A Note on a Weighted Voting Experiment: Human Mistakes in Cooperative Games[*]

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Abstract

We conducted a sensitivity analysis of results in weighted voting experiments by varying the following two features of the protocol by Montero et al. (2008): (a) the way subjects' roles are reassigned in each round (random versus semi-fixed role) and (b) the number of proposals that subjects can approve simultaneously at a time (multiple versus single approval). We found that the possibility of simultaneously approving many proposals (multiple approvals) may result in more mistakes and confusions by subjects than the case without such a possibility (single approval). We also found that frequencies of minimal winning coalitions (MWCs) observed under the protocol with semi-fixed role and single approval are consistent with our hypothesis; each subject prefers a MWC in which his or her relative weight is larger, and the probability of each MWC occurring depends on a score in the social ordering determined by the Borda count, when there is no veto player.

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1 Introduction

The weighted voting, which gives different numbers of votes (voting weights) to different voters, is one of the most popular collective decision-making systems in many contexts such as stockholder voting in corporations and multi-party legislatures. In such a system, however, the distribution of voters' actual voting powers is often remarkably different from the distribution of their nominal voting weights.[1] The relationships between the distribution of voting weights and voting powers are too complex to be foreseen, although several power indices have been proposed to measure "a priori" powers of voters by Shapley and Shubik (1954), Banzhaf (1965), Deegan and Packel (1978), and many other researchers.

Experiments of weighed voting are recently attracting much interest of researchers. This new strand of research emerged to complement the empirical analyses of voting powers, because experiments can control many features that are unobservable in real practices. Among such researchers, Montero et al. (2008) and Aleskerov et al. (2009) conducted the experiments on weighted voting in a cooperative game environment in that no explicit structure as to how negotiations take place is defined.[2] In their experiments, it was observed that subjects eventually learn to form minimal winning coalitions (MWCs), i.e., winning coalitions such that a deviation of any member of the coalition turns the coalition from winning to losing. The formation of MWCs is consistent with the "size principle" proposed by Riker (1962).

The experimental confirmations of the size principle naturally lead to the following question; when there are several possible MWCs, is there any regularity regarding the observed frequencies with which these MWCs are formed? In the theory of power indices, Deegan and Packel (1978) proposed a power index (DP index) that is computed with a focus on the MWCs, but they assumed that all the possible MWCs are equally likely to be formed and, within each MWC, resources are allocated equally among its members. Packel and Deegan (1980) generalized the DP index by giving a system of axioms for the weighted DP index, but they did not provide any insights on the probability of each MWC occurring. Thus, the above question on the observed frequencies of MWCs has remained to be open.[3]

In our earlier experiment (Esposito et al., 2011), the observed frequencies of various MWCs, when there is no veto player, can be explained nicely by hypothesizing that each voter prefers a MWC to another MWC when his or her relative weight in the MWC is larger than the one in

[1] Felsenthal and Machover (1998), for example, noted this in their study of the Council of Ministers in EEC.

[2] Fréchette et al. (2005b), Drouvelis et al. (2010), and Kagel et al. (2010), on the other hand, conducted their experiments in non-cooperative game environments based on the variants of legislative bargaining by Baron and Ferejohn (1989). The analysis by Fréchette et al. (2005a) was based on the demand bargaining model by Morelli (1999).

[3] Shapley and Shubik (1954) and Banzhaf (1965) proposed power indices (SSI and Banzhaf index, respectively) in their seminal works to this topic, assuming that all the winning coalitions are equally likely to be formed.

another MWC, and that the probability of each MWC occurring depends on a score in the social ordering determined by the Borda count, given such individual preferences of voters on MWCs.[4] On the contrary, the results by Montero et al. (2008) and Aleskerov et al. (2009) show MWCs involving two players are disproportionately more likely to be observed, to the extent that the above hypothesis cannot explain, than those with three players.[5] We need, therefore, to accumulate more experimental results in order to shed a light on the above open question regarding the observed frequencies of MWCs and to contribute to future developments in the theory of power indices.

This methodological note is a step toward this goal, and it aims to illustrate the sensitivity of experimental results on small changes in the experimental design. It is often noted by researchers that results of laboratory experiments are sensitive to the exact design of the experiments such as the degree of the abstraction in the description of the strategic situation under study.[6] It is, therefore, of a considerable value to first conduct a sensitivity analysis and to search for a better experimental design, before starting to consider various apportionments of votes in order to experimentally investigate possible regularities of the frequencies with which possible MWCs are formed.

We conducted a set of experiments that vary the following two features of the protocol in weighted voting experiment by Montero et al. (2008): (a) random reassignment of subjects' roles in each round and (b) multiple approval of proposals that subjects can make simultaneously at a time, in order to test the robustness of the experimental results. Namely, we consider two role reassignments, random role and semi-fixed role, as well as two approval schemes, multiple approvals and single approval. It was observed that the possibility of simultaneously approving many proposals (multiple approvals) may result in more mistakes and confusions by subjects than the case without such a possibility (single approval). This observation suggests that, in a complex experiment such as the one we consider here, a certain design features can lead to more confusion or mistakes made by subjects, and thus might result in unreliable observations. It was also observed that the above hypothesis shown in Esposito et al. (2011) is valid only under one of the four protocols we have

[4]Esposito et al. (2011) intended to investigate the possibility of subjects learning about relationship between distribution of voting weights and voting powers from their limited experiences. For this purpose, some of the subjects were chosen to be "learners" in the beginning of the experiment. The learner, for example, as player 1, needs to choose a vote apportionment between [14; 3,5,7,7] and [14; 4,4,5,9] or between [14; 5,3,7,7] and [14; 4,4,6,8] where the quota (the minimum number of votes required to implement a proposal) is 14 and the list of voting weights of four voters is represented by four remaining numbers seperated by commas (first stage). Given the resulting vote apportionment, four members of a group negotiate and allocate 100 points among themselves (second stage).

[5]For example, Montero et al. (2008) examined a weighted voting game $[5; 3, 2, 2, 1]$. They found that, in the later rounds, almost all the winning coalitions were those of player 1 (with 3 votes) and player 2 or 3 (with 2 votes each). The coalition involving players 2, 3, and 4 (with 2 votes, 2 votes, and 1 vote, respectively) were rarely formed. The purpose of their study, however, was not to examine the observed frequencies of MWCs *per se*.

[6]Chou et al. (2009) illustrated how experimenters have to be careful about describing the strategic situation to the subjects. It is possible that subjects do not understand even a remarkably simple strategic situation unless it is described in terms that subjects are familiar with from their day-to-day lives.

tested, i.e., semi-fixed role and single approval.

The rest of the paper is organized as follows. Section 2 describes the experimental procedure. We introduce four possible protocols in weighted voting experiments. The results of our experiments are summarized in Section 3. Section 4 concludes this paper with remarks on the literature and suggestions for further research.

2 Experimental design

In our experiments, four players propose how to allocate 100 points or approve others' proposals. A weighted voting game with four players is represented by $[q; v_1, v_2, v_3, v_4]$, where q is the quota (the least number of votes required to implement a proposal) and v_i is the voting weight (the number of votes) player i has. It is called a game for short in this paper. We deal with two games examined in Esposito et al. (2011), (a) [14; 4, 4, 6, 8] and (b) [14; 7, 7, 3, 5], in which there is no veto player (a voter who belongs to every winning coalition). Our experimental design basically follows the protocol by Montero et al. (2008), varying its two features; thus, we have four treatments.

Each experiment involves 16 subjects. Upon arrival, they are provided with a written instruction, and then the experimenter reads it around. Subjects can ask questions regarding the instruction by raising their hand, but any communication among subjects are strictly prohibited; thus their interactions are only through the information they enter in their computer screens. Each experiment consists of 20 rounds. In each round, subjects propose how to allocate 100 points among four members or approve others' proposals. If a proposal obtains the required number of votes, then the proposal is implemented and the round is terminated. Before proceeding to the experiment, subjects play 1 practice round with a game $[3; 1, 1, 1, 1]$ to familiarize themselves with the software. Subjects play game (a) in the first 10 rounds and (b) in the second 10 rounds. Subjects are informed of the fact that they will face two different situations in these 10 rounds, but are not informed of the apportionment of the votes nor the quota prior to Rounds 1 and 11.

