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AN EXPERIMENTAL NASH PROGRAM: A COMPARISON OF NON-COOPERATIVE V.S. COOPERATIVE BARGAINING EXPERIMENTS

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An experimental Nash program: A comparison of non-cooperative v.s. cooperative bargaining experiments*

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Abstract

This paper aims to contribute to the literature on Nash program by experimentally comparing the results of "structured" (non-cooperative) demand-based and offer-based mechanisms that implement the Shapley value as an ex-ante equilibrium outcome with the results of corresponding "semi-structured" (cooperative) bargaining procedures. A significantly higher frequency of the grand coalition formation, the higher efficiency, and the allocation belonging to the bargaining set is observed in the latter than in the former regardless of whether it is demand-based or an offer-based. While significant differences in the resulting allocations are observed between the two non-cooperative mechanisms, little difference is observed between the two cooperative procedures.

JEL code: C70, C71, C92
Keywords: Nash Program, Bargaining procedures, Shapley value

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1 Introduction

The Nash program (Nash, 1953) provides a noncooperative foundation for cooperative solution concepts. Its main idea "is both simple and important: the relevance of a concept [...] is enhanced if one arrives at it from different points of view" (Serrano, 2005, p. 220). Because if different noncooperative approaches yield the same cooperative solution, it "indicates that the solution is appropriate for a wider variety of situations" (Nash, 1953, p. 136). While many authors have contributed to the development of the Nash program (see, Serrano, 2005, 2008, 2014, 2021, for surveys), experimental investigations have been scarce.

To fill this gap in the literature, Chessa et al. (2022, 2023a,b) have conducted a series of experiments to compare different non-cooperative mechanisms that are theoretically expected to implement the Shapley value (Shapley, 1953).

Chessa et al. (2023b) compare Winter's demand commitment bargaining mechanism (Winter, 1994, referred to as the Winter mechanism below) and the Hart and Mas-Colell procedure (Hart and Mas-Colell, 1996, referred to as the H–MC mechanism below). The authors find that while the offer-based H–MC mechanism better induces players to form the grand coalition and thus achieve a higher efficiency, the demand-based Winter mechanism, provided that the grand coalition is formed, better implements allocations closer to the Shapley value.

Chessa et al. (2022) investigate the effect of choosing a proposer through a bidding procedure as proposed by Pérez-Castrillo and Wettstein (2001), rather than randomly selecting one, as in Hart and Mas-Colell (1996). The authors find that choosing the proposer randomly, instead of via a bidding procedure, not only results in a significantly greater efficiency, but also provides that the average allocation is closer to the Shapley value for those groups that formed the grand coalition. This is due to the tendency of proposers who won the bidding to propose an allocation that favors themselves more often compared to when proposers are selected randomly. Such proposals are more likely to face rejection.

Finally, Chessa et al. (2023a) investigate the potential impact of the simplification introduced in the Winter mechanism considered in Chessa et al. (2023b). On one hand, in the original model of Winter (1994), after every player sequentially makes his/her demand once, those who did not form a coalition, remain in the game, pay a delay cost and make another demand. This process continues until there remains only one player in the game. On the other hand, in Chessa et al. (2023b), instead, those who did not form a coalition after every player has sequentially made his/her demand once, directly exit the game with their singleton value. Chessa et al. (2023a) compare the simplified mechanism considered in Chessa et al. (2023b) with some two steps versions of the mechanism, in which players who did not form a coalition pay either a small or a high cost, and then move to a second step in which they still do their second demand sequentially. They find that outcomes are not significantly different regardless of whether there exists a second chance to make a demand or not.[1]

While Chessa et al. (2022, 2023a,b) experimentally compare the outcomes from different non-cooperative mechanisms, they have not compared the outcomes of these "structured" (non-cooperative) bargaining experiments with "unstructured" (cooperative) bargaining experiments. In light of the objective of the Nash program, a natural

[1]The H–MC mechanism considered in Chessa et al. (2023b) is also a simplified version of Hart and Mas-Colell (1996). While in Hart and Mas-Colell (1996), if a proposal is rejected, the proposer is removed from the game and receives his/her singleton value with a positive probability (thus, it is also possible for the proposer to stay in the game and, if chosen, make another proposal), in Chessa et al. (2023b) the proposer whose proposal is rejected is removed from the game and receives his/her singleton value with probability one. There is no experimental investigation yet for the effect of this difference.

and important question is whether these two types of bargaining experiments yield similar outcomes or not. This is the question we aim to answer in this paper.

It is, however, difficult to design an "unstructured" computerized bargaining experiments, because the very same design of a computer interface necessary puts some structure into the bargaining procedure. For example, Shinoda and Funaki (2019) conduct a computerized "unstructured" three-player bargaining experiment. In their experiment, participants (acting as players in the bargaining game) can freely propose a coalition and an associated allocation that is feasible among the members of the proposed coalition. Participants are also free to modify their proposal anytime during the negotiation, and also free to agree on the proposal made by another participant. A coalition is formed if all its members agree. Furthermore, Shinoda and Funaki (2019) also consider a treatment in which participants can freely send chat messages to others. Similarly, in three-players games that model negotiable conflicts involving two weak players and one strong player, Kahan and Rapoport (1980) also consider two communication conditions: namely a condition where subjects can exchange messages, and a condition where subjects are not allowed to send messages and are unaware that they have been denied this option. While these procedures are much less structured compared to those considered in Chessa et al. (2022, 2023a,b), there remain some constraints in what participants can do and how the coalition is formed.

On the same line than Shinoda and Funaki (2019), it is possible to imagine an alternative procedure where participants, instead of freely proposing a coalition with an associated allocation among its member, freely make their demand for them to join a coalition, and a coalition is formed among participants whose demands are compatible (i.e., can be satisfied with the value the coalition generates). And as shown by Chessa et al. (2023b) for the structured bargaining experiments, such an offer-based and a demand-based bargaining procedure may results in quite different outcome even in much less structured experiments.

We therefore consider both an offer-based and a demand-based "semi-structured" bargaining experiment (Duffy et al., 2021). We call our experiment "semi-structured" because as noted above, while it is much less structured compared to the "structured" non-cooperative bargaining experiments considered by Chessa et al. (2022, 2023a,b), there remains some structure in the bargaining procedures.

