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Bargaining Power in Cooperative Resource Allocations Games

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Abstract: Cooperative game theory provides an appropriate framework to assess the likelihood of conflict resolution, encourage cooperation among parties, and determine each party's share in resource sharing conflicts. In calculating the fair and efficient allocation of the incremental benefits of cooperation, cooperative game theory methods often do not consider the exogenous bargaining powers of the players based on factors, that are external to the game, such as their political, economic, and military powers. This study reformulates three well-known cooperative game theory methods, namely, Nash-Harsanyi, Shapley, and Nucleolus, to account for the exogenous bargaining powers of the players in cooperative games. Using the Caspian Sea international conflict as an example, this paper shows how the negotiators' exogenous bargaining power can change the outcome of resource sharing games. The proposed weighted cooperative game theory approach can help determine practical resolutions for real-world conflicts in which the exogenous powers of players can have a significant influence on the outcome of negotiations.

Keywords: game theory; bargaining power; conflict resolution; resource allocation; Caspian Sea

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1. Introduction

Cooperative game theory has been popular in the resource allocation literature to develop win-win agreements that lead to increased benefits for all parties This quantitative branch of game theory deals with problems in which cooperation can increase the total utility of all players [1]. In such problems, the main question is how to fairly and efficiently allocate the incremental benefits of cooperation to the parties such that they have incentives to resolve the conflict over utility sharing through cooperation. Cooperative game theory methods help answer this question by considering the incremental benefits of full and partial coalitions among players and their non-cooperative (status-quo) utilities [2]. With the growing competition over the scarce natural and environmental resources, decision makers can benefit from cooperative game theory methods to promote cooperation. This is one of the major motivations of the increasing use of cooperative game theory in the natural resource allocation literature [3–10].

Cooperative game theory has also served a valuable framework to provide insights into transboundary water and environmental resources conflicts, project their future evolutions, identify their possible resolution, and design effective mediation strategies [11,12]. Becker and Easter [13,14] used cooperative (and non-cooperative) game theory to find possible resolutions for the Great Lakes dispute between Canada and the USA. Dinar and Wolf [15] applied cooperative game theory to suggest mechanisms to resolve conflicts in the western Middle Eastern water conflict in the Nile, Jordan, and the Tigris-Euphrates River basins. Luterbacher and Wiegandt [16] applied cooperative game theory to compare how cooperative and non-cooperative strategies affected consumable water availability in the

Jordan River Basin conflict. Kucukmehmetoglu and Guldmann [17] used cooperative game theory concepts to determine stable water allocation shares of Turkey, Syria, and Iraq in the Tigris-Euphrates transboundary river system. Babel et al. [7] showed that cooperation and benefit sharing can lead to higher gains for all riparian countries in the Mekong River Basin. A pollution control study by Wang et al. [18] suggested that the stakeholders' gain can be maximized through cooperation when they all agree to transfer a portion of their gain to cover the losses caused by pollution to other players. In a recent study, Mirzaei-Nodoushan et al. [19] investigated the water allocation conflict among Turkmenistan, Afghanistan, and Iran over Harirud River. The authors concluded that cooperative reallocation of water can boost the stability of the cooperation among the countries.

Cooperative game theory methods try to consider each player's value to each possible coalition of players to provide solutions that are potentially acceptable and seem fair to the conflict parties. They deal with what each player brings to the table or their endogenous powers in the benefit-sharing game. While considering the players' endogenous powers in a cooperative game is necessary for developing solutions, overlooking their exogenous powers might make the cooperative game theory solutions impractical. In real-world conflicts and bargaining processes, the negotiating parties also take advantage of the exogenous powers to the game (such as e.g., reputation, fame, popularity, track records, military, political and economic power) to alter the outcome in their favor and increase their gains. Nonetheless, the well-known and popular cooperative game theory methods do not account for the exogenous powers. Thus, in this study, we reformulate three well-known cooperative game theory concepts to show how the players' exogenous powers (weights) can be taken into account besides their endogenous powers in finding solutions to cooperative game theory problems. We apply the proposed weighted cooperative game theory schemes to the Caspian Sea resource sharing conflict to underline the utility of the proposed method in analyzing real-world water and environmental conflicts with heterogonous players in terms of power.