At the beginning of each round, all subjects are re-grouped into groups of four players. Subjects are not informed of who are in the same group. In re-grouping, we consider two role assignments: *random roles* (*RR*) and *semi-fixed roles* (*SFR*). Under RR, the numbers of votes subjects have are randomly re-assigned in every round. Thus, the subjects who are playing the role of player 1 (with 4 votes in case of game (a)) can become player 2, 3, or 4 in the next round. Under SFR, on the other hand, 16 subjects are randomly divided into two groups, group A and B, at the beginning of the experiment. Subjects in group A (B) will be either player 1 or 2 (3 or 4) throughout the experiment and never become player 3 or 4 (1 or 2). Thus, in the first 10 rounds, subjects in group A will always have 4 votes, while those in group B will have either 6 or 8 votes. In the subsequent 10 rounds, those

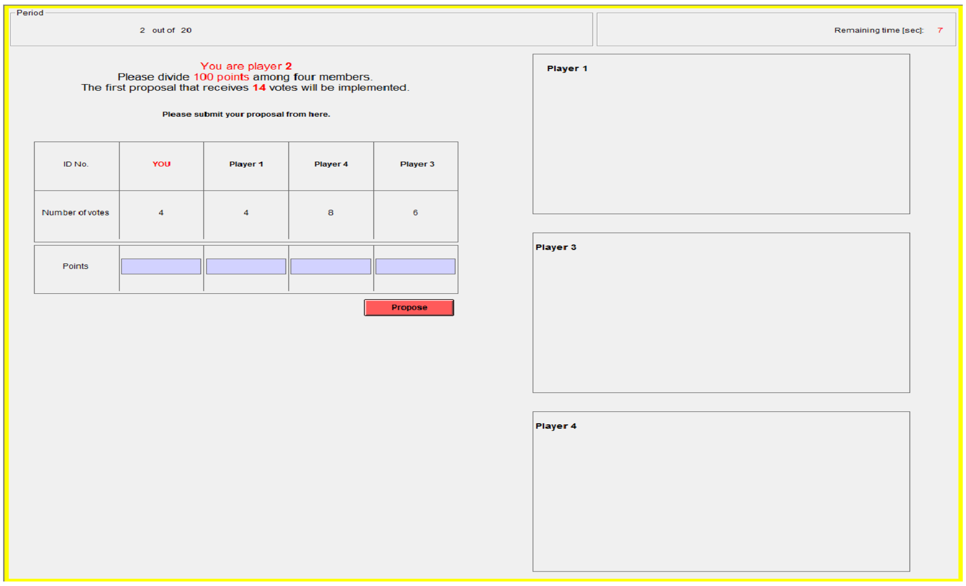


Figure 1: A Screen of player 2. His or her proposal-input table is on the heft-hand side.

in group A will always have 7 votes, while those in group B will have either 3 or 5 votes.

Both Montero et al. (2008) and Aleskerov et al. (2009) adopted RR, and noted its potential (positive or negative) effect on how subject learn to play the game, compared to fixed roles (in which subjects have the same numbers of votes throughout the experiment). They do not, however, investigate experimentally how varying RR affects their observations. We chose SFR, instead of fixed roles, due to the set-up in Esposito et al. (2011), in order to confirm observations in our earlier experiment.

Once a round begins, each subject observes the quota and his or her role on the upper left-hand side of the screen, which are highlighted in red.[7] (See Figure 1). Below the information, there is a table in which the number of votes each player has is shown. In this proposal-input table, by entering four non-negative numbers that add up to exactly 100 and then by pressing a "propose" button in red, each subject can make a proposal at any time during the round. Subjects can make proposals as many times as they wish during the round, but they are allowed to make only one proposal at a time. We randomize the order of players' appearance in the proposal-input table, following Aleskerov et al. (2009), to eliminate the effect of a fixed order on our observations.[8]

[7] The screens were translated into Japanese for experiments in Tsukuba and into French for those in Montpellier.

[8] Aleskerov et al. (2009) noted that a fixed order of players in the proposal-input table might induce a non-trivial impact on the observations. In a game [4; 3,2,2], for example, when the players are ordered from the left to the right as player 1, 2, and 3 in the proposal-input table, it was observed that most of the winning coalitions were either (1,2) or (2,3), although (1,2) and (1,3) are essentially the same. They showed that randomizing the order of players' appearance in the proposal-input table excludes such a puzzling observation.

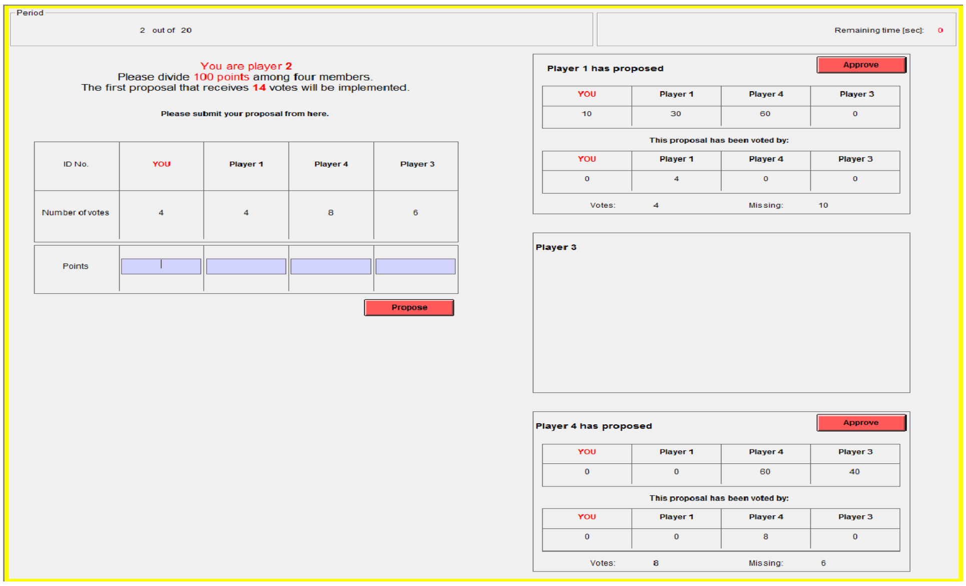


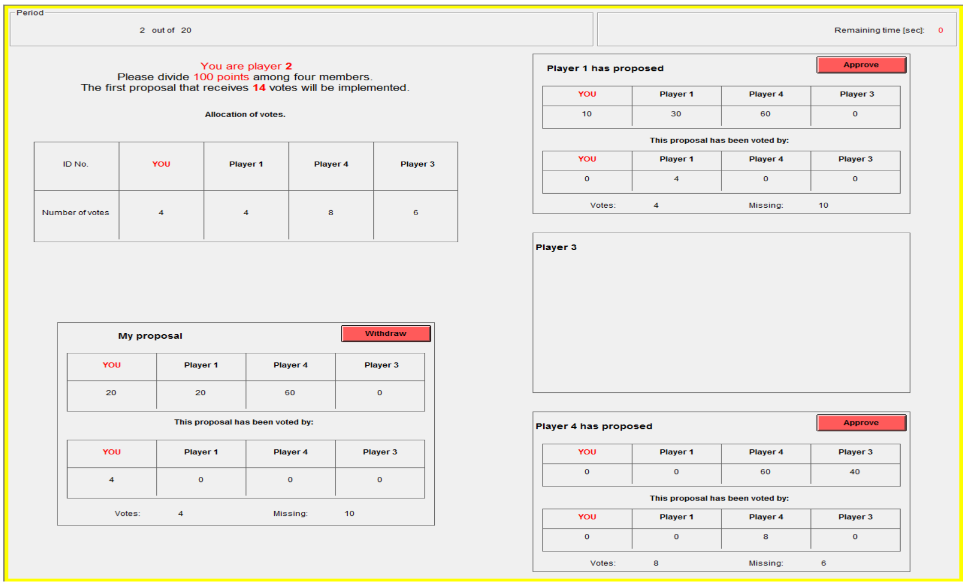
Figure 2: A screen of player 2 who is not currently proposing, while player 1 and 4 in the same group have made their proposals. His or her proposal-approval tables are on the right-hand side. At this time, there is no difference in appearance of the screens under MA and SA.

When a proposal is made, it is immediately shown to the other members of the relevant group in their proposal-approval tables, which is on the right-hand side of their screens. Each of them can approve the proposal by pressing a "approval" button in the table. The proposal-input table of the proposer is replaced with his or her proposal-confirmation table. The proposal is automatically approved by the proposer. If a proposal is approved by a subject, then a "withdraw" button appears in his or her proposal-approval or proposal-confirmation table of the subject. At any time during the round, subjects can withdraw their current proposals and approvals by pressing this button.

We consider two approval schemes: *multiple approval* (*MA*) and *single approval* (*SA*). Under MA, each subject can approve more than one proposal, including his or her own, simultaneously at a time, and all votes the subject has are casted in all proposals he or she approves. Under SA, on the other hand, each subject can be in favor of only one proposal, including his or her own, at a time. Thus, under SA, if a subject, who has made a proposal, wishes to approve a proposal made by another, the subject must first withdraw his or her own proposal. In the same manner, if a subject, who has approved a proposal made by another, wishes to approve yet another proposal or to propose his or her own, the subject must first withdraw his or her current approval. As noted above, neither MA nor SA allows subjects to simultaneously make multiple proposals, so that when they wishes to make a new proposal, they must withdraw their previous proposal before proposing a new one.

