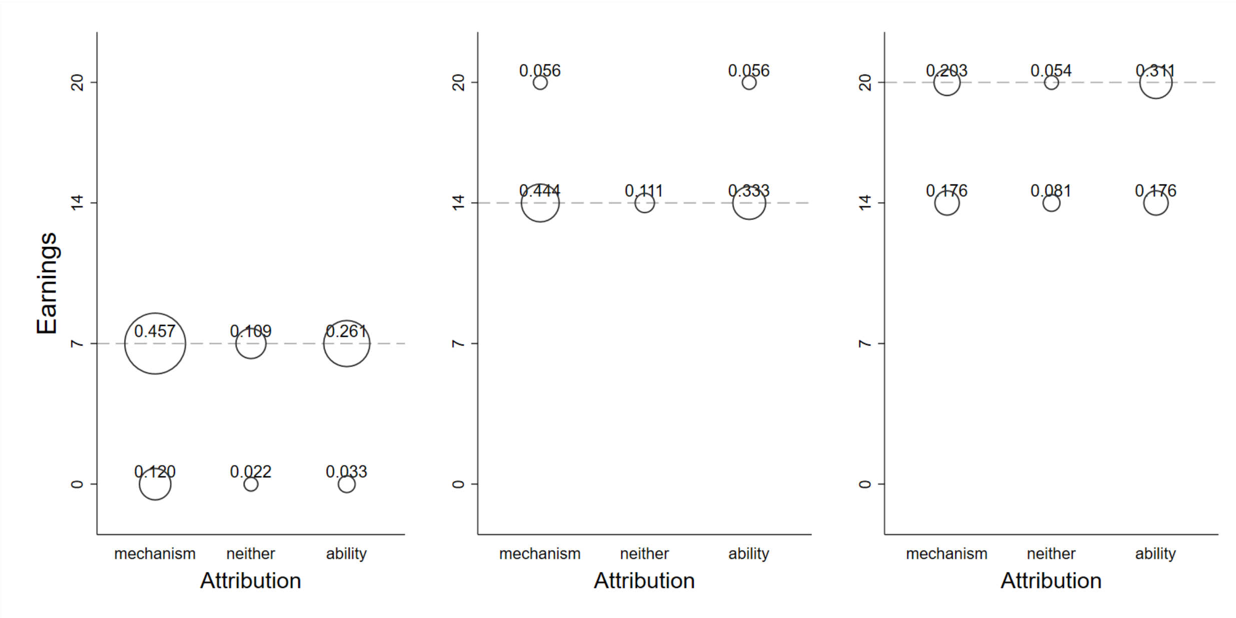
Finally, we note one correlational result that is consistent with the attribution bias. We caution the reader on its full interpretation as the experiment was not designed to find this result ex-ante. Nonetheless, it is quite interesting and adds some nuance to our interpreation of results.

At the end of the school choice game, subjects were asked to what extent they attributed their earnings to the mechanism vs. their own ability. The self-attribution bias suggests subjects attribute favorable outcomes to their own ability, but blame external factors for unfavorable ones (Heider, 2013; Jones and Davis, 1965; Kelley, 1973). We interpret this bias to suggest subjects are more likely to credit themselves (vs. the mechanism) when receiving higher ranked choices.

Result 5 *Subjects self-report differential attribution to ability depending on the rank preference of their assignment. Subjects attribute more weight to ability (mechanism) when they get their higher (low) ranked assignments. Being notified of the condition of justified-envy does not make subjects more likely to blame the mechanism for their assignments.*

Subjects reported to what extent their ability affected their assignment versus to what extent the mechanism was responsible for their assignment on a 7-point slider scale with the extremes corresponding to the mechanism and a subject's own ability (Appendix, Survey Question 3). The slider position was originally placed in the middle. Out of 184 subjects, only 24 chose to keep the slider in that position, equally weighting responsibility between options.

