Cooperative water allocation under economic and hydro–political asymmetry*

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Abstract

We develop a model which formally describes a solution to the problem of cooperative international water allocation under hydrological heterogeneities and imbalances of political power between nations. We argue that the value of water under asymmetric hydro–political conditions is primarily determined by an evaluation of interstate policy outcomes and interstate bargaining. This contrasts the view that allocation outcomes are normally based on inter–comparisons of economic utilities. Based on the condition of non–diminishing basin–wide social welfare, a resulting water allocation balances out the hydro–political differences among nations. We illustrate our model by means of a short case study on the Nile.

1 Introduction

In international river basins, the ability to allocate water becomes more and more challenging due to increasing population pressure and climate uncertainty. Existing research reveals

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that the *fairness* criterion is of growing concern to governments for conflict mitigation [3]. Based on an empirical study of the major global river basins, Wolf [15] identifies several conflicting views which complicate the allocation of river water. These are 1) rights–based view: upstream claim for absolute territorial sovereignty is in conflict with the downstream doctrine of total riverine integrity, 2) needs–based view: prioritization of historic water rights while favoring an allocation to the highest needs and 3) an economics–based view according to which water should flow to the highest use–efficiency. All three views compete with equitability.

Many real–world examples show that allocation according to economic efficiency is often secondary to hydro–political factors [3]. This is for example enshrined in the "Helsinki rules" from 1966 [9] and the UN Convention on the "Law of the Non-navigational Uses of International Watercourses" [14] which are considered as legal standards for the regulation of international waters.

In this paper, we therefore assume that the value of water under asymmetric hydro–political conditions is determined by both, an evaluation of interstate policy outcomes as well as economic benefits. Negotiations on a new allocation policy imply a bargaining process about the allocation of water as well as the valuation of water, for both, consumptive as well as non–consumptive use. We also presume that an inclusive view of watershed allocation policies ensures that any redistribution of water should be constrained by basin–wide, non–diminishing social welfare [1].

If this more inclusive view of evaluating policy outcomes together with economic benefits is taken into consideration, we submit that the real–world dynamics of policy–outcomes in watersheds can be better understood. By acknowledging this, we sketch out the necessary components of a formal model that accounts for this. By means of a case study in the Nile river catchment, we demonstrate this.

[1] Social welfare is understood to incorporate institutions and capital assets (see Arrow et al [2])

2 Problem Statement

We develop a formal model to a cooperative solution for a *fair water allocation* between nations under the condition of economic and hydro–political asymmetry. A fair division of resources, generally speaking, is based on the three criteria of *efficiency, equitability and envy-freeness* [6]. *Efficiency* includes "any allocation that is strictly better for one player is strictly worse for the other". *Equitability* is defined as such that the valuation of each allocation is equal[2]. *Envy-freeness* is interpreted as such, that no player would trade his or her allocation for that of another player (Definitions from Brams and Taylor [6]).

3 Formal Model

3.1 Definitions

Players: The model consists of an upstream and downstream player as determined by the hydrological geography of the problem[3]. In what follows, upstream player u characteristics are denoted with a superscript $(\cdot)^u$ and downstream player d characteristics with the superscript $(\cdot)^d$.

Water requirements and usages: Consumptive water use is denoted as q_c. It refers to agricultural, domestic and industrial water requirements. Similarly, non–consumptive water use is denoted with q_n referring, for example, to hydropower generation as well as to environmental and hydro–political in–stream needs (e.g. claimed transborder flows by a downstream country). Note that in our model, q_n^u is a function of q_c^d which reflects the hydro–political dependence.

Benefits from water use: For simplicity, we assume that allocation costs for both players can be neglected. The ith players' utility function is assumed to be linear in both, q_c^i

[2] In this case this means that costs and benefits are allocated equally according to the valuation of water use as will be shown later.

