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# CAN ISSUE LINKAGE HELP MITIGATE EXTERNALITIES AND ENHANCE COOPERATION?<sup>1</sup>

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## ABSTRACT

Managing transboundary river basins is never easy and usually involves conflicts. This paper introduces a special class of games with externalities and issue linkage to promote cooperation on transboundary water resources. The paper analyzes whether issue linkages can be used as a form of negotiations on sharing benefits and mitigating conflicts. It is shown that whenever opportunities for linkages exist, countries may indeed contribute towards cooperation. In particular, if the linked games are convex, the grand coalition is the only optimal level of social welfare.

**Keywords:** games with externalities, convexity, s-core, transboundary rivers, issue linkage, international water sharing agreement.

**JEL codes:** C71, C72, D62

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## I. INTRODUCTION

Transboundary basins account for 60 percent of global river flows. About 40 percent of the world's population lives in transboundary river basins and 145 countries share river basins (Fox, 2009). Of the world's 263 transboundary basins, 176 are bilateral and 85 are shared by more than 2 riparian states (Wolf et al. 1999). Transboundary water resources are often a cause for conflict among riparian entities and negotiations over water among sovereign nations are typically difficult. As nature has not distributed water resources equitably, there is too much water where so much is not required and too little where it is needed most. Smaller and weaker countries are suffering most because they have neither the political clout nor the economic strength to achieve their goals (Kirmani and Le Moigne, 1997). Negotiations on the allocation of a water resource (or the benefits from using it) are more difficult when one does not know in advance how much water supply or demand will be generated under future conditions (e.g., population growth, economic activities, climate change).

The last two decades have witnessed a growing public and scientific debate about conflict and cooperation, and development of adequate strategies and institutions to manage international water. River basins are used for several purposes and use in one country may have repercussions on possible uses in the other basin countries. Due to externalities<sup>2</sup>, agreements formed by grand coalition (basin-wide accords) are rare in river basins that consist of more than three countries (Just and Netanyahu, 1998; 2000; Zawahri et al. 2010), and enforcement of cooperation particularly in international settings is limited. In general, sharing a water resource will be formed and remain stable only when economic incentives for each riparian party can be identified (Just and Netanyahu, 1998).

Indeed, conflicts between riparians of transboundary river basins are difficult to address because international water laws are not enforceable and grand coalitional agreements are rare. Zawahri et al. (2010) showed that of the 1,084 treaties signed among sovereign countries between 1945 and 2007, only 195 are basin-wide accords and the rest are either bilateral or multilateral agreements among part of the riparian states. They suggest that due to the diversity of interests in multilateral settings, the focus of multilateral treaties is expected to be on issues that involve joint gains from cooperation. Moreover, if distributional problems result from the allocation of gains, then

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<sup>2</sup>An externality is present whenever the activities of one country have direct, non-price-mediated effects on the activities of other countries.

multilateral negotiation can effectively address it through tradeoffs and issue linkages (Snidal 1991). Dombrowsky (2009; 2010) demonstrates, in a simple bilateral context, how riparians may increase their shared benefits from intra-water sector issue linkage by linking of water uses with upstream-downstream effects in river basins in which riparians hold reciprocal positions. In addition to intra-water sector issue linkage, one can also introduce non-water issue linkages that could be even more attractive and flexible.

Economic development which can involve treaty commitments to develop the basin through construction of infrastructure, such as bridges, dams, barrages, or irrigation networks, or even linking trade agreements is the most promising direction perceived by states to generate positive gains. Indeed, Wolf et al. (1999), analyzing the content of 145 treaties, report that non-water issue linkages do appear, where 30 percent are monetary linkages, 4 percent are land linkages, 1 percent are political concessions, and 7 percent are other linkages (58 percent of the treaties do not have issue linkages). In general, a set of countries will form a coalition when each country realizes the potential gains. However, a grand coalition (a basin-wide agreement), including all players is unlikely: some players may act independently or unilaterally to maximize their own welfare and self-interests. Hence, when negotiations address an issue with strong asymmetry, combining (grouping) issues with compensating asymmetry can be advantageous because countries are more likely then to exchange in-kind side payments (compensations) and sustain self-enforceable agreements that facilitate credible threats against defection (Just and Netanyahu, 2000). Moreover, the partition of the water is just one issue to be taken into account, and is insufficient on its own to establish a viable regime (sustainable development) which reflects all water-related problems in a transboundary water context.

This paper focuses on whether, and to what extent, games with externalities can offer options for promoting sustainable development in transboundary river basins through issue linkage. In this paper, unlike the case of interconnected games that are developed based on the noncooperative behavior with more strategies (Ragland, 1995; Cesar and de Zeeuw, 1997; Kroeze-Gil, 2003), we use games with externalities to investigate conditions under which negotiating over different issues can reduce conflict. We consider the cooperative opportunities associated with dealing with different issues in comparison with the cooperative opportunities of dealing with the linked issues.

The paper demonstrates that the outcomes of international negotiations depend on the structures of the independent externality games. Using insights

from game theory, the paper discusses the role/contribution of issue linkage such as between water (e.g., Mekong River Commission) and non-water (e.g., Greater Mekong Subregion trading zone) and examines how linked games can be used for promoting stable arrangements (agreements). An important innovation of the linked games is that it can generate outcomes as scenarios that cannot be obtained when issues are modelled independently without side-payment. In the next section, some basic concepts and notations are introduced. Section 3 introduces two special classes of games with externalities and issue linkage. Section 4 demonstrates a river game with externalities and analyzes several scenarios. Concluding remarks follow in the last section.

## II. NOTATIONS AND DEFINITIONS

Let  $N = \{1, 2, \dots, n\}$  be a finite set of players. A coalition  $S$  is a subset of  $N$ . A *partition*  $\mathcal{P}$  of  $N$ , a so-called *coalition structure*, is a set of disjointed coalitions,  $\mathcal{P} = \{S_1, \dots, S_m\}$ , whose union is  $N$ . Let  $\mathbb{P}(N)$  be the set of all partitions of  $N$ .

The empty set  $\emptyset$  is implicitly a member of each partition. For any coalition  $S \subset N$ ,  $\mathbb{P}(S)$  denotes the set of all partitions of  $S$ . A generic element of  $\mathbb{P}(S)$  is denoted by  $\mathcal{P}_S$ , where for simplicity, we use  $\mathcal{P}$  rather than  $\mathcal{P}_N$ .