Figure 5: The Attribution of School Choice Game Earnings



Notes: Observations pooled from the DA and TTC mechanisms. Low equilibrium payoffs are \$7 in both mechanisms. High equilibrium payoffs under dominant strategy play are \$14 in DA, and \$20 in TTC. Dotted lines denote these equilibrium payoffs.

Figure 5 shows the attribution of school choice game earnings conditional on equilibrium payoffs under truthful revelation. Subjects that receive one of their top two choices are more likely to attribute the result to their ability (43 of 80, 53.75%) than subjects that receive one of their bottom two choices (27 of 80, 29.35%) (chi-square test, $p \approx 0.011$). In reality, many factors influenced the rank of choice subjects received, notably, the random assignment of player type. No Player 1 or 4 subject received one of their top two choices and no Player 2 or 3 subject received one of their bottom two. These results are consistent with a self-serving bias which suggest subjects attribute their assignment to their own ability when favorable outcomes materialize and otherwise attribute unfavorable outcomes to factors outside of their control.

Table 7 provides regression results of the 7-point scale on attribution of received assignments to ability vs. the mechanism. Specification (1) shows us that for each subsequently lower ranking from one's most preferred assignment for the Option a subject receives, they attribute an additional 0.475 points to the mechanism rather than their ability ($p \approx 0.001$). Specification (2) allows us to disentangle how much of this attribution effect is due to ran-

Table 7: Regression of 7-point survey question on outcomes due to ability vs. mechanism by player type and rank of choice received. Higher numbers indicate more attribution to personal ability (than the mechanism). All regression models use cluster-robust standard errors at the session level.

VARIABLES	(1) Ability/mechanism affected outcomes (7-point scale)	(2) Ability/mechanism affected outcomes (7-point scale)	(3) Ability/mechanism affected outcomes (7-point scale)	(4) Ability/mechanism affected outcomes (7-point scale)
ranks from top	-0.475***		-0.511***	
(1st=0)	(0.119)		(0.127)	
top rank for		0.549**		0.522*
Player (1st, 3rd=1)		(0.263)		(0.260)
Player 2 or 3		0.941***		1.019***
		(0.234)		(0.255)
FULL			-0.042	-0.040
			(0.237)	(0.245)
justified-envy			-0.485	-0.486
			(0.716)	(0.718)
full ×			1.249	1.246
justified-envy			(0.904)	(0.911)
Constant	0.342*	-1.128***	0.366*	-1.173***
	(0.192)	(0.314)	(0.206)	(0.377)
Observations	184	184	184	184

p-values (two-tailed): *** p<0.01, ** p<0.05, * p<0.1

domly assigned player types and how much is due to the actual outcome of the mechanism. For subjects that are assigned to roles of players 2 and 3—and empirically always receive their top two choices—we see an increase in attribution to ability of nearly 1 point (0.941) on the seven point scale ($p \approx 0.001$). When subjects receive their higher possible Option given their player type (first choice for players 2 and 3; third choice for players 1 and 4) we see an additional attribution to ability of 0.549 points ($p \approx 0.048$ two-tailed; $p \approx 0.024$ one-tailed). Thus both external uncertainty and strategic uncertainty are credited to the subject's ability under this attribution bias.

A further interpretation of the attribution bias might suggest that subjects self-report differential attribution to ability depending on whether they recognize justified-envy. In this interpretation, subjects would attribute more weight to ability (mechanism) when they experience justified-envy in the PARTIAL (FULL) treatment. Interestingly, we see little evidence that subjects primed with justified-envy would blame the mechanism more for their predicament. Our regression specifications (3) and (4) examine this specific relationship.

Subjects with justified-envy in the FULL treatment on average report points *higher* attribution to self compared to subjects in the PARTIAL treatment ($p \approx 0.180$ two-tailed; $p \approx 0.090$ one-tailed), which goes in the opposite direction of our prediction.