More specifically, we vary (a) whether or not participants can communicate freely via online chat during the negotiation, and (b) whether the negotiation is offer-based or demand-based in our 2×2 between subjects design. The first dimension is motivated by Shinoda and Funaki (2019), who find that the grand coalition is more likely to be formed with than without a possibility of free-form communication among players through a chat window. The second dimension is motivated by Chessa et al. (2023b), who find that demand-based and offer-based mechanism can result in outcomes satisfying much different properties. We also (c) contrast the results of these "semi-structured" experiments with the results of "structured" experiments of Chessa et al. (2023b), and this represents the third motivation of our analysis.

We find that "semi-structured" experiments, both offer-based and demand-based, result in the higher frequency of grand coalition formation and the efficiency than the structured ones. Unlike Chessa et al. (2023b) who find significant differences in the outcome of an offer-based and a demand-based procedures, we did not find significant differences between the two regardless of the possibility of free-form communication. The latter result is assuring in that, at least for the semi-structured bargaining experiments on the games with non-empty core, exact procedure may have little impact on the outcomes. As a consequence of the lower efficiency of "structured" experiments, we find that the average payoffs deviate significantly from the Shapley values for more players in more games under the "structured" experiments than under the "semi-structured" ones. While investigating for the possible sources of deviation of the realized allocations from the Shapley value, applying the approach of Aguiar et al. (2018), we report that which axioms are violated depend on whether the possibility of chatting is allowed, and on whether the experiments are offer-based or demand-based. Finally, in the last part of our analysis, we assess the validity of the prediction of the bargaining set (Aumann and Maschler, 1964). We report that the frequencies of the belonging to the bargaining set are significantly higher under the "semi-structured" bargaining experiments, when compared with the results of the "structured" experiments, and this attests to a greater stability of the allocations obtained under a "semi-structured" bargaining.

The rest of the paper is organized as follows. Section 2 presents the experimental design. The results are presented and discussed in Section 3. And Section 4 concludes.

2 The experimental design

We first describe the four-player bargaining games we consider in our experiment. We then explain our four treatments.

2.1 The games

We consider the four 4-player games shown in Table 1. These games are the same as those considered in Chessa et al. (2022, 2023a,b). The Shapley values of the four games is presented in Table 2. The Equal Division payoff vector is simply equal to $ED(v_k) = (25, 25, 25, 25)$ when $k = 1, 2$, and $ED(v_k) = (50, 50, 50, 50)$ when $k = 3, 4$.

Following Chessa et al. (2022, 2023a,b), in our experiment, each participants played

Table 1: The games

S	1	2	3	4	1,2	1,3	1,4	2,3	2,4	3,4	1,2,3	1,2,4	1,3,4	2,3,4	N
$v_1(S)$	0	5	5	10	20	20	25	20	25	25	50	60	60	60	100
$v_2(S)$	0	20	20	30	20	20	30	45	55	60	45	55	60	100	100
$v_3(S)$								$= v_1(S) + v_2(S)$							
$v_4(S)$								$= 2v_1(S)$							

Table 2: The Shapley value of games 1, 2, 3 and 4

	$\phi_1(v)$	$\phi_2(v)$	$\phi_3(v)$	$\phi_4(v)$
Game 1	22.08	23.75	23.75	30,42
Game 2	0	28.33	30.83	40.83
Game 3	22.08	52.08	54.58	71.25
Game 4	44.16	47.5	47.5	60.83

all four games twice. The order of games was counter balanced across sessions. Namely, participants played these four games in one of the following four orderings: 1234, 2143, 3412, and 4321. At the beginning of a new round (i.e., new play of a game), participants were randomly rematched into groups of four players, and their roles were randomly reassigned within a newly created group.

2.2 Treatments

In our 2×2 between subjects design, we vary (a) whether or not participants communicate freely via online chat during the negotiation, and (b) whether the negotiation is offer-based or demand-based.

In the treatments with free-form communication, participants could freely send chat messages (except for those messages that can identify oneself and those ones that can insult others). Messages could be seen by everyone in the same group, and they can be sent anytime during a play of a game (or a negotiation).

In all the treatments, the maximum duration of a negotiation was randomly determined between 300 and 360 seconds. Participants were informed that a negotiation could continue for at least 300 seconds, but its end would have been terminated at a randomly chosen moment during the following 60 seconds. The negotiation could end earlier, when the grand coalition was formed, or when only one player remained without belonging to any coalition. We now describe the difference between our offer-based and demand-based negotiation protocol in detail.

2.3 Offer-based protocol

This protocol is similar to the one that Shinoda and Funaki (2019) call "unstructured bargaining" protocol. Namely, at any time during a negotiation, each player is free to propose or to approve a coalition that include him/herself among players who remain in the game and an associated allocation within the coalition. Below, let proposing or approving a coalition mean both proposing or approving members of a coalition and the associated allocation among them. For example, at the beginning of a negotiation when all the four players remain in the game, player 1 can propose either {1,2}, {1,3}, {1,4}, {1,2,3}, {1,2,4}, {1,3,4}, or {1,2,3,4}. Note that single player coalition is not considered here as, we explain later, it is the default outcome for the player when s/he ends the game without belonging to any coalition. Instead of proposing a coalition, a player can also approve a coalition, that include him/herself, proposed by another player.

In our experiment, each player can propose or approve at most one coalition at any point in time. Thus, if a player has proposed a coalition but would like to approve the one proposed by another player, first the player has to withdraw his/her proposal. Similarly, if a player has approved a coalition proposed by another player but would like to propose a new one, the player has to first withdraw his/her approval.

If all the members of a proposed coalition approve it, the coalition is formed and its members all exit the negotiation and receive the allocated points. The negotiation continues with remaining players. If there remains only one player, the negotiation ends. The players without an agreed coalition at the end of the negotiation (either because of the time limit or because s/he is the only player left) obtain his/her singleton value.

2.4 Demand-based protocol

In this protocol, at any point during a negotiation, players are free to demand points they want to obtain. Note that, unlike the offer-based protocol, in doing so, players are not proposing a coalition. Instead, they are expressing the points they want to receive for them to join a coalition. Each player can make at most one demand at any time during the negotiation. Players are free to modify their demands anytime during a negotiation.

A coalition can be formed if the sum of the demands made by its members is no greater than its worth. When there is such a coalition for a player, the player is free to agree to form it. Just as in the offer-based protocol, we exclude a single player coalition here, because it is the default outcome for the player when s/he ends the game without belonging to any coalition. Each player can agree to form at most one coalition at any time during the negotiation. Thus, if players want to form a different coalition than the one s/he is currently agreeing to form, they need to withdraw the current agreement before agreeing to form a new coalition.