Figure 2 shows a screen of player 2, where he or she has four possible actions: (1) not doing

Under MA



Under SA

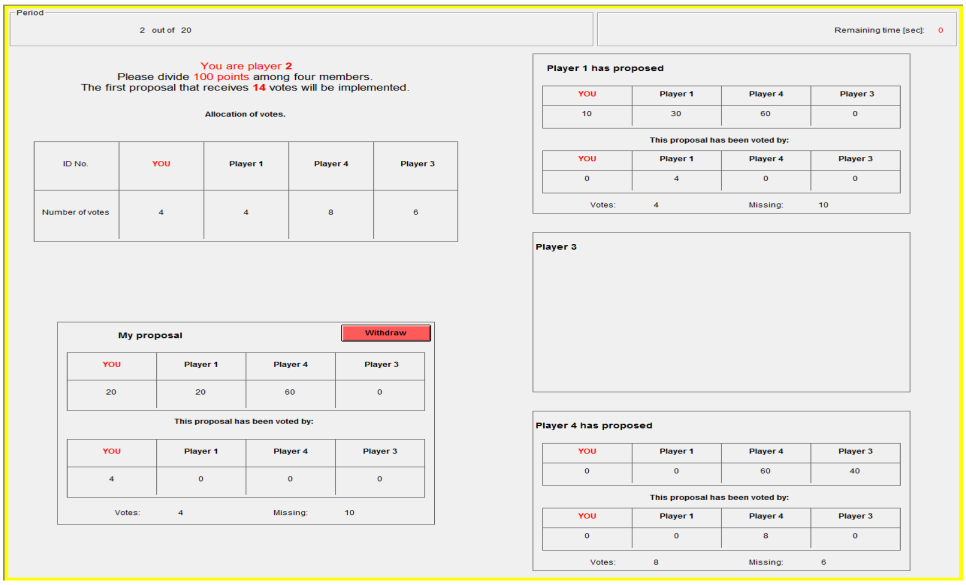


Figure 3: Screen shots for MA (top) and SA (bottom), following Figure 2 after player 2 has proposed and nobody else has done anything yet.

anything (remaining "silent"), (2) to approve the proposal made by player 1, (3) to approve the proposal made by player 4, and (4) to make his or her own proposal to others. When player 2 chooses (4), while nobody else has done anything yet, this screen (Figure 2) will be changed to those shown in Figure 3. The differences in the appearance of screens between MA and SA can be seen in Figure 3, in which the top (bottom) figure shows the screen shot for MA (SA). Under MA, the two "approve" buttons in red on the right-hand side of the screen are still shown in addition to the "withdrawal ’’ button on the left-hand side of the screen, whereas they do not appear any more under SA.

The absence of explicit structures (extensive forms) in cooperative game environments favors MA over SA, although SA still retains remarkably little structure compared to the negotiation protocols pre-determined in detail in non-cooperative game environments such as a legislative bargaining model (Baron and Ferejohn, 1989) and its variants studied by Fréchette et al. (2005b), Drouvelis et al. (2010), and Kagel et al. (2010). MA, however, allows subjects to approve many proposals simultaneously than SA does. This feature may result in subjects not thinking and acting very carefully when they make their decisions. We thus conduct experiments in order to investigate how this difference between MA and SA influences the experimental results. In experiments, RR may also affect subjects' thinking and actions; thus, in this paper, we examine four experimental protocols, which are summarized in Table 1. Both Montero et al. (2008) and Aleskerov et al. (2009) adopted RR-MA. Esposito et al. (2011), on the other hand, adopted SFR-SA.

In all these experimental protocols we examine, there is a common time limit for subjects to reach an agreement in each round. The limit is set randomly between 300 and 420 seconds.[9] If none of proposals made in a group receives at least as many votes as the quota within the time limit, every member of the group receives zero point. Subjects are informed that they will be paid according to the total points they gain in 6 rounds (3 from the first 10 rounds and 3 from the subsequent 10 rounds) randomly selected by a computer at the end of each experiment, with the pre-determined exchange rate in addition to the show-up fee. The exchange rate was 1 point = 0.13 EUR cents in Montpellier and it was 1 point = 14 JPY in Tsukuba. The show-up fee was 5 EUR in Montpellier and it was 1500 JPY in Tsukuba. The Instruction for each protocol is attached in Appendix C.[10]

Finally, note again that there is no veto player in both games we deal with. In games with veto players, they can extract all points by using their veto power in the "core" allocations. In Montero et

[9]Montero et al. (2008) set the random time limit to be between 300 and 600 seconds, and reported that there was no group that could not reach an agreement before 300 seconds. Aleskerov et al. (2009) set a fixed time limit of 300 seconds, and reported that there were several groups that failed to reach an agreement before the time limit, but that they observed almost the same observations except this point as those in Montero et al. (2008).

[10]The instructions, as well as the screens, were translated into Japanese for experiments in Tsukuba and into French for those in Montpellier.

	Random Role	Semi-Fixed Role
Multiple Approval	RR-MA	SFR-MA
Single Approval	RR-SA	SFR-SA

Table 1: Four protocols we examine. Montero et al. (2008) and Aleskerov et al. (2009) adopted RR-MA, and Esposito et al. (2011) adopted SFR-SA.

al. (2008), Aleskerov et al. (2009), and Esposito et al. (2011), it has been actually observed that, as rounds proceeded, the allocations converged to the ones where veto players obtain almost all points.

3 Results

We conducted computerized experiments in the laboratories at University of Montpellier (France) in January 2011 and at University of Tsukuba (Japan) in February 2011. In both laboratories, for each of the 4 protocols, 16 subjects participated in our experiments, respectively (128 subjects in total). 41% of the subjects were female students, and 78% of them were economics or business students. Each experiment lasted about 90 minutes including the instruction. We used "z-tree" (Fischbacher, 2007) as a software. We first present the results concerning the observed frequencies of winning coalitions, which are followed by the discussions on mistakes subjects made and their possible confusions in order to understand the differences in observations across protocols.

3.1 Winning coalitions

In both game (a) [14; 4, 4, 6, 8] and (b) [14; 7, 7, 3, 5], total of 22 votes are distributed among four players, the quota is 14, and there are three possible MWCs. Instead of players' IDs, we hereafter describe MWCs in terms of the number of votes the players have. MWCs are then $(4, 4, 6)$, $(4, 4, 8)$, and $(6, 8)$ in game (a), while $(7, 7)$ and two $(7, 3, 5)$s in game (b). Note that two players with 4 votes each in game (a) and those with 3 or 5 votes in game (b), need to act together in order to be a part of a MWC. We thus suppose that they do so. In our earlier experiment (Esposito et al., 2011), the observed frequencies of various MWCs can be explained nicely by the following hypothesis.

Hypothesis: *Each player prefers a MWC to another MWC when his or her relative weight in the MWC is larger than the one in another MWC. In the case of a tie, he or she gives priority to a MWC of fewer players. When there exists no veto player in a game, the probability of each MWC occurring in the game depends on the score in a social ordering determined by the Borda count,* *given the individual preferences of players on MWCs.*

Suppose that there are n voters and m alternatives. For each voter, give $m - j$ points to the alternative in j-th best position in his or her preference ranking. The Borda count generates a social ordering in scores in such a way that alternative x ranks above alternative y if and only if x's total score added over all n voters is greater than y's score. Under the above hypothesis, e.g., in game (a), the player with 6 votes prefers $(6, 8)$ to $(4, 4, 6)$, and $(4, 4, 6)$ to $(4, 4, 8)$. Two players with 4 votes each prefers $(4, 4, 6)$ to $(4, 4, 8)$, and $(4, 4, 8)$ to $(6, 8)$. The player with 8 votes prefers $(6, 8)$ to $(4, 4, 8)$, and $(4, 4, 8)$ to $(4, 4, 6)$. Treating two players with 4 votes as one, the Borda scores for $(6, 8)$, $(4, 4, 6)$, and $(4, 4, 8)$ are 4, 3, and 2, respectively. We should then expect to observe $(6, 8)$ more frequently than $(4, 4, 6)$, and $(4, 4, 6)$ more frequently than $(4, 4, 8)$. Similarly, in game (b), we should expect $(7, 7)$ to be observed more frequently than each of the two $(7, 3, 5)$s.

Table 2 shows the aggregate frequencies of winning coalitions observed in four protocols. The outcomes observed in game (a) are shown in the top four panels, while those in game (b) are shown in the bottom four panels. For each game, 10 rounds are divided into two blocks of 5 rounds. From the table, we can observe that subjects tend to form MWCs, especially, in later rounds.[11] In addition, observed frequencies of the MWCs of 3 players are less than those of the MWCs of 2 players in all protocols. These results can be summarized as the following two observations.

