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Incorporating Economic and Political Considerations in Inter-Basin Water Allocations: A Case Study

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Abstract When an inter-basin water transfer is expected among basins with some level of unfriendliness or hostility, ignoring political considerations, which are generally not integrated in economic investigations, can impede an integrated and efficient management. In this paper, a new economic-political methodology is proposed for the optimal and efficient allocation of water resources among water users in inter-basin water transfer systems. The proposed framework quantifies both the economic payoffs using an "*n*-person real fuzzy cooperative game", and the political formation prospect of any coalition, using a Modified Political Accounting System (MPAS). The proposed economic-political methodology is applied to a large scale inter-basin water allocation problem including water donor and receiving basins struggling with water scarcity. The results show how including political considerations in the study may provide a more satisfactory solution compared to the just cost-effective water allocations.

Keywords inter-basin water allocation · real fuzzy cooperative game · political considerations · Modified Political Accounting System (MPAS)

1 Introduction

The water resources authorities are facing the challenge of ensuring the access to sufficient water resources for increasing populations and markets, while conserving healthy water ecosystems. One common approach to solve this issue is to transfer the surplus water from some basins to those with shortages, called Inter-basin Water Transfer. Optimal allocation of water from a common pool resource is usually modelled using the cooperative game theory. There are plenty of studies presenting applications of game theory in water resources

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management. Recent researches including Xuesen et al. (2009), Niksokhan et al. (2009), Mahjouri and Ardestani (2010), Sadegh et al. (2010), Madani (2010), Mahjouri and Ardestani (2011), Sadegh and Kerachian (2011), Nikoo et al. (2012) and Abed-Elmdoust and Kerachian (2012) have considered different game-theoretic methodologies for water resources management.

The analysis of the forming coalitions and reallocating the benefits in classic game theory is usually carried out under the assumption that the players in the game are economically rational. Inter-basin water transfer is affected by ideological-political considerations that may affect potential arrangements in the coalition formation. The literature review associated with considering political aspects of water resources is mostly restricted to some case studies. Naff and Matson (1984), Frey and Naff (1985), Dinar and Wolf (1994), and Kucukmehmetoglu (2009a, b) are among them.

In the present paper, a new economic-political methodology is proposed for the operation of inter-basin water transfer systems. The model framework proposed in this paper is explained in Section 2. The initial water allocations to players are determined in Section 3. In Section 4, how to include the political consideration in water transfer projects is explained. In Sections 5 and 6, real fuzzy cooperative games with political considerations and the effectiveness of the proposed methodology are discussed.

2 Model Framework

A flowchart is presented in Fig. 1 to provide understanding of how the proposed methodology would be carried out. As depicted in this figure, at first, basic data and information relating to the physical and hydrological characteristics of the study area are collected and used as methodology inputs.

The purpose of this methodology is attaining optimal and efficient water allocation policies in inter-basin water transfer systems. The next major steps are determining decision-makers and stakeholders and also the objective functions and their uncertainties. Determining political criteria, including, issue position, players' saliences and powers and evaluating the political possibility of forming coalitions based on MPAS are the main steps of the proposed methodology. In this paper, water users would participate in fuzzy coalitions to increase their profits. In this step, the characteristic function of the coalitions would also be fuzzy to consider the existing uncertainties in payoffs that players would receive by participating in different fuzzy coalitions. In this paper, the Shapley function proposed in Abed-Elmdoust and Kerachian (2012) is modified based on political considerations to reallocate the total net benefit of a coalition to its members.

In this methodology, the main objective is to maximize the total fuzzy net benefit of the system and then distribute the gained fuzzy benefit among the players in a way that they have both economic and political incentives to form coalitions. Therefore, the players, who participate in a coalition, would have fuzzy side payments. In the following sections, some of the main components of the flowchart will be discussed in more details.

3 Inclusion of Political Considerations in Water Allocation

The initial water allocation model proposed in Abed-Elmdoust and Kerachian (2012) is applied here to determine the decision variables of the initial monthly allocated water to the players. In this paper, ideological and political considerations are involved in the analysis of forming coalitions and reallocating the benefits to members of a coalition. These