A coalition is formed if all its the members agree to form it. Once a coalition is

Table 3: The number of participants, the mean duration, and the mean payment in four treatments

Treatment	No. of Participants	Mean Duration	Mean payment	When
Demand-based Without chat (No chat)	88 (24x2 + 20x2)	1h34m	2810 JPY	May-June 2022
Demand-based With chat (chat)	84 (24x2,16,20)	1h22m	2860 JPY	May-June 2022
Offer-based Without chat (No chat)	88 (24x2 + 20x2)	1h36m	2810 JPY	June-July 2021
Offer-based With chat (chat)	84 (20x3 + 24x1)	1h36m	2900 JPY	June-July 2021

formed, its members exit the negotiation and receive the points they have demanded. Just as in the offer-based protocol, the negotiation continues with remaining players. If there remains only one player, the negotiation ends. The players without an agreed coalition at the end of the negotiation (either because of the time limit or because s/he is the only player left) obtain his/her singleton value.

3 Results

The experiment was conducted at the Institute of Social and Economic Research (ISER), Osaka University, in May and June 2021 (offer-based) and May and June 2022 (demand-based). A total of 344 students, who have never participated in similar experiments before, were recruited as subjects of the experiment. See Table 3 for the number of participants as well as mean duration and mean payment in each treatment.The experiment was computerized with z-Tree (Fischbacher, 2007) and participants were recruited using ORSEE (Greiner, 2015).

At the end of the experiment, two rounds (one from the first four rounds and another from the last four rounds) were randomly selected for payments. Participants received cash reward based on the point they have earned in these two selected rounds with an exchange rate of 20 JPY = 1 points in addition to 1500 JPY participation fee. The experiment lasted on average around 90 minutes including the instruction, comprehension quiz, and payment. Participants received a copy of instruction slides, and a pre-recorded instruction video were played. Quiz was given on the computer screen after the explanation of the game. The user interface was explained during the practice rounds referring to the handout about the computer screen. See Appendix A for English translations of the instruction materials and the comprehension quiz.

Table 4 summarizes the duration of a negotiation, the frequency of complete break down (no coalition being formed), the number of proposals/demands made within a negotiation, and the number of messages sent during a negotiation (in treatments with chat), and the time until the first coalition being formed in the semi-structured experiments.[2]

The average duration of a negotiation is significantly longer in the offer-based than in the demand-based protocols.[3] The possibility of chat does not significantly affect the duration of the negotiation.[4] Note that while more messages are sent under the offer-based than the demand-based protocol when chat is possible, the difference is

[2]The table is created based on the estimated coefficients of the following linear regressions: $y_i = \beta_1 ONC_i + \beta_2 OC_i + \beta_3 DNC_i + \beta_4 DC_i + \mu_i$ where y_i is the statistics of interest in group i, ONC_i, OC_i, DNC_i, and DC_i are dummy variables that take value 1 if the treatment is offer-based no chat (ONC), offer-based with chat (OC), demand-based no chat (DNC), and demand-based with chat (DC), respectively, and zero otherwise. The standard errors are corrected for within session clustering effect. The statistical tests are based on the Wald test for the equality of the estimated coefficients of treatment dummies.

[3]$p = 0.0069$ and $p < 0.0001$ for without chat and with chat, respectively. Wald test.

[4]$p = 0.207$ and $p = 0.975$ for the demand-based and the offer-based protocols, respectively. Wald test.

Table 4: Summary statistics of semi-structured bargaining

Treatment	The duration[1]	The frequency of complete failure	The number of Proposals or demands[1]	The number of Messages[2]	The number of non-greeting Messages	The duration[3]	The time until the formation of the first coalition[3]
Demand-based	119.27	0.045	7.95			109.82	97.75
Without chat (No chat)	(14.58)	(0.029)	(0.33)			(9.74)	(6.25)
Demand-based	96.92	0.018	6.31	2.03	1.69	92.61	80.50
With chat (chat)	(8.63)	(0.010)	(0.33)	(0.69)	(0.71)	(9.02)	(11.46)
Offer-based	177.05	0.131	4.88			154.41	152.55
Without chat (No chat)	(11.33)	(0.013)	(0.24)			(11.02)	(11.47)
Offer-based	177.56	0.119	3.33	4.68	3.16	157.89	156.23
With chat (chat)	(11.34)	(0.023)	(0.13)	(1.33)	(0.62)	(13.57)	(13.97)
Num. Obs.	688	688	688	336	336	634	634
R^2	0.671	0.265	0.773	0.403	0.312	0.653	0.657

Note: Standard errors are corrected for session-level clustering effects and shown in parentheses.
1: Include those gruops that did not form any coalition (thus terminated by reaching the maximum duration)
2: Include greeting messages.
3: Do not include those gruops that did not form any coalition.

not statistically significant ($p = 0.1200$ and $p = 0.1619$ with and without greeting messages, respectively. Wald test). The complete failure of the negotiation is more frequently observed under the offer-based than the demand-based protocols,[5] and the possibilty of chat does not significantly affect the failure rate.[6]

The longer duration of a negotiation under the offer-based protocol is not just because there are more groups in which negotiation failed completely. Even among those groups where a coalition has been formed, the negotiation took longer under the offer-based than the demand-based protocols.[7] The same is true for the time it has taken before the first coalition being formed.[8]

The number of proposals made under the offer-based protocols is significantly smaller than the number of demands made under the demand-based protocols.[9] The possibility of chat significantly reduces the number of proposals or the demands made.[10] Both the number of demands and the proposals made are, however, large compared to what have been allowed in Winter and H–MC (maximum is 4) considered in Chessa et al. (2023b). One may expect that this difference in the number of demands or proposals made between the structured and semi-structured procedures would affect the outcomes. We now turn to analyzing the outcomes of the negotiation.

[5] $p = 0.0166$ and $p = 0.0013$ for without chat and with chat, respectively. Wald test.

[6] $p = 0.3834$ and $p = 0.6701$ for the demand-based and the offer-based protocols, respectively. Wald test.