For a given coalition  $S \in \mathcal{P}$ , let  $N \setminus S$  denote the coalition which is made up of the outsiders to  $S$ . Moreover, for any subset  $S \subseteq N$ , let  $[S]$  denote the typical partition which consists of the singletons of  $S$ , i.e.  $[S] = \{\{j\} \mid j \in S\}$  and the coalition structure consisting of the grand coalition only by  $\{N\}$ . For a partition  $\mathcal{P} \in \mathbb{P}(N)$  and  $i \in N$ , we denote the coalition  $S$  in  $\mathcal{P}$  to which player  $i$  belongs to by  $S(i; \mathcal{P})$ . Finally, let  $|S|$  be the number of players in  $S$  and  $|\mathcal{P}|$  the number of coalitions in  $\mathcal{P}$ .

For a given  $\mathcal{P} = \{S_1, S_2, \dots, S_k\}$  such that  $|\mathcal{P}| = k \leq n$ . A *transfer function*  $\tau : \mathbb{P}(N) \rightarrow \mathbb{P}(N)$ , a merger in the deviating subset of one coalition to another in a given  $\mathcal{P}$ , is defined as follows:

$$\tau_{S \subset S_i}(S_j; \mathcal{P}) = \begin{cases} S_i \setminus S \\ S_j \cup S \\ S_l, \text{ if } l \neq i, j \end{cases} \quad (1)$$

where  $S_i, S_j \in \mathcal{P}$  and  $S \subset S_i$  is deviated to merge with  $S_j$  forming a new coalition.

The transfer function is just a move of players in a given coalition structure  $\mathcal{P}$  to form a new coalition structure  $\mathcal{P}'$ . Note that the number of coalitions

in the original coalition structure  $\mathcal{P}$  is larger than a new coalition structure  $\mathcal{P}'$ , that is  $|\mathcal{P}| \geq |\mathcal{P}'|$ , if and only if  $S_j \neq \emptyset$ . If  $S_j = \emptyset$  then a deviated group forms a new coalition and  $|\mathcal{P}| < |\mathcal{P}'|$ .

For example, a coalition structure  $\tau_{S_i(m;\mathcal{P})}(S_j; \mathcal{P})$  is formed when player  $S_i(m; \mathcal{P})$  deviates merging to  $S_j \in \mathcal{P}$  as

$$\tau_{S_i(m;\mathcal{P})}(S_j; \mathcal{P}) = \begin{cases} S_i \setminus \{m\} \\ S_j \cup \{m\} \\ S_l, \text{ for any } l \neq i, j \end{cases}$$

**Example 2.1** Let  $\mathcal{P} = \{S_1, S_2, S_3, S_4\}$ , where  $S_1 = \{1, 2, 3, 4\}$ ,  $S_2 = \{5, 6\}$ ,  $S_3 = \{7\}$ ,  $S_4 = \{8\}$ . If player 2 deviates to merge with  $S_2$ , then  $\tau_{S_1(2;\mathcal{P})}(S_2; \mathcal{P}) = \{134, 256, 7, 8\}$ . If both players 1 and 2 deviate to merger with  $S_2$ , then  $\tau_{\{12\} \subset S_1}(S_2; \mathcal{P}) = \{34, 1256, 7, 8\}$ .

## Partition Functions

A pair  $(S; \mathcal{P})$  consisting of a coalition  $S$  and a partition  $\mathcal{P}$  to which  $S$  belongs is called an *embedded coalition*. Let  $\mathbb{E}(N)$  denote the set of embedded coalitions.

We denote by  $(N, w)$  a **game in partition function form** (or a *partition function form game*) where  $w : \mathbb{E}(N) \rightarrow R$  is called a *partition function* that assigns a real value,  $w(S; \mathcal{P})$ , to each embedded coalition  $(S; \mathcal{P})$ . For a given coalition structure  $\mathcal{P}$ , the value  $w(S; \mathcal{P})$  represents the payoff of coalition  $S$ . By convention,  $w(\emptyset; \mathcal{P}) = 0$  for all  $\mathcal{P}$ .

The set of partition function form games (*PFFGs*) with player set  $N$  is denoted by  $PG^N$ .

Let  $w \in PG^N$ .  $w$  is **superadditive** if for  $S, T \in \mathcal{P}$ ,

$$w(S \cup T; \mathcal{P} \setminus (S, T) \cup (S \cup T)) \geq w(S; \mathcal{P}) + w(T; \mathcal{P}). \quad (2)$$

Note that for any characteristic function form games (CFGs), superadditivity implies the efficiency of the grand coalition. However, for PFFGs, superadditivity is not enough to guarantee the efficiency of the grand coalition. It is easy to show that the grand coalition is always efficient for any positive externality games (defined in the next section).

**Example 2.2** Consider the following symmetric game with  $N = 1, 2, 3$  and  
 $w(\{i\}; [N]) = 5$  for all  $i \in N$ ;  $w(N; \{N\}) = 14$ ;  
 $w(\{i\}; \{\{i\}, \{jk\}\}) = 2$  and  $w(\{j, k\}; \{\{i\}, \{jk\}\}) = 11$  for  $\{i, j, k\} = N$ .

This game is superadditive, but the grand coalition is not efficient as  $w(N; \{N\}) = 14 < \sum_{i \in N} w(\{i\}; [N]) = 15$  (possibly because of negative externalities). Though the coalitions gain more by merging, others are worse off, the grand coalition gets less than the total payoff in some other partition. For examples, trading partners deciding upon custom unions, firms competing for market shares and collaboration between different auctioneers with complementary objectives.

**Notation 2.1** For a given partition  $\mathcal{P} = \{S_1, \dots, S_m\}$  and  $w \in PG^N$ , let  $\bar{w}(S_1, \dots, S_m)$  denote the  $m$ -vector  $(w(S_i; \mathcal{P}))_{i=1}^m$ . It will be convenient to economize brackets and suppress the commas between elements of the same coalition. Thus, we will write, for example,  $w(\{ijk\}; \{\{ijk\}, \{lh\}\})$  as  $w(ijk; \{ijk, lh\})$ , and  $\bar{w}(\{ijk, lh\})$  as  $\bar{w}(ijk, lh)$ .

A strong assumption on the value function in CFGs is convexity. Convexity games imply not only that the merging of two coalitions is beneficial for them, but also that merging with a larger coalition is more beneficial (e.g., increasing returns to cooperation). A natural extension of convexity to PFFGs can be given as follows.