Observation 1. *Subjects form MWCs increasingly as they repeatedly play a weighted voting game.*

Observation 2. *MWCs of two players are formed more frequently than MWCs of three players.*

In Table 2, we can also observe that $(6, 8)$ occurred more frequently than $(4, 4, 6)$, and $(4, 4, 6)$ more frequently than $(4, 4, 8)$ in game (a) and that $(7, 7)$ occurred more frequently than each of the two $(7, 3, 5)$s in game (b), which are consistent with what we expect from our hypothesis. In the latter 5 rounds of each game, however, Table 2 also shows that in game (a), the difference in number of observations between $(6, 8)$ and $(4, 4, 6)$ is remarkably large except the one under SFR-SA, and that in game (b), the difference in number of observations between $(7, 7)$ and $(7, 3, 5)$s is extremely large under RR-MA. In each game, however, the difference should not be so large according to our hypothesis, because the scores of MWCs made by the Borda count are not different to that extent. There might be a period for subjects to learn how to play the games, but such a period is likely to be in the early rounds in each game. We thus look into the distribution of allocations realized in the last 5 rounds of each game, to further investigate the differences of outcomes observed under four protocols.

[11] This is not the case for SFR-MA and SFR-SA in game (b), where the increase of non-MWCs in period 16-20 are due to the results in Montpellier. See Figure 5 for more detail.

Game (a) [14; 4, 4, 6, 8]

RR-MA

	Round 1-5	Round 6-10
(6,8)	14	22
(4,4,6)	1	2
(4,4,8)	1	0
Others	24	16

SFR-MA

	Round 1-5	Round 6-10
(6,8)	22	25
(4,4,6)	3	5
(4,4,8)	1	2
Others	14	8

RR-SA

	Round 1-5	Round 6-10
(6,8)	17	20
(4,4,6)	3	6
(4,4,8)	0	2
Others	20	12

SFR-SA

	Round 1-5	Round 6-10
(6,8)	24	17
(4,4,6)	2	11
(4,4,8)	2	4
Others	12	8

Game (b) [14; 7, 7, 3, 5]

RR-MA

	Round 11-15	Round 16-20
(7_1,7_2)	25	33
(7_1,3,5)	1	0
(7_2,3,5)	2	3
Others	12	4

SFR-MA

	Round 11-15	Round 16-20
(7_1,7_2)	20	20
(7_1,3,5)	3	4
(7_2,3,5)	6	4
Others	11	12

RR-SA

	Round 11-15	Round 16-20
(7_1,7_2)	26	21
(7_1,3,5)	4	7
(7_2,3,5)	2	8
Others	8	4

SFR-SA

	Round 11-15	Round 16-20
(7_1,7_2)	26	16
(7_1,3,5)	6	9
(7_2,3,5)	8	10
Others	0	5

Table 2: Aggregate frequencies of winning coalitions observed in four protocols. In game (a), $(6,8)$ forms more frequently than $(4,4,6)$, and $(4,4,6)$ forms more frequently than $(4,4,8)$. In game (b), $(7,7)$ occurred more frequently than each of the two $(7,3,5)$s. Under RR-MA in each game, however, the formation of MWCs is extremely biased to the one including the player with the highest number of votes, which was observed also in Montero et al. (2008) and Aleskerov et al. (2009). The scores of these MWCs made by the Borda count do not expect such a large difference in observed frequencies of MWCs.

Figures 4 and 5 illustrate, in simplices, the allocations realized in the last 5 rounds of games (a) and (b) for 4 protocols, respectively.[12] Let 's take a look at Figure 4 first. In game (a), $(4, 4, 6)$ is not observed at all under SFR-MA and RR-SA in Montpellier, and there is only one observation of $(4, 4, 6)$ under RR-MA both in Tsukuba and Montpellier. These results are far from what we expect from the scores of MWCs made by the Borda count. Under SFR-SA, on the other hand, not only the observed frequencies of MWCs are consistent with our hypothesis, but also the realized allocations indicate a plausible tension between $(6, 8)$ and $(4, 4, 6)$. Look at the realized allocations shown with the red circles under SFR-SA. On the 6-8 edge, the realized allocations are concentrated at the middle, which indicates that two players in $(6, 8)$ equally shared the 100 points. On the 6-(4+4) edge, the realized allocations are located more toward Apex 6 than toward Apex 4+4. This implies that, in $(4, 4, 6)$, the player with 6 votes gained more than 50 points. These results together suggest that two players with 4 votes each are trying to form $(4, 4, 6)$ by offering to the player with 6 votes more than what he or she can expect to gain by forming $(6, 8)$, i.e., more than 50 points. Similar inferences can be made under RR-SA and SFR-MA from the outcomes observed in Tsukuba.

Next, let 's turn to game (b) shown in Figure 5. As in the case of game (a), we find some tensions among MWCs, in particular, $(7, 7)$ versus $(7, 3, 5)$s under SFR-SA, both for outcomes observed in Tsukuba and Montpellier. The similar tension among MWCs is also observed under RR-SA in Tsukuba. Under RR-MA or SFR-MA, however, we do not observe such a tension because the majority of observations are either (7.7) or others. Therefore, we can conclude as follows.

Observation 3. *Our hypothesis was valid only under SFR-SA.*

As noted above, our hypothesis was driven to explain the frequencies of MWCs observed under SFR-SA in our earlier experiment (Esposito et al., 2011). Observations 1 and 2 can be confirmed also in Montero et al. (2008), Aleskerov et al. (2009), and Esposito et al. (2011). Under RR-MA in game (a) [14; 4, 4, 6, 8], moreover, the formation of MWCs is remarkably biased to the one including the player with the highest number of votes, whereas it is rare to observe a MWC that does not include such a player (see Figure 4). Similar observation can be made in a game $[5; 3, 2, 2, 1]$ in Montero et al. (2008) and Aleskerov et al. (2009).[13] All these facts jointly imply the robustness of our results under RR-MA.

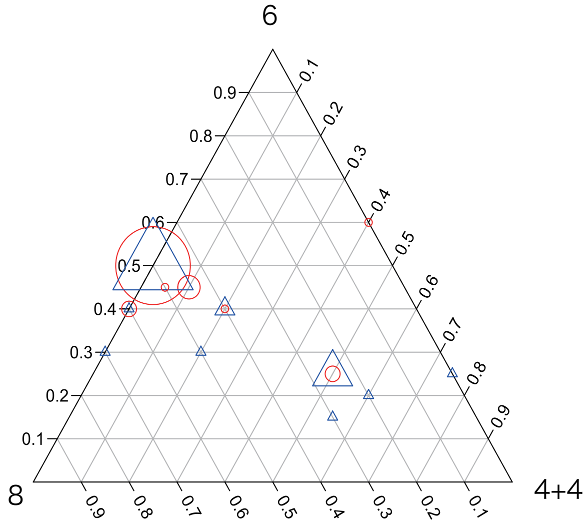
Why, then, does SFR-SA favor our hypothesis while others do not? One of the possible reasons

[12] In these figures, a point in a simplex shows how 100 points are allocated among subjects. See the simplex in Figure 4, for example. The height of a point from the edge that is opposite from the apex labeled 4+4 represents the total points allocated for two players with 4 votes each. Thus, a point on the 6-8 edge represents a realized allocation that gave 0 point to both of two players with 4 votes each, i.e., $(6, 8)$ being formed.

[13] For example, Montero et al. (2008) found that, in the later rounds, in 58 out of 64 observations, the winning coalitions were those consisting of player 1 (with 3 votes) and player 2 or 3 (with 2 votes). The coalition involving players 2, 3, and 4 (with 2 votes, 2 votes, and 1 vote, respectively) were observed only once out of 64 observations.

Game (a) [14; 4, 4, 6, 8]