2. Method

This study applies three cooperative game theory methods to develop a fair and efficient scheme for allocating the oil and gas resources of the Caspian Sea: Nash-Harsanyi (N-H) [20,21], Shapley Value [22], and Nucleolus [23]. Cooperative game theory deals with allocating the additional benefits achieved through cooperation. If a given allocation of the benefits satisfies all the sets of the following constraints, it will be considered a possible allocation that belongs to the core of the game:

$$U_i^* \geq U_i \quad \forall i \in N \tag{1}$$

$$\sum_{i \in s} U_i^* \geq V(s) \quad \forall s \in S,\ S \subset N \tag{2}$$

$$\sum_{i \in N} U_i^* = V(N) \tag{3}$$

where S is the feasible coalition (a group of players) in the game; i the player number (i = 1, 2, ..., n); N is the finite set of players in the game called the grand coalition; $V(s)$ is the total obtainable benefits of coalition s, a subset of N; $V(N)$ is the grand coalition's value, i.e., the total obtainable benefits if all parties decide to cooperate and join the grand coalition; U_i^* is the benefit that player i can secure under cooperation; and U_i is the status-quo gain of player i under non-cooperation.

2.1. Weighted Approaches

The above constraints, respectively, evaluate the individual rationality, group rationality, and efficiency conditions. Equation (1) ensures that the benefit that player i can achieve under cooperation will be more than the benefit that the same player can gain under non-cooperation (status-quo). Equation (2) ensures that the sum of the cooperative allocations of all players is greater than the total obtainable benefits of any coalition they can form together Equation (3) ensures that the grand coalition's overall gain equals the total benefits allocated to all the members of that grand coalition, ensuring that the incremental gains of cooperation are fully allocated to the cooperating parties. This set of equations establish the Core of the cooperative game [24]. A given cooperative game theory solution must belong to the Core to be potentially acceptable and stable. The Core allocation is a driving force for players to cooperate as it ensures that players can gain more through cooperation rather than acting individually. It also ensures that the grand coalition can provide the best gains to the players. The core can contain an infinite number of cooperative solutions but can be also empty when no cooperative solutions exist. The cooperative game theory methods, used in this study, select their solutions out of the Core, i.e., they can provide solutions that are potentially acceptable to the players only when the Core is non-empty.

Nash-Harsanyi (N-H)

The N-H solution [25,26] is the expanded form of the Nash bargaining solution for an n-players bargaining game:

$$\begin{gathered} Max \prod_{i=1}^{n} \left(U_i^* - U_i\right) \\ \text{Subject to Equations } (1)-(3) \end{gathered} \tag{4}$$

where $\left(U_i^* - U_i\right)$ is player i's gain under cooperation.

Shapley value

The Shapley [27] value is a cooperative solution that considers the weighted average of a player's contribution to all possible coalitions as the fair and efficient gain of that player under cooperation:

$$U_i^* = \sum_{s \subset N,\, i \in S} \frac{(n-|S|)!(|S|-1)!}{n!} (V(s) - V(S - \{i\})) \tag{5}$$

where $V(S - \{i\})$ is the total value of coalition S without player i.

Nucleolus value

The Nucleolus solution is another cooperative game solution concept first introduced by Schmeidler [23]. This method minimizes the worst-case dissatisfaction of the most displeased coalition. The benefit allocated to each beneficiary through the Nucleolus solution is determined by finding ε through the following optimization model:

$$Max \quad \varepsilon \tag{6}$$

Subject to :

$$\begin{gathered} \varepsilon \leq \sum_{i \in s} U_i^* - V(s) \quad \forall s \in S,\ S \subset N \\ \text{Equations } (1)\text{–}(3) \end{gathered} \tag{7}$$

where ε is the maximum imposable tax on all coalitions to keep them in the Core.