Let  $w \in PG^N$ .  $w$  is **convex** if for any  $S_i, S_j \subset N$  such as  $|S_i| < |S_j|$ , and for any  $m \in N \setminus \{S_i, S_j\}$  and  $\mathcal{P} = \{S_i, S_j, \mathcal{P}_{N \setminus \{S_i, S_j\}}\}$ ,

$$w(S_i \cup \{m\}; \tau_{S(m; \mathcal{P})}(S_i; \mathcal{P})) - w(S_i; \mathcal{P}) \leq w(S_j \cup \{m\}; \tau_{S(m; \mathcal{P})}(S_j; \mathcal{P})) - w(S_j; \mathcal{P}). \quad (3)$$

A **solution concept** on  $PG^N$  is a function  $\varphi$  which associates with each game  $(N, w)$  in  $PG^N$  a vector  $\varphi(N, w)$  of individual payoffs in  $\mathbb{R}^n$ , i.e.  $\varphi(N, w) = (\varphi_i(N, w))_{i \in N} \in \mathbb{R}^n$ , where  $\varphi_i(N, w)$  is the payoff to player  $i$ . A solution is called **efficient** if  $\sum_{i \in N} \varphi_i(N, w) = w(N; \{N\})$  for all  $w \in PG^N$ .

**Social welfare** (for given  $\mathcal{P}$ ) is defined by  $SocW(\mathcal{P}) = \sum_{S \in \mathcal{P}} w(S; \mathcal{P})$ .

For a given partition function form game  $(N, w)$ ,  $v^W(N) = \max_{\mathcal{P} \in \mathcal{P}(N)} SocW(\mathcal{P}) = \max_{\mathcal{P} \in \mathcal{P}(N)} \sum_{S \in \mathcal{P}} w(S; \mathcal{P})$  is the *efficient outcome* that players in  $N$  can achieve via forming coalitions and working together to get the highest total payoff (social welfare).

## The core

The core is an important concept in cooperative game theory and has been used for assessing the stability of arrangements that can be made within a society in various contexts. In the case of externality, however, the predictions given by the core may run into difficulties as some individuals or coalitions' benefit depends not only on how benefits are shared but also on which coalitions form. Therefore, one has to make assumptions about what a deviating coalition conjectures about the reaction of the others while defining the core.

Since the core is not in general a singleton (i.e. has a single value), one can have many definitions of core (further details, for example, see Hafalir, 2007; Demange, 2009). In this paper, we focus on two particular core concepts relating to the two extremes of behaviour of the agents<sup>3</sup>. Two simple definitions of the core can be given by presuming that when coalition  $S$  is formed then the agents outside will either play as singleton (Hafalir, 2007; Chander, 2010) or form a coalition (Markin, 2003; Chander, 2010).

**Definition 2.1** *A vector of payoffs  $x = (x_1, x_2, \dots, x_n)$  is in the core with singleton expectations, named the  $s$ -core, if for all  $S \subseteq N$ , we have*

$$\sum_{i \in S} x_i \geq w(S; \{S, [N \setminus S]\}).$$

Note that the  $s$ -core definition assumes that the defecting coalitions are very pessimistic in PFGs with positive externalities but very optimistic in the case of PFGs with negative externalities. The  $s$ -core does not require  $x_i \geq w(i, \{i; \{N \setminus i\}\})$  (similar to the  $\gamma$ -core, see Chander, 2010).

**Definition 2.2** *A vector of payoffs  $x = (x_1, x_2, \dots, x_n)$  is in the core with merging expectations, named the  $m$ -core, if for all  $S \subseteq N$ , we have*

$$\sum_{i \in S} x_i \geq w(S, \{S; \{N \setminus S\}\}).$$

## III. GAMES WITH EXTERNALITIES AND ISSUE LINKAGE

Transboundary externalities occur when actions in one country affect the welfare of residents or the environment in another country. Externalities can

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<sup>3</sup>Ambec and Ehlers (2008) consider two special behaviors of agents outside of coalition  $S$ : either they play as a singleton (in non-cooperative core lower bounds) or as a coalition against  $S$  (in cooperative core lower bounds).

be classified into two categories: unidirectional and reciprocal (Dasgupta, 2002). Damage inflicted by upstream pollution on downstream victims without compensation is an example of the former, whereas the “tragedy of the commons” (Hardin, 1968) is a metaphor for the latter. Groundwater withdrawal under the riparian doctrine is an example of the tragedy of the commons. For any given environmental objectives, society would like to achieve efficient and equitable outcomes. That is, maximize total welfare and then share it among its members in an equitable way. In this section, we construct a special class of games, the so-called game with externalities, where the efficient social welfare is not easily achieved due to externalities.

### 3.1 Game with externalities

**Definition 3.1.** Let  $w \in PG^N$ .  $w$  is called an *externality game (EG)* if for  $S \subset N$ ,  $w(S; P) \neq w(S; P_{N \setminus S} \cup S)$  for any  $P_{N \setminus S} \in P(N \setminus S)$ .

**Proposition 3.1** If an externality game is convex, then the  $s$ -core is non-empty.

**Proof.** We observe that if  $w \in PG^N$  is convex, then for any  $l, m \in N$ ,  $l \neq m$ ,  $S \subset N \setminus \{l, m\}$  and any partition  $\mathcal{P} = \{S, l, m, \mathcal{P}_{N \setminus \{S \cup \{l, m\}\}}\}$ ,

$$w(S \cup \{l, m\}; \tau_{\{l, m\}}(S; \mathcal{P})) - w(S \cup l; \tau_{\{l\}}(S; \mathcal{P})) \leq w(S \cup m; \tau_{\{m\}}(S; \mathcal{P})) - w(S; \mathcal{P}). \quad (4)$$

One can easily derive the condition above from the convex condition (3) in Section 2 by letting  $S_j = S \cup l$ , and  $S_i = S$ . Then the proof of the proposition is straightforward from the previous condition (4) and Proposition 2 in Hafalir (2007).

For a given  $w \in PG^N$ ,  $w$  has **positive** (*negative*) **externalities** if for any coalition  $S \in \mathcal{P}$ , and for any partition  $\mathcal{P}' \in \mathbb{P}(N)$  such that  $|\mathcal{P}| > |\mathcal{P}'|$

$$w(S; \mathcal{P}) \geq w(S; \mathcal{P}') \quad (5)$$

$$(\leq)$$

In words, a game has positive (negative) externalities if a merger between two coalitions makes other coalitions better (worse) off. In this paper, we focus on two special classes of games with externalities, namely free riding (positive externality) and trading (negative externality) games defined as follows.