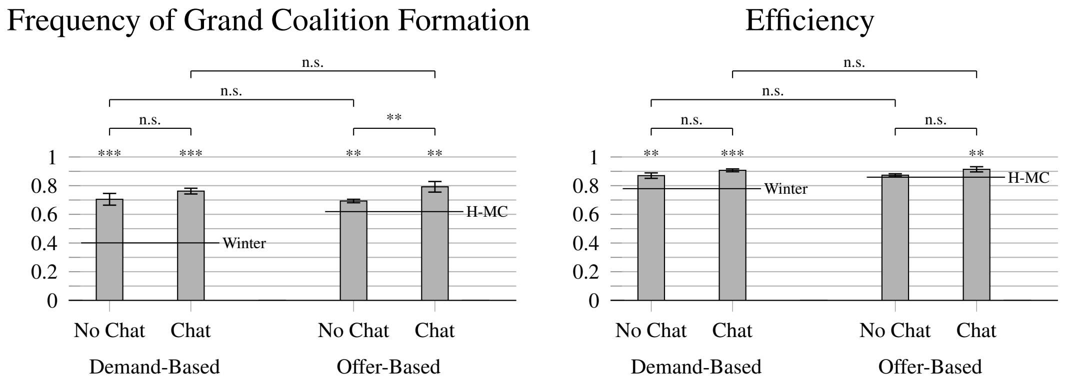
[7] $p = 0.0084$ and $p = 0.0011$ for without chat and with chat, respectively. Wald test.

[8] $p = 0.0008$ and $p = 0.0008$ for without chat and with chat, respectively. Wald test.

[9] $p < 0.0001$ and $p < 0.0001$ for without chat and with chat, respectively. Wald test.

[10] $p = 0.0030$ and $p = 0.0001$ for the demand-based and the offer-based protocols, respectively. Wald test.

Figure 1: All the games combined



Note: Error bars show one standard error range. Horizontal lines marked with Winter or H-MC indicate the outcomes of experiments on these two structured bargaining mechanisms reported in Chessa et al. (2023b). ***, **, and * indicates the outcome is significantly different from results of the Winter (demand-based) or H-MC (offer-based) at 0.1%, 1%, and 5% significance level, respectively (what is the test used?). The "n.s." indicate the absence of significant difference at 5% level between the two treatments compared.

3.1 Grand coalition formation and efficiency

We first compare the frequency of the grand coalition formation and the efficiency across four treatments. We also compare these outcomes with the results from the experiments on the structured bargaining mechanisms reported in Chessa et al. (2023b). Namely, the outcomes of a simplified version of the demand-based Winter mechanism (Winter, 1994) and those of a simplified version of the offer-based Hart and MasColell (H-MC) mechanism (Hart and Mas-Colell, 1996).

Figure 3 presents the frequency of the grand coalition formation (left) and the efficiency (right) of the four treatments. The efficiency is defined as the share of the sum of the points obtained by four players relative to the worth of the grand coalition. We pool the data from all the sessions and all the games.[11] The horizontal line with indi-

[11]The figure is created based on the estimated coefficients of the following linear regressions: $y_i = \beta_1 ONC_i + \beta_2 OC_i + \beta_3 DNC_i + \beta_4 DC_i + \beta_5 Winter_i + \beta_6 H - MC_i + \mu_i$ where y_i is a dummy variable that takes the value 1 if the grand coalition is formed, and zero otherwise, in group i, for the

cation of Winter and H-MC are the experimental results of these two non-cooperative mechanisms reported in Chessa et al. (2023b).

We reject the null hypothesis that the average frequency of the grand coalition formation is the same across four treatments ($p = 0.0004$, Wald test). We also reject the null hypothesis that the average efficiency is the same across four treatments ($p < 0.0001$, Wald test). The frequency of the grand coalition formation as well as the efficiency are slightly higher in the treatments with chat than those without, although the difference is significant at 5% only for the frequency of grand coalition formation in the offer-based protocols.[12] There is no significant difference between the offer-based and the demand-based protocols regardless of possibility of chat.[13]

The frequencies of the grand coalition formation are significantly higher under the semi-structured bargaining protocols, both with and without chat, than under Winter (for the demand-based) and H-MC (for the offer-based) mechanisms.[14] While the efficiencies are also significantly higher under the semi-structured demand-based protocol than under Winter mechanism,[15] the difference is significant at 5% level only between the semi-structured offer-based protocols with chat and H-MC mechanism.[16] These results

grand coalition formation and $y_i = \frac{\sum_j \pi_j}{\nu(N)}$ for the efficiency, $Winter_i$, and $H - MC_i$ are dummy variables that take value 1 if the treatment is winter, and H-MC, respectively, and zero otherwise. Other treatment dummies are the same as the one explained above. The standard errors are corrected for within session clustering effect. The statistical tests are based on the Wald test for the equality of the estimated coefficients of treatment dummies.

[12]For the frequency of the grand coalition formation, $p = 0.2433$ for the demand-based, $p = 0.0115$ for the offer-basedt, Wald test. For the efficiency, $p = 0.1723$ for the demand-based , $p = 0.0608$ for the offer-based, Wald test.

[13]For the frequency of the grand coalition formation, $p = 0.8228$ without chat, $p = 0.3686$ with chat. For the efficiency, $p = 0.8780$ without chat, $p = 0.5244$ with chat.

[14]$p = 0.0001$, Winter (=0.401, s.e.=0.0339) vs the demand-based without chat, $p < 0.0001$, Winter vs the demand-based with chat, $p = 0.0082$ H-MC (0.619, s.e.=0.0196) vs the offer-based without chat, and $p = 0.0016$ H-MC vs the offer-based with chat. All are based on Wald tests.

[15]$p = 0.0075$, Winter (=0.779, s.e.=0.0198) vs the demand-based without chat, and $p = 0.0001$, Winter vs the demand-based with chat, based on Wald test.

[16]$p = 0.2235$, H-MC (0.859, s.e.=0.0057) vs the offer-based without chat, and $p = 0.0142$ H-MC vs the offer-based with chat, based on Wald test.

are in line with Kahan and Rapoport (1980) establishing that the type of communication (allowing or not the sending of messages) does not affect significantly the frequency of coalition structures.