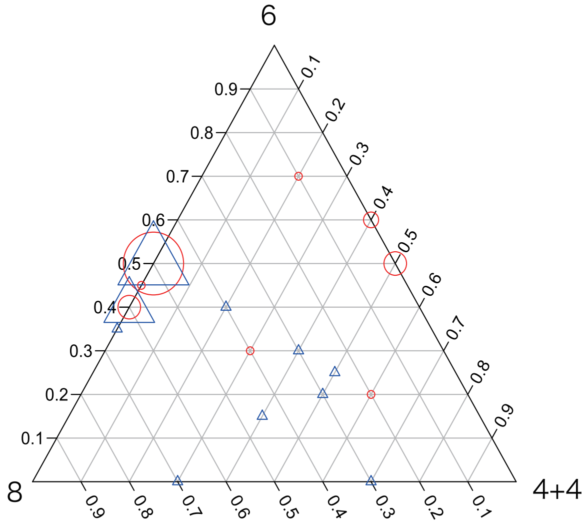
RR-MA



Number of Observations

	(6,8)	(4,4,6)	(4,4,8)	Others
JP	12	1	0	7
FR	10	1	0	9

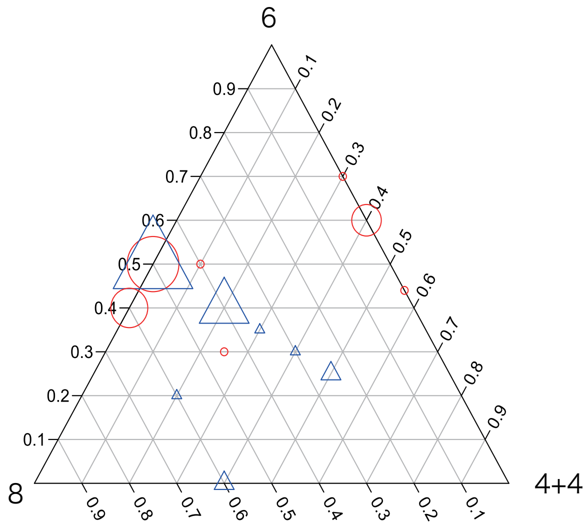
SFR-MA



Number of Observations

	(6,8)	(4,4,6)	(4,4,8)	Others
JP	12	5	0	3
FR	13	0	2	5

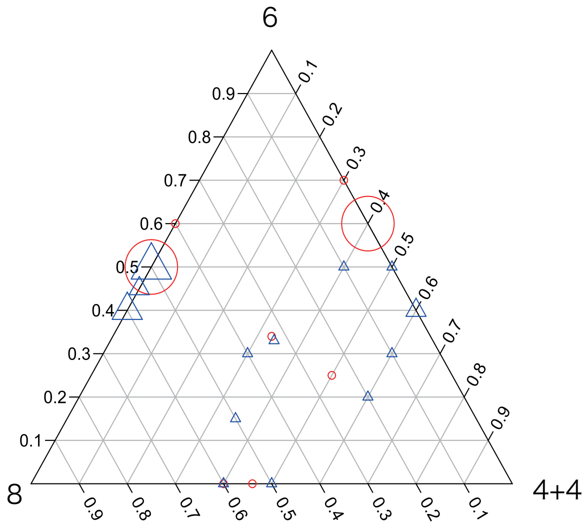
RR-SA



Number of Observations

	(6,8)	(4,4,6)	(4,4,8)	Others
JP	12	6	0	2
FR	8	0	2	10

SFR-SA



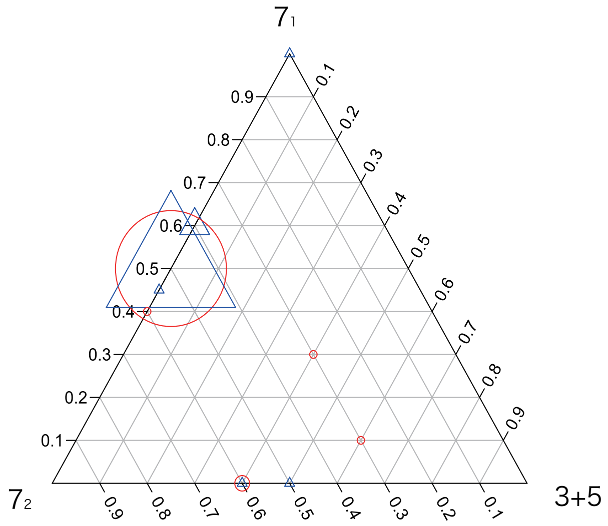
Number of Observations

	(6,8)	(4,4,6)	(4,4,8)	Others
JP	8	8	2	2
FR	9	3	2	6

Figure 4: Distribution of allocations realized in period 6-10 for game (a) under four protocols. Red circles (blue triangles) in simplices show the outcomes in Tsukuba, Japan (Montpellier, France). The size of a circle (and a triangle) is proportional to the number of observations falling on the center of the circle (a triangle). The tables below simplices show the frequencies of winning coalitions, separately, for Tsukuba (JP) and Montpellier (FR).

Game (b) [14; 7, 7, 3, 5]

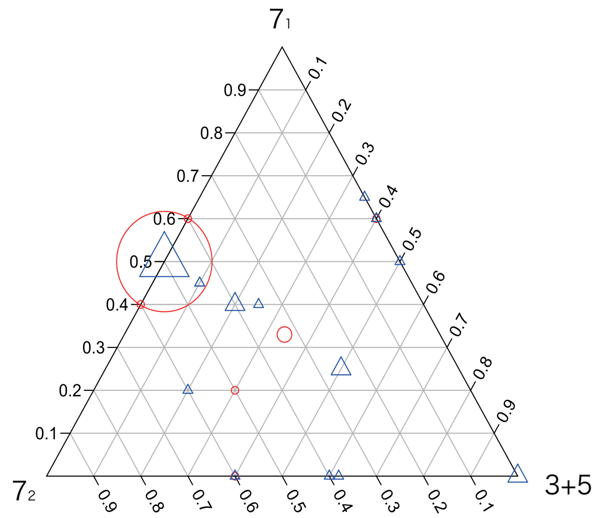
RR-MA



Number of Observations

	$(7_1,7_2)$	$(7_1,3,5)$	$(7_2,3,5)$	Others
JP	16	0	2	2
FR	17	0	1	2

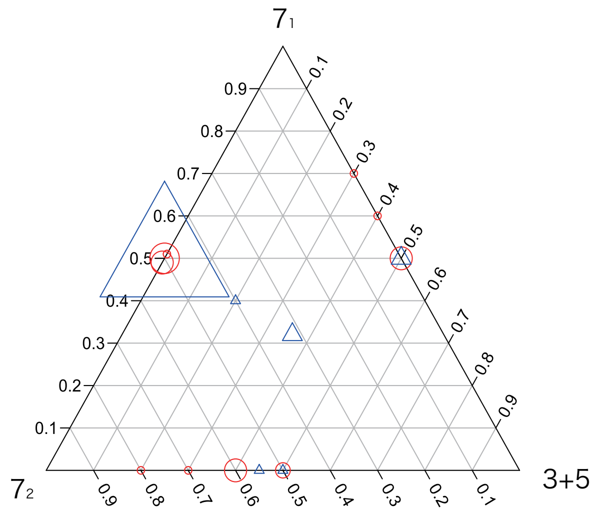
SFR-MA



Number of Observations

	$(7_1,7_2)$	$(7_1,3,5)$	$(7_2,3,5)$	Others
JP	15	1	1	3
FR	5	3	3	9

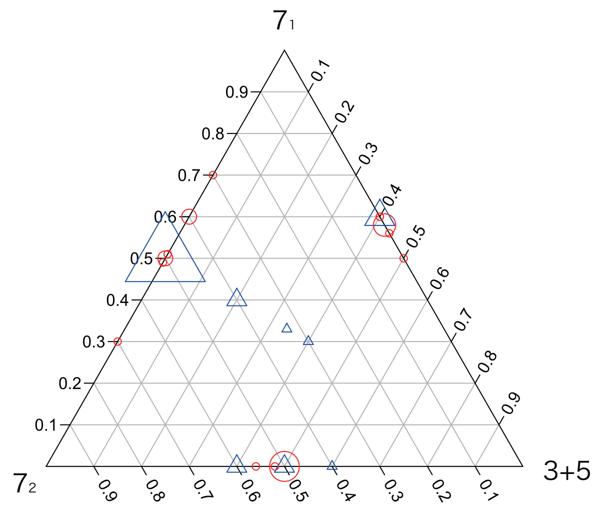
RR-SA



Number of Observations

	$(7_1,7_2)$	$(7_1,3,5)$	$(7_2,3,5)$	Others
JP	8	5	6	1
FR	13	2	2	3

SFR-SA



Number of Observations

	$(7_1,7_2)$	$(7_1,3,5)$	$(7_2,3,5)$	Others
JP	8	6	6	0
FR	8	3	4	5

Figure 5: Distribution of allocations realized in period 16-20 for game (b) under four protocols. Red circles (blue triangles) in simplices show the outcomes in Tsukuba, Japan (Montpellier, France). The size of a circle (and a triangle) is proportional to the number of observations falling on the center of the circle (a triangle). The tables below simplices show the frequencies of winning coalitions, separately, for Tsukuba (JP) and Montpellier (FR).

is simply due to the number of “clicks” required for a proposal to be implemented. MA favors MWCs involving a fewer members, because the first proposal that obtains at least as many votes as the quota is implemented, although subjects can click many “approve” buttons under MA. This effect is a real problem, if subjects fail to think carefully and merely click whatever the proposals shown in their proposal-approval tables. The lack of “tensions” among MWCs in outcomes observed under RR-MA and SFR-MA suggests that this should be indeed a potential cause. In fact, several subjects in Tsukuba noted informally after the experiments under MA, “the negotiation process was too fast to carefully compare several proposals shown in the screen.”

If the number of “clicks” matters under MA, another question still remaining will then arise; why do the outcomes observed under RR-SA not support our hypothesis as clearly as those under SFR-SA? A possible reason is that when subjects’ roles are changed randomly, the subjects without many votes do not think hard enough how to obtain a higher payoff. Another possible reason is that subjects make more mistakes in entering their proposals in the proposal-input tables under RR than under SFR, partly because the order in which players are shown in the screen changes every period. (See, footnote 8.) We now turn to address these possibilities by examining data across four protocols.

