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Abstract

In the cooperative game theory, we study only how to distribute payoffs by assuming that the grand coalition is formed. However, in real bargaining situation, the payoff distribution is considered with the coalition formation simultaneously. The players can make not only the grand coalition but also smaller coalitions. Also, they have to reach an agreement on just one payoff distribution. In order to know what happens in this situation, we design and run a laboratory experiment. As experimental results, we find the following things. First, the grand coalition is more likely to be formed when the core is non-empty than empty. Availability of the chat window is also positively correlated with formation of the grand coalition. Second, the payoff distribution the subjects agree with is depending on their power in bargaining. Unlike the others' bargaining experiment, the equal division is not very frequently adopted.

Keywords: laboratory experiment, cooperative game, coalition formation, payoff distribution, bargaining

JEL Classification: C71, C92

1 Introduction

The cooperative game theory studies how to distribute payoffs gained by a group of players to its members. Our great predecessors have made mathematical formulae called *solutions* that indicate how much each member of the group should get. They are usually evaluated by axiomatic characterization, in which we can see what properties they uniquely satisfy. We have many solutions, which means that there are a lot of possibilities of sharing the payoff.

However, in the real world, we usually have to choose only one of the solutions. Moreover, we may even choose one that is different from them.

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Which one should we choose? Which one is the most acceptable for those who are not familiar with the theory? The theory does not give us any answers. In order to answer these questions, we design and run a laboratory experiment where subjects are in groups of three to negotiate with each other about how to share the payoff. One of the purposes of this experiment is to simulate the so-called *payoff distribution* problem.

Another problematic point of the theory is that it focuses only on payoff distribution. According to many textbooks of the basic theory, it first assumes that every player of the game cooperates with all the others when the game is superadditive. All solutions of cooperative games are based on this assumption. However, is this convincing? Does it not occur that some players prefer forming a smaller coalition and sharing the payoff in it? In order to give an answer, experimental subjects can form not only the grand coalition but also smaller coalitions. This kind of problem is called *coalition formation* problem. Payoff distribution should not be separated from coalition formation especially in a situation where players do not have to form the grand coalition. The main purpose of this experiment is to see if the theory may assume formation of the grand coalition.

Although the value of the coalitions in our experiment is the same as the ones in Nash et al.[2], our experiment uses a totally different bargaining protocol. Their experimental protocol is rather non cooperative than cooperative, and they divide a round into three phases. In the first and the second phase, subjects are in groups of three and decide a splitter by giving his or her right to split to another subject. These phases are regarded as coalition formation. If the splitter is given the right by the others, it means the grand coalition is formed. On the other hand, he or she is given the right by another subject, it means a two-person coalition is formed. Then in the third phase, the splitter decides how to divide the value of the formed coalition. There is no restriction of his or her division and no chance for the others to reject it. In other words, he or she can even get as much as the value of the formed coalition. As a result of their experiment, they reported that almost all of the groups formed the grand coalition. They also reported that they observed the equal split frequently. Why did the splitter not take all? That might be because they used partner matching and the subjects played the same role throughout the session. The subjects might have thought that if they took all in one round, then they would not be chosen as the splitter after that round. Our study does not employ their protocol and uses stranger matching, so the experimental result should change.

We also refer to Vyrastekova et al.[8] in which they ran an experiment of the five-person cooperative game in the context of a social dilemma game. Their experimental protocol is, unlike that of Nash et al.[2], rather similar to that of our study. Each subject makes an offer about coalition formation and payoff distribution, and there is no order to offer. After one offer is proposed, those who are not included in the proposed coalition are given a chance to make a counteroffer. Repeating offers and counteroffers, the subjects reach an agreement with one offer by acceptance of all members in the proposed coalition. Their protocol is rather cooperative than noncooperative because once one offer is agreed upon and executed, its members cannot deviate from it. As an experimental result, they reported that the subjects formed the grand coalition most frequently and the equal split was employed quite often.

In both experiments, the equal split was frequently observed and the grand coalition was most likely to be formed. However, these results are caused by their experimental protocols. Therefore, even a slight difference of the protocol can change its experimental results.