**(FRG)** A positive externality game  $w$  is called a *free riding game (FRG)* if  
 (i)  $w(N; \{N\}) \geq \sum_{S \in \mathcal{P}} w(S; \mathcal{P})$ ,  $\forall \mathcal{P} \in \mathbb{P}(N)$  and

(ii) *There exists a coalition  $S \subset N$  such that for  $w(S; \mathcal{P}) > w(S; \mathcal{P}')$  where  $|\mathcal{P}| > |\mathcal{P}'|$ .*

Condition (i) implies that the grand coalition is the most efficient coalition, while condition (ii) implies that a coalition  $S$  expects to benefit from the merger of coalitions by not joining the merger. When  $S = \{i\}$ , player  $i$  is called a **free rider**.

**(NEG)** An *externality game*  $w$  is called a **trading game** or a strict *negative externality game (NEG)* if

- (i)  $w(N; \{N\}) \geq \sum_{S \in \mathcal{P}} w(S; \mathcal{P}), \forall \mathcal{P} \in \mathbb{P}(N)$  and
- (ii) *There exists a coalition  $S \subset N$  such that for  $w(S; \mathcal{P}) \leq w(S; \mathcal{P}')$  where  $|\mathcal{P}| > |\mathcal{P}'|$ .*

For  $i \in N$ , let  $\mathcal{P}^i$  be a coalition structure where player  $i$  plays as a singleton. Let  $\mathcal{P}^i(N) = \{\mathcal{P}^i = \{i, \mathcal{P}_{N \setminus i}\}\}$ .

For a given  $w \in PG^N$  and  $\mathcal{P} \in \mathbb{P}(N)$ . Let  $w_*(\{i\}) = \min_{\mathcal{P}^i \in \mathcal{P}^i(N)} \{w(i; \mathcal{P}^i)\}$  and  $w^*(\{i\}) = \max_{\mathcal{P}^i \in \mathcal{P}^i(N)} \{w(i; \mathcal{P}^i)\}$  for all  $i \in N$ ;  
and  $w_*(S) = \min_{\mathcal{P}_{N \setminus S} \in \mathbb{P}(N \setminus S)} \{w(S; \mathcal{P}_{N \setminus S})\}$  and  $w^*(S) = \max_{\mathcal{P}_{N \setminus S} \in \mathbb{P}(N \setminus S)} \{w(S; \mathcal{P}_{N \setminus S})\}$  for all  $S \in \mathcal{P}$ .

The following proposition contains some basic relationships for a class of free rider games (similar to the non-cooperative core lower bounds and cooperative core lower bounds introduced by Ambec and Ehlers, 2008).

**Proposition 3.2** *Let  $w \in PG^N$ . If  $i$  is a free rider, then the following conditions hold for any partition structure  $\mathcal{P}^i \in \mathcal{P}^i(N)$*

$$w_*(\{i\}) = w(i; [N]) \leq w(i; \mathcal{P}^i) \leq w(i; \{i; \{N \setminus i\}\}) = w^*(\{i\}).$$

**Proof.** By properties of free rider games, merging between two coalitions makes other coalitions better off, the proof of this Proposition is obvious and is left to the reader (or see Ambec and Ehlers, 2008).

### Issue linkage

In many economic environments, the payoff resulting from the formation of the grand coalition may be inefficient because the total surplus may not be maximized. Due to increased transaction cost of managing larger groups, some players (free riders) may be better off by remaining separate when others form a coalition. The main challenge of this paper is to look at solutions that can be motivated by the principle of Territorial Integration of

all Basin States (TIBS) in a broader sense that could satisfy both upstream and downstream countries. The topic of issue linkage is not new. Issue linkage has been studied in noncooperative games representing international negotiations across countries and it has been argued that combining negotiations over different dimensions (trade, protection of environment) may have beneficial effects (Carraro and Siniscalco, 1994, Conconi and Perroni, 2002).

When negotiations address an issue with strong asymmetry, grouping issues with opposite asymmetry can be advantageous because countries are more likely to exchange in-kind side payments rather than monetary side payments and facilitate credible threats against defections (Just and Netanyahu, 2000). In their works, Bennett et al. (1997), Kliot et al (2001) and Kemfert (2004) suggested that the complexity of international negotiations can be better modeled by linking independent games.

The linkage principle argues for tying river sharing agreements (RSAs) to other (not necessarily related) issues that are of concern and can benefit one or more countries. Examples of potential issue linkages include total water allocation of shared water among countries and non-water environmental degradation such as pollution of the common watershed and economics trade. We selected two issues for the preliminary linked game in our analysis: a river sharing problem and the trade in food products. These two issues may produce results preferred to bargaining over the water alone.

We assume that negotiating countries can play noncooperatively in order to determine (evaluate) their policy (variables)<sup>4</sup>. Efficiency for a group of countries (a coalition), be it  $N$  or any subset  $S$  of it, is a joint policy of the members of the group that maximizes the group's aggregate welfare. For example, issue linkage<sup>5</sup> is considered to provide cooperation opportunities related to either water flow control or technological innovation or trade sanctions against free riders. The coalition structures associated with the linked game, therefore, are simply the coalition structures that have been considered by all players in the bargaining process. Hereby their values are determined by the sum of the partition functions that are associated with each issue (taken separately)<sup>6</sup>. Formally,

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<sup>4</sup>That means (depending on the outcomes) that players decide whether or not to act cooperatively (i.e. join a coalition and sign a agreement).

<sup>5</sup>For example, the first issue of a linked game, "the water stage", is a river game (Ambec and Ehlers, 2008) while the second issue is a trading game where a group of countries announces forming a coalition and members of the coalition expect the outsiders to play non-cooperatively when they compute their highest outcomes (welfares).

<sup>6</sup>One can also consider the linked games as the 2-stage (or 3-stage) games where all play

Let  $w^i \in PG^N$ ,  $i = 1, 2$ , we construct a **(2-) linked game** as the sum of two independent (directed) games<sup>7</sup>. The new game, denoted by  $w^{\overline{12}}$ , has its value is determined by the sum of the two values of two independent games in the same structures. Formally,

$$w^{\overline{12}}(S; \mathcal{P}) = w^1(S; \mathcal{P}) + w^2(S; \mathcal{P}), \forall S \in \mathcal{P} \in \mathbb{P}(N).$$

**Example 3.1** Let  $N = \{1, 2, 3\}$  and  $w^i \in GP^N$ ,  $i = 1, 2$ , defined as follows  
 $w^1(\{i\}; [N]) = 5$  for all  $i \in N$ ;  $w^1(N; \{N\}) = 14$ ;  
 $w^1(\{i\}; \{\{i\}, \{jk\}\}) = 2$   
and  $w^1(\{j, k\}; \{\{i\}, \{jk\}\}) = 11$  for  $\{i, j, k\} = N$ .  
 $w^2(\{i\}; [N]) = 4$  for all  $i \in N$ ;  $w^2(N; \{N\}) = 12$ ;  
 $w^2(\{i\}; \{\{i\}, \{jk\}\}) = 6$   
and  $w^2(\{j, k\}; \{\{i\}, \{jk\}\}) = 6$  for  $\{i, j, k\} = N$ .  
Then  $w^{\overline{12}}(\{i\}; [N]) = 7$  for all  $i \in N$ ;  $w^{\overline{12}}(N; \{N\}) = 26$ ;  
 $w^{\overline{12}}(\{i\}; \{\{i\}, \{jk\}\}) = 8$   
and  $w^{\overline{12}}(\{j, k\}; \{\{i\}, \{jk\}\}) = 17$  for  $\{i, j, k\} = N$ .