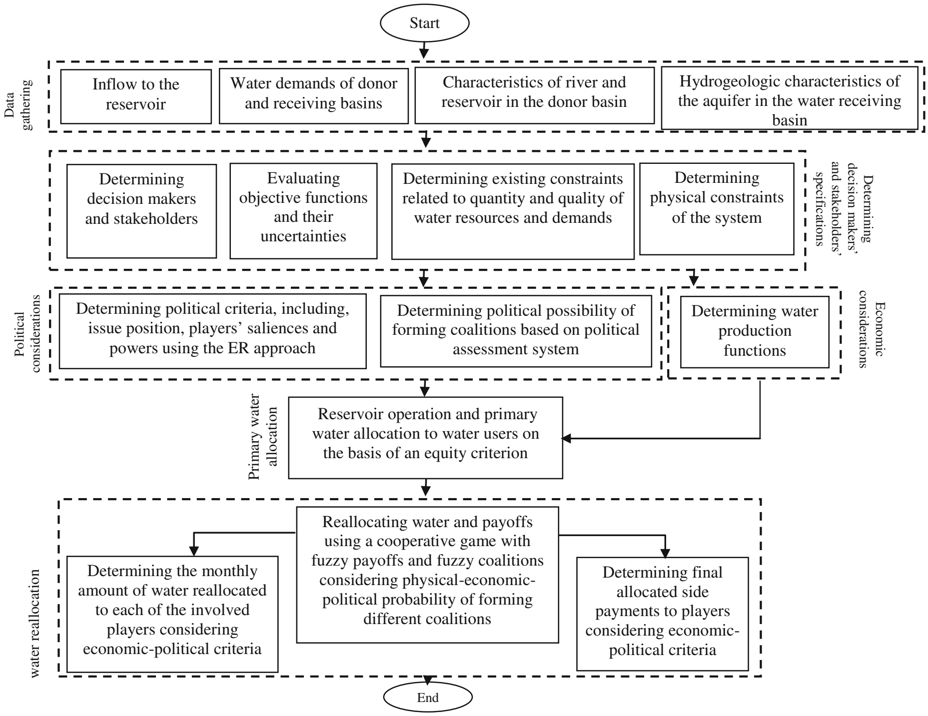

Fig. 1 A flowchart of the proposed methodology for inter-basin water allocation

considerations are generally ignored in the modelling frameworks due to the complexity of calculations.

This section challenges to extend appropriate analyses that will include political consideration in the modelling framework of inter-basin water allocation. Among these important analyses would be the comprehensive definition of some terms presenting players' political attitudes, namely *issue positions*, *power*, and *salience*.

In order to consider the political possibility of forming a coalition, the PAS described by Coplin and O'leary (1976) is modified and used. This PAS incorporates the modifications for hydro-politics presented by Frey and Naff (1985), as well as some extra modifications for political inter-basin water transfer project presented in this paper. In this modified PAS (MPAS), all players' political attitudes (Issue, Power, and Salience) are ranked for each possible coalition. Three mentioned political attitudes are evaluated based on the following definitions:

- **Issue position**: One of the elements in the PAS that expresses how strong the participant is for or against each of the coalitions. Values used for quantifying this element are in the range $[-\alpha_1; +\alpha_1]$. Frey and Naff (1985) used the scored range of [−3; +3] for evaluating Issue position for hydro-politics projects.
- **Salience**: The other element in the PAS is the salience which is the importance or the rank each participant assigns to a certain coalition. Values used in Frey and Naff analysis (1985) are in the range $[1,\alpha_2]$, $\alpha_2 \geq 1$. The same range would be considered here.
- **Power**: Power of a player over a coalition is defined as "the ability of each party to accomplish or prevent the occurrence of each coalition" (Dinar and Wolf 1994). Values used are in the range $[1,\alpha_3]$, $\alpha_3 \geq 1$.

By multiplying the values of these three criteria and adding those up for a specific coalition, the extent of agreement or disagreement of any player about any coalition formation is obtained. Finally, using the formula $\xi(s) = A/(A + B + C)$ in PAS proposed by Coplin and O'Leary (1976) absolute level of political risk of the formation of coalition s is achieved. In the above formula, A is the total sum of scores of players who are sympathetic to the coalition. B is the total sum of scores of players who are against the formation of the coalition and C is the total sum of scores of players who are indifferent about the coalition formation. $\xi(s)$ shows the relative survival ratio of scenario s. In the present paper, scenarios are in fact coalitions which the players have three mentioned political attitudes i.e. issue position, salience, and power for or against participating in them. Therefore, by incorporating these political considerations, the possibility of forming a coalition will be corrected. The next subsection explains how to calculate these three criteria more precisely.