2.2. Weighted Approaches

The conventional cooperative game theory methods, consider the endogenous weights of the players in negotiations. As specified above, these methods have different rationales for determining such weights including the players' status-quo gains and/or the value they can bring to different coalitions. In real-world situations, the players' negotiation power is not limited to only driven by endogenous factors, but also by some variables (e.g., economic, and political) that are exogenous to the game. Overlooking the exogenous weights of the players in negotiations can produce misleading and impractical results. Therefore, here, we propose new formulations for the three overviewed conventional cooperative game theory methods that take both exogenous and endogenous negotiation powers of the players into account to determine their cooperative shares.

To add exogenous weights to the N-H, Shapley, and Nucleolus concepts, we propose replacing Equations (4), (5), and (7), with the following three equations, respectively:

$$Max \prod_{i=1}^{n} (U_i^* - U_i)^{P_i} \tag{8}$$

$$U_i^* = \frac{V(N) \times P_i \times \left\{ \sum_{s \subset N,\, i \in S} \frac{(n-|S|)!(|S|-1)!}{n!} (V(s) - V(S - \{i\})) \right\}}{\sum_i \left\{ \sum_{s \subset N,\, i \in S} \frac{(n-|S|)!(|S|-1)!}{n!} (V(s) - V(S - \{i\})) \right\} \times P_i} \tag{9}$$

$$\varepsilon \leq \sum_{i \in s} U_i^* / P_i - V(s) \quad \forall s \in S,\ S \subset N \tag{10}$$

where P_i is the exogenous bargaining power of player i and $\sum_{i \in N} P_i = 1$.

3. A Real-World Example: The Caspian Sea International Conflict

Caspian Sea is the largest lake in the world by area. With an area of 371,000 square kilometers. Caspian is home to different marine species and the major provider of caviar in the world [28]. Based on different estimations, the Caspian seabed is believed to have considerable quantities of crude oil and natural gas reserves [29,30] that turns it into a major potential energy supplier. Before the collapse of the Soviet Union, the Caspian Sea was bound by Iran and the USSR. The two countries had agreements in place, giving them equal rights to the Sea and its resources, including exclusive fishing rights within 10 miles of their shoreline according to the 1929 and 1940 treaties. With the collapse of the Soviet Union, the legal arrangement for governing the Caspian Sea became the subject of negotiations between Iran, Russia, Azerbaijan, Turkmenistan, and Kazakhstan (Figure 1). Considering themselves as "clean states", the newly independent countries have argued that they are not subject to the Vienna Convention on Succession of States in Respect of Treaties, remaining reluctant to respect the agreements between Iran and their "mother state" and have not seen themselves. Thus, negotiations over determining a fair governance regime for the Caspian Sea have been going on for the last three decades, making this conflict one of the longest international conflicts among neighboring states over sharing and international landlocked body of water [31]. This has prevented the littoral states from full the exploitation of the Caspian Sea energy resources. Also, in the absence of effective governance system, Caspian Sea has been suffering from increasing environmental pollution and accelerated ecosystem degradation [32].

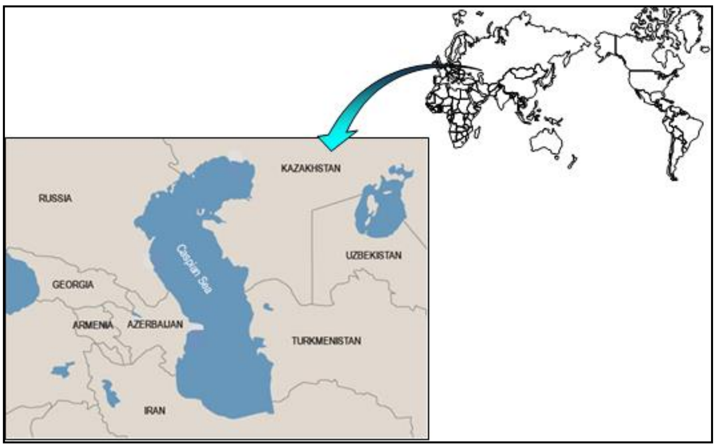

Figure 1. Caspian Sea's and its five littoral states.