**Remark 3.1.** One can easily see that any linked game formed by two externality games is associated with externalities. However, these externalities may be positive or negative.

To explore in further detail the linkage argument, consider the following example.

There are two countries, upstream and downstream that share a river. The countries have two options, to cooperative or to defect, and they do not mix strategies for improving their welfare, based on two issues: *water and trading*. Cooperate and defect refer to the country's strategies for each game (each issue). The payoffs for each outcome of the game are represented by  $B_{jk}^i$  (water issue) and  $V_{jk}^i$  (trade issue), with the superscript representing the player  $i = U, D$  (e.g., Upstream and Downstream countries).

<b>Water game</b>		<b>Trade game</b>	
		<i>Down</i>	
		Not Pay	Pay
$U_P$	Not Share	$(B_{dd}^U, B_{dd}^D)$	$(B_{dc}^U, B_{dc}^D)$
	Share	$(B_{cd}^U, B_{cd}^D)$	$(B_{cc}^U, B_{cc}^D)$
		<i>Down</i>	
		Restrict	Open
$U_P$	Restrict	$(V_{dd}^U, V_{dd}^D)$	$(V_{dc}^U, V_{dc}^D)$
	Open	$(V_{cd}^U, V_{cd}^D)$	$(V_{cc}^U, V_{cc}^D)$

non-cooperatively at their first stage and then forming coalitions at the second stage. The final outcomes as the results of linked issues can offer potential advantages for cooperation.

<sup>7</sup>It also holds and can be extended for  $n$ -linked game, where  $n > 2$ .

Without loss of generality, the first letter  $j$  in the subscript identifies the strategy played by  $U$  ( $c =$  cooperate,  $d =$  defect) while the second letter  $k$  played identifies the strategy played by  $D$ .

**Water issue:** Assuming that each country has two strategies<sup>8</sup>: the upstream country chooses between sharing (cooperate) or not sharing (defect) water with the downstream. The downstream country chooses whether it makes a side payment (cooperate) or not (defect) to the upstream country. For a transboundary river, static games may generate outcomes in which the upstream country has a dominant strategy not to cooperate with the downstream country, namely, not share or clean up water. The essence of the transboundary problems can be presented as a prisoner dilemma (PD) with a payoff structure given by

$$B_{dc}^U > B_{cc}^U > B_{dd}^U > B_{cd}^U, \text{ and } B_{cd}^D > B_{cc}^D > B_{dd}^D > B_{dc}^D. \quad (\text{C1})$$

The conditions above<sup>9</sup> show that the upstream country's dominant strategy is to choose not to share, because sharing the water always costs it some welfare reduction. The downstream country's dominant strategy is not to pay because making side payment always reduces its welfare. For this PD outcome, the Nash equilibrium is not socially an optimal outcome. Both countries could receive higher payoffs if they could agree to cooperate.

In this issue, a partition function  $w^W$  can be obtained as follows

(i) From *Nash equilibrium (NE)*:

$$w^W(i; [N]) = B_{dd}^i \text{ and } w^W(N; \{N\}) = B_{cc}^U + B_{cc}^D.$$

(ii) From *free rider (optimistic) behavior*:

$$w^W(i; [N]) = \max B_{jk}^i \text{ for any } j \neq k \text{ and } w^W(N; \{N\}) = B_{cc}^U + B_{cc}^D$$

The above implies that there are two options: either

$$B_{dd}^U + B_{dd}^D = w^W(U; [N]) + w^W(D; [N]) \leq w^W(N; \{N\}) = B_{cc}^U + B_{cc}^D \quad (6)$$

or

$$B_{cc}^U + B_{cc}^D = w^W(N; \{N\}) \leq w^W(U; [N]) + w^W(D; [N]) = B_{dc}^U + B_{dc}^D. \quad (7)$$

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<sup>8</sup>Defect and cooperate are terms that stem from the famous prisoners' dilemma (PD). The meaning here is that defect stands for the policy without share/release water, whereas cooperate stands for the sharing policy.

<sup>9</sup>For simplicity, we can assume that  $B_{dc}^U > B_{cc}^U > B_{dd}^U = 0 > B_{cd}^U$ , and  $B_{cd}^D > B_{cc}^D > B_{dd}^D = 0 > B_{dc}^D$ .

Therefore, deriving from Nash equilibrium we obtain a positive externality game (i), while the second case (ii) is an externality only (grand coalition is less than the sum of free ridding values).

**Trade issue:** Assuming the countries choose between restricted (higher – trade barriers) or openness policies. The payoff structure<sup>10</sup> of trading is assumed to be

$$V_{cc}^U > V_{dc}^U = 0 = V_{dd}^U > V_{cd}^U \text{ and } V_{cc}^D > V_{cd}^D = 0 = V_{dd}^D > V_{dc}^D \quad (\text{C2})$$

In this game, there are two Nash equilibria: one corresponding to mutual protectionism (or punishment) and the other to mutual openness only if they can be assured that other nations will do likewise; open trade is only beneficial if reciprocated<sup>11</sup>.

The partition functions  $w^T$  can be determined based on one of two NE<sup>12</sup> as follows

(i) For openness:

$$w^T(i; [N]) = \max V_{jj}^i \text{ and } w^T(N; \{N\}) = V_{cc}^U + V_{cc}^D.$$

(ii) For protectionism:

$$w^T(i; [N]) = \min V_{jj}^i \text{ and } w^T(N; \{N\}) = V_{cc}^U + V_{cc}^D.$$

It is now assumed that these two issues are linked based on the countries' preferences. According to all possible outcomes, there exists 4 linked games representing 4 options (scenarios)<sup>13</sup> given as follows.