3.1 Evaluation of the Political Attitudes: Issue Position, Salience and Power

In order to obtain the political possibility of forming a coalition, the political criteria of issue position and salience would easily be determined for each of the players using a survey. Proposed in this paper, decision makers' powers in inter-basin water transfer policy making that directly influence the political probability of formation of cooperative coalitions are estimated considering their economic powers. Decision makers' economic powers are evaluated based on their net benefit coefficient (i.e. the higher net benefit coefficient, the higher decision maker's power).

4 Real fuzzy Games with Political Considerations

When the water users receive their initial shares of water, they would participate in cooperative fuzzy coalitions with fuzzy characteristic functions (real fuzzy cooperative game) to increase their own fuzzy benefits as well as the total fuzzy profit of the system. Participation in fuzzy cooperative coalitions leads to achievement of less water for one or more water users, and greater amounts of water for others. For equity, it is necessary to reallocate the earned fuzzy profits among water users (players or participants in real fuzzy cooperative game), so that the harms to water users receiving less water than the amount of their water rights, be compensated.

Reallocation of fuzzy profits among the players is carried out by means of side payments, based on a modified version of generalized Hukuhara-Shapely function with Choquet integral form, which was introduced in Abed-Elmdoust and Kerachian (2012). The novel modified function of this paper is called Generalized Shapley Value with Modified Probabilities (GSVMP) and is able to consider political probability of coalition formation. The function is called generalized because it incorporates the uncertainties about the participation rates the users would choose for entering any coalition and the payoff they would receive from entering any coalition (this special characteristic was considered and explained in detail in Abed-Elmdoust and Kerachian (2012)). It is also called modified because it incorporates the political considerations in deciding if a coalition is possible to be formed, besides incorporating the economic criteria.

Given $C \in G_F(I)$, where, I is the set of players, $G_F(I)$ denotes the subset of players participating in real fuzzy game. let $L(C) = \{C(i) | C(i) > 0, \quad i \in I\}$, where, $C(i)$ is the participation rate of player i in fuzzy coalition C and let $l(C)$ be the cardinality of $L(C)$. We denote the elements of $L(C)$ in increasing order as $h_1 < h_2 < \ldots < h_{l(C)}$. When the users participate in more than one coalition, redistributing fuzzy profits for fuzzy coalition will be achieved using the Choquet integral form game as follows:

$$g_i(\widetilde{\omega})(D) = \sum_{l=1}^{l(D)} f_i(\omega)\left([D]_{h_l}\right).(h_l - h_{l-1}), \quad (1)$$

$$f_i(\omega)(S) = \begin{cases} \sum\limits_{T \in P(S \setminus \{i\})} \xi(T).\beta(|T|;|S|).[\omega(T \cup \{i\} -_H \omega(T)] & if \quad i \in S \\ 0 & otherwise, \end{cases} \quad (2)$$

where, $\beta(|T|;|S|) = |T|!.(|S| - |T| - 1)!/|S|!$, $|S|$and$|\mathrm{T}|$ are respectively the number of players in crisp coalitions S and T, $[D]_{h_l}$ is a subset of players whose participation rates in coalition D are more than h_l, $\xi(T)$ is the political probability of forming coalitions, $\omega(T)$ is the fuzzy profit of forming crisp coalition T with fuzzy characteristic function, $[\omega(T \cup \{i\} -_H \omega(T)]$ is the fuzzy profit which player i would add to profit of coalition T and is called the fuzzy profit margin of player i participating in coalition T. This fuzzy profit will be calculated by Hukuhara-difference between two fuzzy numbers (Banks and Jacobs 1970). In fact, the function based on Hukuhara-difference is also called the Shapely-Hukuhara function. For more information about the Hukuhara-difference between two fuzzy numbers and Shapely-Hukuhara function, the reader is referred to Abed-Elmdoust and Kerachian (2012). In Eq. 2, uncertainty in the payoff of the formed coalition is calculated by the Shapley-Hukuhara function. It also incorporates the possibilities of forming coalitions based on political and economic criteria.

5 Case Study

In order to evaluate the performance of the proposed methodology, a water transfer project from the great Karoon River to Rafsanjan plain located in Loot desert in Iran, is studied as a case study. The purpose of this project is to transfer water from Solegan reservoir, which is planned to be constructed on one of the tributaries of the great Karoon River, to Rafsanjan plain. The water users of the donor basin include modern agro-industrial (player 1), old agro-industrial (player 2), and Khuzestan local agricultural (player 3) sectors and the water user of the receiving basin is Rasanjan agricultural sector (player 4). Table 1 presents the monthly demands of the players in the study area which should be supplied by the Solegan reservoir. The main characteristics of the inter-basin water transfer system, the main statistical characteristics of water resources in water donor and receiving basins are illustrated in more details in Mahjouri and Ardestani (2010).