2 Preliminaries

2.1 Cooperative Game

Let a pair (N, v) be a *game* with transferable utility and Γ denote the set of all games. The set $N = \{1, 2, ..., n\}$ denotes a finite player set and v is a characteristic function that assigns a real number $v(S)$ to each coalition $S \subseteq N$. $v(S)$ is called a *value of coalition* S.[1]

Also, let $x = (x_1, x_2, ..., x_n) \in \mathbb{R}^n$ be a *payoff vector* that indicates who gets how much. A *solution* of game $\varphi(N, v)$ is a function which assigns an n-dimensional vector to each game $(N, v) \in \Gamma$.

2.2 Superadditivity and the Core

First, we define superadditivity, which is a fundamental property of games.

Definition 1. *A game (N, v) is superadditive if it satisfies*

$$v(S \cup T) \geq v(S) + v(T) \quad \forall S, T \subseteq N \quad S \cap T \neq \emptyset.$$

Superadditivity implies that if two disjoint coalitions merge, its value is not less than the sum of their respective values. Superadditivity is essential when we assume that cooperation is efficient. Let Γ^{SA} denote the class of superadditive games.

Solutions of cooperative games can be classified into two types: one is a set solution, and the other is a one-point solution. The core $C(N, v)$ defined as follows is the most basic one of the set solutions.

Definition 2. *Let $C(N, v)$ denote the core, which is as follows:*

$$C(N, v) = \{x \in \mathbb{R}^n | \sum_{i \in S} x_i \geq v(S) \quad \forall S \subseteq N, \sum_{i \in N} x_i = v(N)\}.$$

[1] $v(\emptyset) = 0$.

The definition of the core consists of the two conditions. The former is called *coalitional rationality*, which means that the total payoff of the members of every coalition is greater or equal to its value. If it is not satisfied, there exists a coalition which can be better off by deviation from the grand coalition. From this point of view, the core is said to be *stable*. The latter condition is called *efficiency*, which implies that the value of the grand coalition is allocated to the players with no leftover or excess.

The core is not always non-empty. A game with the non-empty core is called a *balanced game*. Let Γ^B denote the class of balanced games. There is a logical relationship between Γ^{SA} and Γ^B, that is $\Gamma^B \subset \Gamma^{SA}$. It means that if a game has the non-empty core, then it is superadditive, and that there is a game that is superadditive but has an empty core.

2.3 Research Interests

As written in many textbooks of the basic theory, it is usually assumed that the grand coalition is formed in all superadditive games to concentrate on studying the payoff distribution problem. This is the reason almost all of the one-point solutions satisfy efficiency. However, is this assumption convincing? In other words, does it truly happen that every player cooperates with each other whenever the game is superadditive? An empty core implies that for any payoff vector $x \in \mathbb{R}^n$, there exists a coalition $S \subset N$ whose excess $e(S, x)$ is positive. This means that the coalition S has an incentive to deviate from the grand coalition. From this point of view, it seems to be acceptable to suppose that superadditivity is not a sufficient condition to induce the grand coalition. Then what condition can induce the grand coalition?

If a game has the non-empty core, it implies that no coalition can be better off by deviation from the grand coalition. Therefore, it seems to be reasonable to think that players will make the grand coalition in balanced games and they will also make an agreement with a payoff vector that is an element of the core. In other words, the non-empty core, balancedness, is supposed to induce the grand coalition. Hence, our experimental hypothesis is as follows and this is the first research interest.

Hypothesis 1. *If a game has the non-empty core, then experimental subjects are more likely to make the grand coalition than when a game has an empty core.*

The other research interest is to see which payoff vector the players agree with. The theory does not give us any answers. The Shapley value, for example, does not seem to be achieved by those who are not familiar with the theory. If another payoff vector is more frequently agreed with by them, it would be said to be more acceptable for them. Also, since the theory is based on the assumption of forming the grand coalition, there is no solution of payoff distribution of smaller coalitions. If players make not the grand coalition but smaller coalitions, then we need to see how they share the payoff.

The assumption of forming the grand coalition seems to separate the payoff distribution problem from the coalition formation problem. Moreover, it seems to be saying that players cooperate with each other to get as many as the value of the grand coalition first, and after that they begin to discuss how to share it. Is this reasonable? Do they cooperate with each other without discussing payoff distribution? We can and should confirm whether the theory may assume their cooperation by observing people's behavior on the laboratory experiment.