Considering its abundant transboundary natural resources, the governance regime of the Caspian Sea that the littoral states will eventually agree to is strategically significant. Since the start of the negotiations, different resolutions have been proposed, each having implications for the conflict parties and how they benefit from its valuable resources. Due to its vast area and oceanographic characteristics, the Caspian Sea could be classified as a sea rather than a lake. In that case, the United Nations Convention on the Law of the Sea (UNCLOS) can be applied as the governing law of the Sea [33]. Based on the UNCLOS, median lines from states' shorelines are considered maritime boundaries for the coastal state. Accordingly, the littoral states can gain from both the surface (e.g., sturgeon and navigation rights) and seabed (e.g., oil and gas) resources within the maritime boundaries [34]. Over the years, the negotiating countries have also discussed the option of governing the sea based on alternative mechanisms such as the Soviet division rule and the 1970 treaty [35], sharing it as a common resource (with equal division of its resource values), and applying various combination of rules for sharing the seabed and sea surface [36]. While there is no established consensus among all the littoral states on the Caspian Sea boundaries or resource allocation, military forces and international corporates seem poised to compete over the benefits of this international resource [37]. O'lear [38] states that neither of the territorial approaches nor any commercial and diplomatic agreement has fully surpassed the other ones in terms of their popularity for the negotiating parties. But Orazgaliev and Araral [39] claim that Azerbaijan, Kazakhstan, and Russia have already agreed to solve their differences over the oil fields; however, Turkmenistan, Iran, And Azerbaijan, have failed to do so due to strategic political calculations.

Bayramov [40] argues that the existing literature misunderstand the nature of the game by excluding the differences in economics, history, and politics of the littoral states, thus cannot systematically promote the discussion. While, multiple scholarly works have been developed to determine the fair and likely mechanism for sharing the Caspian Sea [41,42], these studies: (1) only consider the governance mechanisms suggested by the negotiating parties, overlooking the opportunity of developing and recommending new resolutions; (2) do not simultaneously consider the exomoons and endogenous bargaining powers of the negotiating parties; and/or (3) fail to recognize the Caspian Sea's valuable environmental resources in addition to its energy resources. This study bridges the gap of previous studies by trying to identify new cooperative solutions for the allocation of the Caspian Sea environmental and energy sources among the littoral countries while taking the impacts of the exogenous and endogenous bargaining powers of the parties into consideration using weighted cooperative game theory methods.

Since cooperative game theory methods consider each party's gain in case of non-cooperation, as an essential input, the first step to finding a solution for conflict resolution in the case of the Caspian Sea is to determine the status-quo shares of the littoral states. The Caspian Sea Negotiation Support System (NSS) [43] provides a spatial distribution of oil and gas resources across the Caspian Sea using a 200 × 300 pixels map (Figure 2). One can use this NSS to estimate the value of the current shares of the littoral states from the sea and its resources. We used the 1940 treaty between Iran and USSR as the basis for estimating the status-quo shares. Based on this treaty, one can assume that the resources within ten miles (nautical) of each country's shoreline constitute its non-cooperative share. We used three different scenarios as the basis of valuation of the countries' non-cooperative shares within their marine territories:

- Scenario 1: What matters to the countries the most is their areal shares. So, they negotiate over their areal shares regardless of their gains from the energy and environmental resources.
- Scenario 2: What matters to the countries is the value of energy resources that can eventually secure for themselves without being concerned about their areal and environmental shares as well as.

- Scenario 3: What matters to the countries is the total value their shares from the energy and environmental resource of the Sea regardless of their corresponding areal shares from the sea.

Following [35,44], the corresponding values of the shares as specified above was calculated using the Caspian Sea NSS (Table 1). Based on the estimated values, Kazakhstan has the highest non-cooperative areal share of the sea, followed by Russia and Iran. This is because these countries have the longest shorelines. When it comes to the monetary values of their shares from the sea resources, however, both the order and differences between the values (in percentage) change. In this case, again Kazakhstan has the highest share, followed by Turkmenistan and Iran. When compared in terms of percentages, Russia and Azerbaijan have a very small share of the sea energy and environments resources in the non-cooperative case due to the limited availability of oil and gas fields in their status-quo marine territories. Comparison of the values under Scenarios 2 and 3 suggests that the monetary value of environmental resources of the sea are insignificant when compared to the monetary values of oil and gas resources [45]. This can be mainly blamed on the method of valuation of environmental resources in comparison to energy resources with clear market prices.

