The costs and benefits of symmetry in common-ownership allocation problems*

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Abstract

In experimental partnership dissolution problems with complete information, the divide-and-choose mechanism is significantly superior to the winner's-bid auction. The performance of divide-and-choose is mainly affected by reciprocity issues and not by bounded rationality. The performance of the winner's-bid auction is significantly affected by bounded rationality. Contrary to theoretical predictions divide-and-choose exhibits no first-mover bias.

JEL classification: C91, D63, C72.

Keywords: experimental economics; no-envy; divide-and-choose; winner's-bid auction; behavioral mechanism design.

1 Introduction

We experimentally study mechanisms for the allocation of an indivisible good among two agents when ownership of the good is symmetric and compensation with an infinitely divisible good, e.g., money, is possible. Examples are a partnership dissolution (Cramton et al., 1987), a divorce settlement (McAfee, 1992), and the allocation of ball possession in National Football League overtime (Che and Hendershott, 2008). We assume complete information, i.e., agents know each other well—more on this key assumption below. We experimentally compare the performance of two prominent mechanisms: the winner's-bid auction (Cramton et al., 1987), a simultaneous move mechanism, and the popular divide-and-choose (McAfee, 1992), a sequential move mechanism. Over all measures, divide-and-choose is superior to winner's-bid auction. The

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performance of the winner's-bid auction is affected mainly by subject's bounded rationality and not by coordination failure. Divide-and-choose is affected by reciprocity issues and not by a lack of subject's sequential rationality. Contrary to theoretical predictions, divide-and-choose gives no advantage to the first-mover.

Our study will likely impact the practice of fair division. In particular, our results inform smartphone and computer applications that are currently attempting to provide users with arbitration mechanisms to solve the type of allocation problems we consider in our study (e.g., Fair Outcomes Inc., 2007-2013; Splitwise Inc., 2014; and Spliddit, 2014). Some of these mechanisms theoretically deliver desirable outcomes. However, theory does not allow one to differentiate them from competing proposals. Our experimental study fills this need. We are able to document sharp differences in the performance, in a laboratory environment, of some of the most prominent mechanism available. Behavioral biases exhibited by subjects in our experiments, affect different mechanisms in different degrees. As a consequence, theoretically equivalent mechanisms, turn out to be significantly different in practice. Curiously, none of the services cited above offers our best performing mechanism.[1] Our results also open the possibility to design normatively compelling mechanisms that minimize the effect on their performance of the behavioral biases that we observe (Sec. 5).

We frame our experiments as the allocation of a social endowment of two indivisible goods, "items," among two agents, each agent receives exactly one item, and there is the possibility of monetary compensation. This is an equivalent formulation of the allocation of a single indivisible good with monetary compensation. We find our environment more appropriate for our experimental setting. Having two items allows us to avoid, to some extent, agents' non-monetary incentives to "win" items, which is documented in auction settings (e.g., Cooper and Fang, 2008; Roider and Schmitz, 2012) —notice that our results also inform the allocation of rooms and division of rent among two roommates who collectively lease an apartment (Abdulkadiroğlu et al., 2004). For simplicity of exposition in this introduction, we use the language of allocation of a single good.

Complete information is a relevant benchmark for situations like the dissolution of a long standing partnership or a marriage. When agents know each other well, their actions in the "game" induced by an allocation mechanism convey their intentions. When these intentions are revealed in a game, reciprocity issues systematically affect agents' behavior (see Charness and Rabin, 2002, among many others). More importantly, these issues can have a different effect in competing mechanisms (Andreoni et al., 2007).[2] We concentrate on the evaluation of these differential effects and implement a complete information environment in the laboratory. Our results confirm that they are rele-

[1] In Sec. 5 we discuss the relevance of our results for the mechanisms used by Fair Outcomes Inc. (2007-2013) and Spliddit (2014). Splitwise Inc. (2014) offers allocation of rent and rooms among roommates based on surveys of preferences over the verifiable features of rooms like size, number of windows, etc., not the actual preferences of the agents in the division problem.

[2] In a seller-buyers auction setting, as information structure becomes closer to complete information, the spite motive considerably affects the outcomes of the second-price auction, but not the first-price auction.

vant and have to be taken into consideration when designing mechanisms for common-ownership distributive situations in which one expects agents will know each other well.

We evaluate our mechanisms with two criteria. First is efficiency, i.e., an agent who values the object the most receives it. Second is equity. Here, we evaluate whether the allocation obtained can be sustained as the outcome of a market in which both agents have an equal share of the aggregate income. These allocations, which we refer to as equal-income market allocations, are arguably the most normatively compelling in our environment (Thomson, 2010; Varian, 1976). They not only are efficient, but also, in our environment, they coincide with the set of envy-free allocations, i.e., those at which no agent prefers the allotment of the other agent to her own. They can be easily described as follows. An agent who values the object the most receives it and transfers the other agent an amount between half the low-value agent's value and half of the high-value agent's value. Thus, the set is isomorphic to an interval. Between two allocations in this interval the low-value agent prefers the allocation on the right and the high-value agent prefers the allocation on the left (Sec. 2).

We evaluate the performance of two of the most prominent mechanisms that theoretically obtain equal-income market outcomes among strategic rational agents. Our first mechanism, the winner's-bid auction, operates as follows: both agents simultaneously bid for the object; then, an agent with the highest bid receives the object and pays her bid to the other agent. The set of Nash equilibria of the game induced by this mechanism for some given valuation structure is the set of equal-income market allocations with respect to the true preferences (Sec. 2.2). Our second mechanism, divide-and-choose, operates as follows: a randomly selected first-mover, which we refer to as "divider," proposes a transfer from the agent who receives the object to the other agent; then the second-mover, which we refer to as "chooser," decides whether to get the object and make the proposed transfer or to give up the object and get the transfer. The outcome in sub-game perfect equilibria of the game induced by this mechanism is the divider's preferred equal-income market outcome for the true values (Sec. 2.2).

Both mechanisms we evaluate are intended to provide a form of *end-state* justice, for their equilibrium outcomes are equal-income market allocations. One can argue that divide-and-choose lacks *procedural justice*, however (Moulin, 2006). After divider and chooser are selected, the mechanism not only loses symmetry, but also gives the divider a considerable advantage. Thus, theory provides a clear benchmark for the evaluation of these mechanisms: (i) the winner's-bid auction should provide an equal-income market allocation, free of any bias predetermined by the mechanism designer; and (ii) divide-and-choose should provide an equal-income market allocation that is biased towards the divider. Our study is the first to evaluate the extent to which this normative ranking based on equilibrium predictions is realized in an experimental environment.

Our first result is that divide-and-choose is superior to winner's-bid auction over all measures. Divide-and-choose obtains 81% equal-income market allocations and 85% efficient allocations. The more procedurally fair winner's-bid auction obtains 41% equal-income market allocations and 73% efficient allocations. The differences are statistically

significant. Our second result is that the winner's-bid auction is affected by subjects underbidding and not by coordination failure. Symmetry turns out to be a costly feature for this mechanism. Among boundedly rational players, as in our experiments, it induces a distortion caused by the simultaneity of play. Our data suggest that this distortion slowly improves over time, but does not improve to the level of divide-and-choose. This result points in a precise direction for the improvement of the winner's-bid auction (Sec. 5). Our third result is that divide-and-choose is affected mainly by reciprocity issues. Even though divide-and-choose performs better than the winner's-bid auction, it obtains inefficient allocations with positive probability. Essentially, in the sub-game perfect equilibrium of the divide-and-choose game, the chooser is nearly indifferent among the bundles selected by the divider. Thus, when the divider selects a proposal that is close to the sub-game perfect one, the chooser may choose the inefficient allocation and get almost the same payoff that she would obtain with her best response. This "rejection strategy" induces a considerable loss for the divider and is responsible for the majority of inefficient outcomes. This suggests that the mechanism may be improved by returning some symmetry without losing the sequentiality of play (Sec. 5). Our fourth result is that the divide-and-choose mechanism, contrary to theoretical predictions, exhibits no first-mover advantage. Indeed, if at all, there is a second-mover advantage. Finally, our fifth result compares payoffs for different roles in our mechanisms. First, the efficiency gains achieved by the divide-and-choose mechanism over the winner's-bid auction are realized mainly for low-value and second-mover subjects. Second, there is no significant loss for high-value first-mover subjects in the divide-and-choose mechanism compared to the winner's-bid auction. This implies that "behind the veil of ignorance," the divide-and-choose mechanism dominates the winner's-bid auction.

