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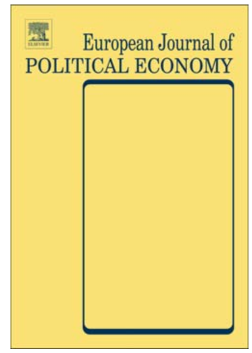

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Contested water rights

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Abstract

In many international river basins disputes over property rights to water lead to inefficient water allocation and a waste of resources. In this paper, we examine how contested water rights impede water trade. To show this, we use a model in which property rights to water are contested because countries have overlapping claims to water. In the model, countries decide whether to bargain over the allocation of contested river water or not. If not, they engage in conflict. In the conflict, countries spend their resources on production, which also requires water, or on fighting to secure part of the contested water. The resulting equilibrium is inefficient as both countries spend a positive amount of resources on fighting which is not productive. However, a third party may be requested to intervene in the looming conflict and allocate the water in an equitable way. The results show that for certain model parameters countries prefer not to bargain an efficient allocation, but to engage in conflict, hoping for third party intervention. The mere possibility of third party intervention may give rise to an inefficient equilibrium. Two new features of this paper are the application of a conflict model to the issue of water rights and the introduction of (overlapping) claims to non-cooperative bargaining problems.

Keywords: bargaining, claims, conflict, property rights, third party intervention, water allocation

JEL classification: C7, P14, Q25, Q34

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1 Introduction

With growing population and increasing water demand, competition for water in international river basins gets fiercer. In many cases, water rights are contested and a source of conflict. In this paper we want to shed light on the question under which conditions countries will jointly define property rights to contested water in transboundary river basins. Our motivation for this analysis is the general absence of international trade in river water.

The economics discipline advocates water trade in order to maximise the basin-wide benefits of this scarce resource (Easter et al., 1998). Even in situations without a social planner who can allocate water to maximise benefits, efficient outcomes are expected to prevail through bargaining. When water is scarce and when property rights are well defined, a difference in the marginal value of water between two users—greater than the costs of transferring the water—is expected to lead to a trade in water (Rosegrant and Binswanger, 1994; Holden and Thobani, 1996). Nevertheless, the International Freshwater Treaties Database (Wolf, 1998) contains only nine (out of 49) water allocation agreements where payments are explicitly coupled to water delivery, see Table 1 in the Appendix. This is a surprisingly low fraction of transboundary river basins where contractual agreements on water are established. Especially so given the existence of over 250 transboundary rivers world-wide, many of which face water scarcity.

The presence of contested water rights is, in our view, a major cause for missing international water trade. We argue in this paper that if water rights are contested, this may obstruct water trade. To show this, we use a conflict model in which water rights are contested. Conflict models have been introduced by Bush and Mayer (1974); for an overview of the economics of conflict see Garfinkel and Skaperdas (2007).

The core idea is as follows. Two countries share a river and each claims a portion of river water. Water is scarce and claims are overlapping, making water a contested resource. Countries bargain over the allocation of contested river water. If the bargaining succeeds, property rights to water are defined, based on which countries may trade water. If not, they engage in conflict. In the conflict, countries spend their resources on production, which also requires water, or on fighting to secure part of the contested water. The resulting equilibrium—the "natural distribution" (Buchanan, 1975)—is inefficient as both countries spend a positive amount of resources on fighting which is not productive. The natural distribution serves as the disagreement point of the bargaining game. During the bargaining each country may use its outside option and request intervention by a third party.[1] This third party would settle the conflict and allocate the water in an equitable way. Successful intervention, however, cannot be expected with certainty, so that conflict may still emerge. Hence, the mere possibility of third party intervention may give rise to an inefficient equilibrium.

Our contribution to the literature is twofold. First, we apply a conflict model to the issue of water rights. Although the lack of property rights has been recognised as a problem in the water literature (Richards and Singh, 2001), no supporting theory has been constructed yet.[2] Conventional explanations for missing international water trade in this strand of literature are mostly based on empirical studies of the economic and demographic characteristics of riparian countries. A key finding in this literature is that power distribution, governance, scarcity, and trade relations are important determinants for riparians to either have negotiated water allocation agreements or engage in international water trade (Song and Whittington, 2004; Dinar et al., 2007; Dinar, 2007). In this paper we aim to shed light on these findings from a theoretical angle. A study close to ours is Janmaat and Ruijs (2006), although they are more interested in the probability of conflict over river water, while our focus is on the role of contested water rights in explaining the general absence of water trade.