3 Experiment

3.1 General Settings

In order to prove that our hypothesis is correct, we designed and ran a laboratory experiment. We conducted eight sessions at Waseda University from November, 2016 to June, 2017 by using z-Tree (Fischbacher[1]), a computer program for running experiments. Each session consists of a practice round and 10 paying rounds. We employed 30 students of the university from various majors as subjects for each session. They were divided into 10 groups consisting of 3 students and the members of a group were randomly decided by the computer. They were not able to identify who belonged to his or her group. To make them surely understand the rules of the experiment, we asked them not only to read an experimental instruction with looking at a screenshot of the bargaining stage, but to play a practice round with the instruction before the paying rounds.

3.2 Procedure

At the beginning of each round, the subjects were randomly given a role of a manager of virtual firms A, B or C. They are going to carry out a project which can be done not only by cooperation of three or two firms but a sole firm. They were also given accurate information about profits, i.e. they precisely knew the value of the coalitions. After that, the bargaining stage starts. In this stage, the subjects make offers to each other. The offers involve the following two factors: one is coalition formation and the other is payoff distribution. Assume that you are the manager of firm A, then you have three options on coalition formation, i.e. the grand coalition, coalition AB or coalition AC. Also, assume that you would like to make coalition AB, then you have to input how to distribute the profit to you and B with nonnegative integers. You also must make the sum of the distributed profits equal to the value of the coalition, i.e. $v(AB)$. After that, the offer will be sent by clicking the OFFER button on the computer screen.

All the players can make offers whenever they want to, but they cannot make more than one offer at the same time. Those who want to make a new offer must cancel their previous offer unless it has been rejected by others. After cancellation of the offer, the proposer becomes able to make a new offer immediately. When the others make an offer, it appears on the computer screen even if you are not included in the proposed coalition. If you are included in the proposed coalition, you choose accepting or rejecting the offer. Rejection is available soon after proposal, while we made restriction on acceptance. Those who want to accept an offer must wait for fifteen seconds after the proposal. We made it possible for the subjects to make a counteroffer. Suppose that you are the manager of firm C, and firm A has just proposed an offer which suggests coalition AB. If it reaches an agreement, you will get 0 from that round because you will be regarded to do the project solely. This is the reason we thought we should make an interval for making a counteroffer.

An offer reaches an agreement if it is accepted by all players who are included in the proposed coalition. For example, firm A's offer of the grand coalition needs to be accepted by firm B and C to reach an agreement. On the other hand, firm C's offer of coalition BC can reach an agreement by only firm B's acceptance because firm A is not included in the proposed coalition. When an offer reaches an agreement, the profits will be distributed according to the offer and that round will end. If no offer reaches an agreement and the subjects use up five minutes, they will be regarded to do the project respectively, so all members of the group will get 0 from that round.

The subjects can negotiate with each other not only by offers, acceptance and rejection, but also by using the chat window in the bargaining stage. They can freely type their messages onto it to communicate with each other. We put it in order to make it possible for them to share their ideas of bargaining.

After 10 paying rounds, their total points are exchanged for JPY with the following rate and paid to the subjects: 1 point equals 3 JPY. Also, 800 JPY of the show-up fee was paid to all the participants.

3.3 Value of Coalition

The subjects are told that the value of the two-person coalitions differs in each round. $v(N) = 120$ and $v(A) = v(B) = v(C) = 0$ in every round, so we focus on $v(AB), v(AC)$ and $v(BC)$ here. We decided to employ the same value of the coalitions as ones used in Nash et al.[2]. The following is a table of the value of the two-person coalitions.