(L1) From Nash equilibrium and protectionism:

$$w^{\overline{WT}}(i; [N]) = B_{dd}^i + V_{dd}^i \text{ and } w^{\overline{WT}}(N; \{N\}) = B_{cc}^U + V_{cc}^U + U_{cc}^D + V_{cc}^D$$

<sup>10</sup>The standard trade theory uses a cooperative trading game with the assumptions  $V_{cc}^U > V_{cd}^U > V_{dc}^U > V_{dd}^U$  and  $V_{cc}^D > V_{dc}^D > V_{cd}^D > V_{dd}^D$ , which is one dominant strategy to restrict trade barriers. Hence, there is no need for negotiations-that nations should liberalize unilaterally (Krugman, 1997).

<sup>11</sup>This reality may reflect the political difficulties of persuading the public that unilateral trade liberalization is not tantamount to unilateral disarmament (Hauer and Runge, 1999).

<sup>12</sup>This is an assurance problems in which the equilibrium outcome may be either a successful agreement to match concessions, or an unsuccessful one, in which nations fail to expand the domain of non discrimination. In other words, while the outcome of trade liberalization is not always achieved, it is achievable in principle, and is Pareto superior, offering net gains to both players.

<sup>13</sup>Note that individual rationality implies that countries could play Nash and protectionism but consider conditions for getting better outcomes.

**(L2)** From free ridding and and protectionism:

$$w^{\overline{WT}}(i; [N]) = \max_{k \neq j} B_{jk}^i + V_{dd}^i \text{ and } w^{\overline{WT}}(N; \{N\}) = B_{cc}^U + V_{cc}^U + U_{cc}^D + V_{cc}^D$$

**(L3)** From Nash equilibrium and openness:

$$w^{\overline{WT}}(i; [N]) = B_{dd}^i + V_{cc}^i \text{ and } w^{\overline{WT}}(N; \{N\}) = B_{cc}^U + V_{cc}^U + U_{cc}^D + V_{cc}^D$$

**(L4)** From free ridding and openness:

$$w^{\overline{WT}}(i; [N]) = \max_{k \neq j} B_{jk}^i + V_{cc}^i \text{ and } w^{\overline{WT}}(N; \{N\}) = B_{cc}^U + V_{cc}^U + U_{cc}^D + V_{cc}^D$$

Observe that in options (L1) and (L3),  $w^{\overline{WT}}(N; \{N\}) > w^{\overline{WT}}(i; [N]) + w^{\overline{WT}}(j; [N])$  because  $B_{cc}^i > B_{dd}^i$  and  $V_{cc}^i > V_{dd}^i$ . In these two cases, the grand coalition is socially optimal and cooperation can be achieved. For the second option (L2), the grand coalition is optimal iff  $\max_{k \neq j} B_{jk}^i \leq U_{cc}^i + V_{cc}^i$  for all  $i = U, D$ . (note that  $V_{dd}^i = 0$  for all  $i$  as conditions (C2)). For the last option (L4), the grand coalition is not efficient<sup>14</sup> because  $\max_{k \neq j} B_{jk}^i > B_{cc}^i$ . However, regarding rationality, the two options (L1) and (L3) that are determined by Nash equilibria are feasible/possible for the players. This implies that linking two independent issues can lead to more opportunities for cooperation.

#### IV. A RIVER GAME WITH EXTERNALITIES

This section investigates whether incentives exist for free rider countries (or the situation resembles the PD) to join an existing transboundary resource control cooperating coalition. In the following we consider a group of countries in the two regions of a river basin: upstream and downstream. In the absence of agreement, each country chooses the policy that suits it best, given policies it believes other countries selected. If marginal benefits are higher for players located more downstream (or upstream), then it may be profitable to form a coalition  $S$  to pass some water from one member (component) to another member (component). We first present the river sharing problem introduced by Ambec and Sprumont (2002), extended by Ambec and Ehlers (2008) and Ambec and Dinar (2010). We then will study a combined partition function form game (linked games) in which players negotiate a river sharing agreement (RSA) based on water flows (with multiple objectives) among countries.

<sup>14</sup>It can be efficient if  $\max_{k \neq j} B_{jk}^i = B_{cc}^i$  for all  $i$ .

Let  $N = \{1, 2, \dots, n\}$  be the set of players along the river, numbered successively from upstream to downstream and  $e_i \geq 0$  be the amount (inflow) of water on the territory of country  $i$ . Assume that the water  $e_i$  flowing into the river from country  $i$  can only be consumed by the countries which are located downstream from country  $i$  (as natural water flows)<sup>15</sup>. Moreover, every country has its utility (benefit) function  $b_i(x)$ , from diverting/controlling  $x$  units of water flows, which is a strictly concave function.

A *water allocation plan*  $x = (x_i)_{i \in N}$  ( $= (x_1, x_2, \dots, x_n)$ ) assigns an amount of water  $x_i$  to every country  $i$  under restrictions

$$\sum_{i=1}^j x_i \leq \sum_{i=1}^j e_i, \quad j = 1, 2, \dots, n.$$

and to a coalition  $S \subseteq N$  restrictions

$$\sum_{i \in S} x_i \leq \sum_{i \in S} e_i, \quad S \in \mathcal{P}.$$

For every coalition  $S \subseteq N$ , denote by  $x(S) = \sum_{i \in S} x_i$  and  $e(S) = \sum_{i \in S} e_i$  the sum of  $x = (x_i)_{i \in S}$  and  $e = (e_i)_{i \in S}$ , respectively.

We assume that each country has its own optimal (water) plan  $x_i$  based on the total water flows  $e(N) = \sum_{j=1}^n e_j$  and it never consumes more than its satiated point  $x_i^{sp}$  (that is  $x_i < x_i^{sp}$ ) for all  $i \in N$ . Since the benefit function is strictly concave, the satiation point  $x_i^{sp}$  exists and is unique (Ambec and Ehlers, 2008). However, the existence of satiation points may cause serious consequences such as positive/negative externalities on sharing water flows (seasons or ability to take  $x^{sp}(S) = \sum_{i \in S} x_i^{sp} \geq e(S)$ ). Some countries can form a coalition  $S$  to make them more profitable so that they agree to release/pass more water to supply their downstream members or other reasons, including having power to block water to downstream or modifying its satiated point, which could cause available water to be reduced to downstream.

We also assume that when  $S$  is formed (for sharing water flows) the outsiders of  $S$  acts non-cooperatively and consume at least their own water flow<sup>16</sup>. A

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<sup>15</sup>It implies that each country can be assigned at most the water inflow at the territories of itself and its upstream countries, but the water inflow downstream of some countries cannot be allocated to this country.