[3] The model applies to more than two players as well. In such a case an upstream player potentially is at the same time downstream player related to another one – and vice versa.

and q_n^i, where $i \in \{u, d\}$. Therefore, for a particular allocation, the total utility for i can be described as $b^i = u_c^i q_c^i + u_n^i q_n^i$. u_c and u_n are marginal utilties[4]. The total, basin–wide welfare (benefit) can be described as $U = \sum_{i \in \{u,d\}} u_c^i q_c^i + u_n^i q_n^i$ (see Griffin [8]).

3.2 Hydrological Model

Total water availability is given by precipitation p^i. Transborder flows from u to d are $q_n^u = p^u - q_c$. Outflow at the end of the river is defined as $q_n^d = p^i - q_c^i$. A claimed allocation for a certain minimum transborder flow q_n^u limits therefore implicitly the amount of q_c^u. Hence d is dependent on u only by the amount of q_c^u.

p^i (besides q_n^u) primarily determines the total potential benefit of a country. Obviously no allocation rule can alter the amount of p^i. Hence we look only at inducable changes in river flow and resulting changes in total utilities. The change in downstream availability is denoted as $dq_n^d = p + q_n^d - q_c^d + dq_c^u$ where dq_c^u is negative for the case $dq_c^u / dq_n^u > 0$, and positive for the case $dq_c^u / dq_n^u < 0$. Consumptive behavior downstream q^d has no influence on river flows upstream.

3.3 Game–Theoretic Model

The game–theoretic model is represented as an algorithm consisting of two components: 1) The players negotiate their marginal utilities and a new water allocation policy. We consider the outcome as an *envy–free allocation* of u^i and a balanced water flow. 2) The players calculate their total utility and distribute potential benefits in a cooperative bargaining game. If an *efficient* solution exists and a suggested compensation is *equitable* then the algorithm ends. Otherwise the game continues at step 1).

[4]Our results apply also in the case where $u = f(q)$ with monotonicity and concavity constraints fulfilled

3.3.1 Efficient and equitable allocation

We assume that a negotiation process (formalized later) on a proposed policy reveals specific marginal utilities u_c^i and u_n^i assumed to be true. By testing if an efficient and equitable solution is achieved, a policy implying u_c^i and u_n^i is accepted or rejected.

Efficiency: Arrow et al. [2] define a sustainability criterion which indicates that intertemporal social welfare does not decline while utilities might change[5]. Using this as a constraint we assume that an efficient solution should exists if marginal utilities are true. Analytically this can be tested by comparing changes in total basin–wide benefit[6] without new policy U^0 and with new policy U^1. If $U^1 - U^0 < 0$ then the valuation of u_c^i and u_n^i is rejected and no agreement is possible.

Equitability: If an efficient solution can be achieved (mostly a set of pareto–efficient solutions), a potential surplus in benefits can be allocated in a cooperative bargaining game. Bargaining solutions are suggested e.g. through a Nash-product [13], the Kalai-Smorodinsky solution [10] or in particular for a river by [1]. A practical solution to allocate goods (in this case benefits and costs would be adjusted) is given by the Adjusted Winner (AW) solution of Brams [4]. Here I suggest, as adaptation to AW, that we alterating allocate first the lowest benefits (which have to be paid into the "distribution–pool") and then the highest costs (which are compensated) before the equitability adjustment. This would prevent players to overestimate their costs and underestimate their benefits. The resulting allocated share of benefit is b_e^i (used later). A welfare distribution in reality that assigns to any country a share which is lower than what the bargaining game reveals would be rejected and require re–negotiation.

[5]This argument is supported qualitatively by Diamond [7] who argues that societies which can not use their resources sustainably will diminish.

[6]The matter of dispute in water allocation is not about total benefits but only about changes in benefits or costs. This is naturally given by hydrological heterogeneities as a result of climatic conditions.

3.3.2 Envy-Free and fair allocation through negotiation

The process of an envy-free allocation is modeled as 2x2 normal form game which considers the four states as outcome of sequential moves. This means that each player can at each stage change his strategy unilaterally by anticipating possible countermoves of the other player. This process is explained by the Theory of Moves (TOM) [5].