Note that all games are superadditive and games 1-5 are not balanced. On the contrary, games 6-10 are balanced, which means there is the non-

Game	$v(AB)$	$v(AC)$	$v(BC)$	Core
1	120	100	90	empty
2	120	100	70	empty
3	120	100	50	empty
4	120	100	30	empty
5	100	90	70	empty
6	100	90	50	nonempty
7	100	90	30	nonempty
8	90	70	50	nonempty
9	90	70	30	nonempty
10	70	50	30	nonempty

Table 1: the value of the two-person coalitions (Nash et al.[2])

empty core. We can easily check balancedness of these games by seeing whether the following inequality holds:

$$v(AB) + v(AC) + v(BC) \leq 2v(N) = 240.$$

If our experimental hypothesis is correct, the subjects are more likely to make the grand coalition in games 6-10 than games 1-5.

Also, note that power of the players is not symmetric in all games: A is the strongest, B is the second and C is the weakest. Most one-point solutions reflect their power and if the subjects also take it into account, then their agreed payoff vector $x = (x_A, x_B, x_C)$ should satisfy the following inequality: $x_A \geq x_B \geq x_C$.

3.4 Treatments

We ran four treatments to check if there are the following things: the effect of the chat window and the order effect. In T1 (baseline treatment) and T2 the subjects can use the chat window, while in T3 and T4 they cannot. It is possible that availability of the chat window affects coalition formation and payoff distribution. Also, in T1 and T3 they played game 1 first, game 2 second, ..., and game 10 finally. On the other hand, in T2 and T4 they played game 10 first, game 9 second, ..., and game 1 finally. It is also possible that subjects' learning affects coalition formation and payoff distribution. We ran two sessions for each treatment, so we invited 60 students to have 200 group observations.

4 Results

4.1 Coalition Formation

First, the following table shows how many times the grand coalition was formed in each treatment.

Game	T1	T2	T3	T4
1	6	1	2	0
2	4	4	1	0
3	3	2	0	0
4	4	5	1	0
5	4	9	1	3
6	3	12	0	5
7	1	11	3	5
8	13	16	5	8
9	12	6	7	9
10	20	18	18	17
Total	70 (35%)	84 (42%)	38 (19%)	47 (23.5%)
Observation	200	200	200	200

Table 2: frequency of the grand coalition(T1: Chat 1→10, T2: Chat 10→1, T3: No Chat 1→10, T4: No Chat 10 →1)

In each session, 30 subjects were randomly divided into 10 groups, and we ran two sessions for each treatment. Thus, we collected 20 observations for each game and 200 in total. The figures on the table indicate how many groups formed the grand coalition. The grand coalition was formed 239 times, coalition AB 332 times, coalition AC 190 times, coalition BC 29 times and time up happened 10 times in total.

In games 1-5 with an empty core, the subjects were less likely to form the grand coalition than in games 6-10 with the non-empty core. Moreover, as the core gets larger, frequency of the grand coalition also gets higher and almost all the groups formed the grand coalition in game 10, where the core is the largest in the 10 games. Roughly speaking, we can say that the existence and the size of the core affect coalition formation.

Also, it is quite interesting that there is difference between T1, T2 and T3, T4. Frequency of the grand coalition in T3 and T4 without the chat window is apparently lower than T1 and T2 with the chat window. Thus we can also say that the availability of the chat window affects coalition formation.

Before looking at a statistical analysis, we introduce the quota solution defined by Shapley[5]. Let q_A, q_B and q_C be players' quotas and they are calculated by solving the following equations.

$$\begin{cases} q_A + q_B = v(AB) \\ q_A + q_C = v(AC) \\ q_B + q_C = v(BC) \end{cases}$$

They are regarded to represent players' strength in bargaining. It is reasonable to assume that the subjects mainly look at the value of two-person coalitions they can form during the experiment. Although we can see relative strength of the players in each round by using these quotas, we cannot see its change from one game to another. So we use the ratio of q_B to q_A and q_C to q_A, that is q_B/q_A and q_C/q_A. The following table shows their values.