3.2 Allocations

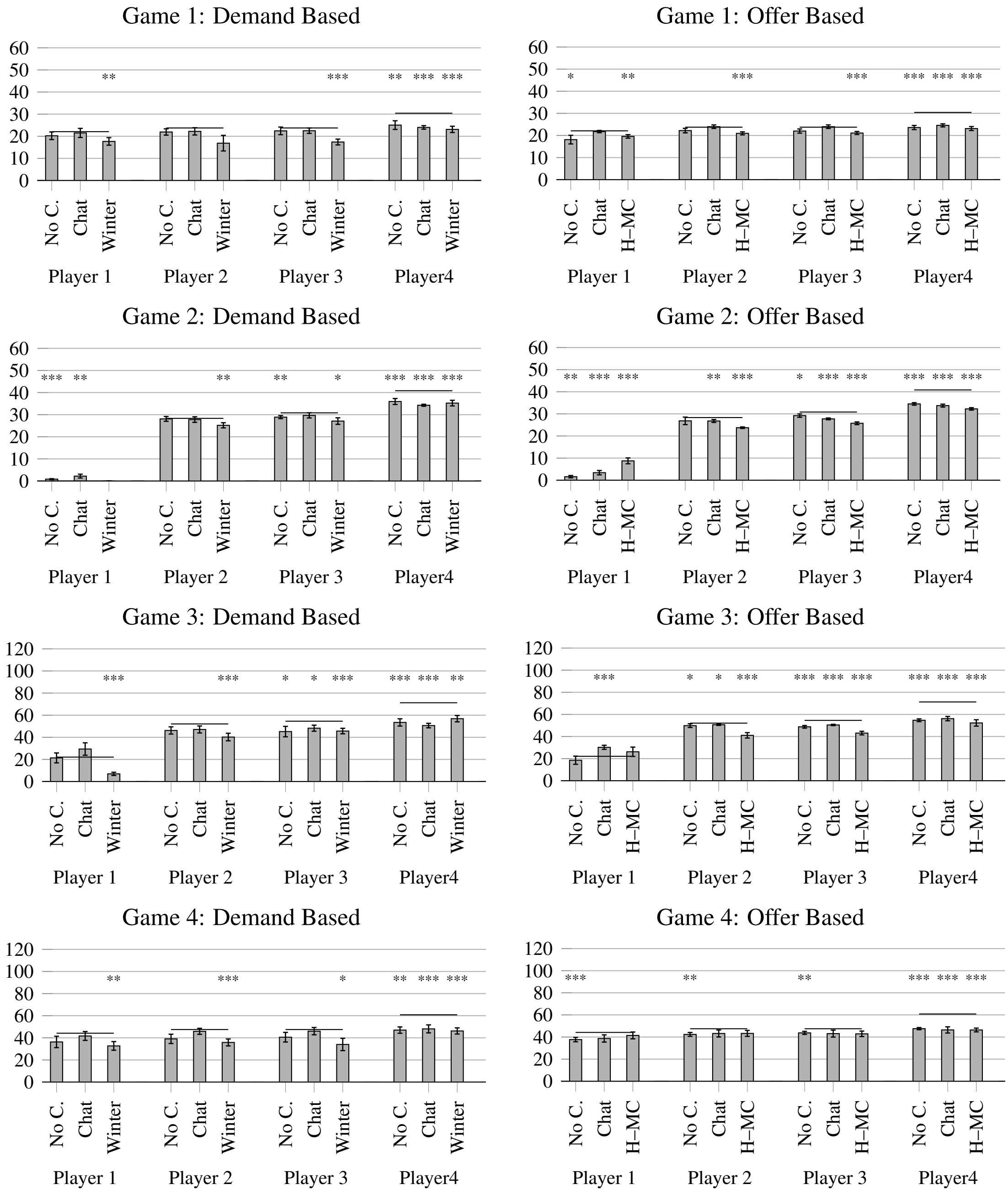
Figure 2 shows the mean payoffs for each player in four games. Treatments are divided into those demand-based (without chat (No C.), with chat (chat), and Winter) and those offer-based (without chat (No C.), with chat (chat), and H-MC). The horizontal lines indicate the Shapley values for each player in each game. The mean and the standard errors are obtained by running a set of ordinary least squares (OLS) regressions for the following system of equations for each treatment separately:

$$\begin{aligned}\pi_1 &= a_1 g_1 + a_2 g_2 + a_3 g_3 + a_4 g_4 + u_1 \\ \pi_2 &= b_1 g_1 + b_2 g_2 + b_3 g_3 + b_4 g_4 + u_2 \\ \pi_3 &= c_1 g_1 + c_2 g_2 + c_3 g_3 + c_4 g_4 + u_3 \\ \pi_4 &= d_1 g_1 + d_2 g_2 + d_3 g_3 + d_4 g_4 + u_4\end{aligned} \tag{1}$$

where π_i is the payoff of player i, g_j is a dummy variable that takes a value of 1 if the game $j \in \{1, 2, 3, 4\}$ is played, and zero otherwise. Because participants play all four games twice, we correct the standard errors for within-group clustering effects. Note that the estimated coefficients a_j, b_j, c_j, and d_j are the average payoffs in game j for players 1, 2, 3, and 4, respectively.

Because the frequency of grand coalition formation is significantly lower under Winter and H–MC, compared to semi-structured protocols, we observe that the average payoffs tend to be lower under Winter and H–MC than semi-structured ones. As a result, the average payoffs deviate significantly from the Shapley values for more players in

Figure 2: Mean payoffs for each player in each treatment



Note: the horizontal lines indicate the Shapley values. Error bars show one standard error range. ***, **, and * indicate the average payoff being significantly different from the Shapley value at 0.1, 1, and 5 % significance level (Wald test).

more games under the structured experiment than under the semi-structured one.

Furthermore, there is a notable difference in terms of the average payoff of the null player, i.e., player 1 in game 2, between the structured and semi-structured experiment. On one hand, in Winter, the average payoff of the null player was zero and equal to the Shapley value. On the other hand, in H–MC, the average payoff of the null player is much higher. The average payoffs of the null player under the semi-structured experiments are between Winter and H–MC, and is higher when chat is possible. As we will see next, the null player property tend to fail by a larger extent under the offer-based experiment than under the demand-based experiment regardless of whether it is structured (Winter vs H–MC as shown by Chessa et al., 2023b) or semi-structured, although the differece is smaller in the latter. We now investigate the sources of the deviation of the realized allocation of the Shapley value.

3.3 Shapley distance

We apply the approach of Aguiar et al. (2018) to decompose the deviation of the realized allocation from the Shapley value[17] into the failure of efficiency, symmetry, additivity, and null player property.[18] The same method of decomposition is used in Chessa et al. (2022, 2023a,b) in their experiments on non-cooperative mechanisms. Although the procedure is presented in these papers, in order to be self-contained, we re-present the procedure.