Strategies: Hydrologically speaking only u can alter consumtive water use q_c^u in favor or disfavor to d. This if u is decreasing his valuation for q_c^u and/or if he is increasing his valuation for q_n^u. Hence the room to negotiate[7] for u is denoted as ν with $\nu_c^u \in \{0, u_c^u\}$ and $\nu_n^u \geq 0$ with resulting changes in total benefit for u: $db^u = (u_n^u - \nu_n)dq_n^u + (u_c^u + \nu_c)q_n^u + b_e^u$. The allocated share from an efficient and equitable allocation is denoted with b_e^u (see Section 3.3.1). u cooperates by indicating $\nu > 0$ otherwise $\nu = 0$.

While political power applies to both players it is primarily not in the interest of u to induce changes. The upstream player, by showing his power, only strengthens his position being in a hydrological advantaged situation. Hence changes are only possible if d dominates. Therefore p denotes the domination of the downstream user by exerting pressure on the upstream user. Pressure includes possible threats and diplomatic measures but could also be based on water needs downstream which induce u to reassess his water valuation based on ethical values. d dominates if $p > 0$ otherwise $p = 0$.

Preferences: The preferences for the downstream country are obvious: On one hand, d prefers always to have more water than less[8]. On the other hand by dominating u costs arise for d as well which decrease d's benefit even if u is willing to comply. u has a unique ranking of preferences as well, based on the considerations above and as shown on the left side in Figure 1.

[7] In this setting it is d asking u to collaborate and not vice–versa. Hence, changes in u^d are in this game less important than changes in u^u.

[8] We assume overall water scarcity. Floods are not considered.

Downstream	Upstream $\nu > 0$	Upstream $\nu = 0$
$\gamma > 0$	$dU_u(\phi_u, \nu) - p$	$dU_u(\phi_u = 0, \nu) - p$
$\gamma = 0$	$dU_u(\phi_u, \nu)$	$dU_u(\phi_u = 0, \nu)$

Downstream	Upstream $\nu > 0$	Upstream $\nu = 0$
$p > 0$	I pressure $(3, 1)^M$ [2,4]	II pressure and resistance $(1, 2)$ [2,4]
$p = 0$	III compliance $(4, 3)^{*mtd}$ [4,3]	IV dominance of u $\underline{(2, 4)}^*$ [2,4]

Figure 1: Changes in benefits for u who can reduce his valuation of water ($\nu > 0$) or insist ($\nu = 0$). d dominates $p > 0$ (or does not dominate $p = 0$). The resulting interaction game is on the right side. Key for the interaction game: (x,y) = (payoff for u, payoff for d); [x,y] = payoffs in the anticipation game (AG); 4=best; 3=next best; 2=next worst; 1=worst; Nash equilibrium *underlined*; $(\cdot)^*$ NME; $(\cdot)^{td}$ deterrent threat state of d; $(\cdot)^m$ best state d can induce with moving power; $(\cdot)^M$ best state u can induce with moving power.

$$U_u = \phi_u q_{u,c}^a q_{u,n}^{1-a} \tag{1}$$

$db^u(0)$ is a potential change in total utility for u in case he would change q_c^u without a suggested policy. This based on status quo marginal utilities which are subject of dispute. Negotiation is only necessary if $db^u(0) > db^u(\nu)$ when u's valuation of water is similar to d.

Mechanism of the game: We assume that at the beginning u and d consider to cooperate based on a suggested policy. If u is not satisfied with the policy (If efficiency and/or equitability is not achieved) it will initiate state IV where u can rely on its geographically advantageous situation. The game is weakly cycling in counterclock direction. Hence d can force u to move to the breakdown state II by changing its strategy which is unfavorable for both. From state II, u will move to state I by anticipating d's move to state III where pressure is released.

Intending to remain in state III, u and d will reset their marginal utilities according to the values of ν an according the benefit: $db^{u,d}(0) \Leftarrow db^{u,d}(\nu)$. By assessing if efficiency and/or equitability can be fulfilled (see Section 3.3.1) u will decide to comply or not. If a cooperative solution is feasible, then the game is stable, otherwise the cycling continues.