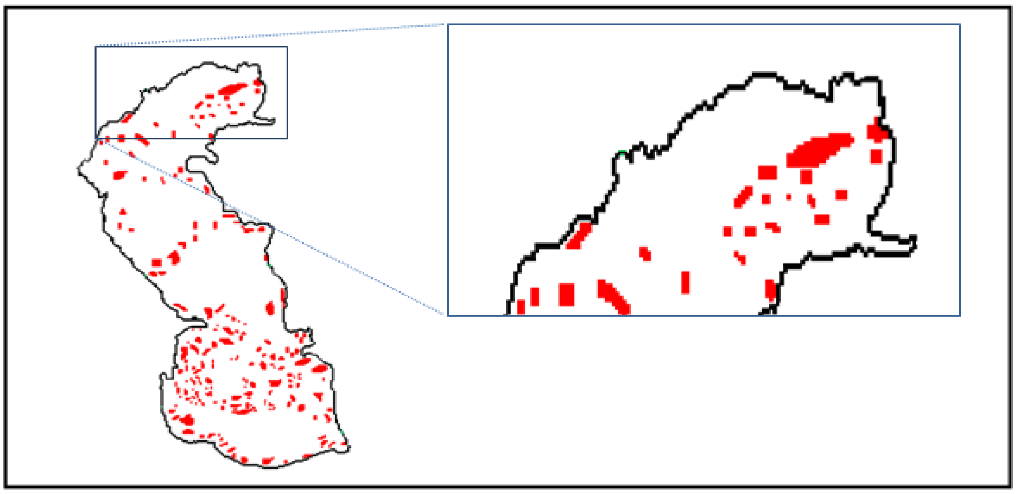

Figure 2. Spatial distribution of the oil and gas resources of the Caspian Sea (Caspian Sea NSS [43]).

Table 1. Countries' non-cooperative shares for each proposed scenario.

Country	Scenario 1		Scenario 2		Scenario 3	
	Sq Miles	**%**	**Million $**	**%**	**Million $**	**%**
Azerbaijan	364	14.55	25,351	3.75	25,427	3.76
Iran	402	16.07	160,555	23.75	160,639	23.74
Kazakhstan	876	35.01	253,508	37.50	253,692	37.50
Russia	470	18.78	25,351	3.75	25,449	3.76
Turkmenistan	390	15.59	211,257	31.25	211,339	31.24

Estimating the asymmetric bargaining powers of negotiating parties is necessary for calculating their cooperative shares based on the proposed method in this study. We used the previously estimated weights of the barging powers [42,46] based on the Data Envelopment Analysis (DEA) using a range of socio-economic and political criteria outlined in Table 2. We normalized those weights, ensuring that the summation of all weights would be equal to one (Table 3) to make them applicable in this study. According to the estimated weights, Russia and Turkmenistan are the most and least powerful negotiators in the Caspian Sea conflict, respectively.

Table 2. Criteria used to assess power of negotiators [46].

Criteria	Indicator
Economic independence and self sufficiency	GNI/Capita
	Net trade/GDP
	GDP/Claimed Caspian Sea resources
Military status	Yearly military expenditures
	Military expenditures/GDP
	Active troops/population
	Nuclear power status
US Support	US financial support
	US political support
Political influence and structure	Political influence
	Democracy level

Table 3. The normalized weights of each state in the Caspian negotiation (the original weights were previously estimated by Shikhmohammady et al. [42]).

Country	Normalized Weights
Azerbaijan	0.181
Iran	0.167
Kazakhstan	0.165
Russia	0.367
Turkmenistan	0.120

We use the weighted cooperative game theory methods to take the effects of each littoral state's political, economic, and military power in resolving the Caspian Sea conflict.