5 Discussion

In this paper, we propose a novel approach to examine welfare properties under mechanism design: through involuntarily provided biometric feedback. Specifically, we look at whether subjects exhibit more discontentment in the form of increased galvanic skin response in the presence of envy with and without justification. The preference profiles that underlie the theoretical framework of our design are specifically chosen so that two out of four subjects will not attain their first or second-choice school. Both subjects will envy the assignment of the other two subjects that received their first (or second) choice. In the equilibrium outcome of the TTC, one player profile will lead to justified-envy. That specific subject would have been preferred by the school that selected another subject. We randomly vary across subjects whether the assignments of others are observed and whether we emphasize this particular type of (justified) envy.

We initially document the perceived importance of envy, specifically, preferring another subject's assignment, through increased arousal as captured by dynamic galvanic skin response and magnitude. We then follow through by noting additional arousal of similar types in the presence of justified-envy. Our results suggest that justified-envy is a meaningful fairness criterion, and situations of priority violation may be perceived as an obvious conflict with the very role of priorities which is in line with the views of some theorists and school board administrators. It is paramount we emphasize, however, that subjects do not actively seek information about whether they may be prone to justified-envy. We do note, though, that when justified-envy is accentuated with explicit messages, subjects are negatively affected by this information.

The welfare interpretation of our biometric estimates are not so clear for the social planner when the entire group of four agents is considered. For our experimental game, moving from the DA to the TTC mechanism under dominant strategy play presents a Pareto-improvement where players 2 and 3 are assigned to strictly better schools and players 1 and 4 are assigned to the same schools. We estimate being informed of justified-envy generates a negative emotional response equivalent to dropping 2.8 ranks in one's choice. However, imposing a matching free from justified-envy will drop two players one rank. Even if we make the heroic assumption that GSR is fully representative of utility, we are very close between these two allocations in terms of net utility.

At the same time, we note confirmation of the comparative statics of theoretical predictions and an extrapolation of a well-known psychological result, the self-attribution bias, in our data.

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A Regressions of eye gaze by player role and stage

Table A1: Regression of differential eye gaze duration by Area of Interest (AOI) between Player 4 and Player 1, restricted to outcomes with justified-envy only (outcomes μ' and ν'). Values from Results Stage (1) Message Stage (2) and difference between the two stages (3) shown. Fixed effects for each AOI are included and absorbed in regression model. All regression models use cluster-robust standard errors at the session level.

VARIABLES	(1) percentage of dwell time	(2) percentage of dwell time	(3) percentage of dwell time
Player 4 × . . .			
Assignment	-0.634	0.924	1.558
Notification	(2.075)	(0.720)	(2.284)
Earnings	2.494**	0.212	-2.282
Statement	(0.982)	(1.580)	(1.944)
Message		5.503	5.503
(Message Stage Only)		(3.435)	(3.435)
Player 1	-0.232	-1.058	-0.826
Earnings Table	(1.151)	(1.618)	(1.190)
Player 2	-1.912	1.595	3.507
Earnings Table	(1.853)	(1.188)	(2.390)
Player 3	2.981	0.061	-2.920*
Earnings Table	(1.780)	(1.076)	(1.394)
Player 4	3.170***	1.166*	-2.004**
Earnings Table	(0.871)	(0.636)	(0.820)
Option A	0.720	5.918	5.198
Priority Table	(1.276)	(3.623)	(3.454)
Option B	-0.952	-0.020	0.932
Priority Table	(0.906)	(0.920)	(1.259)
Other Player	2.202	1.945**	-0.257
Assignment (Row 1)	(2.084)	(0.843)	(2.291)
Other Player	3.931**	1.484	-2.447
Assignment (Row 2)	(1.474)	(1.513)	(1.494)
Other Player	1.803*	1.170	-0.634
Assignment (Row 3)	(0.972)	(1.239)	(1.006)
Constant	2.606***	2.099***	-0.290
	(0.526)	(0.232)	(0.547)
Observations	198	216	216

*** p<0.01, ** p<0.05, * p<0.1

Table A2: Regression of differential number of total fixations by Area of Interest (AOI) between Player 4 and Player 1, restricted to outcomes with justified-envy only (outcomes μ' and ν'). Values from Results Stage (1) Message Stage (2) and difference between the two stages (3) shown. Fixed effects for each AOI are included and absorbed in regression model. All regression models use cluster-robust standard errors at the session level.