There is relatively little experimental work in the area of common-ownership problems under complete information. Guth et al. (1982) study the outcomes of the divide-and-choose mechanism for the allocation of a set of indivisible "chips" that have different value for divider and chooser.[3] Their results are qualitatively consistent with ours; they observe responders' willingness to reject proposals. Our experimental design differs in two dimensions. First, in our experiments subjects can propose arbitrary transfers and thus divide-and-choose results can be compared with those of the winner's-bid auction. This comparison is a central contribution of our paper. Second, in our experiments for the divide-and-choose mechanism, the role of the divider is randomly assigned among all subjects as opposed to being assigned among high-value agents only as in Guth et al. (1982). Thus, our experiment can answer the question whether the second-movers in divide-and-choose are more prone to reject inequality increasing proposals that have low rejection cost (only available to low-value second-movers) than equality generating proposals that have low rejection cost (only available to high-value second-movers). Finally, since in our experiment both high-value and low-value agents get to be first and second movers, we are able to evaluate the first-mover bias of the mechanism. In Guth et al. (1982) it is not clear whether differences in earnings should be attributed

[3] Guth et al. (1982) refer to the divide-and-choose games as "complicated ultimatum games."

to divider bias or valuation structure. Herreiner and Puppe (2009) investigate whether equal-income market allocations result from an "infinitely many proposals" bargaining mechanism under a time limit. They document that this mechanism achieves few equal-income market allocations. However, it is difficult to interpret these results, for it is not clear that Nash equilibrium outcomes of this bargaining procedure are equal-income market allocations. Schneider and Krämer (2004) and Dupuis-Roy and Gosselin (2009, 2011) experimentally evaluate the performance of the divide-and-choose mechanism. However, in their environment, monetary compensation is not possible. Thus, their experiments are silent about the performance of this mechanism in the distributive situations that motivate our study. Finally, in an incomplete information setting Kittsteiner et al. (2012) compared the performance of the winner's-bid auction and the divide-and-choose mechanism. The result there is that divide-and-choose weakly dominates the auction in terms of percentage of efficient allocations achieved in laboratory experiments. However, the difference is not large and only weakly statistically significant. Our results show that when players know each other well, the difference in performance is substantial and significant.

The remainder of the paper is organized as follows. Section 2 introduces the model and mechanisms we study. Section 3 presents our experimental design. Section 4 presents our results. Section 5 discusses our results and concludes.

2 Model

2.1 environment

We consider two agents, $\{1,2\}$, who collectively own two indivisible goods, $\{A,B\}$, which we refer to as items. Each agent receives one item and either transfers or receives an amount of money to or from the other agent. The value that agent $i \in \{1,2\}$ assigns to item $\alpha \in \{A,B\}$ is v_i^α. We normalize the value of item A to be 100 for each agent. Agent i's utility of receiving item α and transferring an amount $x_i \in \mathbb{R}$ to the other agent is $u_i(x,\alpha) = v_i^\alpha - x_i$ (when $x_i < 0$, agent i receives $|x_i|$ from the other agent). We assume budget balance, so $x_1 + x_2 = 0$.

It is convenient for our purpose to keep track of each agent's **net value of item** B, i.e., the amount of money x_i^B such that $v_i^B - x_i^B = v_i^A + x_i^B$ (agent i is indifferent between paying x_i^B for B or receiving A and being paid x_i^B). Since we normalize $v_i^A = 100$, then $x_i^B = (v_i^B - 100)/2$. Clearly, having the higher value of item B is equivalent to having the higher net value of item B. Let $\underline{x}^B = \min\{x_1^B, x_2^B\}$ and $\overline{x}^B = \max\{x_1^B, x_2^B\}$. We refer to an agent with the maximal value of item B as a **high-value agent** and to an agent with the minimal value of item B as a **low-value agent**.

An allocation is **efficient** if there is no other allocation that both agents weakly prefer and at least one agent strictly prefers. These allocations are those at which a high-value agent receives item B. One can graphically represent them by means of the transfer from

the agent who receives item B, i.e., a high-value agent, to the other agent (Figure 1). We refer to the difference $\max\{v_1^B, v_2^B\} - \min\{v_1^B, v_2^B\}$ as the **efficiency surplus**.

We are interested in the set of **equal-income market** allocations. That is, there are prices p_A and p_B for the items; each agent has an income $\frac{p_A+p_B}{2}$ and chooses between buying A at p_A or buying B at p_B; and market clears. These allocations were proposed by Foley (1967) in order to achieve no-envy, i.e., that no agent prefers the allotment of the other agent to her own. In our environment equal-income market allocations are efficient and coincide with the set of envy-free allocations (Svensson, 1983). One can easily characterize them by using the no envy conditions (1 does not envy 2 and vice versa) as the efficient allocations at which the agent who receives item B transfers an amount to the other agent in the interval $[\underline{x}^B, \overline{x}_B]$ (Figure 1). We follow Tadenuma and Thomson (1995b) and refer to the length of the set of equal-income market transfers, i.e., $\overline{x}_B - \underline{x}^B$, as the **equity surplus**. The equity surplus is half of the efficiency surplus.

2.2 Mechanisms implementing equal-income market allocations

We are interested in experimentally testing mechanisms to obtain equal-income market allocations. No mechanism does so in dominant strategies (Tadenuma and Thomson, 1995a). However, mechanisms that do so with respect to other non-cooperative predictions exist. The following, which have been focal in the literature on partnership dissolution, achieve this (Cramton et al., 1987; McAfee, 1992).[4]

Winner's-bid auction*: Both agents simultaneousy bid for item B (bids can be negative). An agent with a highest bid receives item B and transfers her bid to the other agent, who receives item A and the transfer. In our experimental setting we break ties in favor of an agent with true higher value for item B.*

The set of pure-strategy Nash equilibrium outcomes of the game induced by our winner's-bid auction, i.e., the one in which we break ties in favor of the true high-value agent, is exactly the set of market allocations (Figure 1). In equilibrium both agents report equal bids in the interval $[\underline{x}^B, \overline{x}^B]$.[5] Intuitively, agents will not coordinate on an inefficient allocation because in that case there is always an agent who prefers the consumption of the other agent. By bidding just above or below the other agent, an agent

[4] It is also relevant to consider the possibility that a mechanism whose non-cooperative equilibrium outcomes are not market allocations may produce them because of the behavioral deviations that agents usually exhibit in the laboratory. With this purpose we also run experiments with the popular ultimatum bargaining, which we do not report in this paper. It turns out that both divide-and-choose and winner's-bid auction perform significantly better than ultimatum bargaining in terms of the percentage of equal-income market allocations obtained and ultimatum bargaining is significantly biased towards the first mover.

[5] This characterization applies also to an environment with integer bids as in our experiment. Depending on the way one breaks ties when bids are equal, the bidding game induced by the winner's-bid auction may have no pure-strategy Nash equilibria when bids are not restricted to integer amounts. A sensible prediction for these games, that intuitively bypasses the role of the tie-breaker, is limit equilibria (Radner, 1980). Independently of the tie breaker, if preferences are quasi-linear, the set of limit equilibrium outcomes of the winner's-bid auction is again the set of equal-income market allocations with respect to true preferences (Velez, 2015).

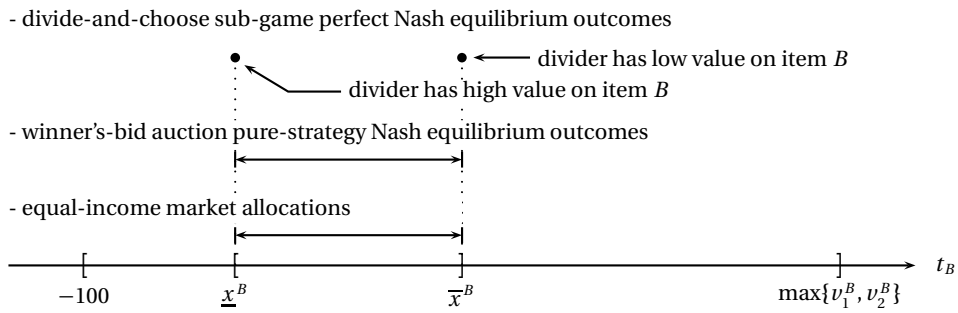

Figure 1: Efficient allocations, market allocations, and non-cooperative equilibrium outcomes from popular mechanisms. At each efficient allocation a high-value agent receives item B. Thus, these allocations can be graphically represented by means of t_B, the transfer from the agent who receives B to the other agent.

can essentially guarantee to obtain the other agent's allotment. A high-value agent will never bid more than $\overline{x}^B$ and receive B. Otherwise, she could just bid $\overline{x}^B$ and either pay less for B or let the other agent get B and transfer her no less than $\overline{x}^B$. A low-value agent will never receive A and a transfer to the left of $\underline{x}^B$. Otherwise, she could just bid $\underline{x}^B$, get B, and transfer $\underline{x}^B$ to the other agent.[6] Consistent with this characterization of Nash equilibria for this mechanism, we refer to a bid that is less than $\underline{x}_B$ as a **below-Nash bid**; to a bid in the interval $[\underline{x}_B, \overline{x}_B]$ as a **Nash bid**; and to a bid greater than $\overline{x}_B$ as an **above-Nash bid**.