Let π be the realized allocation (i.e., vector of payoffs) in a game. First, we find an

[17]Rapoport (1987) considers alternative metrics to measure the distance between payoff vectors and solution concepts such as the Bonacich's error measure (Bonacich, 1979) and the net rate of success (Selten and Krischker, 1983).

[18]Aguiar et al. (2018) decompose the deviation into the failure of efficiency, symmetry, and marginality. While these three components are orthogonal to each other, in our decomposition, the failure due to additivity and null player property are not orthogonal.

allocation, π^{sym}, that satisfies the symmetry and is closest to π. We do so by summing the payoffs obtained by symmetric players s (players 2 and 3 in games 1 and 4) and divide it equally among them. That is, in games 1 and 4, $\pi_s^{sym} = \sum_{s \in \{2,3\}} \pi_s/2$. For other players k, $\pi_k^{sym} = \pi_k$.

Second, we find a new allocation, $\pi^{sym,eff}$, that satisfies efficiency and is closest to π^{sym}. For each player $i = 1, 2, 3, 4$, $\pi_i^{sym,eff} = \pi_i^{sym} + [v(N) - \sum_{j \in N} \pi_j]/4$.

Third, we find yet another allocation, $\pi^{sym,eff,null}$, that satisfies null player property and is closest to $\pi^{sym,eff}$. For a null player n (player 1 in game 2), $\pi_n^{sym,eff,null} = 0$. And for other players j in the game, $\pi_j^{sym,eff,null} = \pi_j^{sym,eff} + \pi_n^{sym,eff}/3$. That is, three other players in the game equally share $\pi_n^{sym,eff}$ of the null player. If there is no null player, $\pi_i^{sym,eff,null} = \pi_i^{sym,eff}$ for all i.

Let $e_i^{sym} = \pi_i - \pi_i^{sym}$, $e_i^{eff} = \pi_i^{sym} - \pi_i^{sym,eff}$, $e_i^{null} = \pi_i^{sym,eff} - \pi_i^{sym,eff,null}$, and $e_i^{add} = \pi_i^{sym,eff,null} - \phi_i(v)$ for all i.

Aguiar et al. (2018, Theorem 3) shows that an allocation π from game v can be decomposed as $\pi = \phi(v) + e^{sym} + e^{eff} + e^{null} + e^{add}$. Therefore, the Shapley error, $e^{\phi} = \pi - \phi(v)$, is $e^{\phi} = e^{sym} + e^{eff} + e^{null} + e^{add}$, and the Shapley distance, $||e^{\phi}||^2$, can be decomposed into

$$||e^{\phi}||^2 = ||e^{sym}||^2 + ||e^{eff}||^2 + ||e^{null}||^2 + ||e^{add}||^2 + 2 < e^{add}, e^{null} >$$

where $< \cdot, \cdot >$ is the scalar product and for any vector $y \in \mathbb{R}^n$, $||y||^2 =< y, y >= \sum_{i \in N} y_i^2$. As noted above, in general, vectors e^{null} and e^{add} are not orthogonal so that $< e^{add}, e^{null} >$ is not equal to zero. Its magnitude, however, is much smaller than the remaining components in our experimental data.

We perform the Shapley distance decomposition of each realized allocation and the

Table 5: Result of Shapley distance decomposition. Based on pooling the data of all groups and all games

	$\|\|e^{sym}\|\|^2$	$\|\|e^{eff}\|\|^2$	$\|\|e^{null}\|\|^2$	$\|\|e^{add}\|\|^2$	$\|\|e^{\phi}\|\|^2$
Demand-Based	16.03	448.09	7.03	216.50	687.59
No chat	(5.29)	(127.33)	(1.37)	(20.29)	(145.27)
Demand-Based	10.53	241.08	19.45	281.07	552.09
With chat	(4.96)	(76.67)	(6.34)	(28.56)	(98.00)
Offer-Based	7.98	478.02	13.49	164.30	663.74
No chat	(1.78)	(74.28)	(2.73)	(11.71)	(64.54)
Offer-Based	0.07	363.13	25.64	211.55	600.37
With chat	(0.07)	(119.73)	(6.94)	(13.49)	(115.54)
Winter	85.18	606.81	7.28	321.49	1020.68
	(18.55)	(99.11)	(1.83)	(14.95)	(70.63)
H-MC	38.19	429.96	63.97	270.84	802.88
	(12.45)	(52.23)	(8.08)	(20.25)	(61.32)
No. Obs	1040	1040	1040	1040	1040
R^2	0.121	0.146	0.079	0.343	0.300
p-value*	0.0047	0.0068	0.0000	0.0000	0.0007

Note: Standard errors are corrected for session-level clustering effects and shown in parentheses. $< e^{add}, e^{null} >$ are not reported in the table as they are negligible (the mean values are 0.0020, 0.0031, 0.0039, 0.0046, 0.0026, 0.0093 for demand-based no chat, demand-based with chat, offer-based no chat, offer-based with chat, Winter, and H–MC, respectively.).
*: The null hypothesis is the estimated coefficients of four treatment dummies (excluding Winter and H-MC) are the same (Wald test).

corresponding Shapley value, and compute the average distance, pooling data of all groups and all games, to compare across four treatments by regressing each of them onto four treatment dummies (without constant).[19] Results of the regressions are presented in Table 5.

[19]Namely, we run the following regressions $||e_i||^2 = \beta_1 ONC_i + \beta_2 OC_i + \beta_3 DNC_i + \beta_4 DC_i + \beta_5 Winter_i + \beta_6 H - MC_i + \mu_i$ where $||e_i||^2$ is the decomposed distance in group i, ONC_i, OC_i, DNC_i, DC_i, $Winter_i$, $H - MC_i$ are dummy variables that take value 1 if the treatment is offer based no chat (ONC), offer based with chat (OC), demand based no chat (DNC), demand based with chat (DC), Winter, and H-MC, respectively, and zero otherwise. The standard errors are corrected for within session clustering effect. The statistical tests are based on the Wald test for the equality of the estimated coefficients of treatment dummies.