VARIABLES	(1) no. of fixations	(2) no. of fixations	(3) no. of fixations
Player 4 × . . .			
Assignment	0.875	1.300	0.425
Notification	(1.372)	(3.027)	
Earnings	3.600**	0.875	-2.725
Statement	(1.353)	(1.673)	(2.084)
Message		8.775*	8.775*
(Message Stage Only)		(4.449)	(4.449)
Player 1	0.625	-1.100	-1.725
Earnings Table	(2.245)	(2.321)	(1.543)
Player 2	-1.950	2.200	4.150
Earnings Table	(2.340)	(1.942)	(3.009)
Player 3	4.075*	1.150	-2.925
Earnings Table	(2.138)	(1.507)	(1.734)
Player 4	4.725***	0.950	-3.775***
Earnings Table	(1.546)	(1.001)	(1.205)
Option A	1.125	6.025*	4.900*
Priority Table	(1.579)	(3.157)	(2.717)
Option B	-0.275	0.400	0.675
Priority Table	(1.068)	(1.109)	(1.318)
Other Player	4.525	2.725*	-1.800
Assignment (Row 1)	(3.264)	(1.458)	(3.639)
Other Player	6.675***	2.350	-4.325*
Assignment (Row 2)	(1.780)	(1.643)	(1.987)
Other Player	3.475**	1.025	-2.450
Assignment (Row 3)	(1.275)	(1.179)	(1.458)
Constant	2.966***	2.427***	-0.292
	(0.724)	(0.455)	(0.810)
Observations	198	216	216

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A3: Regression of differential eye gaze duration by Area of Interest (AOI) of Player 4s between FULL and PARTIAL information treatments, restricted to outcomes with justified-envy only (outcomes μ' and ν'). Values from Results Stage (1) Message Stage (2) and difference between the two stages (3) shown. Fixed effects for each AOI are included and absorbed in regression model. All regression models use cluster-robust standard errors at the session level. Note that the FULL treatment features three more AOIs concerning the allocations for other subjects that are not included in the PARTIAL treatment. Thus, the three AOIs are excluded from the regression analysis.

VARIABLES	(1) percentage of dwell time	(2) percentage of dwell time	(3) percentage of dwell time
Player 4 $\times \ldots$			
Assignment	-1.594	-0.844	0.750
Notification	(1.168)	(1.004)	(1.655)
Earnings	-1.304	-0.903	0.401
Statement	(0.997)	(0.705)	(1.230)
Message		4.158	4.158
(Message Stage Only)		(3.209)	(3.209)
Player 1	0.415	1.068	0.653
Earnings Table	(1.022)	(0.751)	(1.128)
Player 2	-1.310	2.281*	3.591
Earnings Table	(1.812)	(1.249)	(2.101)
Player 3	-0.707	0.136	0.843
Earnings Table	(2.175)	(0.758)	(2.027)
Player 4	-3.355	-4.700*	-1.345
Earnings Table	(2.756)	(2.273)	(2.069)
Option A	-0.863	2.418	3.281
Priority Table	(1.642)	(4.676)	(3.823)
Option B	-3.000	-1.274	1.726
Priority Table	(1.966)	(1.480)	(1.170)
Constant	4.802***	3.711***	-0.558
	(0.444)	(0.626)	(0.709)
Observations	136	153	153

*** p<0.01, ** p<0.05, * p<0.1

Table A4: Regression of differential number of total fixations by Area of Interest (AOI) between Player 4 and Player 1, restricted to outcomes with justified-envy only (outcomes μ' and ν'). Values from Results Stage (1) Message Stage (2) and difference between the two stages (3) shown. Fixed effects for each AOI are included and absorbed in regression model. All regression models use cluster-robust standard errors at the session level. Note that the FULL treatment features three more AOIs concerning the allocations for other subjects that are not included in the PARTIAL treatment. Thus, the three AOIs are excluded from the regression analysis.