Divide-and-choose. *A randomly selected agent, the divider, names a transfer $t_B \in \mathbb{R}$. The other agent, the chooser, selects either to get item B and transfer t_B to the divider, or to get item A and receive t_B from the divider. The divider receives the residual allotment.*

A sensible prediction for the sequential game induced by the divide-and-choose mechanism for utility maximizing agents is sub-game perfect equilibria. Standard arguments show that if a high-value agent is the divider, in the equilibrium path, she proposes $\underline{x}^B$ and the chooser selects to get item A and receive $\underline{x}^B$ from the divider. Symmetrically, if the divider is the low-value agent, in the equilibrium path, she proposes $\overline{x}^B$ and the chooser selects to get item B and transfer $\overline{x}^B$ to the divider (Figure 1).[7]

Table 1 summarizes the two mechanisms that we experimentally study. The winner's-bid auction is symmetric, i.e., in its induced game each agent has the same action space. It achieves in non-cooperative equilibria equal-income market allocations, which are efficient. The equilibria of the winner's-bid auction game requires agents coordination. Since it is a simultaneous move game, no agent ever replies to the action of another

[6] See our discussion of Result 2 in Sec. 4 for a description of mixed-strategy equilibria in the winner's-bid auction.

[7] With integer bids there are two additional equilibrium outcomes when $\overline{x}^B > \underline{x}^B$. A high-value proposer may propose $\underline{x}^B + 1$ and the low-value chooser selects to receive A. A low-value proposer may propose $\overline{x}^B - 1$ and the high-value chooser selects to receive B.

Mechanism	Efficient	Equal-income market allocations	Symmetric	Coordination required	Reciprocity issues
Winner's-bid auction	yes	yes	yes	yes	no
Divide-and-choose	yes	yes	no	no	yes

Table 1: Properties of mechanisms we experimentally evaluate. The winner's-bid auction is the only mechanism to satisfy three normative theoretical properties. Because of its simultaneity, it is also the only mechanism to require coordination.

player and is affected by the perceived intention of that action. Thus, one can expect that reciprocity is not an important source of deviations from Nash behavior. The divide-and-choose mechanism achieves in sub-game perfect Nash equilibria equal-income market allocations, which are efficient. After the divider is determined, the induced game is not symmetric. Since the game is sequential, it requires no coordination of players. Moreover, the chooser's action may be affected by the perception of the divider's intentions.

3 Experimental Design and Procedures

We implement the environment and mechanisms described in Sec. 2. Subjects, randomly selected each round into groups of two, chose how to allocate two indivisible items with possible transfer payments.[8] In all possible allocations, each subject received *exactly* one item. Each period, subjects received points for acquiring an item, equal to their value of that item. Thus, the values for each item are induced values.

The experiment consisted of 50 periods, with 5 different valuations occurring sequentially over 10 consecutive periods each. For any period, for each grouping of subjects, one subject was randomly assigned the high value on item B, the other was assigned the low value on item B. Thus a subject's value on item B could change for any period, but the valuation structure (the high and low values for item B) remained the same for the 10 periods. Subjects always valued item A at 100. In order of appearance, the pairing of subject values for item B were $(40,80)$, $(120,160)$, $(40,120)$, $(160,160)$, and $(0,40)$.[9] Table 2 provides an example of a valuation structure, the third used in the experiments. Here, both subjects have the same value for item A, but their values for item B are different: player 1 has the high value for item B (120 points), and player 2 has the low value for item B (40 points).

[8] We chose to have subjects bid over two items to match the generalized theoretical environment more closely and reduce the possibility that of subjects are motivated by the non-monetary desire to "win" an item (e.g., Cooper and Fang, 2008; Roider and Schmitz, 2012).

[9] The ordering of the valuations was chosen at random, but remained constant across both mechanisms. The valuations were specifically chosen to allow for two possibilities where both players value item A more than B $(40,80)$ and $(0,40)$, two possibilities where both players value item B more than A $(120,160)$ and $(160,160)$, and one where one player one player values B more than A and one values A more than B $(40,120)$. Additionally the fourth valuation $(160,160)$ was chosen to allow an environment where there is one unique equilibria over all three mechanisms, and coordination should not be an issue.

Player	Value of Item A	Value of item B
Player 1	100	120
Player 2	100	40

Table 2: A sample valuation. In this valuation, one subject valued item A at 100 and item B at 120. As in our theoretical environment, the other subject with whom she is paired had the same value for item A, but valued item B at 80. Each player had an equal chance of receiving the high value on item B for any period. Values were common knowledge to both players. This specific valuation structure ("valuation 3") was used for periods 21–30.

To avoid incentives associated with repeated play, subjects were randomly re-assigned to each other at the beginning of each period. Subjects were instructed that they were to be randomly rematched each period, and no identifying information (e.g., subject number) was disclosed to a subject about her match in any round. Each period began with each subject seeing the valuation structure for the period.

3.1 Winner's-bid auction

In the winner's-bid auction session, after observing the valuation structure for the period, subjects simultaneously submitted their bids for item B. The subject with the higher bid received item B, and the subject with the lower bid received item A. In this way, the winner's-bid auction is a first-price auction *to acquire item B over item A*. In the case of equal bids, the subject with the higher value of item B received item B.[10] The subject who received item B, then paid the subject who received item A the full amount of her bid.[11]

After submitting a bid, each subject was allowed to submit a possible value for the other player's bid. The experimental software then displayed the outcome (i.e., who gets which item, what amount is transferred for each player, each players' earnings for that period) that would occur with those two bids as well as a table that showed all possibilities that could happen if the other player's bid were below, equal to, or above the subject's bid (see Figure 2). After a subject viewed these possibilities, she could chose to confirm her bid, or chose an alternate bid. If she chose an alternate bid, the process repeated. The process ended when a subject confirmed her bid.

After both subjects submitted their bids, they were asked to guess what they believed

[10] In the case of the fourth valuation where both subjects value item B at 160, one subject was randomly selected to win ties, this was known before bids were submitted (i.e., ex-ante). The tie-breaking rules were chosen to allow for easier analysis of equilibrium.

[11] To eliminate the possibility of grossly negative earnings, bids were restricted so that no bid could be lower than the opposite of twice the value of item A (-200, always) and no bid could be higher the twice the maximum value of item B (varies by valuation, i.e, 160, 320, 240, 320, and 80 for each valuation, respectively). Of the 1200 observed bids in the winner's-bid auction, 11 were at the bid minimum and 0 were at the bid maximum.

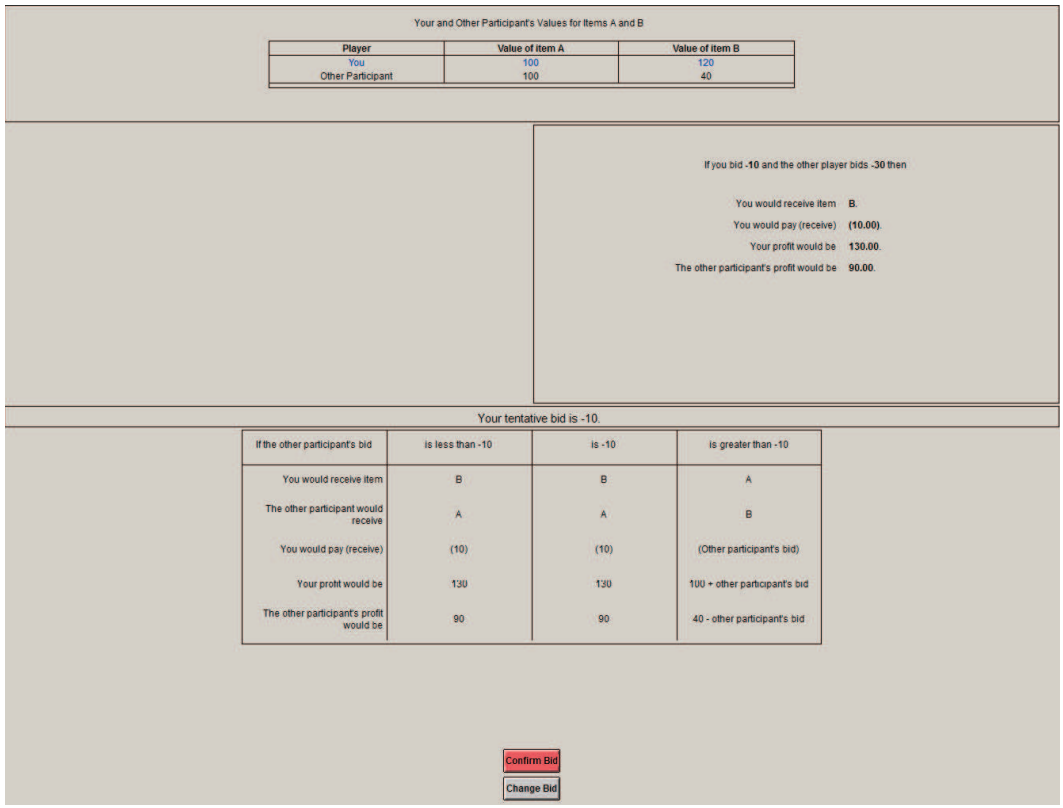

Figure 2: Confirmation screen for subjects. Subjects have the option to review their bid and the possible outcomes associated with it after submitting their initial bid.

was the other subject's bid.[12] If they guessed correctly they received a small bonus of 5 points. The value of this bonus was deliberately chosen to be small, so that subjects did not alter their bidding strategy to receive the bonus. After both subjects submitted their guesses they saw the outcome of their bidding. They learned what the other player bid, which items they both received, the transfer payment between them, their earnings, and their partners' points earned. Subjects learned if they received a bonus for guessing the other player's bid correctly, but did not learn if the other player had received the bonus for guessing their bid correctly. After this information was disclosed, a new period began. This process continued for 50 periods.