<sup>16</sup>Other options can be extended and left for our future works.

water allocation plan  $x \in R^n$  is optimal if it maximizes the social welfare maximization problem, that is

$$\max_{x \in R^n} \sum_{i=1}^n b_i(x_i), \text{ s.t } x(S) \leq e(S) \text{ for all } S \subseteq N \quad (8)$$

Note that given the water flows  $e$ , a country's optimal water is determined from a backwards induction algorithm (details, see Remarks 1 and 2 in Ambec and Ehlers, 2008) and the value of each coalition  $S$  is defined as the sum of benefits of their members based on the available water flows  $e(S)$  ( $\leq sp(S) = \sum_{i \in S} sp_i$ ). However, the existence of the efficient allocations on sharing water for each coalition depends not only on their commitment of releasing water among members but also on their rights over water flows. Kilgour and Dinar (1995) have proposed several principles, concerning the "water right" assigned to the different countries along the river, to prevent or resolve disputes on water allocation within a transboundary water basin. Indeed, both the Absolute Territorial Sovereignty (ATS) and Territorial Integration of all Basin States (TIBS) principles depend on how property rights over water are defined. In the absence of a binding international agreement on water allocation, there are positive externalities (the ATS) and negative externalities (the TIBS) for individuals and groups of countries. For example, the existence of satiation points may cause (i) positive externalities for transferring water from upstream to downstream when there is some country,  $j$ , such that  $i < j < k$  does not want to join a coalition  $S$  where  $i$  and  $k$  are already members; (ii) negative externalities for the TIBS principle.

Let  $w(S; \mathcal{P})$  be the highest secured welfare<sup>17</sup> that coalition  $S$  can secure by signing its own RSA with water flows  $e$ .

A partition function  $w$ , obtained from the unique values by computing a backward induction mechanism (for every coalition) is called a *river game with externalities* if there is a coalition  $S \in \mathcal{P}$  such that  $w(S; \mathcal{P}) \neq w(S; \mathcal{P}')$ .

The following Proposition is obtained directly from Ambec and Ehlers (2008, Proposition 1).

**Proposition 4.1** Let  $\mathcal{P} \in \mathbb{P}(N)$  and  $S \in \mathcal{P}$ . Then for every river game

<sup>17</sup>That is  $w(S, \kappa) = \sum_{i \in S} b_i(x_i^\kappa(N))$ , where  $x_i^\kappa(N)$  is the efficient allocation of water among members  $i \in S$ , given that the countries outside  $S$  divert water up to their satiated point (details, see Ambec and Ehlers, 2008).

$$(i) \ w(S; \{S, [N \setminus S]\}) \leq w(S; \mathcal{P})$$

$$(ii) \ \text{For any } S, T \in \mathcal{P}, \ w(S; \mathcal{P}) + w(T; \mathcal{P}) \leq w(S \cup T; \{\mathcal{P} \setminus (S, T); S \cup T\})$$

Note that (i) also implies that  $w(S; \{S, [N \setminus S]\}) = \min_{\mathcal{P} \in \mathbb{P}(N), S \in \mathcal{P}} w(S; \mathcal{P})$  and that (ii) implies that a coalition can achieve at least as much as the sum of what its parts can; i.e. the partition function  $w$  is *superadditive*.

**Corollary 4.1** *For every river game with positive externalities, the grand coalition is the only efficient outcome (e.g., maximal social welfare).*

**Proof.** Let  $w$  be a river game with positive externalities. By Proposition 4.1 (ii),  $w$  is superadditive. Moreover, for all  $\mathcal{P} \in P(N)$ ,  $\sum_{S \in \mathcal{P}} w(S; \{S, [N \setminus S]\}) \leq \sum_{S \in \mathcal{P}} w(S; \mathcal{P}) \leq w(N; \{N\})$ .

This Corollary implies that the highest social welfare can be achieved only at the basin-wide level.

**Remark 4.1** As mentioned above, there are two aspects of achieving RSAs based on controlled water flows and developing sustainability at a basin level. In particular, every river game can include both negative and positive externalities due to lack of water property rights.

**Remark 4.2** Note that the s-core is a nonempty set for every river game with positive externalities. However, achieving an RSA is not easy because the s-core does not satisfy the maximal outcome that the free riders have expected.

We assume that locations of water flows play an important role in determining a value of coalitions in a river game only and that the countries could reach an agreement at the same time that they are involved in a set of negotiations on another issue such as trading or technological innovations. In this situation, assuming that a group of countries, coalition  $S$ , restricts imports from other groups (i.e.  $N \setminus S$ ), but all countries could base an agreement on an exchange of concessions by linking the water issue with the trading for getting better outcomes. It is furthermore assumed that the constituting games are strategy and payoff independent. However, all coalition structures' values are determined based on the water flow constraints. In addition, each country has the right to a specific share of water (depending on the water flows) and welfare (from free trade) to form its coalitions.

Let  $w^R$  be a river game and  $w^T$  be a game with externalities (Section 3). Note that we have not introduced any budget-balance constraint in a river

game, i.e. transferring moneys, as of Ambec and Ehlers (2008) and Ambec and Dinar (2010). In the following, we pay attention to the core as conditions for designing fair RSAs.

Let  $w^{RT}$  be the linked game defined as  $w^{RT}(S; \mathcal{P}) = w^R(S; \mathcal{P}) + w^T(S; \mathcal{P})$  for every  $S \in \mathcal{P} \in P(N)$ . From section 3, it follows that  $\sum_{S \in \mathcal{P}} w^{RT}(S; \mathcal{P}) \leq w^{RT}(N; \{N\}) = w^R(N; \{N\}) + w^T(N; \{N\})$ . Moreover, if the linkage game  $w^{RT}$  is convex, there exists a payoff  $x = (x_i)_{i \in N}$  such that for any coalition  $S \subset N$ ,

$$\sum_{i \in S} x_i \geq w(S; \{S, [N \setminus S]\}).$$

**Proposition 4.2** If a linked game is convex, the s-core is nonempty.

The proof of this proposition follows from Section 3 in this paper.

**Example 4.1** Consider a river shared by three countries,  $N = \{1, 2, 3\}$ . Let the ordering of upstream to downstream be 1, 2, 3. Assume that countries may consider a plan of negotiations for improving their welfare in both water uses and trading agricultural products. Assume furthermore that countries 2 and 3 have more potential for producing food while country 1 has power of controlling water flows. Once water is released by country 1, then country 2 has power to control the water flow further downstream, but to a lesser extent. This water game represents the situation in the Euphrates-Tigris (Turkey, Syria and Iraq) during several conflicting incidents in the past (Kibaroglu and Unver, 2000; Kibaroglu 2002).