VARIABLES	(1) no. of fixations	(2) no. of fixations	(3) no. of fixations
Assignment	-3.786	-1.557	2.229
Notification	(2.599)	(1.766)	(3.233)
Earnings	-3.114	-1.500	1.614
Statement	(1.913)	(1.131)	(2.241)
Message		6.186*	6.186*
(Message Stage Only)		(2.958)	(2.958)
Player 1	-0.500	1.543	2.043
Earnings Table	(2.289)	(1.243)	(2.298)
Player 2	-3.986	3.200	7.186*
Earnings Table	(3.032)	(1.821)	(3.317)
Player 3	-3.729	-0.171	3.557
Earnings Table	(3.518)	(1.261)	(3.339)
Player 4	-6.400	-8.086**	-1.686
Earnings Table	(3.743)	(2.999)	(2.333)
Option A	-1.143	1.971	3.114
Priority Table	(1.999)	(4.383)	(3.222)
Option B	-3.471	-1.600	1.871
Priority Table	(2.736)	(1.599)	(1.969)
Constant	7.929***	4.968***	-2.079**
	(0.792)	(0.745)	(0.846)
Observations	136	153	153

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

SUPPLEMENTAL MATERIALS

Instructions (DA)

Introduction

This is an experiment in economic decision making. If you pay attention to these instructions, you can earn a significant amount of money. If you have any questions, raise your hand and we will come to assist you. Your earnings will depend on the decisions you make and the decisions made by other participants during the experiment. These earnings will be paid in addition to your $10 show-up payment.

Instructions

This experiment consists of 1 round, and your earnings depend on the decisions you make and the decisions made by other players in that round. First, there will be 4 practice rounds for you to familiarize yourself with the decision environment. These practice rounds will not affect your earnings. At the beginning of each round, you will be randomly assigned to groups of 4. Each round has 4 options: Option A, Option B, Option C and Option D. Each option will be exclusively assigned to one of the players in the group. For every round, each player submits a preference ranking for every option from the most preferred to the least preferred. The ranking reports submitted by the four players determine the options that they will receive. Your earnings are based on the option you receive.

At the beginning of each round, the computer will assign each option a priority ranking for all players. A priority ranking is a list of all players in order from highest priority to lowest priority. Each option may be assigned a different priority ranking, so you may have a different level of priority for each of the four options. After all players submit their ranking reports, the computer uses the following method to decide which player is assigned to which option:

Step 1: Players are considered for the option they ranked first. If only 1 player is considered for that option, the player is provisionally assigned to it. If more than 1 player is considered for the same option, the option is provisionally assigned to the player with the highest priority rank at that option. Players that are not provisionally assigned to an option are permanently excluded from that option.

Step 2: Players that have been provisionally assigned in Step 1 are considered again for the respective option. Players that were rejected in Step 1 are considered for the next option in their ranking report. If only 1 player is considered for an option, the player is provisionally assigned to it. If more than 1 player is considered for the same option, the option is provisionally assigned to the player with the highest priority rank. Players that are not provisionally assigned to an option are permanently excluded from that option.

Step 3: Players that have been provisionally assigned in Step 2 are considered again for the respective option. Players that were rejected in Step 2 are considered for the next option in their ranking report. If only 1 player is considered for an option, the player is provisionally assigned to it. If more than 1 player is considered for the same option, the option is provisionally assigned to the player with the highest priority rank. Players that are not provisionally assigned to an option are permanently excluded from that option.

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The computer continues to follow this process until all players are provisionally assigned to an option. At this step, all provisional assignments become permanent assignments.