3.2 Mistakes and possible confusions

In Subsection 3.1, we pointed out that there is a problem in using MA when we analyze what kinds of coalitions are likely to be formed, because of subjects’ potential mistakes or careless choices. Table 3 shows an example of those things leading to a MWC of two players, with a negotiation dynamic realized under RR-MA in game (b) [14; 7, 7, 3, 5]. The implemented allocation was (50, 50, 0, 0); thus the winning coalition in this group consisted of players 1 and 2 (with 7 votes each) who shared 100 points equally. What is rather strange in this realization, however, is the behavior of player 1. At 20.2 seconds, player 2 proposed an allocation (50, 50, 0, 0). At 21.6 seconds, player 4 proposed another allocation (60, 0, 20, 20), which was more favorable for player 1 than the proposal that had made by player 2. Between these two proposals, however, player 1 approved the former at 29.8 seconds, which gave him 10 points less than the latter.[14]

We found many kinds of “strange” behaviors as well as the one described above.[15] To quantify

[14]At 29.7 seconds, player 3 proposed the same allocation as the one proposed by player 4 at 21.6 seconds, somehow not pressing “approve” button. Player 3 might be busy entering his or her own proposal and did not take a careful look at player 4’s proposal. (The time difference between the two proposals, however, is rather long for this interpretation.)

[15]For example, look at the simplex for SFR-MA in Figure 5. We can see a blue triangle on the top of Apex 3+5. This point corresponds to the allocation that gives zero point to players with 7 votes while two players with 3 or 5 points are dividing 100 points between themselves. This strange outcome is possible either because players with 7 votes made a mistake or because considered something other than ones’ own payoffs while playing the game.

players' IDs of proposer +approver(s)	elapsed time in second	points for player 1 (7 votes)	points for player 2 (7 votes)	points for player 3 (3 votes)	points for player 4 (5 votes)
2	20.2	50	50	0	0
4	21.6	60	0	20	20
3	29.7	60	0	20	20
2+1	29.8	50	50	0	0

Table 3: A negotiation dynamic realized within a round (Round 18) under RR-MA taken from game (b) in Tsukuba. Some "strange" behaviors (mistakes) of subjects are observed.

how often we observe strange behaviors, we define an action (i.e., proposal or approval) to be an error if one of the following four criteria is satisfied: (1) proposing or approving an allocation that gives zero point to the proposer or the approver oneself, (2) proposing or approving an allocation consisting of a coalition that cannot win unless others make errors that satisfies criterion (1), (3) proposing or approving an allocation that gives lower points to the proposer or to the approver than the existing proposals (i.e., proposals that has not been withdrawn), (4) proposing an allocation that gives lower points to those belongs to the proposed coalition than the existing proposals. Criteria (3) and (4) are applied only to such actions that are not classified into errors by criteria (1) or (2).

The adequacy for criterion (1) is obvious. If, in game (b) [14; 7,7,3,5], player 4 proposes an allocation (0,0,50,50), such a proposal is then naturally regarded as an error, because this proposal will never be implemented unless player 1 or 2 commits an error that satisfies criterion (1). Thus, we have criterion (2). The approval made by player 1 shown in Table 3 is an example of an error that satisfies criterion (3), where player 1 approved the proposal of an allocation (50,50,0,0) although (60,0,20,20) was existing. Also in the example shown in Table 3, if player 3 proposed another allocation (40,0,30,30), instead of proposing (60,0,20,20), then such a proposal would be considered as an error, because it gives a lower payoff to player 1 than existing proposals. Thus, we have criterion (4).

Criteria (1) and (2) capture errors that come from subjects failing to recognize their roles shown in their screens (i.e., the potential problem of RR over SFR) and making or approving proposals that do not make sense. Criteria (3) and (4), on the other hand, capture the failures of subjects to pay careful attention to existing proposals. The total number of actions varies across rounds and groups. We thus divide the number of errors in each negotiation by the total number of actions observed in the negotiation, and call such a percentile the normalized number of errors (NE).

We first consider the potential problem of RR over SFR. Figure 6 shows the empirical cumulative distribution functions (CDFs) of NE that satisfy criteria (1) and (2) only. In the left panel of the

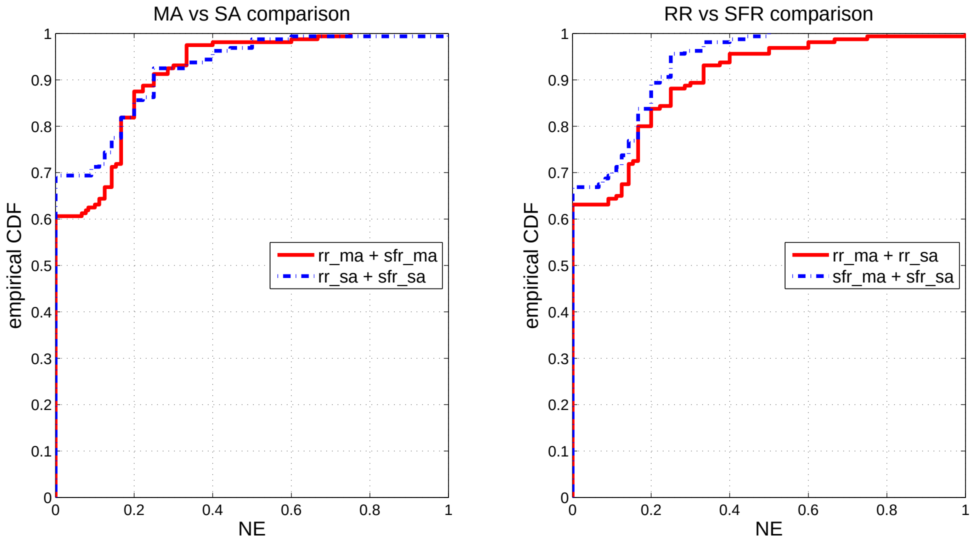


Figure 6: Empirical Cumulative distribution Functions (CDFs) of the normalized number of errors (NE) that satisfy criteria (1) and (2) only. MA vs SA (left) and SFR vs RR (right). The data are taken from Rounds 6-10 and Rounds 16-20 in both games (a) and (b) played in Tsukuba and Montpellier. In both cases of comparison, there in no statistically significant difference between the CDFs.

figure, CDFs under MA (solid) and SA (dashed) are depicted, while in the right panel, CDFs under RR (solid) and SFR (dashed) are plotted. In generating CDFs under MA, for example, we pooled the data observed under SFR-MA and RR-MA. The similar pooling of data is done for other cases. We present in Figure 6 the results taken from Rounds 6-10 and Rounds 16-20, because subjects may make more errors in the earlier rounds of a given game.

In the right panel of Figure 6 (RR versus SFR), the CDF of NE made under SFR lies left of the CDF of NE made under RR, which might imply that RR can indeed result in subjects making more mistakes in entering their proposals than SFR. The difference, however, is not statistically significant (p-value $= 0.196$ in Wilcoxon rank sum test). The left panel of the figure (SA versus MA) shows that there is no clear difference between SA and MA. The difference is not statistically significant (p-value $= 0.276$ in Wilcoxon rank sum test).

We next consider the errors that satisfy all criteria (1)-(4). It is possible that subjects do not see the relevant proposals that exist prior to taking their own actions, especially, when the actions in question take place immediately after the relevant proposals are made public. To allow for such a time lag, we apply criteria (3) and (4) only to these types of errors that made in T seconds after the relevant proposals have been made public. Figure 7 presents the empirical cumulative distribution functions (CDFs) of NE that satisfy all criteria with $T = 3$. The CDFs are generated in the same manner as those in Figure 6.

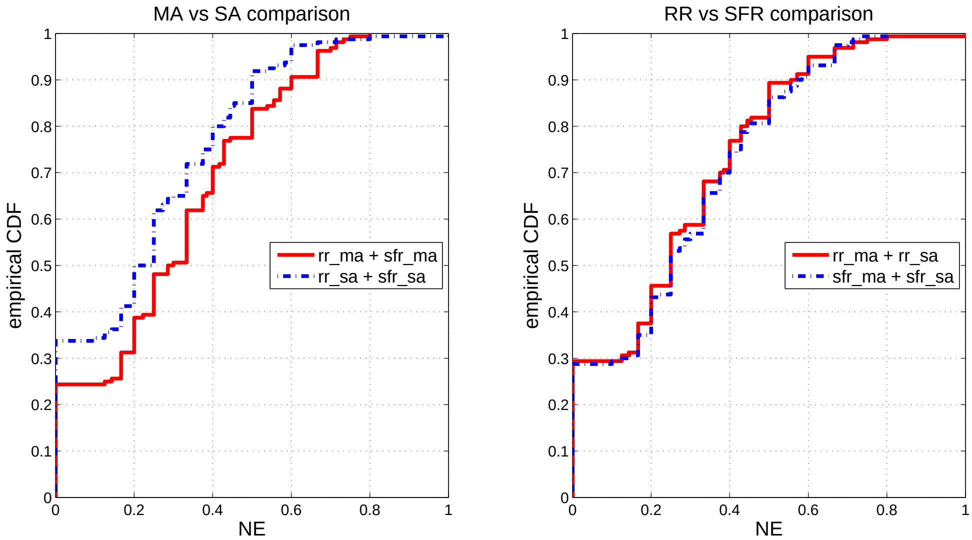


Figure 7: Empirical cumulative distribution functions (CDFs) of the normalized number of errors (NE) that satisfy all criterria (1)-(4). MA vs SA (left) and SFR vs RR (right). Criteria (3) and (4) are applied only to errors made in $T = 3$ seconds after the relevant proposals have been made public. The data are taken from Rounds 6-10 and Rounds 16-20 in both games (a) and (b) played in Tsukuba and Montpellier. In the comparison of MA to SA, there is a statistically significant difference between the CDFs.