Second, we introduce the concept of (overlapping) claims in non-cooperative bargaining problems. These claims can be based on, for instance, historic water use or a perceived "equitable" use of available river water. In this paper, the focus is on river basins with water scarcity, so claims are likely to overlap. The concept of claims has been introduced in the axiomatic approach to bargaining, starting with O'Neill (1982) and Chun and Thomson (1992). The focus of this literature is the characterisation of solutions with certain attractive properties for the division

[1]In the setting of international river basins interventions can be expected from international organisations, such as the World Bank or the United Nations. These third parties are expected to allocate the water in an equitable way, based on, for instance, the 1966 "Helsinki Rules" proposed by the International Law Association. Note that the model developed in this paper is applicable to intranational water allocation too. In this case, a national government may act as the intervening third party.

[2]Various reasons for poorly defined property rights have been proposed in the literature, most of them related to hydrological characteristics. For example, Brennan and Scoccimarro (1999) discuss difficulties of defining property rights to water, given the spatial and temporal setting of the resource; see also Randall (1981) and Ward (2007). Return flows and conveyance losses are two important characteristics that may hamper the determination of property rights too (Griffin and Hsu, 1993; Chakravorty and Umetsu, 2003; Chakravorty et al., 1995).

of contested resources. Our focus is on the strategic role that claims can play in non-cooperative bargaining. Note that Grossman (2001) also constructs a conflict model with claims; these claims are, however, not overlapping.

Our results show that, for certain model parameters, countries prefer not to bargain an efficient allocation. Instead, they may prefer to stick to their claims, hoping for a favourable settlement of the bargain by a third party. As intervention might not occur or fail, conflict may emerge. Thus, the prospect of third party intervention can cause persisting conflict and thereby obstruct water trade.

We analyse a bargaining game with probabilistic outside options. If an agreement is reached, water rights are allocated according to the agreement, production takes place and payoffs are realised. If either country opts out, a third party is asked to intervene. Whether or not intervention will settle the conflict is uncertain. If intervention is successful, water is allocated by the third party, production takes place and payoffs are realised. If intervention does not occur or is unsuccessful, or if bargaining breaks down for any other reason, conflict results. Both countries invest in fighting to secure part of the contested water, production takes place and payoffs are realised. We analyse the game backwards. Therefore the remainder of this paper is organised as follows. In section 2 we present the conflict model and derive the natural distribution of water that determines the disagreement point of the bargaining game. In section 3 we analyse countries' incentives to bargain over the property rights to water or to take up their outside option. In section 4 we illustrate the results using a numerical example. In section 5 we discuss the results and conclude.

2 A conflict model for transboundary rivers

2.1 Model structure

In this section we construct a conflict model inspired by Grossman and Kim (1995). Our conflict model contains two assumptions that are relevant for water allocation, thereby setting this model apart from conventional conflict models. First, we assume that only water is fought over, instead of produce or endowments. In general, property rights to goods and production factors have been defined and are respected by countries. Countries may, however, contest water resources of a shared river, even when they respect property rights to all other goods. This is caused by the transboundary nature of river water, flowing from one country to the other. In the setting of our conflict model, property rights have been defined over all goods except water. This implies that water is the only good that is contested.

Second, we explore the role of claims to water that make (part of the) river water a contested resource. Ample evidence of the existence of claims can be found in, for instance, Asian river basins; see Wirsing and Jasparro (2007). Clearly, these claims can be overlapping as is demonstrated by the vast amount of conflicts over river water (Wolf, 1998). We assume that claims are exogenous, they can be based on for instance historical use or irrigation needs (Wolf, 1999). Claims are the main drivers of the results in this paper. They are both the cause of river water being contested and the basis for a possible settlement induced by a third party.