After all players in your group submit their ranking reports, you will find out the option you were assigned to and the corresponding earnings.

Instructions (TTC)

Introduction

This is an experiment in economic decision making. If you pay attention to these instructions, you can earn a significant amount of money. If you have any questions, raise your hand and we will come to assist you. Your earnings will depend on the decisions you make and the decisions made by other participants during the experiment. These earnings will be paid in addition to your $10 show-up payment.

Instructions

This experiment consists of 1 round, and your earnings depend on the decisions you make and the decisions made by other players in that round. First, there will be 4 practice rounds for you to familiarize yourself with the decision environment. These practice rounds will not affect your earnings. At the beginning of each round, you will be randomly assigned to groups of 4. Each round has 4 options: Option A, Option B, Option C and Option D. Each option will be exclusively assigned to one of the players in the group. For every round, each player submits a preference ranking for every option from the most preferred to the least preferred. The ranking reports submitted by the three players determine the options that they will receive. Your earnings are based on the option you receive.

At the beginning of each round, the computer will assign each option a priority ranking for all players. A priority ranking is a list of all players in order from highest priority to lowest priority. Each option may be assigned a different priority ranking, so you may have a different level of priority for each of the four options. After all players submit their ranking reports, the computer uses the following method to decide which player is assigned to which option:

Step 1: Each player is provisionally assigned to the option at which he/she has the highest priority. If a player ranks his/her provisionally assigned option first, a 1-way cycle is formed and he/she is permanently assigned to that option (see Figure 1a). Assignments may also be resolved by 2-way, 3-way or 4-way cycles.

For example, if Player 1 ranks Player 3's provisionally assigned option first, and Player 3 ranks Player 1's provisionally assigned option first, this is a 2-way cycle (see Figure 1b). Both players are permanently assigned to their first-ranked option. (This example is for illustrative purposes; other similar combinations of players and options also form 2-way cycles.) A 3-way cycle is formed, for example, if Player 1 ranks Player 2's provisionally assigned option first, Player 2 ranks Player 3's provisionally assigned option first and Player 3 ranks Player 1's provisionally assigned option first (see Figure 1c). All three players are permanently assigned to their first-ranked option. (This example is for illustrative purposes; other similar combinations of players and options also form 3-way cycles.)

A 4-way cycle is formed in a similar fashion.

Options that are permanently assigned are removed from the list of available options.

Step 2: If a player is not permanently assigned and his/her first-ranked option is not permanently assigned to another player after Step 1, assignments may be resolved by 2-way or 3-way cycles with the first-ranked option in his/her ranking report and the available options. Step 2 is repeated until either (a) a player is permanently assigned to his/her first ranked option or (b) until his/her first-ranked option is permanently assigned to another player.

Options that are permanently assigned are removed from the list of available options.

Step 3: If a player is not permanently assigned and his/her first-ranked option is permanently assigned to another player after Step 2, assignments may be resolved by 1-way, 2-way or 3-way cycles with the second-ranked option in his/her ranking report and the available options. Step 3 is repeated until either (a) a player is permanently assigned to his/her second-ranked option or (b) until his/her second-ranked option is permanently assigned to another player.

Options that are permanently assigned are removed from the list of available options.

Step 4: If a player is not permanently assigned and his/her second-ranked option is permanently assigned to another player after Step 3, assignments may be resolved by 1-way or 2-way cycles with the third-ranked option in his/her ranking report and the available options. Step 4 is repeated until either (a) a player is permanently assigned to his/her third-ranked option or (b) until his/her third-ranked option is permanently assigned to another player.

Options that are permanently assigned are removed from the list of available options.

Step 5: If a player is not permanently assigned after Step 4, a 1-way cycle is formed with the fourth-ranked option in his/her ranking report, and he/she is permanently assigned to his/her provisional assignment.

After all players in your group submit their ranking reports, you will find out the option you were assigned to and the corresponding earnings.