[12] Subject guesses appear to be unrelated any other part of their behavior. The data are not meaningful and not presented here. Subjects are clearly not best responding to their guesses; this result is consistent with Costa-Gomes and Weizsäcker (2008) who study this issue in detail.

3.2 Divide-and-choose

In the divide-and-choose session, at the beginning of each period, one subject was randomly selected to be the divider. That subject chose which item should receive a transfer and the amount of that transfer. Transfer payments were limited so that no subject received negative earnings for each period (so, for example in Table 2, the divider could propose whomever receives item A could get a transfer up to 80, the minimum value of B, or whomever receives item B could get a transfer up to 100, the minimum value of A).

After one subject made a proposal, she saw a table of possible outcomes similar to Figure 2 that displayed the two possible outcomes (i.e., who gets which item, what amount is transferred for each player, each players earnings for that period) when the other subject choose to take item A or item B. The subject had the opportunity to confirm her decision or make another one. If she chose to try another proposal, the process repeated until she confirmed a proposal. Once a proposal was confirmed, the other subject viewed the proposal. The display showed her two outcomes—both her own and the other subject's total earnings if she chose to take item A or item B. The chooser then had the opportunity to choose either item. After that decision was made, both subjects viewed the outcome of the period. They saw what the divider proposed, which item the chooser selected, the items and transfers received by each subject (if applicable) and the points earned by each subject for the period. After this information was disclosed, a new period began. This process continued for 50 periods.

3.3 Experimental Procedures

All experiments were held at the Economic Research Laboratory (ERL) in the Economics Department at Texas A&M University. Subjects were recruited using ORSEE software (Greiner, 2004) and made their decisions on software programmed in the z-tree language (Fischbacher, 2007). Subjects sat at computer terminals with dividers to make sure their anonymity was preserved. Subjects were 52 Texas A&M undergraduates from a variety of majors; twenty-four subjects took part in the winner's-bid auction session on October 22, 2010; twenty-eight subjects took part in the divide-and-choose session on April 12, 2012. Experiments lasted about three hours. Subject point values were totaled and converted to cash at the rate of 400 points=$1.00, rounded up to the nearest dollar. Subject earnings ranged from $16.20 to $31.70 ($27.65 average earnings), $14.20 to $33.80 ($26.40 average), for the divide-and-choose and winner's-bid auction sessions, respectively.[13]

[13] Once the 50 periods were complete, subjects completed a survey about their opinions of the other players with whom they had been matched, the mechanism used, and their general feelings of what fairness means. They were also given the opportunity to provide a tip up to $5, which was be doubled and divided among all other subjects. The final survey question told them they were to play one more period at values 10 times greater than before and they voted on the mechanism to be used by all subjects for that round. Subjects in the divide-and-choose session voted between their current mechanism and the winner's-bid auction; subjects in the winner's-bid auction session voted between the winner's-bid auction and the ultimatum bargaining. Since only one mechanism was used per experimental session a brief description was provided of the other mechanism. After all subjects completed the vote, the winning mechanism was

Mechanism:	winner's-bid auction	divide-and-choose
efficient outcomes (percent)	437 (0.728)	594 (0.849)
equal-income market outcomes (percent)	283 (0.472)	567 (0.810)
average profit (in points) (standard error)	99.917 (1.111)	102.40 (1.128)
percent of maximum possible profit (standard error)	0.935 (0.005)	0.962 (0.001)

Table 3: Summary of outcomes for each subject pair by divide-and-choose and winner's-bid auction mechanisms. Across all measures efficient outcomes, equal-income market outcomes, average profit and percent of profit realized, the divide-and-choose outperforms the winner's-bid auction.

4 Results

Result 1. *Over all measures, the divide-and-choose mechanism outperforms the winner's-bid auction.*

Over all measures, i.e., efficient outcomes achieved, equal-income market outcomes achieved, average profit per subject pair, and percent of profit realized per subject pair, divide-and-choose mechanism outperforms the winner's-bid auction (Table 3). Figures 3(a–c) show these results hold over all valuations. (Recall that each mechanism was tested for 50 periods, divided into five 10-period segments with a different type of valuation structure.) For every valuation, subjects in divide-and-choose achieve a greater percentage of efficient outcomes realized, a greater percentage of equal-income market outcomes realized, and higher average payoffs realized.

We use panel data regressions to determine statistical significance. Unless specified otherwise, we use crossed random effects for each subject pair (i.e., a separate random effect for each subject), and one dummy variable for each period in our data (i.e., fixed effects), to control for idiosyncratic properties of certain subjects or periods, respectively. Formally, for binary outcomes we will use the regression model

$$\text{logit}\left(\Pr\left(y_{ijk}=1\,\middle|\,X_{ijk},\zeta_{1j},\zeta_{2k}\right)\right)=\beta X_{ijk}+\gamma_i+\zeta_{1j}+\zeta_{2k}, \tag{1}$$

where y_{ijk} represents the outcome of the pairing of subject j and subject k in period i. The random coefficients $\zeta_{1j}\sim N(0,\psi_1)$, $\zeta_{2k}\sim N(0,\psi_2)$ are determined for subject j and

implemented for the final period. The results of this last period are not included in the data analysis. As carefully explained to the subjects a majority vote was required to change to the new mechanism, meaning the status-quo won all ties. The status-quo won in both sessions. After the high-stakes period subjects again completed more surveys, a demographic survey and a five-factor personality assessment (from John et al., 2008). Survey results are not reported in this paper. We did not find any interesting interactions between survey responses and mechanism type or subject behavior. They are available from the authors upon request.

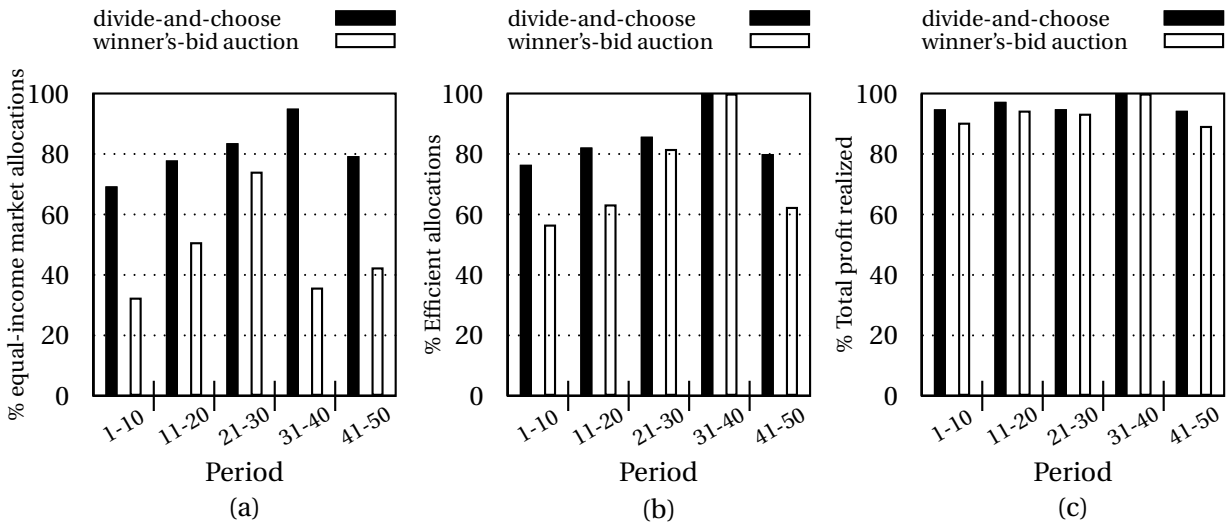

Figure 3: Percentage of equal-income market allocations obtained, efficient outcomes obtained, and total profit realized under the divide-and-chooseand winner's-bid auction by valuation type. In each session, over 50 periods, five valuations occurred sequentially for ten periods each. In order of appearance, the pairing of subject values for item B were $(40,80)$, $(120,160)$, $(40,120)$, $(160,160)$, and $(0,40)$. **(a, left)** For all valuations, the percentage of equal-income market allocations realized was highest for the divide-and-choose mechanism over all valuations. **(b, middle)** For each valuation, the divide-and-choose achieved the highest number of efficient outcomes. **(c, right)** For all valuations, the divide-and-choose mechanism realized the highest percentage of total profit.

subject k by their valuations. Subject j has the higher value on item B and k has the lower value on item B;[14] γ is a vector of fixed effects for each period; X_{ijk} contains other data of interest, such as mechanism type, and β is a vector of coefficients.