Game	q_A	q_B	q_C	q_B/q_A	q_C/q_A
1	65	55	35	0.846	0.538
2	75	45	25	0.600	0.333
3	85	35	15	0.412	0.176
4	95	25	5	0.263	0.053
5	60	40	30	0.667	0.500
6	70	30	20	0.429	0.286
7	80	20	10	0.250	0.125
8	55	35	15	0.636	0.273
9	65	25	5	0.385	0.077
10	45	25	5	0.556	0.111

Table 3: value of q_A, q_B, q_C, q_B/q_A, q_C/q_A

Our experimental hypothesis is that if a game has the non-empty core, subjects are more likely to form the grand coalition. A statistical analysis below shows whether it is correct or not. Let *Coalition* be a category variable which equals 4 when the group forms the grand coalition, 3 for coalition AB, 2 for coalition AC, 1 for coalition BC and 0 for time up. It is sorted according to the value of the coalitions. Also, let *Coreness* be a dummy variable which equals 1 when the core is non-empty and 0 when the core is empty. Likewise, let *Order* be a dummy variable which equals 1 in T1 and T3, and 0 in T2 and T4, and *Chat* be a dummy variable which equals 1 when the chat window is available (T1 and T2), and 0 when it is not available (T3 and T4). The following tables show the result of estimating equation by the ordered probit model. Since q_B/q_A has a strong positive correlation with q_C/q_A, we use only q_B/q_A as an explanatory variable.

We can say that existence of the core and availability of the chat window is positively and strongly correlated to formation of the highly valued

	Coalition
Chat	0.321***
	(0.078)
Order	-0.067
	(0.077)
Coreness	0.674***
	(0.083)
q_B/q_A	0.568**
	(0.223)
cut1	-1.520***
	(0.184)
cut2	-0.970***
	(0.159)
cut3	0.128
	(0.146)
cut4	1.305***
	(0.153)
N	800

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: regression analysis of coalition formation by the ordered probit model

coalition at 1% significant level. Next, take a look at the marginal effects for each possible outcome.

From the table of the marginal effects, we can say that our experimental hypothesis is correct. Existence of the core, availability of the chat window and q_B/q_A are positively correlated to formation of the grand coalition, while they are nevatively correlated to coalition AC, coalition BC and time up. Also, there seems to be no order effect. An interesting thing is that any of the explanatory variables is not correlated to formation of coalition AB. It might be because coalition AB is the best candidate to form among the players.

As mentioned in section 3.3, we use the same value of the coalitions as ones in Nash et al.[2]. They reported that considerably high percentage of groups formed the grand coalition while only around 30% of the groups

	Grand	*AB*	*AC*	*BC*	*timeup*
Chat	0.110***	-0.004	-0.076***	-0.019***	-0.010***
	(0.026)	(0.005)	(0.019)	(0.006)	(0.004)
Order	-0.023	0.001	0.016	0.004	0.002
	(0.026)	(0.002)	(0.018)	(0.005)	(0.002)
Coreness	0.228***	-0.009	-0.156***	-0.041***	-0.022***
	(0.027)	(0.010)	(0.020)	(0.008)	(0.006)
q_B/q_A	0.195**	-0.008	-0.135**	-0.034**	-0.017**
	(0.076)	(0.010)	(0.053)	(0.223)	(0.008)
N	800	800	800	800	800

Standard errors in parentheses

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

Table 5: the marginal effects for each coalition

formed the grand coalition in our experiment. What makes this difference? It should depend on the different experimental protocol. That is especially because of difference of matching. They used partner matching and players' role did not change throughout their experiment, but we use stranger matching and players' role is different from one game to another. In their experiment, if a subject is chosen as a splitter and he or she takes all in one round, then he or she would get punished by the others. On the contrary, in our experiment, even if two subjects make a two-person coalition to deviate from the grand coalition, they would not get punished. Thus, they do not have to hesitate to make two-person coalitions.

4.2 Payoff Distribution

Let x_A, x_B and x_C be the distributed payoff to A, B and C in each round, respectively. We estimate the following equation with the OLS model. For x_A, for example,

$$x_A = \beta_0 + \beta_1 Chat + \beta_2 Order + \beta_3 Coreness + \beta_4 q_B/q_A$$

All variables are the same as the ones in the previous section. The following table shows the results of estimation.