6 Results and Discussion

6.1 Decision Makers' Powers in the Study Area

In this paper, estimation of the players' powers in forming coalitions among different water users in donor and receiving basins is carried out based on their net benefit coefficients which are retrieved from Mahjouri and Ardestani (2011). The players' powers are presented in Table 2.

Table 1 The monthly demands (in million cubic meters) of the main players in the study area which should be supplied by the Solegan reservoir (Mahjouri and Ardestani 2010)

Month	Rafsanjan agricultural sector	Khuzestan local agricultural sector	Khuzestan modern agro-industrial sector	Khuzestan old agro-industrial sector
April	17	18.8	2.1	2.5
May	39.8	24.8	2.7	3.3
June	49.6	27	3.0	3.6
July	47	34.2	3.8	4.6
August	45	30.4	3.4	4.0
September	38	25	2.7	3.3
October	28.2	15.4	1.7	2.1
November	8.8	9	1.0	1.2
December	0.2	6.2	0.7	0.9
January	0	5.6	0.6	0.8
February	0	6.6	0.7	0.9
March	1.2	13.8	1.5	1.9
Annual demand	274.8	216.8	24.1	28.9

6.2 MPAS for the Inter-Basin Water Allocation

To reflect the real-world regional hydro-politics, all players which have both an interest (salience and position) in the issue of inter-basin water transfer, and enough power to force their interests should be included.

The salience of each scenario (coalition) for every player is estimated based on his satisfaction with that coalition comparing to other coalitions. In fact, a player would like to participate in coalitions in which he will receive more water share. The calculation of the saliences which the fourth player assigns to coalitions he can be a member of is presented in Table 3 for instance. Moreover, the position parameter of each player against each coalition is considered based on his attitude about the geographical distance of him and other players participating in that coalition. For instance, the players in the donor basin tend to cooperate with each other more than with the receiving basin. To summarize the political considerations of each scenario, the MPAS for the inter-basin water transfer project is presented in Table 4. As mentioned in Section 3, the political probabilities of forming coalitions, are calculated based on the formula $\xi(s) = A/(A+B+C)$.

Table 2 The players' powers in the study area considering their Net benefit coefficient

Player	Net benefit coefficient-(Rials/m^3)	Power (Percent)	Rank
Khuzestan modern agro-industrial sector	3300	16.19	2
Khuzestan old agro-industrial sector	3000	14.72	3
Khuzestan local agricultural sector	2800	13.74	4
Rafsanjan agricultural sector	11277	55.34	1

Table 3 The calculation of the salience which the fourth player assigns to each coalition

Year	Player 4's allocated water (MCM) when he participates in different coalitions							The difference between the player 4's annual water demand (274.8 MCM) and his allocated water in different coalitions						
	{1,4}	{2,4}	{3,4}	{1,2,4}	{1,3,4}	{2,3,4}	{1,2,3,4}	{1,4}	{2,4}	{3,4}	{1,2,4}	{1,3,4}	{2,3,4}	{1,2,3,4}
1978	233	237	275	275	275	275	275	1745	1431	0	0	0	0	0
1979	267	271	275	275	275	275	275	66	14	0	0	0	0	0
1980	230	234	275	275	275	275	275	1977	1643	0	0	0	0	0
1981	160	163	275	275	275	275	275	13191	12533	0	0	0	0	0
1982	174	177	275	275	275	275	275	10191	9575	0	0	0	0	0
1983	169	173	275	275	275	275	275	11092	10461	0	0	0	0	0
1984	65	67	134	275	142	144	153	43915	43197	19881	0	17519	17067	14884
1985	175	178	275	275	275	275	275	9990	9380	0	0	0	0	0
1986	143	146	250	275	263	266	275	17326	16633	615	0	131	77	0
1987	179	183	275	275	275	275	275	9099	8503	0	0	0	0	0
1988	176	179	275	275	275	275	275	9853	9243	0	0	0	0	0
1989	141	144	247	275	260	263	275	17852	17158	762	0	208	139	0
1990	174	177	275	275	275	275	275	10169	9557	0	0	0	0	0
1991	215	218	275	275	275	275	275	3616	3189	0	0	0	0	0
1992	274	275	275	275	275	275	275	1	0	0	0	0	0	0
1993	202	205	275	275	275	275	275	5351	4851	0	0	0	0	0
1994	134	136	236	275	248	251	264	19923	19224	1521	0	694	569	125
1995	222	226	275	275	275	275	275	2798	2411	0	0	0	0	0
1996	102	104	188	275	198	201	211	29988	29251	7604	0	5832	5510	4020
1997	136	139	238	275	251	253	266	19254	18561	1340	0	574	460	77
1998	98	101	184	275	194	197	207	31099	30363	8281	0	6456	6123	4570
1999	57	59	121	275	129	131	139	47345	46660	23654	0	21255	20797	18550
2000	27	28	74	275	80	81	87	61291	60728	40240	0	37935	37493	35269