A similar model is used for non-binary outcomes with the residual error term $\epsilon_{ijk} \sim N(0,\theta)$.

$$y_{ijk} = \beta X_{ijk} + \gamma_i + \zeta_{1j} + \zeta_{2k} + \epsilon_{ijk}. \tag{2}$$

Table 4 shows the results of four regressions using the models described in equations 1 and 2. The variable of interest is the divide-and-choose term, a dummy variable that indicates if the mechanism used is divide-and-choose; it indicates the difference between the divide-and-choose mechanism and the winner's-bid auction. The regressions confirm the results found in Table 3. In the first two regressions, (1) and (2), the average marginal effect of the divide-and-choose term suggests that mechanism achieves efficient outcomes with 0.16 greater probability and equal-income market outcomes with 0.35 greater probability than the winner's-bid auction. The later two regressions, (3) and (4) suggest the divide-and-choose mechanism is associated with higher earnings as well. All results are significant at the 1% level.

[14] In the case of valuation 4, j is favored by the tiebreaker in the winner's-bid auction or the divider in the divide-and-choose, k is the remaining subject.

Dependent variable:	Efficient outcome[a] (1)	Market outcome[a] (2)	Average earnings of pair (3)	Percent of total possible earnings (4)
Divide-and-choose	0.164***	0.349***	2.687***	0.029***
	(0.046)	(0.049)	(0.761)	(0.008)
Regression Type?	logistic	logistic	linear	linear
Fixed effects?[b]	each period	each period	each period	each period
First random effects term?	subject with high value	subject with high value	subject with high value	subject with high value
Second random effects term?[c]	subject with low value	subject with low value	subject with low value	subject with low value
observations	1040[d]	1300	1300	1300
log likelihood	-526.539	−673.199	−4729.761	1212.373

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.
a. Average marginal effects reported.
b. Using fixed terms for each valuation type (five dummy variables for valuations 1–5), and valuation within period (ten dummy variables for periods 1–10) does not significantly alter results.
c. Sorting random effects by subject favored by mechanism (high value or tie-break winner in auction, divider in divide-and-choose) does not significantly alter regression results.
d. This regression omits 260 observations from valuation 4 where all outcomes are efficient.

Table 4: Regressions of mechanism outcomes on type of mechanism, controlling for period fixed effects and subject random effects.

Result 2. *The failure to achieve equal-income market and efficient outcomes in the winner's-bid auction is primarily due to subject underbidding relative to Nash behavior, rather than a failure to coordinate over multiple Nash equilibria. The underbidding is especially pronounced among low-value subjects.*

It is not obvious why subjects in the winner's-bid auction achieve equal-income market outcomes less than half of the time and efficiency only 72% of the time (66% excluding valuation 4 for which all allocations are efficient). Two explanations come to mind. First, subjects may have difficulty deducing how to play equilibrium strategies. Second, the multiplicity of equilibria, which can be quantified by means of the equity surplus (i.e., the length of the equilibrium set $[\underline{x}_B, \overline{x}_B]$), leads to a coordination failure when low-value and high-value subjects keep trying to enforce different surplus divisions.

There is little support for the coordination failure explanation. Only 36% of outcomes were equal-income market outcomes in valuation 4 (i.e., (160,160)) (Figure 3 (a)). There are no coordination issues in this valuation structure, for it has zero equity surplus and

Efficient outcomes

		HV		
		Below	Nash	Above
LV	Below	6%	25%	3%
	Nash	0%	25%	6%
	Above	0%	0%	1%

Inefficient outcomes

		HV		
		Below	Nash	Above
LV	Below	4%	0%	0%
	Nash	14%	8%	0%
	Above	2%	5%	1%

Table 5: Bid distribution. The tables show the percentage of outcomes that are either efficient or inefficient, discriminated by the bid type of the low-value (LV) and high-value (HV) subjects. Bid types are below Nash, i.e., less than $\underline{x}_B$; Nash, i.e., in the interval $[\underline{x}_B, \overline{x}_B]$; and above Nash, i.e., greater than $\overline{x}_B$. Excludes valuation 4 in which both agents have the same values.

thus a unique Nash equilibrium payoff. On average, for all other valuations, 50% of the outcomes were equal-income market outcomes. A modified version of the regression analysis we report in Table 6, in which we drop the high-value/low-value variable and include valuation 4 (not shown), confirms that Nash bids are *least* likely in valuation 4, where the equity surplus is minimal. Nash bids are *most* likely in valuation 3, where the equity surplus is maximal (Table 6).

Subjects had great difficulty in playing equilibrium strategies. Nearly half of all bids (49.8%) were non-Nash (i.e., outside the range $[\underline{x}^B, \overline{x}^B]$). Excluding valuation 4, for which each allocations is efficient, non-Nash bids caused 78% of all inefficient outcomes (Table 5) and 85% of all outcomes that failed to be equal-income market allocations. In 52% of all inefficient outcomes and in 48% of all outcomes that failed to be equal-income market allocations, the high-value subject bid below Nash and lost to a low-value subject who was not overbidding, i.e., whose bid was at most $\overline{x}_B$ (Table 5). Non-Nash bids were more common among the low-value subjects (48%) than the high-value subjects (37%) (Table 5)—all of our statistics discriminated by low-value and high-value subject exclude valuation 4, for which both agents have equal values. For valuation 4, below-Nash bids were 94% of all non-Nash bids. For other valuations, below-Nash bids were 75% of all non-Nash bids, with low-value subjects responsible for 60% of all below-Nash bids (Table 5). Table 6 provides a multinomial logistic regression on bid types. The average marginal effects estimates on the high value of item B term suggest that being a high-value subject is associated with a 0.107 greater probability of making a Nash bid and a 0.124 lesser probability of making a below Nash bid. Both estimates are significantly different from 0 at the 1% level.

The winner's-bid structure is likely the reason why low-value agents are more prone to bid below Nash. If the high-value subject chooses a Nash bid, say b, there is no incentive for the low-value subject to bid over b and there is no penalty for bidding below b. The low-value subject's maximin bid is $\underline{x}_B$, with which she obtains at least her lowest equal-income market payoff. This maximin bid is a best response to any bid $b \geq \underline{x}_B$. If the low-value agent believes the high-value agent may bid below $\underline{x}_B$, her best response involves bidding below $\underline{x}_B$ as well. In case of losing the auction when her bid is ε units

to the left of $\underline{x}_B$, her loss, compared to her maximin payoff, is at most ε. If the low-value subject bids below Nash with some probability, the high-value subject has the incentive to lower her bid too. The incentive is not symmetric however. The high-value subject's maximin bid is $\overline{x}_B$, with which she obtains at least her lowest equal-income market payoff. If the high-value subject bids below Nash and loses the auction, her worst case scenario loss, compared to her maximin payoff, is at least the equity surplus (see Figure 6). If high-value subjects respond to these incentives, they will be less likely to bid below Nash for valuation structures with higher equity surplus. Regression analysis confirms this is so in our experiments (Table 6). This also explains why the auction is more efficient for valuation structures with higher equity surplus (Figure 3). The cost of biding below Nash and losing the auction for a high-value subject increases with the efficiency surplus. This discourages high-value subjects to bid below Nash while low-value subjects retain their incentive to hover around their lowest Nash bid. The consequence is that the percentage of efficient allocations and the percentage of equal-income market outcomes increases as the equity surplus increases.

Below-Nash bids are a persistent phenomenon among low-value and high-value subjects. Figure 4 provides a breakdown of bid types averaged over the period within valuation. Bids above Nash levels appear to be decreasing as subjects gain more experience within a valuation. If anything, subjects appear to be increasing their number of Nash bids. The regression in Table 6 is supportive of these general trends: with each successive period within a valuation, subjects increase their likelihood of making a below Nash bid by 1.1 percentage points (p-value<0.05). They increase their probability of making a Nash bid by 1.4 percentage points (p-value<0.01). They decrease their probability of making an above Nash bid by 2.5 percentage points (p-value<0.01).

The persistence of below-Nash bids is a tell-tale of bounded rationality. Even if one considers mixed strategies, no Nash equilibrium can sustain bids below $\underline{x}_B - 1$ for the high-value subject.[15] In order to sustain bids below $\underline{x}^B - 1$, high-value subjects should not anticipate the incentives that are induced by their behavior. Table 5 reveals the extent to which below-Nash bids are not a best response for high-value subjects to the distribution of play in our experiment. Of the high-value subjects who bid below Nash,

[15] No above-Nash bid can be sustained in equilibrium, for $\overline{x}^B$ strictly dominates, for both high-value and low-value subjects, a greater bid that wins with positive probability. If $\overline{x}_B - \underline{x}_B > 0$, the high-value subject will never choose a below-Nash bid that loses with certainty (her expected payoff would be below her maximin payoff). Consider now the the winner's-bid auction in which bid ties are decided at random, assigning item B to an agent, say i, with probability γ whenever there is a tie. In a mixed-strategy Nash equilibrium of this mechanism and in which both agents bid below Nash with positive probability, the left extreme of the support of each subject's strategy has to be the same (recall that in our experiments bids are bounded below). This is so because no agent will choose a below-Nash bid that loses with certainty and also loses with positive probability to some other below-Nash bid (the subject would be better off by bidding the lowest bid that wins with positive probability, which is necessarily weakly to the left of $\underline{x}^B$). Let b be the lowest bid of both agents in some mixed-strategy Nash equilibrium of the mechanism that breaks ties with probability γ for an agent. Then, $b \geq \underline{x}^B - 1$, for otherwise the agent who wins ties with probability at most 1/2 would gain by bidding $b+1$ instead of b. Thus, independently of the tie-breaker, a high-value agent would never bid below $\underline{x}^B - 1$ in a mixed-strategy equilibrium.