Figure 1a: 1-way cycle

Figure 1b: 2-way cycle

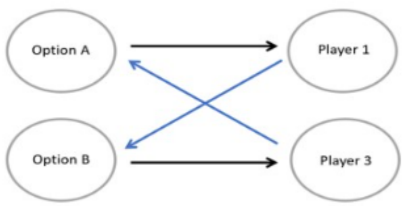
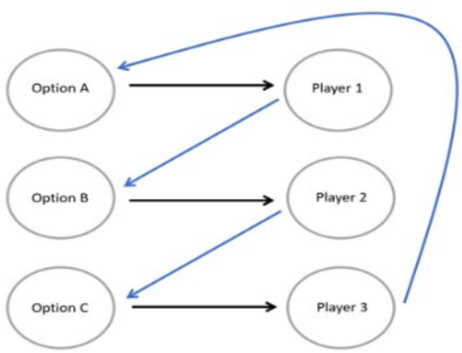


Figure 1c: 3-way cycle



Comprehension Quiz - Each question was displayed on a different page

1. An option can be assigned to more than 1 player in a group.

○ True

○ False

2. In the figure below, the player who is viewing the screen is:

○ Player 1

○ Player 2

○ Player 3

○ Player 4

Practice Round 1: In this round, you are Player 3

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$7	$14	$0
Player 2	$14	$0	$20	$7
Player 3	$7	$20	$0	$14
Player 4	$14	$7	$0	$20

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 1	Player 3	Player 2	Player 4
Second	Player 4	Player 2	Player 3	Player 1
Third	Player 3	Player 4	Player 1	Player 2
Fourth	Player 2	Player 1	Player 4	Player 3

Please mark your ranking below:

First Choice: --------- Second Choice: --------- Third Choice: --------- Fourth Choice: ---------

3. According to the figure below, if I'm assigned to option A, my payoff would be:

○ $0

○ $7

○ $14

○ $20

Practice Round 1: In this round, you are Player 3

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$7	$14	$0
Player 2	$14	$0	$20	$7
Player 3	$7	$20	$0	$14
Player 4	$14	$7	$0	$20

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 1	Player 3	Player 2	Player 4
Second	Player 4	Player 2	Player 3	Player 1
Third	Player 3	Player 4	Player 1	Player 2
Fourth	Player 2	Player 1	Player 4	Player 3

Please mark your ranking below:

First Choice: --------- Second Choice: --------- Third Choice: --------- Fourth Choice: ---------

4. According to the figure below, I have a higher priority than Player 1 at Option C.

○ True

○ False

Practice Round 1: In this round, you are Player 3

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$7	$14	$0
Player 2	$14	$0	$20	$7
Player 3	$7	$20	$0	$14
Player 4	$14	$7	$0	$20

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 1	Player 3	Player 2	Player 4
Second	Player 4	Player 2	Player 3	Player 1
Third	Player 3	Player 4	Player 1	Player 2
Fourth	Player 2	Player 1	Player 4	Player 3

Please mark your ranking below:

First Choice: --------- Second Choice: --------- Third Choice: --------- Fourth Choice: ---------

5. Based on the figure below, if I submit Option B as my first choice, and players 2, 3 and 4 submit Options A, D and C as their first choice, respectively, I would be assigned to:

- ○ Option A
- ○ Option B
- ○ Option C
- ○ Option D

Practice Round 4: In this round, you are Player 1

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$14	$20	$0	$7
Player 2	$20	$7	$0	$14
Player 3	$14	$7	$0	$20
Player 4	$7	$14	$20	$0

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 4	Player 3	Player 1	Player 2
Second	Player 2	Player 1	Player 3	Player 4
Third	Player 3	Player 2	Player 4	Player 1
Fourth	Player 1	Player 4	Player 2	Player 3

Please mark your ranking below:

First Choice: ---------

Second Choice: ---------

Third Choice: ---------

Fourth Choice: ---------

Survey - Each question was displayed on a different page

1. Please describe how you decided to rank options from first to last.

2. How difficult was this game? Please indicate your answer by moving the slider accordingly.

Very Easy — Very Difficult

3. To what extent do you think your ability affected your assignment versus to what extent do you think the computer was responsible for your assignment? Please indicate your answer by moving the slider accordingly.