Table 3 (continued)

Year	Player 4's allocated water (MCM) when he participates in different coalitions							The difference between the player 4's annual water demand (274.8 MCM) and his allocated water in different coalitions						
	{1,4}	{2,4}	{3,4}	{1,2,4}	{1,3,4}	{2,3,4}	{1,2,3,4}	{1,4}	{2,4}	{3,4}	{1,2,4}	{1,3,4}	{2,3,4}	{1,2,3,4}
2001	96	98	181	275	192	194	205	31852	31092	8798	0	6901	6550	4928
2002	134	136	234	275	247	249	262	19923	19224	1665	0	792	658	169
2003	137	140	239	275	252	255	268	18904	18201	1267	0	515	404	52
2004	131	134	231	275	243	246	258	20543	19844	1918	0	982	833	269
2005	157	160	272	275	275	275	275	13879	13223	9	0	0	0	0
Summation:								482233	466151	117556	0	99794	96679	82913
Ranking coalitions in the range of [1, 3]:								3	3	1	1	1	1	1

Table 4 A modified political accounting system for the inter-basin water transfer project in the study area

Coalitions {1}, {2}, {3}, {4}	Players	Power	Salience	Positions	Total	Probability 1.00
{1,2}	KMAIS	2	1	2	4	0.40
	KOAIS	3	2	−1	−6	
	Total:				−2	
{1,3}	KMAIS	2	1	3	6	0.60
	KLAS	4	1	−1	−4	
	Total:				2	
{1,4}	KMAIS	2	3	−1	−6	0.33
	RAS	1	3	1	3	
	Total:				−3	
{2,3}	KOAIS	3	1	3	9	0.69
	KLAS	4	1	−1	−4	
	Total:				5	
{2,4}	KOAIS	3	3	−1	−9	0.25
	RAS	1	3	1	3	
	Total:				−6	
{3,4}	KLAS	4	3	−2	−24	0.11
	RAS	1	1	3	3	
	Total:				−21	
{1, 2, 3}	KMAIS	2	1	2	4	0.71
	KOAIS	3	1	2	6	
	KLAS	4	1	−1	−4	
	Total:				6	
{1, 2, 4}	KMAIS	2	3	−1	−6	0.12
	KOAIS	3	3	−1	−9	
	RAS	1	1	2	2	
	Total:				−13	
{1, 3, 4}	KMAIS	2	2	−1	−4	0.10
	KLAS	4	3	−2	−24	
	RAS	1	1	3	3	
	Total:				−25	
{2, 3, 4}	KOAIS	3	2	−1	−6	0.09
	KLAS	4	3	−2	−24	
	RAS	1	1	3	3	
	Total:				−27	
{1, 2, 3, 4}	KMAIS	2	2	−1	−4	0.08
	KOAIS	3	2	−1	−6	
	KLAS	4	3	−2	−24	
	RAS	1	1	3	3	
	Total:				−27	

player 1 = Khuzestan modern agro-industrial sector (KMAIS), player 2 = Khuzestan old agro-industrial sector (KOAIS)

player 3 = Khuzestan local agricultural sector (KLAS), player 4 = Rafsanjan agricultural sector (RAS)