Table 6: p-values for pair-wise comparisons

$||e^{sym}||^2$

Test	p-value
Demand, No Chat vs Demand, With Chat	0.323
Offer, No Chat vs Offer, With Chat	0.867
Demand, No Chat vs Offer, No Chat	0.361
Demand, With Chat vs Offer, With Chat	0.859
Demand, No Chat vs Winter	0.220
Demand, With Chat vs Winter	**0.041**
Offer, No Chat vs H–MC	0.552
Offer, With Chat vs H–MC	0.550

$||e^{eff}||^2$

Test	p-value
Demand, No Chat vs Demand, With Chat	0.131
Offer, No Chat vs Offer, With Chat	0.441
Demand, No Chat vs Offer, No Chat	0.859
Demand, With Chat vs Offer, With Chat	0.309
Demand, No Chat vs Winter	0.346
Demand, With Chat vs Winter	**0.014**
Offer, No Chat vs H–MC	0.607
Offer, With Chat vs H–MC	0.619

$||e^{null}||^2$

Test	p-value
Demand, No Chat vs Demand, With Chat	0.135
Offer, No Chat vs Offer, With Chat	0.078
Demand, No Chat vs Offer, No Chat	**0.003**
Demand, With Chat vs Offer, With Chat	0.637
Demand, No Chat vs Winter	0.913
Demand, With Chat vs Winter	0.092
Offer, No Chat vs H–MC	**0.0001**
Offer, With Chat vs H–MC	**0.0042**

$||e^{add}||^2$

Test	p-value
Demand, No Chat vs Demand, With Chat	0.102
Offer, No Chat vs Offer, With Chat	0.063
Demand, No Chat vs Offer, No Chat	**0.035**
Demand, With Chat vs Offer, With Chat	0.107
Demand, No Chat vs Winter	**0.0022**
Demand, With Chat vs Winter	0.249
Offer, No Chat vs H–MC	**0.0008**
Offer, With Chat vs H–MC	**0.0330**

$||e^{\phi}||^2$

Test	p-value
Demand, No Chat vs Demand, With Chat	0.364
Offer, No Chat vs Offer, With Chat	0.627
Demand, No Chat vs Offer, No Chat	0.891
Demand, With Chat vs Offer, With Chat	0.699
Demand, No Chat vs Winter	0.064
Demand, With Chat vs Winter	**0.0026**
Offer, No Chat vs H–MC	0.146
Offer, With Chat vs H–MC	0.150

Column $||e^{\phi}||^2$ of Table 5 shows that the Shapley distance is lower under the semi-structured bargaining than Winter or H–MC. As one can observe from Table 6, however, among these differences between semi-structured and structured protocol, the difference between the demand-based with chat and Winter is only statistically significant at 5% level. Tables 5 and 6 further shows that this significant difference of $||e^{\phi}||^2$ between the demand-based with chat and Winter is due to the significant difference in $||e^{sym}||^2$ and $||e^{eff}||^2$.

Other significant differences between semi-structured experiments and structured ones are $||e^{null}||^2$ and $||e^{add}||^2$ between offer-based protocol (with and without chat) and H–MC. As we have seen in Figure 2, the average payoffs of the null player was particularly high in H–MC, compared to the other treatments. Chessa et al. (2023b) conjectured this to be caused by proposers trying to avoid their proposal to be rejected by the null player. Indeed, in the version of H–MC considered in Chessa et al. (2023b), it was not possible for the proposer to propose a coalition excluding the null player unless the null player has been removed from the game already. In the offer-based protocol, it is possible for non-null players to propose such a coalition without fear of the null player rejecting it. The possibility of chat makes is more likely for the null player property to be violated both under the demand-based and the offer-based protocols although the differences, from the treatment without chat, are not statistically significant.[20]

3.4 The bargaining set

Many social scientists have focused on experimentally validating conflict theories using the cooperative game representation, with a particular emphasis on a set of solutions re-

[20]In the same vein,Kahan and Rapoport (1980) demonstrated that the presence or absence of messages (conditions R and N in their paper, respectively) affects their discrepancy score index from the bargaining sets defined as the mean absolute deviation of each player's payoff in a winning coalition from his quota.

ferred to as bargaining set (Aumann and Maschler, 1964). According to the bargaining set theory, each resolution to conflict problems specifies a set of payoff vectors, each element of which is stable in a psychologically interpretable sense, allowing legitimate counter-threats to address any threats made by one player against another within the same coalition. Several experiments have substantiated the significant success of bargaining set theory in accurately predicting payoff vectors in three-person games (see, for example, Kahan and Rapoport (1974); Medlin (1976); Rapoport and Kahan (1976); Murnighan and Roth (1977); Levinshon and Rapoport (1978), among others). In the case of games involving more than three players, particularly in the context of four-player apex games, Funk et al. (1980) experimentally validated the predictive capacity of bargaining sets, contrasting them with alternative solution concepts like the kernel. Likewise, Rapoport and Kahan (1984) illustrated the significance of bargaining set predictions in experiments featuring five-player market games.

In this paper, we employ a methodology similar to that of the previously mentioned studies to assess the validity of the prediction of the bargaining set between semi-structured experiments and structured ones applied to the four-player convex games introduced in Section 2. Notably, in these games, the bargaining set (Aumann and Maschler, 1964) coincides with the kernel (Davis and Maschler, 1965) and the core (Gillies, 1959).[21]

Before presenting the analysis, we provide some definitions. Let (N, v) be a cooperative game. Let $x \in \mathbb{R}^n$ be an imputation, i.e., a payoff vector such that $\sum_{k \in N} = v(N)$, and for each $k \in N$ $x_k \geq v(\{k\})$. Let i and j be two distinct players in N. An objection of i against j at x is a pair (C, y) satisfying: *(i)* $C \subset N$, $i \in C$, $j \notin C$; *(ii)*

[21] Similarly, in the context of the three-player games studied by Kahan and Rapoport (1980), when considering the α-power model, the bargaining set, the kernel and the core all coincide at the point $\alpha = 0$.