4. Results

Table 4 shows the cooperative shares of each state (all belonging to the Core per Equations (1)–(3)) under each scenario using the three selected cooperative game theory methods when the parties do not enforce their exogenous bargaining powers in negotiation. Yet, we know that in practice, the negotiating parties will take advantage of their power to influence the outcome of the game and increase their gains. The primary purpose of introducing bargaining power into the cooperative games was to capture such effects and develop a practice-oriented conflict resolution mechanism. As expected, the values of cooperative shares varies when the exogenous bargaining power of the players are taking into account (Table 5) using the methods developed in this study. A comparison between Tables 4 and 5 reveals how bargaining powers affect each country's cooperative share. Since Russia is the most powerful state (Table 3) among others, it gains the largest cooperative share in all three proposed scenarios despite having the least non-cooperative share in two out of three considered scenarios (Table 1). In contrast, Turkmenistan has the least bargaining power which leads to this country having the lowest cooperative share, despite having the largest non-cooperative share.

When the exogenous bargaining powers are not considered (Table 4), cooperative game theoretic allocations to the five countries are close to 20% for each country. This is mainly due to the fact that the total value of the non-cooperative shares of the littoral states is minimal compared to the value of the grand coalition (size of the cooperative pie to share). Thus, in this case, the endogenous powers of the players are very similar. The equal share solution (20% for each country) is similar to what the countries gain under the Condominium governance regime, one of the methods that have been on the negotiations table since the early phase of negations in 1990's. Nonetheless, the parties have not been successful in reaching an agreement over this allocation solution so far. When the countries' bargaining powers are taken into account, their cooperative shares range from 12-36%. These results suggest that reaching a resolution might be possible if the negotiating countries consider new allocation solutions that have not been considered so far.

Table 4. Percent of cooperative shares under proposed cooperative game theory methods excluding bargaining power.

Country	Scenario 1 (% of Total Share)			Scenario 2 (% of Total Share)			Scenario 3 (% of Total Share)		
	N-H	Nucleolus	Shapley	N-H	Nucleolus	Shapley	N-H	Nucleolus	Shapley
Azerbaijan	19.90	19.98	19.96	19.19	19.83	19.68	19.19	19.83	19.68
Iran	19.93	19.99	19.98	20.19	20.04	20.08	20.19	20.04	20.08
Kazakhstan	20.26	20.05	20.11	20.87	20.18	20.35	20.87	20.18	20.35
Russia	19.98	20.00	19.98	19.19	19.83	19.67	19.19	19.83	19.67
Turkmenistan	19.92	19.98	19.97	20.56	20.12	20.22	20.56	20.12	20.22

Table 5. Percent of cooperative shares under proposed cooperative game theory methods including bargaining power.

Country	Scenario 1 (%)			Scenario 2 (%)			Scenario 3 (%)		
	N-H	Nucleolus	Shapley	N-H	Nucleolus	Shapley	N-H	Nucleolus	Shapley
Azerbaijan	18.04	18.05	18.04	17.38	17.95	17.85	17.38	17.95	17.85
Iran	16.69	16.73	16.72	17.05	16.81	16.87	17.05	16.81	16.87
Kazakhstan	16.83	16.53	16.58	17.55	16.67	16.84	17.55	16.67	16.84
Russia	36.40	36.71	36.68	35.05	36.48	36.26	35.05	36.48	36.26
Turkmenistan	12.06	11.98	11.98	12.97	12.09	12.18	12.97	12.09	12.18

5. Acceptability and Stability of the Solutions

In cooperative game theory, ensuring that a solution belongs to the Core is the first step to examine if that solution is potentially acceptable by all parties. One can also use additional measures to evaluate the stability and acceptability of cooperative game theory solutions [47]. Shapley and Shubik [48] defined "power index" as a measure for "a priori evaluation of the division of power among the various bodies and members of a legislature or committee system." Accordingly, one can benefit from the following index to evaluate the stability of a cooperative solution using the following procedure:

$$\propto_i = \frac{x_i - V(\{i\})}{\sum_{j\in N}\left(x_j - V\{j\}\right)}, \quad i \in N; \sum_{i\in N} \propto_i = 1 \tag{11}$$