First of all, as we know by looking at mean of the dependent variables, A gets most and B gets more than C. This can be said to reflect players' strength. When relative strength of B to A gets larger, A gets less while B and C gets more. This is because the grand coalition is more likely to be formed. When coalition AB or coalition AC is formed, C or B gets

	A's Payoff	B's Payoff	C's Payoff
Chat	-5.115***	4.252***	4.313***
	(1.208)	(1.523)	(1.027)
Order	2.965**	-1.993	-1.472
	(1.208)	(1.523)	(1.027)
Coreness	-14.210***	-2.409	7.927***
	(1.265)	(1.595)	(1.076)
q_B/q_A	-30.603***	14.303***	14.964***
	(3.514)	(4.431)	(2.988)
constant	80.573***	26.440***	1.957
	(2.302)	(2.902)	(1.957)
N	800	800	800
R^2	0.186	0.032	0.094
adj. R^2	0.182	0.027	0.090

Standard errors in parentheses

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

Table 6: regression analysis of payoff distribution by the OLS model

nothing. However, the grand coalition gives all players positive payoffs. Hence, whether the grand coalition is formed or not strongly affects their payoffs. Likewise, existence of the core and availability of the chat window affects their payoffs because they are also correlated to formation of the grand coalition as the previous section shows.

4.3 Relationship with the solution concepts

First, we take a look at if the subjects agree with an element of the core. The following table shows how many groups reached an agreement with an element of the core when the grand coalition was formed.

Game	Core element / #Grand coalition (%)
1	empty
2	empty
3	empty
4	empty
5	empty
6	0 / 20 (0%)
7	3 / 20 (15%)
8	29 / 42 (69.05%)
9	24 / 34 (70.59%)
10	71 / 73 (97.26%)

Table 7: ratio of the element of the core to the number of the grand coalition

We have 80 observations for each game. Games 1-5 have an empty core, so we cannot see if the subjects agree with an element of the core. From game 6 to 10, the core gradually becomes larger. As we can see, the larger the core is, the more frequently the subjects agree with an element of the core.

Next, we look at the distance between the distributed payoffs and the nucleolus, the Shapley value or the equal division. As dependent variables, we calculated Euclidean distance between the payoff vector and them. The following is the result of regression analysis. We limit the observations to the groups where the grand coalition is formed because the solutions are based on the assumption of formation of the grand coalition.

It is interesting that when B is relatively strong to A and when the non-empty core exists, the agreed payoff vector comes close to the solution concepts. Also note that the estimation for the nucleolus is remarkably fitting well.

5 Conclusion

We hypothesized that the grand coalition is not necessarily formed, especially when the core is empty. That is because if there is an empty core, there must be a coalition that can be better off by deviation from the grand coalition. From our experimental results, we can say the following things.

First, when the core is non-empty, the grand coalition is more likely to be formed than when it is empty. Hence, it can be said that our hypothesis is correct: the non-empty core induces the grand coalition. Moreover, availability of the chat window also induces the grand coalition. It is also interesting that the subjects hardly used the chat window when it is available. The reason they hardly used it is that they were too busy with making

	Nucleolus	Shapley value	Equal division
Chat	4.255***	-0.855	-5.080**
	(1.255)	(1.114)	(2.174)
Order	-4.039***	0.717	4.527**
	(1.191)	(1.057)	(2.064)
Coreness	-9.370***	-7.525***	-8.014***
	(1.521)	(1.349)	(2.634)
q_B/q_A	-48.796***	-22.726***	-31.957***
	(4.208)	(3.733)	(7.289)
constant	56.067***	34.671***	41.715***
	(2.978)	(2.642)	(5.159)
N	239	239	239
R^2	0.445	0.192	0.115
adj. R^2	0.436	0.179	0.100

Standard errors in parentheses

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

Table 8: regression analysis of Euclidean distance between payoffs and the nucleolus, the Shapley value and the equal division

an offer or a counteroffer to communicate with each other through the chat window.

Second, experimental subjects take their strength in bargaining into account to reach an agreement about payoff distribution. Their strength is represented by their quotas, and the regression analysis reveals that their quotas, existence of the core and availability of the chat window are correlated with their payoffs. Also, we see that as the core gets larger, the subjects are more likely to agree with an element of the core.

These results are quite different from those of the previous researches. In our research, unlike the others, formation of the grand coalition is minority and the equal split is rare. A characteristic of our experiment is that it is quite similar to the real bargaining situation. There is no restriction of offers, acceptance or rejection. This should be the reason the different results arose.

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