Bid type:	below Nash bid[a]	Nash bid[a]	above Nash bid[a]
period within valuation	0.011** (0.005)	0.014*** (0.005)	-0.025*** (0.004)
has high value on item B	-0.124*** (0.028)	0.107*** (0.029)	0.018 (0.018)
valuation 1[b] (40-80)	0.120*** (0.043)	-0.187*** (0.046)	0.074** (0.033)
valuation 2 (120-160)	0.228*** (0.046)	-0.120** (0.047)	-0.108*** (0.027)
valuation 3 (40-120)	-0.160*** (0.037)	0.257*** (0.044)	-0.097 (0.026)
Type of regression?	multinomial logistic		
Dummy variables?[b]	each valuation (shown above)		
First random effects term?	subject		
Second random effects term?	none		
observations[c]	304	554	102
log likelihood	-884.377		

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

a. Average marginal effects reported.
b. Valuation 5 dummy variable is omitted.
c. There are 960 total observations used in the regression.

Table 6: Regression of bid type for winner's-bid auction on valuation, period within valuation, and subject's value on item B, controlling for subject random effects. (Valuation 4, for which there is no well-defined high-value/low-value subjects, is excluded).

24% win the auction and 16% lose to a below Nash bid. This reflects that low-value subjects have lower cost of underbidding and end up doing it with higher probability. This is not enough to make bidding below Nash a rational choice for a high-value agent. Of the high-value subjects who bid below Nash, 53% lose to a Nash bid. The average Nash bid by the low-value subjects is closer to $\underline{x_B}$ than $\overline{x_B}$.[16] The result is that a high-value subject who underbids in our experiment would be better off, on average, by attempting to capture half of the equity surplus. Indeed, high-value subjects' average profit would increase by 3.5% if, ceteris paribus, their below-Nash bids were replaced by $(\overline{x_B}+\underline{x_B})/2$. Since high-value subjects are underbidding, low-value subject's best response to high-value subject's distribution of play involves underbidding. Low-value subjects that underbid in our experiment do it more aggressively than it is optimal, however. Of the low-value subjects who bid below Nash, 16% lose to a below-Nash bid and 11% win against a below-Nash bid; low-value subjects' average profit would increase by 0.15% if all below-

[16] On average, low-value players with Nash bids, attempt to obtain 38% of the equity surplus, i.e., bid on average $\underline{x_B}+0.38(\overline{x_B}-\underline{x_B})$.

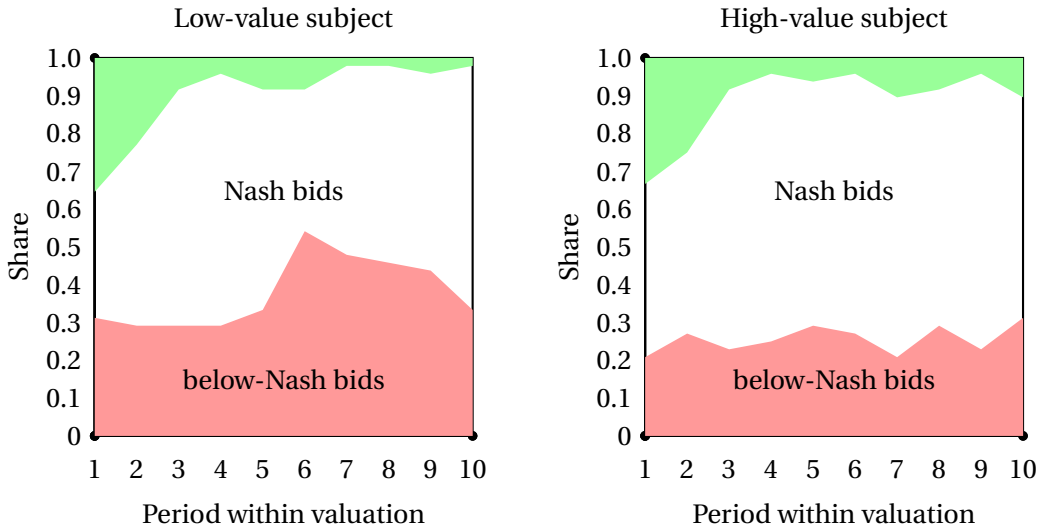

Figure 4: Share of bid types in the winner's-bid auction over period within valuation by subject value on item B. Valuation 4 excluded.

Nash bids were replaced by $\underline{x_B}$ and by 1.1% if all below-Nash bids were replaced by $\underline{x_B}-9$ (low-value subjects' average profit would decrease if below-Nash bids were replaced by a bid below $\underline{x_B}-9$).

It is worth noting that the prevalence of below Nash bids is consistent with a Quantal Response Equilibrium (QRE) model (McKelvey and Palfrey, 1995). QRE has been successful in describing subjects play distribution in a wide range of simultaneous move games (Goeree et al., 2005). It assumes that subjects noisily best respond with a distribution that is monotone with respect to the agent's utility. In our winner's-bid auction, this monotonicity implies that the low-value agent is more prone to underbid, for conditional on losing the auction, she has no penalty for lowering her bid. This is a plausible explanation that sustains the actual distributions of play. Since the main purpose of this paper is to compare the winner's-bid auction with the divide-and-choose mechanism, we do not pursue the fit of our data to the QRE hypothesis. We do so in the companion paper, Brown and Velez (2015), in which we test the comparative statics that QRE behavior predicts for winner's-bid auction and competing simultaneous-move mechanisms —more on this in Sec. 5.

Result 3. *The failure to achieve equal-income market and efficient outcomes in the divide-and-choose is primarily due to the second-mover choosing against self-interest and efficiency, rather than the divider's failure to make equal-income market divisions. Nearly all of these suboptimal choices occur when the chooser receives less than one-third of the equity surplus. Consistent with inequality aversion, the chooser is far more likely to choose against self-interest and efficiency when holding the low value on item B.*

With the divide-and-choose mechanism, there were 133 (of 700, see Table 3) outcomes that were not equal-income market outcomes. Of these, 45 involved the divider

proposing a non-equal-income market division, meaning that independently of the choice of the second-mover, the outcome would not be an equal-income market outcome. In the remaining 88 cases, the divider proposed a division that would have been an equal-income market outcome provided the chooser selects the option in line with her self-interest.[17] Instead, the chooser chose the least preferred bundle (i.e., item and transfer payment). We refer to these situations in which the chooser chose against self-interest as "rejections." Interestingly, while the tendency of dividers to propose non-equal-income market divisions abates with experience, the tendency of choosers to reject market proposals persists. Only 7 of the 45 (15.6%) non-equal-income market divisions occur after more than 5 periods of experience within a valuation, but 45 of the 88 (51.1%) of the choices against self-interest do. Regression results, using valuation fixed effects and the period within valuation variable (not shown) suggest non-equal-income market proposals and choices against self interest reduce by 34% ($p < 0.01$) and 4% ($p \approx 0.388$), respectively, each successive period within a valuation.

The choices by the second mover against self-interest are hardly random (Fig. 5). They occur most frequently when the divider's proposal is close to the sub-game perfect prediction. Moreover, among the proposals that are close to sub-game perfect proposals, those made by the high-value subject are rejected with higher probability than those made by the low-value subject. To more carefully analyze this behavior, we classify each equal-income market division by whether the chooser receives less than a third of the equity surplus (divider-favored divisions), between one-third and two-thirds of the equity surplus (even divisions), and over two-thirds of the equity surplus should she choose the option consistent with self-interest and efficiency (chooser-favored divisions)—this is equivalent to dividing the interval $[\underline{x}^B, \overline{x}^B]$ in three subintervals of equal size. The results are striking: the chooser chose against self-interest in 26.6% (87 of 327) of divider favored divisions, in 0.4% (1 out of 225) of the even divisions, and in 0% (0 of 103) of the chooser-favored divisions (Figure 5).

A first observation is that in a proposal that is close to the sub-game perfect one, there is little payoff difference between the second mover's choices (Fig. 6 (a)). Indeed, the "rejection cost," i.e., the difference in payoff between the two options for the chooser, is zero for a sub-game perfect proposal and increases linearly as the proposal moves away from this sub-game perfect prediction (Fig. 6 (b)). For the 88 choices against self-interest of equal-income market divisions, the average difference between the two options for the chooser was 4.35 experimental units. For the 567 choices consistent with self-interest of equal-income market divisions, the average difference was 15.67 experimental units. It is not just about personal incentives, however. With the divide-and-choose mechanism, low incentives for the chooser to choose self interest are also tied with reciprocity motivations. If the rejection cost for a chooser is r, the divider would lose the efficiency surplus minus r in case of rejection. Thus, a small difference between two options for the chooser means the divider has proposed to capture much of the ef-

[17] In only one case did the divider propose a non-equal-income market division and the chooser chose against self-interest. That case is only counted as one of the 45 non-equal-income market divisions.