The numerator of the above equation shows the amount each player can gain under cooperation, whereas the denominator indicates the amount all players would gain by collaboration. To assess the acceptability and stability of a solution using this index, one needs to calculate the coefficient of variation ($S_{\propto} = \frac{\sigma_{\propto}}{\propto}$) of powers, in which σ is the standard deviation. A higher value for this coefficient reflects a higher stability of a potential solution, i.e., if all players in a game have the same power index, the coalition has the most stability. We modify the above formulation to incorporate exogenous bargaining:

$$\propto_i = \frac{[x_i - V(\{i\})]/P_i}{\sum_{j\in N}(x_j - V\{j\})/P_j}, \quad i \in N \tag{12}$$

Another commonly used index to evaluate the acceptability of cooperative game theory solutions is "Propensity to Disrupt." Gately [49] defines the propensity of player *i* to refuse to join the grand coalition as follows:

$$D_i = \frac{\sum_{j\neq i} x_j - V(N-i)}{x_i - V(\{i\})}, \quad i \in N \tag{13}$$

where the numerator shows the utility that the members of the coalition ($N - i$) would lose in a case where player *i* refuses to cooperate. In contrast, the denominator shows the amount player *i* would lose by refusing to join the coalition. A higher relative value of D_i

shows that player i is likely to disrupt the coalition [50]. We extended the propensity to disruption for cooperative games with asymmetric exogenous bargaining games:

$$D_i = \frac{\left[\sum_{j \neq i} x_j - V(N-i)\right] / \sum_{j \neq i} p_j}{[x_i - V(\{i\})] / P_i}, i \in N \quad (14)$$

The results of the stability analysis are shown in Table 6. Based on these results, under all scenarios, the N-H method gives us the highest stability, followed by Shapley and Nucleolus. The propensity to disrupt values are shown in Table 7. Comparison of these values suggest that the propensity to disrupt is more equally distributed when the allocation is done based on the N-H concept.

Table 6. The power index of the proposed solutions under different scenarios.

Scenario 1			Scenario 2			Scenario 3		
N-H	**Nucleolus**	**Shapley**	**N-H**	**Nucleolus**	**Shapley**	**N-H**	**Nucleolus**	**Shapley**
0.01	0.01	0.003	0.06	0.05	0.02	0.06	0.05	0.02

Table 7. The propensity to disrupt for the game theoretic solutions under different scenarios.

Country	Scenario 1			Scenario 2			Scenario 3		
	N-H	**Nucleolus**	**Shapley**	**N-H**	**Nucleolus**	**Shapley**	**N-H**	**Nucleolus**	**Shapley**
Azerbaijan	0.998	0.997	0.997	0.998	0.959	0.965	0.998	0.959	0.965
Iran	1.003	1.000	1.001	1.003	1.022	1.017	1.003	1.022	1.017
Kazakhstan	0.998	1.021	1.017	0.999	1.070	1.056	0.999	1.070	1.056
Russia	1.000	0.987	0.988	1.001	0.938	0.948	1.001	0.938	0.948
Turkmenistan	0.999	1.007	1.007	0.999	1.094	1.083	0.999	1.094	1.083

6. Conclusions

This study aimed to adapt and reformulate cooperative game theory methods to include players' exogenous negotiating powers to develop cooperative solution for real-world games. The study was motivated by the idea that considering the bargaining power of the decision makers can better capture the complexity of real-world games and would lead to more feasible path to conflict resolution [51]. We reformulated the Nash-Harsanyi, Shapley, and Nucleolus methods and applied to them ongoing Caspian Sea negotiation between five littoral states. Based on the study results, the Condominium governance regime or any other mechanism that results in equal shares for all players is potentially acceptable. When the players' bargaining powers based on various economic, military, and political factors are considered, the countries' cooperative shares varied between a high of 37% for Russia to a low of 12% for Turkmenistan. The study also reformulated two commonly used methods for evaluating the potential acceptability and stability of cooperative solutions in cooperative games with asymmetric bargaining powers. The stability analysis results suggest that resource allocation based on the Nash-Harsanyi solution has the highest potential degree of stability and acceptability.

The study results suggest that new allocation solutions that have not been considered in the negotiations can help the Caspian Sea conflicts reach a resolution. Future studies can use the Caspian Sea NSS [43] to explore how the potentially acceptable game theoretic allocation solutions can be implemented in practice by developing optimal geographical boundaries.

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