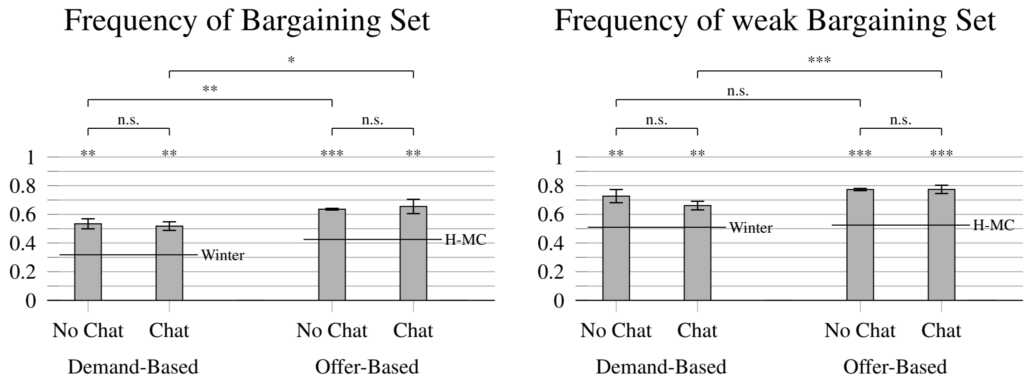
$\sum_{k \in C} y_k = v(C)$; *(iii)* $y_k \geq x_k$ if $k \in C$. Given a game (N, v) and an imputation x, let (C, y) be an objection of i against j at x, with i, j distinct players in N. A counter-objection of j against i at y is a pair (D, z) satistying: *(i)* $D \subset N$, $j \in D$, $i \notin D$; *(ii)* $\sum_{k \in D} z_k = v(D)$; *(iii)* $z_k \geq y_k$ is $k \in C \cap D$; *(iv)* $z_k \geq x_k$ if $k \in D \setminus C$.

The bargaining set is the set of imputations that have no justified objection, i.e., whose objections that always have counter-objections.

Let π be a realized allocation (i.e., vector of payoffs) in one of our games. We first compare how frequently these payoff vectors belong to the bargaining set across four treatments. We also consider a weak bargaining set, in which we relax the hypothesis of efficiency (this to allow to take into account also the payoff vectors when the grand coalition did not form). We also compare these outcomes with the results from the experiments on the structured bargaining mechanisms reported in Chessa et al. (2023b). Figure 3 presents the frequency of a payoff vector belonging to the bargaining set, according to the standard definition (on the left) and in its weak version in which we relax efficiency (on the right) of the four treatments. We pool the data from all the sections and all the games. The horizontal line with indication of Winter and H-MC are the analogous experimental results of the two non-cooperative mechanisms implemented in Chessa et al. (2023b).

We reject the null hypothesis that the average frequency of belonging to the bargaining set is the same across four treatments, both for the standard bargaining set definition, and for its weak version ($p < 0.0001$, Wald test, in both cases). The frequencies of the belonging to the bargaining set are higher for the offer-based treatments. We report a significant difference both when restricting to treatments with chat ($p = 0.01394$, Wald test) and to treatments without chat ($p = 0.0060$, Wald test), for the standard bargaining set, and a significant difference when restricting to treatments with chat ($p < 0.0001$,

Figure 3: All the games combined



Note: Error bars show one standard error range. Horizontal lines marked with Winter or H-MC indicate the outcomes of experiments on these two structured bargaining mechanisms reported in Chessa et al. (2023b). ***, **, and * indicates the outcome is significantly different from results of the Winter (demand-based) or H-MC (offer-based) at 0.1%, 1%, and 5% significance level, respectively (what is the test used?). The "n.s." indicate the absence of significant difference at 5% level between the two treatments compared.

Wald test), for the weak bargaining set. The frequencies of belonging to the bargaining set, both for the classical and the weak version of the bargaining set are significantly higher under the semi-structured bargaining protocols, both with and without chat, than under Winter (for the demand-based) and H-MC (for the offer-based) mechanisms.[22]

4 Concluding remarks

This paper aims to contribute to the literature on Nash program (Nash, 1953) by experimentally comparing the results of "structured" (non-cooperative) and "semi-structured" (cooperative) bargaining experiments. In particular, it contrasts the experimental outcomes of two non-cooperative mechanisms that implement the Shapley value (Shapley,

[22]For the classical bargaining set: Demand No Chat vs. Winter ($p = 0.0013$), Demand Chat vs. Winter ($p = 0.0014$), Offer No Chat vs. H-MC ($p < 0.0001$), Offer Chat vs. H-MC ($p = 0.0024$). For the weak bargaining set: Demand No Chat vs. Winter ($p = 0.0040$), Demand Chat vs. Winter ($p = 0.0099$), Offer No Chat vs. H-MC ($p = 0.0001$), Offer Chat vs. H-MC ($p = 0.0006$). All based on Wald test.

1953) as an ex-ante equilibrium outcome considered in Chessa et al. (2023b), simplified versions of the demand-based mechanism proposed by Winter (1994) and the offer-based mechanism proposed by Hart and Mas-Colell (1996), with those of the corresponding, but much less structured, cooperative bargaining procedure.

We found that semi-structured bargaining procedure resulted in significantly higher frequency of the grand coalition formation, the higher efficiency, and the higher frequency of allocations belonging to the bargaining set than the structured ones. This is partly because participants are able to try out much more proposals or demands during a negotiation in the former than the latter. Yet, this also suggests that one should consider seriously the potential effects of various restrictions, in terms of who can do what and when, imposed by various non-cooperative mechanisms on the outcomes if to advance the Nash program while taking various behavioral biases and cognitive limitations into account.

We also found significant differences in terms of the duration of the negotiations or the likelihood of complete failure of the negotiation such that no coalition is being formed between the offer-based and the demand based semi-structured protocols. However, unlike the sharp differences between the outcomes of the demand-based and the offer-based structured bargaining reported by Chessa et al. (2023b) in terms of the frequency of the grand coalition formation, the efficiency, and the way realized allocations deviate from the Shapley value, no significant differences between the demand-based and the offer-based semi-structured bargaining procedure in these dimensions except that the null player property and additivity are violated by a larger extent under the latter than the former when there is no chat. In terms of the design of bargaining experiments, this results is encouraging because it suggests that when the participants are less constrained in terms of the timing and the number of times they can act, the outcomes of the negotiations become similar regardless of whether the protocol is an offer-based or a demand-based.

In our experiment used only the four games considered by Chessa et al. (2022, 2023a,b). Future studies should consider more varieties of games to better understand the possible impacts of various behavioral biases, such as fairness consideration and loss aversion, in advancing Nash program while incorporating the fruits of the advances in the behavioral and experimental economics.

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A Instructions

English translation of instructions (of the game and of the experimental software) as well as comprehension quiz are available at `https://osf.io/kqw6n/?view_only=ea41e1284a1347d09760fba82fda37ea`

File names starting with demand-based are for the demand-based treatments, and those starting with offer-based are for the offer-based treatments.