Remaining in state III is rational for both players. On one hand, d receives here its best payoff but has as well a deterrent threat to exert pressure if u does not comply. For u on the other hand it is rational as well to stay in this state, because it can avoid domination by d or avoid "ethical pressure" by being magnanimous and voluntarily reassess marginal utilities. Like this u can avoid cycling which at the end is costly for both. Eventually, envy-freeness is the outcome of this bargaining and negotiation process over marginal utilities.

4 An illustration: Fair division of the Nile waters

The distribution and allocation of the Nile waters has a long history and has been discussed broadly in literature. The management of this river which includes eight countries is highly complex and probably one of the most politicized water management problems globally. Being aware of this complexity we concentrate only on events related to the construction of the Aswan dam and negotiations between Egypt (E)downstream and Sudan (S) upstream. The knowledge and the descriptions in the following paragraphs are based on [12] and [11]. The different states relating to the game in Figure 1 are indicated by (I-IV). The bargaining–process for an equitable and of efficient allocation (Section 3.3.1) is indicated by (EE).

The proposal to build a single large dam at Aswan was put forward in 1949. It included multiple objectives like flood control, year-to-year water storage, and hydro-power generation. Construction of the high dam started in 1960 and was completed in 1970. Needing the assurance of S to guarantee sufficient flows to E negotiations with S started in May 1949 when E asked S to participate in the building of a water and dam project. After several talks where both countries expressed their willingness to cooperate a first negotiation rounds took place in autumn 1954 (EE). The negotiations were broken off "inconclusively" without concessions by S (IV). Being at this stage, S indicated that a dam in Sudan would yield the same profit than Aswan dam and announced to build its own dam upstream Aswan. Strengthening its own position additionally, S condemns in April 1955 the plans of E to build Aswan dam as being "destructive" for S. Following negotiations (EE) in June 55 on the distribution of the

Nile waters end by S declaring a deadlock in negotiations (IV). In July 1955 E offers to share some of the benefits of Aswan-Dam (EE). There is no agreement made but S considers to reevaluate the possibility of sharing even though, more negotiations were needed (IV). End 1955 and beginning 1956 E gets support from USSR, USA, GB, France and Japan to build Aswan Dam. All of them support a cooperative allocation policy to ensure the efficiency of the future dam. After a short while USA withdraws its proposed help but E can still count on the help of the other countries. In January 1958 E confers again with S on regulating flows and sends an (unsuccessful) military expedition into S with S defensively violating an old Nile agreement potentially harming E (II).

End of the year 1958, German Federal Republic offers aid to E as well and both parties agree in Autumn 1959 to renegotiate on sharing Nile waters (EE). An agreement is signed in November 1959: E receives 48 mio m^3/year and S 4 mio m^3/year. E offers as compensation 34 percent of benefits from hydropower production (III).

This short case–study illustrates how players switch from bargaining for efficiency and equitability to negotiations for an envy-free allocation. The cycling process, breakdown and the evolving deterrent threat which induce the final outcome as shown in Figure 1 are clearly visible. Summarized, the sequence of moves looks as follows: EE - IV - EE - IV - EE - IV - II - EE - III. Insisting at the beginning on its doctrine of territorial sovereignty S implicitly assumes to get the same potential profit than E. E, claiming riverine integrity can induce S eventually to reduce u^u to 34 percent of the initial value. The remaining 66 percent are now contained in S' hydro–political in–stream needs.

5 Conclusion

While it is not our intention to improve cooperative bargaining solutions per se, the goal of this paper is to reveal a possible path to a fair allocation of water resources under hydro–political asymmetry.

The underlying mechanisms given by hydrological heterogeneities and imbalances of political power between nations are highly complex and rarely connected. We try to do this by linking marginal utilities of water to a hydrological model and to the political system as well. So, if an upstream country has the power to insist on the doctrine of absolute territorial sovereignty and valuates his own consumptive water use higher relative to the downstream country it will be accordingly harder to implement a new policy. We suggest to include individual valuations of water by countries better into negotiation processes. This as improvement of the present practice where negotiation mainly on water quantities and economic benefits prevails.

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