In the left panel of Figure 7 (MA versus SA), the CDF of NE made under SA lies left of the CDF of NE made under MA. One can thus easily see that subjects tend to commit less errors under SA than under MA. The difference is statistically significant (p-value $= 0.01$ in Wilcoxon rank sum test). On the other hand, such differences cannot be observed between RR and SFR shown in the right panel of the figure (p-value $= 0.66$ in Wilcoxon rank sum test). These results are robust for all the value of $T \in \{1, 2, 3, 4, 5\}$ we tested. (See Appendix A.) These differences are primarily due to subjects failing to carefully examine existing proposals, in light of the results reported above that concern criteria (1) and (2) only. Criterion (4) can be seen as too strong as it requires subjects always to propose an allocation that is Pareto improving for the members of the proposed coalition. Dropping criterion (4) and defining errors with criteria (1), (2), and (3) only, however, do not change our results. (See Appendix B.) Thus we state the following observation.

Observation 4. *MA results in subjects making more mistakes than SA. RR does not result in subjects making more mistakes than SFR.*

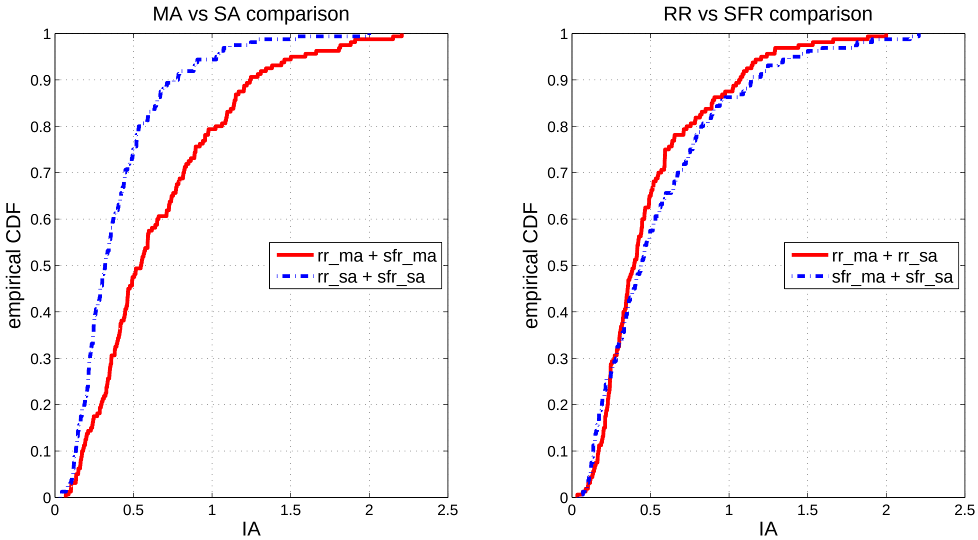


Figure 8: Empirical cumulative distribution functions of the intensity of activities (IA). MA vs SA (left) and SFR vs RR (right). The data are taken from Rounds 6-10 and Rounds 16-20 in both games (a) and (b) played in Tsukuba and Montpellier. There are significantly more actions per second under MA than under SA. No clear difference between RR and SFR can be found.

3.3 Intensity of activities

Why, then, do subjects tend to make more mistakes under MA than under SA? As quoted above, some subjects, who participated in the experiment under MA, expressed that the negotiation process was too fast to carefully compare several proposals, i.e., there were simply too much going on. To quantify the speed in negotiations, we define the intensity of activities (IA) in a negotiation by the average number of actions per second in the negotiation. Here, as above, an action is either to propose or to approve. We consider duration of a negotiation to be between the time of the first proposal in a group is made public and the end of the round for the group (either by a proposal obtaining at least as many as the quota or by the random termination).

Figure 8 shows the empirical cumulative distribution functions for the intensity of activities. As one can easily see from the left panel of the figure, there are significantly more actions per second under MA than under SA. The difference is statistically significant (p-value < 0.01 in Wilcoxon rank sum test). This fact confirms the remark made by subjects we quoted above.

Observation 5. *Subjects take significantly more actions per second under MA than under SA.*

We obtain the same results as Observation 5 quantitatively, even if we consider the duration of negotiation to be between the start of the round and the end of the round.[16] Observation 5 provides

[16] MA versus SA: p-value < 0.01 in Wilcoxon rank sum test.

a plausible reason for the former statement in Observation 4. In the right panel of Figure 8 (RR versus SFR), there is no clear difference between RR and SFR. The difference is not statistically significant (p-value $= 0.18$ in Wilcoxon rank sum test).[17]

4 Conclusion

The recent experimental analyses on weighted voting games in a cooperative game environment made by Montero et al. (2008) and Aleskerov et al. (2009) show that subjects eventually learn to form minimal winning coalitions (MWCs). Such an observation leads to the following question; is there any regularity regarding the observed frequencies of various MWCs? This question is of interest in the theory of power indices. A power index called DP index (Deegan and Packel, 1978; Packel and Deegan, 1980), for example, is based on the probability of each MWC occurring as well as allocations within MWCs. The DP index, however, is silent as to what are the plausible frequency distributions for various MWCs. Our ultimate aim is, therefore, to provide enough experimental results, while remaining within the cooperative game environment as much as possible, in order to shed a light on this open question and to contribute to future theoretical developments.

As a step toward such a goal, this paper conducted a sensitivity analysis of the observed frequencies of MWCs by varying the two features of the experimental protocol adopted in Montero et al. (2008): the random reassignment of subjects' roles and multiple approval. Namely, we consider two role assignments, random role (RR) and semi-fixed role (SFR), as well as two approval schemes, multiple approval (MA) and single approval (SA). Our main finding is that only under SFR-SA, observed frequencies of MWCs are consistent with our hypothesis; each subject prefers a MWC to another MWC when his or her relative weight in the MWC is larger than the one in another MWC, and the probability of each MWC occurring depends on a score in the social ordering determined by the Borda count, when there is no veto player. Under RR-MA, however, the formation of MWCs is extremely biased to the one including the player with the highest number of votes, which was observed also in Montero et al. (2008) and Aleskerov et al. (2009). The scores of these MWCs made by the Borda count do not expect such a large difference in observed frequencies of MWCs.

It turns out, from further data analyses, that the difference between these experimental results comes from the mistakes and possible confusions made by subjects under MA, which was also verified by our observation that subjects take significantly more actions per second under MA than under SA. Indeed, some subjects, who participated in the experiment under MA, noted that the negotiation process was too fast to carefully compare several proposals, i.e., there were simply too

[17] If we consider the duration of a negotiation to be between the start of the round and the end of the round, the p-value $= 0.08$ in Wilcoxon rank sum test.

much going on. For the future research, we need to accumulate sufficiently many data regarding the observed frequencies of various MWCs in various weighted voting games. The results of our analyses suggest that the SA protocol is preferable to the MA protocol for this purpose because it results in subjects making less mistakes.

Finally, we briefly refer to the main finding in Montero et al. (2008) and Aleskerov et al. (2009). The main purpose of their research was to examine whether the paradox of new members is confirmed also in the laboratory. The enlargement of a voting body (the number of voters) may affect the balance of power between originally existing members and some of voters actually gain, even if the numbers of votes they have and the decision rule remain intact. This phenomenon is called the paradox of new members and well known in political sciences. Montero et al. (2008) and Aleskerov et al. (2009) defined the power of a voter by the average earnings of subjects who play the games with the same player ID in their experiments. Thus, the observed frequencies of various MWCs did not affect their main finding that the paradox was confirmed, although the actual formation of MWCs is extremely biased to the one including the player with the highest number of votes. In light of the additional confirmation of the paradox of new member by Drouvelis et al. (2010) under a non-cooperative game environment in which subjects consider one proposal at a time, we think the paradox will be also confirmed under SFR-SA. It will be of interest, however, to re-examine the game [5; 3,2,2,1] under SFR-SA to put our hypothesis regarding the likelihood of MWCs to a further test.

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Appendix A: Robustness with respect to T

In the main body of this paper, we showed the analysis of errors by defining the time lag between two actions to be 3 seconds ($T = 3$). Here, we present the result of Wilcoxon rank sum test for other values of T. As one can see from the Table 4, the our results stated in the body are robust for the values of T we have considered.