The Computer — My Ability

4. It was always in my best interest to report my most preferred option (the option that yielded $20) as my first choice.

- ○ True
- ○ False
- ○ I don't know

Accentuating Justified-Envy

FULL

- If assigned to the best option:
  - If highest priority: "You had the highest priority at Option X."
  - If 2nd highest priority: "You were second in priority at Option X."
  - If 3rd highest priority: "You were third in priority at Option X."
  - If 4th highest priority: "You were fourth in priority at Option X."
- If assigned to the 2nd best option:
  - with justified-envy:
    - "Player I had a lower priority than you at Option X."
  - without justified-envy
    - "Player I had a higher priority than you at Option X."
- If assigned to the 3rd best option:
  - with justified-envy:
    - once: "Player I had a lower priority than you at Option X."
    - twice: "Player I had a lower priority than you at Option X.
      Player J had a lower priority than you at Option Y."
  - without justified-envy
    - "Player I had a higher priority than you at Option X.
      Player J had a higher priority than you at Option Y."
- If assigned to the 4th best option:
  - with justified-envy:
    - once: "Player I had a lower priority than you at Option X."
    - twice: "Player I had a lower priority than you at Option X.
      Player J had a lower priority than you at Option Y."

    * thrice: "Player I had a lower priority than you at Option X.
      Player J had a lower priority than you at Option Y.
      Player K had a lower priority than you at Option Z."

  - without justified-envy

    * "Player I had a higher priority than you at Option X.
      Player J had a higher priority than you at Option Y.
      Player K had a higher priority than you at Option Z."

<u>PARTIAL</u>

- "This concludes the stage of this game."

Example Screenshots from the Feedback Stage

FULL - Results Stage

Time left on this page: **0:27**

Round 5: Results

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$14	$7	$0
Player 2	$20	$14	$0	$7
Player 3	$14	$20	$7	$0
Player 4	$14	$20	$0	$7

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3

In this round, you were Player 2

My Assignment: B
Player 1 Assignment: C
Player 3 Assignment: A
Player 4 Assignment: D
Earnings: $14.00

FULL - Message Stage

Time left on this page: **0:28**

Round 5: Results

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$14	$7	$0
Player 2	$20	$14	$0	$7
Player 3	$14	$20	$7	$0
Player 4	$14	$20	$0	$7

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3

In this round, you were Player 2

Player 3 had a higher priority than you at Option A.
My Assignment: B
Player 1 Assignment: C
Player 3 Assignment: A
Player 4 Assignment: D
Earnings: $14.00

PARTIAL - Results Stage

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Round 5: Results

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$14	$7	$0
Player 2	$20	$14	$0	$7
Player 3	$14	$20	$7	$0
Player 4	$14	$20	$0	$7

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3

In this round, you were Player 1

Assignment: Option C

Earnings: $7.00

PARTIAL - Message Stage

Time left on this page: **0:19**

Round 5: Results

Earnings by Assignment				
	Option A	Option B	Option C	Option D
Player 1	$20	$14	$7	$0
Player 2	$20	$14	$0	$7
Player 3	$14	$20	$7	$0
Player 4	$14	$20	$0	$7

Priority Ranking				
	Option A	**Option B**	**Option C**	**Option D**
First	Player 3	Player 2	Player 4	Player 1
Second	Player 4	Player 3	Player 1	Player 2
Third	Player 2	Player 1	Player 3	Player 4
Fourth	Player 1	Player 4	Player 2	Player 3

In this round, you were Player 1

This concludes the stage of this game.

Assignment: Option C

Earnings: $7.00