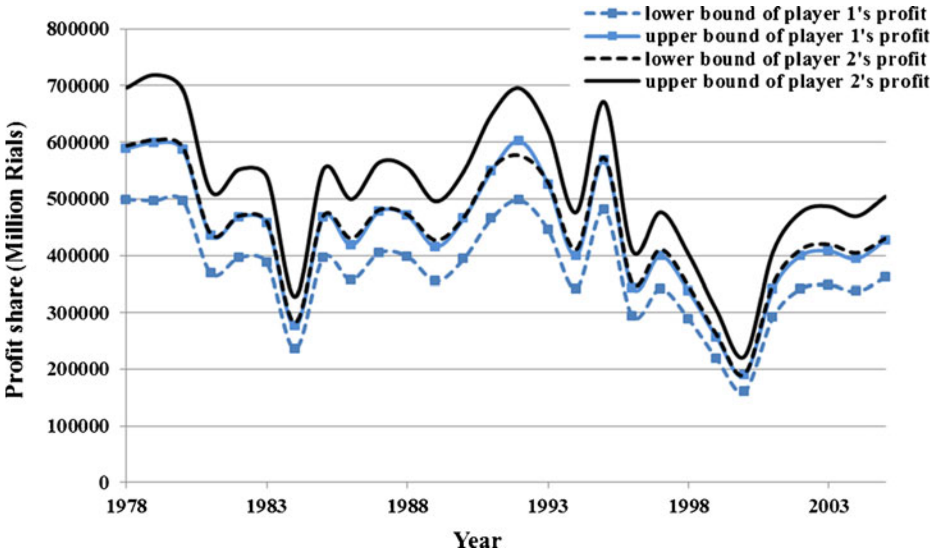

Fig. 2 The lower and upper bounds of profit shares for players 1 and 2 during the planning horizon

6.3 Real Fuzzy Games Based on MPAS Results

The initial water allocations to the four players, which were presented in Abed-Elmdoust and Kerachian (2012), are considered as the players' initial water rights in this paper. In the previous section, we examined the political probability that any of the coalitions may or may not arise at the initial steps of an inter-basin water transfer project. In this section, the GSVMP function presented in Section 5 is used. The lower and upper bounds of profit shares in the planning horizon which are the sum of the players' profit shares participating in

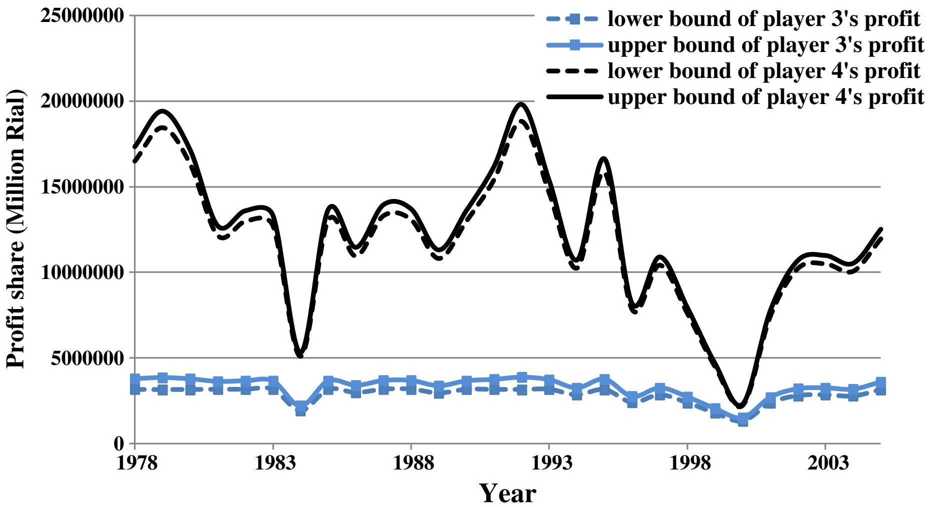

Fig. 3 The lower and upper bounds of profit shares for players 3 and 4 during the planning horizon

different coalitions are shown in Figs. 2 and 3 respectively for players 1 and 2 and for players 3 and 4.

7 Summary and Conclusion

Optimal allocation of water from a common pool resource is usually modelled using the cooperative game theory. Based on previous literature, economic efficiency is not an enough incentive for cooperation, particularly when it comes to water resource. In this paper, a new game-theoretic methodology, which incorporates ideological and political considerations in the decision-making process, was developed to adjust the probabilities of forming different coalitions in the game, and equitably reallocate the fuzzy profits. The players formed cooperative coalitions for maximizing their total net benefits. Unlike previous studies, we also included a political analysis intended for addressing related issues other than only economic considerations. The inclusion of such analysis is so important in the case of an inter-basin water allocation because of the political nature of water transfer.

The economic-political methodology was applied to a large scale inter-basin water allocation project in which the water donor and receiving basins struggle with water scarcity. The results show how including political considerations in the study may provide a more satisfactory solution comparing to the just cost-effective water allocations. More comprehensive structure for determining the political criteria of power, issue position and players' saliences can be studied in future researches. A fuzzy core-based version of the applied game theory-based model can also be studied in future studies.

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