	T=1	T=2	T=3	T=4	T=5
SFR vs RR	0.360	0.366	0.660	0.807	0.815
SA vs MA	0.000	0.001	0.012	0.019	0.056

Table 4: P-values is Wilcoxon rank sum tests regarding the comparison of the distributions of normalized number of errors for five values T in defining errors. The value 0.000 means that the p-value is less than 0.001.

Appendix B: Another definition of errors

In the main body of this paper, we showed the analysis of errors that satisfy criteria (1) and (2) only as well as all the four criteria. In this appendix, we present the analysis based on the errors defined by criteria (1), (2) and (3) but without (4). As noted, the results are basically the same as the one presented in the main body.

Figure 9 presents the empirical cumulative distribution functions (CDFs) of the normalized number of errors (NE). In the left panel of the figure, CDFs of MA (solid) and SA (dashed) are compared, while in the right panel, we compare those of RR (dashed) and SFR (dashed). These results are robust for all the values of T we have considered as shown in Table 5.

	T=1	T=2	T=3	T=4	T=5
SFR vs RR	0.739	0.964	0.887	0.813	0.993
SA vs MA	0.000	0.000	0.000	0.001	0.004

Table 5: P-values is Wilcoxon rank sum tests regarding the comparison of the distributions of normalized number of errors for five values T in defining errors. The value 0.000 means that the p-value is less than 0.001.

Appendix C: Instructions

The instructions for four protocols are the same for the most part. Thus, in this appendix, we show a generic instruction while noting the parts that are different between four protocols. Of course, the

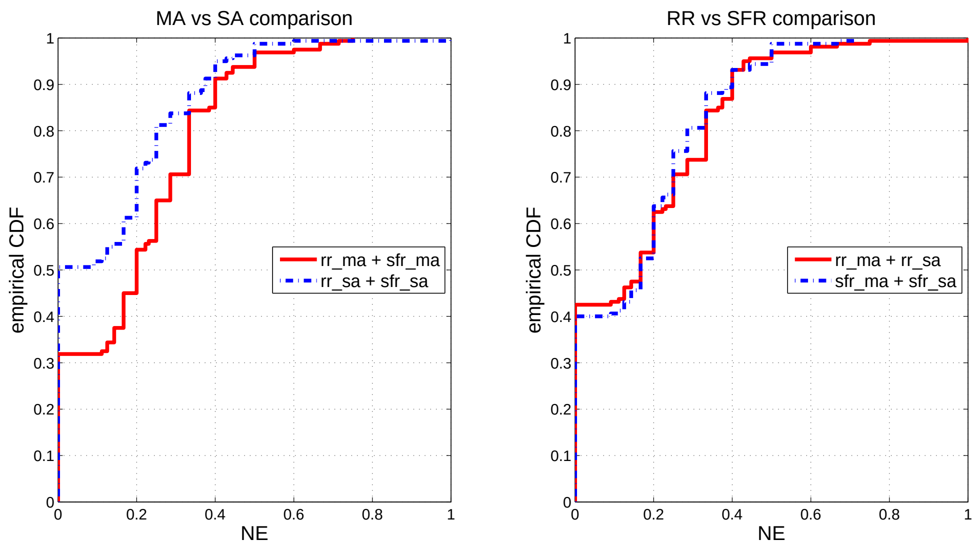

Figure 9: Empirical cumulative distribution functions of the NE defined based on criteria (1), (2), and (3) only. MA vs SA (left) and SFR vs RR (right). The data are taken from Rounds 6-10 and Rounds 16-20 in both games (a) and (b) played in Tsukuba and Montpellier. Subjects make significantly more errors under MA than under SA. No clear difference between RR and SFR can be found.

subjects in one protocol are only instructed about the relevant protocol. These instructions were then translated into Japanese and French for our experiments in Tsukuba and Montpellier. Instructions in Japanese as well as in French are available upon request.

INSTRUCTIONS OF THE EXPERIMENT

Welcome! Thank you very much for taking part in our laboratory experiment.

You are a participant in an experiment in a group decision making. During the experiment, you, as well as other participants in this room, will be making decisions. The experiment will take about two hours.

RECOMMENDATION

We ask you to comply with these rules and respect the instructions of the experimenter. Any communication with other participants is strictly prohibited. During the experiment, you must not talk, exchange notes, watch other participants ’ actions, and use mobile phones. It is important that during the experiment you remain SILENT. If you have any questions, or need assistance of any kind, RAISE YOUR HAND but DO NOT SPEAK. We expect and appreciate your cooperation.

PROTOCOL

There are 20 rounds in this experiment. In each round, you and three other randomly chosen participants will form a group of four people and the four players decide how to divide 100 points in the manner described later

Matching

===== ONLY FOR THE SFR ==========

At the beginning of the experiment, the computer will randomly divide you into two types, A and B. If you are type A, your player ID will ALWAYS be either 1 or 2. If you are type B, your player ID will ALWAYS be either 3 or 4. Each round your player ID will be randomized BETWEEN THE TWO, WHILE YOUR TYPE REMAINS THE SAME THROUGHOUT THE EXPERIMENT.

At the beginning of each round, the computer will randomly group four participants, two from A and two from B, into one group. You will not be able to know which participants are in the same group.

You will repeat the same procedure for 20 rounds, but your ID number may change from round to round, the other people in your group also change. In each round, you will be clearly informed on your player ID for that round.

===== ONLY FOR THE RR ============

At the beginning of each round, the computer will randomly group four participants into one group. You will not be able to know which participants are in the same group. You will repeat the same procedure for 20 rounds, but your ID number either 1, 2, 3 or 4, may change from round to round, and the other people in your group also change. In each round, you will be clearly informed on your player ID for that round.

==

The negotiation

You will be making a decision in a group with three other people, on how to divide 100 points among four of you.

You will not know who the people in your groups are, and the people in your group will change randomly every round.

Each player has a certain number of votes and the information will be shown in the table in the left side of the screen. In the first 10 rounds, the same votes allocation will be used, and anther votes allocation will be used from Round 11 to the end.

Any member of the group at any moment during the negotiation may make a public proposal about how to divide 100 points. To make a proposal, you need to enter 4 numbers in the respective boxes in the left hand side of the screen and press “propose” button shown in red.

Any member of a group could also vote for already submitted proposals. Proposal made by others are shown in the right side of screens. You can vote for a proposal by pressing an ”approve” button shown in red.

============ ONLY FOR MA =============

You can use your votes to support more than one proposal. Each proposal you support will receive all your votes. For each proposal, who are supporting it will be shown clearly.

To submit a new proposal, you need to withdraw your current proposal. You can withdraw your proposal by pressing ”withdraw” button in the left side of your screen anytime during the negotiation. All the members in your group will be informed about withdrawal of your proposal.

You can also withdraw your vote for other’s proposal by pressing ”withdraw” button shown in the right side of the screen anytime during the negotiation.

============ ONLY FOR SA =============

Please remember, you can only be in favor of at most one proposal, including your submitted proposal, at any given time. You cannot divide your votes up and support multiple proposals. All your votes will be casted in the proposal that you decide to support. For each proposal, who are supporting it will be shown clearly. You can change your approval whenever you want during the negotiation.

You can withdraw your proposal in order to propose a new one or to vote for other’s proposal by pressing ”withdraw” button in the left side of your screen. All the members in your group will be informed about withdrawal of your proposal.

You can also withdraw your vote for other’s proposal to propose or to vote for different proposal by pressing ”withdraw” button shown in the right side of the screen.

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The first proposal that receives the necessary number of votes will be implemented and the negotiation ends. Each of your group members will receive the number of points specified in that proposal.

There is a time limit to the negotiation. The time limit will be between 300 and 420 seconds. In each round, before the start of negotiation, the computer will randomly set the time limit, and you will not be informed of the exact time limit. This means that the round could end suddenly at any time between 300 seconds and 420 seconds after its start. If none of the proposal has received the necessary number of votes during this time limit, then all the members of your group will receive 0 points in this round.

If you have any questions please raise your hand.

PAYMENT

At the end of the experiment, the computer will randomly select 3 rounds out of the first 10 rounds and 3 rounds out of the second 10 rounds. You will be paid only according to the points you have obtained in these selected rounds, and not according to the points of the whole protocol. The total points you have earned in the selected 6 rounds will be converted to cash at the exchange rate of 1 point = 14 JPY (13 cents in EUR).

In addition to this, you will be paid 1500 JPY (5 EUR) as a show up fee. The maximum earning you can make is, therefore, 1500 + 0.14 x 6 x 100 JPY = 9900 JPY (5+0.13 x 6 x 100 =78 EUR). The minimum earning you can make is the show up fee of 1500 JPY (5 EUR).

PRACTICE ROUND

In order to make you familiar with the interface and mechanism of the experiment, we now do 1 practice round. What you will do in the practice will not affect your final payment. The number of votes given to four members of your group is not related to what you will see in the real experiments to follow.

IF YOU HAVE ANY QUESTIONS, PLEASE RAISE YOUR HAND.