Cooperation in water use means that the members of a coalition can get a transfer/release of new technology or innovation along with water releases. If no cooperation over water takes place, country 1 keeps most of the water for regional development in its territory and holds a large surplus behind dams. Then, countries 2 and 3 get the remaining flow on an egalitarian basis, but without coordination of the releases between country 1 and 2, which leads to waste (inefficiencies). Cooperation between country 1 and 2, and country 1 and 3 takes the form of the transfer of efficient irrigation technologies, mainly from the more developed country 1 to the others (for details, see Dinar and Wolf, 1994) and coordination of water releases to prevent waste. It is assumed that water released in country 1 for country 3 will not be challenged or confiscated by country 2. Cooperation between country 2 and 3 takes the form of agreed allocation with coordination of the flow released by country 1. Basin-wide cooperation takes the form of exchange of technologies and agreed releases to address each country's needs.

Cooperation over trade takes the form of opening the market for trade in the various crops, or reducing tax on trade in certain crops<sup>18</sup>. Cooperation over agricultural trade is also possible as the three countries specialize in different crops and have different relative advantages in growing some crops due to their climate and soil properties. In the following trade game, a country not part of a regional agreement achieves a lower economic payoff or even faces losses from taxes needed to enter the market of the cooperating countries. Basin-wide cooperation (grand coalition) then takes the form of all types of actions mentioned above (agreed allocations and coordinated release times, and transfer of irrigation technologies), which reduce waste and culminates in higher payoff to the grand coalition.

Let  $w^R$  and  $w^T$  be partition functions for water and trade games, respectively and defined as follows.

$$\begin{aligned}\bar{w}^R(1, 2, 3) &= (10, 3, 3); \bar{w}^R(12, 3) = (15, 3); \bar{w}^R(13, 2) = (12, 8) \\ \bar{w}^R(23, 1) &= (7, 10); \bar{w}^R(\{N\}) = 20 \text{ and} \\ \bar{w}^T(1, 2, 3) &= (1, 2, 3); \bar{w}^T(12, 3) = (8, 3); \bar{w}^T(13, 2) = (10, 1) \\ \bar{w}^T(23, 1) &= (15, 0); \bar{w}^T(\{N\}) = 15.\end{aligned}$$

The 2- linked game  $w^{\overline{RT}}$  is constructed such that

$$\begin{aligned}\bar{w}^{\overline{RT}}(1, 2, 3) &= (11, 5, 6); \bar{w}^{\overline{RT}}(12, 3) = (23, 6); \\ \bar{w}^{\overline{RT}}(13, 2) &= (22, 9); \bar{w}^{\overline{RT}}(23, 1) = (22, 10); \bar{w}^{\overline{RT}}(\{N\}) = 35.\end{aligned}$$

From the linked game  $w^{\overline{RT}}$  one can easily see that there exists some potential cooperation because the grand coalition can cover/transfer all loser and free riders' values ( $35 > 10 + 9 + 6 = 25$ ) while it is impossible in the case of the water game ( $20 < 10 + 8 + 3 = 21$ ) and it is not feasible in the trade game ( $\bar{w}^T(\{N\}) = 15 = w(23; \{23, 1\})$ ). In addition, the structure  $\{13, 2\}$  is not stable in the river game because of free riding (of player 2).

Notice that in this example, player 2 is a free rider in both the river and linked games, while player 1 is a loser both in the trade and linked games. However, the role of player 3 remains unchanged. By changing the outcomes or the rule of games, one can introduce several scenarios such as a scenario in which there is no free rider.<sup>19</sup>

<sup>18</sup>In a trade game, negative values imply a loss of market supply or high tax.

<sup>19</sup>For example, given all values in the two independent games (player 1 is more powerful in water game only) but player 3 has more power on trading such as  $\bar{w}^T(13, 2) = (10, -3)$ , then there is no free rider in the linked game.

**Remark 4.3** *If the grand coalition of a linked game  $w^{\overline{RT}}$  constructed by two games with externalities does satisfy  $\sum_{S \in \mathcal{P}} \max_{\mathcal{P}_{N \setminus S} \in \mathbb{P}(N \setminus S)} w^{\overline{RT}}(S; P_{N \setminus S}) \leq w^{\overline{RT}}(N; \{N\})$  then the  $m$ -core is nonempty.*

This remark follows the fact that for every positive externality game, the free riders' value is  $\max_{\mathcal{P}_{N \setminus S} \in \mathbb{P}(N \setminus S)} w^{\overline{RT}}(S; \mathcal{P}_{N \setminus S})$ . Moreover, Proposition 3.2 shows that a free rider value  $\max_{\mathcal{P}_{N \setminus i} \in \mathbb{P}(N \setminus i)} w^{\overline{RT}}(i; \mathcal{P}_{N \setminus i}) = w^{\overline{RT}}(i; \{i, \{N \setminus i\}\})$ .

## V. CONCLUDING REMARKS

This paper applies the notion of partition function forms to international river games with externalities and investigates incentives for cooperation that could be enhanced by issue linkage. We show that there exist incentives for non-cooperating countries to join a coalition by inducing issue linkage such as linking water control and trade (or technological innovation). A full cooperation on water use control and other (issue) improvements benefit all countries in comparison with unilateral strategy.

In particular, we showed that if an externality game is convex, then the  $s$ -core is nonempty. We also found that for every river game with positive externalities, the grand coalition (basin-wide agreement) is the only efficient outcome (i.e. maximizes social welfare), and further, if a linked game is convex, the  $s$ -core is nonempty. These three findings allow us to move to the objective of our paper and to show that whenever opportunities for linkages exist, countries may indeed move towards cooperation.

This conclusion supports the Integrated Water Resource Management (IWRM) discipline that has been promoted by water managers, but faced opposition from others (economists, international relations and political science scholars) on the grounds that due to inter-linkages leading to negative externalities among riparian states, it would not allow a cost-effective basin-wide arrangement due to high transaction costs and little basis for developing joint interests (narrow, or empty cores). However, we were able to demonstrate in our analysis that, especially for situations in which externalities exist, the basin-wide arrangement is the best solution. It can be achieved by identifying issue linkages and linking them into one optimal basin-wide agreement. In a future paper, we plan on demonstrating how issue linkage can help mitigate the externalities, using a river basin model with application to a specific basin.

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