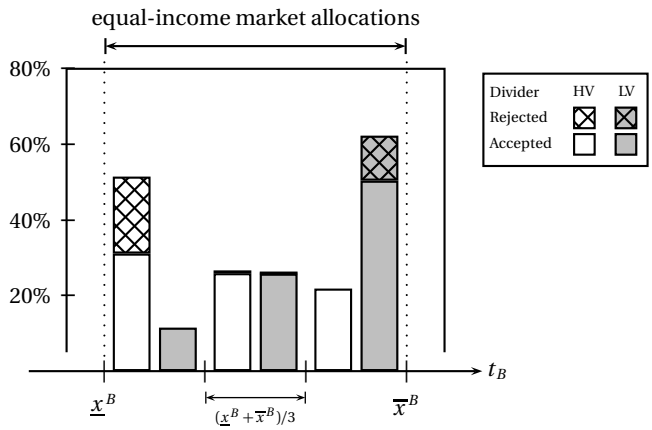

Figure 5: Distribution of equal-income market proposals from high-value (HV) and low-value (LV) subjects in divide-and-choose mechanism. Horizontal axis shows t_B, the transfer from the agent who receives item B to the other agent. Excludes valuation 4, i.e., (160, 160). Low-value subject's proposals are closer to sub-game perfect Nash proposals than high-value subject's proposals. Proposals made by the low-value subject that are closer to sub-game perfect Nash proposals are rejected with lower probability than those made by the high-value subject. Rejection means the chooser chooses the inefficient allocation that does not increase her payoff and induces a loss for the divider. Compare to the theoretical predictions of the divide-and-choose mechanism in Fig. 1.

ficiency surplus. For example, in valuations 1, 2 and 5, a difference of 4.35 experiment units between the efficient option and the non-efficient option for the chooser means the divider will get 35.65 experiment units more, should the chooser pick her preferred option.[18]

Rejection incentives are not symmetric for low-value and high-value subjects. Figure 6 (b) shows the effect in the difference in final payoffs that is induced by a rejection decision. This change is independent of who is making the rejection decision. On the one hand, if the left extreme proposal, i.e., $\underline{x}^B$, is accepted, the difference in payoffs is the efficiency surplus. If this proposal is rejected, there is equality of payoffs. Thus, rejection of such a proposal decreases inequality of payoffs by an amount equal to the efficiency surplus. This means that the rejection by a low value subject of a sub-game perfect proposal reduces inequality of payoffs. On the other hand if the right extreme proposal, i.e., $\overline{x}^B$, is accepted, the difference in payoffs is zero. If this proposal is rejected, the difference in payoffs is the efficiency surplus. Thus, rejection of such a proposal increases inequality of payoffs by an amount equal to the efficiency surplus. This means that the rejection by a high-value subject of a sub-game perfect proposal increases inequality of payoffs. Our data largely supports that agents take into consideration the inequality of payoffs consequences of their rejection decisions: of the sub-game-perfect divisions, the chooser chooses against efficiency 59.0% of the time (13 of 22) with the low value and only 33.3% (18 of 54) with the high value. With divider-favored divisions (i.e., those at

[18] In valuation 3, the efficiency surplus is 80, meaning such a proposal would give the divider 75.65 should the chooser follow her self interest. In valuation 4, all outcomes are efficient so the only equal-income market division gives equal earnings to each agent.

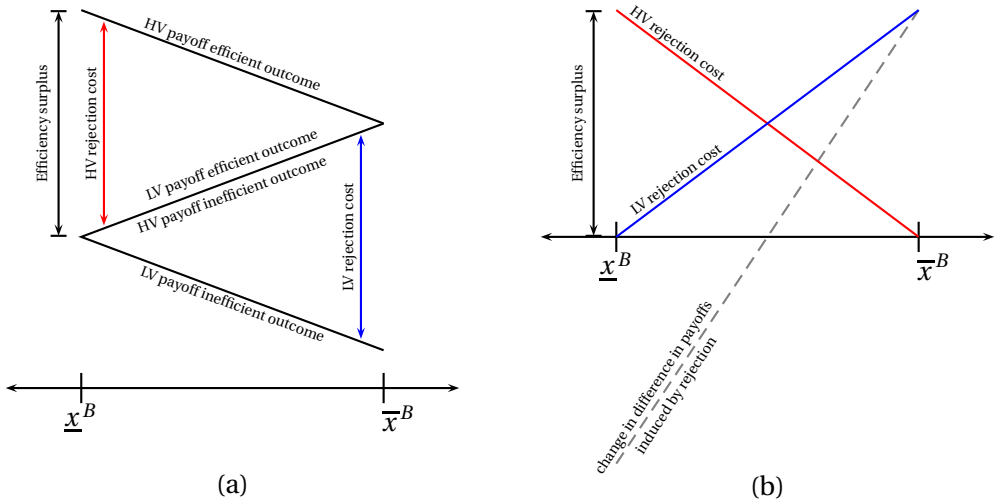

Figure 6: Incentives in divide-and-choose. (a) Subjects payoffs from divisions in the range $[\underline{x}^B, \overline{x}^B]$. For a given proposal $x \in [\underline{x}^B, \overline{x}^B]$, the payoff of the high value subject in case the proposal is accepted, i.e., the chooser choses the efficient outcome, is given by the line labeled "HV payoff efficient outcome." The other lines represent the respectively labeled payoffs. (b) A subject's rejection cost is given by the difference between her payoff if the efficient outcome is chosen and her payoff if the inefficient outcome is chosen (solid lines). The gray dashed line shows the change in difference in payoffs that is induced by rejecting a proposal. For instance, rejecting proposal $\underline{x}^B$ generates equal payoffs. Accepting this proposal generates payoffs that differ by the efficiency surplus. Thus, rejecting proposal $\underline{x}^B$ reduces the difference in payoffs by the efficiency surplus.

which the chooser receives up to one third of the efficiency surplus), she chooses against efficiency 37.8% of the time (56 of 148) with the low value and only 17.3% (31 of 179) with the high value.

Table 7 provides regression analysis of the propensity for dividers to choose against self interest using our classification of proposals in three regions of equal lenght (divider-favored, neutral, chooser-favored), the cost in making this choice, and the difference in inequality induced by rejection. The analysis confirms the general trends noted earlier. Every additional experimental earning point lost when choosing against self interest reduces the probability of choosers choosing against self interest by 1.8 percentage points. For every additional one point difference in the magnitude of inequality of earnings that can be eliminated by choosing against self interest, choosers increase their probability of choosing against self-interest by 0.2 percentage points. It is also interesting to note the terms not found to be significant in the regression. The sign on the "period within valuation" term is not significantly different than 0, suggesting these type of decisions by the chooser do not depend on experience. Further, the "divider-favored proposal term" is also not significantly different than 0. As these type of proposals are the type that are most favorable to the divider, it is reasonable to expect they should generate the most negative reciprocity from the chooser. As these proposals do not produce a differential

Dependent variable:	Choice against self interest[a]
period within valuation	-0.001
	(0.004)
difference in individual payoffs	-0.018***
between choices	(0.003)
difference in inequality	-0.002***
between choices	(0.000)
divider-favored proposal	0.038
	(0.075)
Type of regression?	logistic
Fixed effects?	each valuation (shown above)
First random effects term?	second-mover (chooser)
Second random effects term?	none
observations	522[b]
log likelihood	-132.286

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

a. Average marginal effects reported. A similar table showing logit coefficients is provided in our supplemental materials.
b. Results are restricted to equal-income market proposals that are not in valuation 4 or chooser-favored divisions. As choices are equal for equal-income market proposals in valuation 4, there is no way a chooser could choose against self-interest or efficiency. No chooser chose against self-interest with a chooser-favored division, so estimating its logistic term is problematic.

Table 7: Regressions of chooser choice against self-interest (and efficiency) with equal-income market divisions in divide-and-choose mechanism, controlling for subject random effects.

reaction from the chooser, we may speculate that these reciprocal motives are less important in the divide-and-choose mechanism.

Result 4. *There is no evidence of the theoretically-predicted first-mover bias in the divide-and-choose mechanism.*

Sub-game perfect equilibrium predicts that the divide-and-choose mechanism favors the divider. In our experimental environment, this is not the case. Table 8 provides the results from six regressions of subject profit and share of combined profit with dummy variables for first mover and high value on item B. The regressions use similar fixed and random effects as before (see equations (1) and (2)). The first two regressions indicate a second-mover advantage in divide-and-choose. Dividers receive on average about 4.5 points (2.5%) *less* ($p<0.01$) than choosers (see row 2, columns 1 and 2).

Result 3 provides some explanation as to why there is no first-mover advantage in the divide-and-choose mechanism. First-movers do not often propose to capture all the surplus; when they propose to capture more than two-thirds of the surplus, choosers choose against their self-interest and efficiency about 26.6% of the time. Table 8 also provides regressions on "proposed allocations," i.e., how allocations would be decided

if the second-mover never rejected a proposal. Recall that for divide-and-choose we consider a "rejection" to be any time the chooser chose an option that provided the *lower* payoff for both players.[19] As expected, these results (Table 8, columns 3 and 4) favor the first mover more. First movers propose to take about 1.5 points (1% share) more than the second mover, a significant difference ($p < 0.05$ and $p < 0.01$, respectively).[20]

The last two columns of Table 8 (columns 5 and 6) show regressions on subject earnings restricted to proposals that are not rejected. The first-mover advantage falls between the values for overall results (columns 1 and 2) and proposed allocations (columns 3 and 4). Not surprisingly, this indicates that proposals that favor the second-mover more are more likely to be accepted. Also, the act of rejection reduces the discrepancy between the first and second mover's earnings. These rejections cause an outcome with higher earnings for the second player, enough to erode any first-mover advantage.

One can relate the absence of first-mover advantage in our experimental results and the chooser's advantage predicted for divide-and-choose under incomplete information when agents are risk averse (McAfee, 1992; Kittsteiner et al., 2012). With incomplete information a divider is uncertain of the the other agent's valuations. The consequence is that her equilibrium proposal, which best responds to her prior on the other agent's willingness to pay for the good, may induce inefficient allocations with positive probability (McAfee, 1992).[21] Similarly, a divider in our experiments has uncertainty about what proposals will be "accepted" by the chooser. In both cases, the divider bears all risk in the allocation process and absorbs a disproportionate share of the efficiency loss.

Result 5. *The efficiency gains from using the divide-and-choose mechanism instead of the winner's-bid auction are primarily realized by low-value subjects and second-movers in the divide-and-choose. Profits for high-value first-movers are not significantly different under either mechanism.*

The additional surplus generated by the divide-and-choose mechanism compared with the winner's-bid auction (Result 1) is not distributed equally among the different roles in this mechanism. Our regression analysis (Table 8) allows us to conclude that the profit difference between high-value and low-value subjects in the winner's-bid auction is greater than in the divide-and-choose (23.052 vs 19.560, total points, $p < 0.05$; 14.438% vs. 10.186%, percent share, $p < 0.01$). Since the divide-and-choose mechanism favors the second mover (Result 4), low-value choosers would benefit the most and high-value dividers would benefit the least from using the divide-and-choose mechanism instead of the winner's-bid auction.

[19] In the case of equal payoffs, a rejection is when the second player would choose inefficiency (and giving the first mover less) over efficiency (and giving the first mover more).

[20] If we restrict these regressions to only equal-income market proposals (not shown), first movers take 6.27 points (4%) more in their proposals ($p<0.01$), suggesting off-equilibrium play is responsible for some of the reduction in the first-mover advantage with divide-and-choose.

[21] Efficiency of the divide-and-choose mechanism is recovered if the role of the divider is assigned in an ascending price auction (de Frutos and Kittsteiner, 2008).

conditon:	overall		proposed offers[a]		accepted offers[a]	
dependent variable:	profit (in points) (1)	share of total profit (percent)[a] (2)	profit (in points) (3)	share of total profit (percent)[a] (4)	profit (in points) (5)	share of total profit (percent)[a] (6)
Divider/first mover in divide-and-choose	-4.481*** (1.200)	-2.560*** (0.694)	1.663** (0.811)	1.184*** (0.475)	-0.950 (0.875)	-0.273 (0.508)
High value on B in divide-and-choose	19.560*** (1.20)	10.582*** (0.696)	19.745*** (0.811)	10.186*** (0.461)	18.388*** (0.857)	9.248*** (0.498)
High value on B in winner's-bid auction	23.052*** (1.298)	14.438*** (0.526)	-	-	-	-
Winner's-bid auction	-7.195*** (1.968)	-3.200*** (1.222)	-	-	-	-
Type of regression?	linear	linear	linear	linear	linear	linear
Fixed effects?	each period	each period	each period	each period	each period	each period
First random effects term?	subject	subject	subject who is first mover	subject who is first mover	subject	subject
Second random effects term?	player paired with subject	player paired with subject	none	none	player paired with subject	player paired with subject
observations	2080	2080	1120	1120	942	942
log likelihood	-9193.165	-8057.151	-4507.566	-3875.03	-3777.262	-3263.333

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

a. In divide-and-choose, a rejection is the divider choosing the option that gives him less points, or in a case of equal points, the inefficient outcome. Thus a divider's proposal is what would be implemented given the chooser does not reject. Auction data are not included for these four regressions.

Table 8: Regressions of subject earnings on mechanism, valuation, first mover, and item B value, controlling for period fixed effects and subject random effects. Valuation 4 is excluded from analysis.

value type:	low	high
divider	2.714	-0.778
	(1.987)	(1.968)
chooser	7.195***	3.703*
	(1.968)	(1.987)
1/2 divider + 1/2 chooser	4.954***	1.463
	(1.884)	(1.884)

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table 9: Average payoff in divide-and-choose mechanism minus average payoff in winner's-bid auction. Results are linear combinations of the coefficients found in regression (1) in Table 8.

Table 9 interprets the coefficients from regression (1) in Table 8 to show the gain or loss from moving from the divide-and-choose mechanism to the winner's-bid auction by role and valuation type. We can conclude that a chooser is better off using the divide-and-choose mechanism than the winner's-bid auction, especially if she held the low value on item B. A divider in the divide-and-choose does slightly better than the winner's-bid auction if she holds the low value. By contrast, a divider in the divide-and-choose does slightly worse than the winner's-bid auction if she holds the high value. However, neither result is statistically significant. Since the decision to use these mechanisms may be made independent of knowing the role in the divide-and-choose for either player, we also include this comparison in the case where there is a random (50/50) chance of being a divider or chooser.[22] In this case the net earnings gain form using the divide-and-choose is positive for high-value and low-value subjects, but only significantly different from zero in the low-value case.

5 Discussion and concluding remarks

We have presented evidence that the divide-and-choose mechanism is superior to the winner's-bid auction in an experimental environment in which agents know each other's payoffs. Our understanding of the reasons why behavior in both mechanisms deviates from theoretical predictions points to clear directions in which they can be improved.

First, our results show that agents reject proposals that are perceived as biased towards the divider in the divide-and-choose mechanism. These proposals are less likely to be rejected when they induce equality instead of inequality of payoffs. Thus, it is plausible that a mechanism that selects in sub-game perfect equilibria an allocation that is

[22] One should think of our results as providing evidence for agents who write a partnership contract behind the veil of ignorance. If subjects, after values are realized, choose the mechanism to be used in the allocation process, they may favor inefficient options (Brooks et al., 2010).

a better compromise in the set of equal-income market allocations may attain a better performance than divide-and-choose in terms of our two criteria of efficiency and equity. Based on this intuition Nicolò and Velez (2014) have designed an offer-counter-offer mechanism, which allows agents to compromise in a more balanced market allocation which does not depend on who is selected as first mover.

Second, since the winner's-bid auction is substantially affected by the effect that simultaneous play has on bounded rationality of subjects, it is plausible that the same effect is extended to other simultaneous move mechanisms that implement in Nash equilibria equal-income market allocations. Relevant alternatives include the so called α-auctions (Cramton et al., 1987) and the direct revelation mechanism that selects the equal-income market allocation whose transfer is closest to zero (Abdulkadiroğlu et al., 2004).[23] The α-auctions, where $\alpha \in [0,1]$, operate as follows. Ask both agents to report bids for the item; then, an agent with the highest bid receives the item and transfers the other agent the α convex combination between the highest and the lowest bid.[24] In an independent private-value setting, all α-auctions are ex-post-efficient, interim-individually-rational, and incentive-compatible for a non-trivial set of ownership distributions that contains and is centered in the symmetric ownership case (Cramton et al., 1987). When information is complete, each α-auction is strategically equivalent to a direct mechanism that selects an equal-income market allocation for the reported preferences. The equilibria of all these mechanisms for a given preference profile is exactly the set of all equal-income market allocations for the true preferences (Tadenuma and Thomson, 1995a) —notice that the mechanism proposed by Abdulkadiroğlu et al. (2004) also belongs to this family.[25] It is plausible that the QRE model (McKelvey and Palfrey, 1995), which is consistent with the distribution of play in our experiments with the winner's-bid auction, is also consistent with the distribution of play in these alternative simultaneous-move mechanisms. Thus, our results point to a behavioral model that can be used to discriminate among otherwise equivalent options. This, which is beyond the scope of this paper, is investigated by Brown and Velez (2015).

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[23] The mechanism proposed by Abdulkadiroğlu et al. (2004) can be framed as an auction in which bids are interpreted as half values. This mechanism is used by Spliddit (2014).

[24] Fair Outcomes Inc. (2007-2013) uses the average price auction, i.e., the 1/2-auction.

[25] The result in (Tadenuma and Thomson, 1995a) applies only to the single-good or two-agent case. This result has been generalized to the n-agent and n-item case (Beviá, 2010; Āzacis, 2008; Velez, 2011).

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