The setting of the conflict model is as follows. A river flows from country 1 to country 2. River water W is normalised to unity, so water use w_i can be seen as the share of water used by country i ($i = 1, 2$), such that $W = w_1 + w_2 = 1$. Each of the two countries has an initial endowment of resources e_i that can be used as production input x_i or fighting input g_i:

$$e_i = x_i + g_i. \tag{1}$$

Water is an input in the production function $y_i(w_i, x_i)$ with production increasing in w_i and in x_i (hence decreasing in g_i). Note that this production function requires both water and non-water input. Irrigation is the obvious example of a production function with water being one of the production factors. We use a simplified Cobb-Douglas production function, where non-water input can be used to increase productivity, for instance through irrigation efficiency:

$$y_i(x_i, w_i) = (x_i w_i)^{\alpha_i} \quad \text{with } 0 < \alpha_i \leq \frac{1}{2}, \tag{2}$$

where α_i are parameters that capture asymmetry between the countries in terms of agricultural productivity. Note that this production function reflects non-increasing returns to scale. The differences between α_1 and α_2 on the one hand and x_1 and x_2 on the other hand create opportunities for water trade as they define the marginal productivity of water in each country.

In terms of fighting, a higher level of g_i increases country i's fighting capacity. Note that "fighting" does not necessarily refer to military efforts. It may also refer to lobbying or diplomatic activity. Moreover, even if it refers to military efforts, open conflict need not occur (Skaperdas, 1992).

Because property rights to water are not established, water use depends on countries' water claims $c_i \in [0, 1]$ and their inputs to fighting (g_i) to secure these claims. As long as $c_1 + c_2 \leq 1$, no water is contested. The interesting case is, of course, where $c_1 + c_2 > 1$. The target of fighting is the portion of water that is contested: $c_1 + c_2 - 1 > 0$. The portion of contested water that is secured by country i is determined by a contest success function (CSF) $p_i(g_1, g_2)$, with $p_i \in [0, 1]$. We have p_1 increasing in g_1 and decreasing in g_2. Similarly, p_2 is decreasing in g_1 and increasing in g_2. The interpretation of p_i is country i's spending on fighting relative to the other country, which gives country i the possibility to secure water.

Hirshleifer (1989, 2000) and Garfinkel and Skaperdas (2007) discuss two common functional forms for a CSF. When the *difference* in inputs to fighting is considered important for the portion captured, a logistic form of the CSF is appropriate. We will use the alternative and more common form where the *ratio* of inputs to fighting is considered important for the portion captured:

$$p_1 = \frac{g_1}{g_1 + g_2}, \tag{3}$$

$$p_2 = \frac{g_2}{g_1 + g_2}. \tag{4}$$

The cost of fighting is production foregone. An equilibrium is obtained when, for each country, marginal costs of fighting equal marginal benefits of fighting, given the other country's distribution of resources over production and fighting.[3] There are three steps to determine the equilibrium of the contest game. First, countries independently and simultaneously choose levels of g_i (which determines x_i). Second, countries fight over the contested water, securing $p_i(c_1 + c_2 - 1)$, based on the chosen levels of g_1 and g_2. This determines water use w_i:

$$w_1 = 1 - c_2 + p_1(c_1 + c_2 - 1), \tag{5}$$

$$w_2 = 1 - c_1 + p_2(c_1 + c_2 - 1). \tag{6}$$

The first terms in equations (5) and (6), $1 - c_j$, represent the amount of water that is not contested by the other country (country j) and is therefore secure to country i. The second terms represent the portion of contested water that is secured through conflict. Third, countries receive payoffs π_i, where payoffs are due to production

[3] See Hirshleifer (1995) for further comments on the costs of fighting.

only. Using (1) and (2) we have

$$\pi_1 = y_1(x_1, w_1) = \left((e_1 - g_1)\left(1 - c_2 + \frac{g_1(c_1 + c_2 - 1)}{g_1 + g_2}\right)\right)^{\alpha_1}, \tag{7}$$

$$\pi_2 = y_2(x_2, w_2) = \left((e_2 - g_2)\left(1 - c_1 + \frac{g_2(c_1 + c_2 - 1)}{g_1 + g_2}\right)\right)^{\alpha_2}. \tag{8}$$

This completes the description of our conflict model; the equilibrium is determined in the following subsection.

2.2 The natural distribution of water

An equilibrium—the natural distribution—of the conflict model presented in section 2.1 can be found by combining the countries' best response functions. Country 1's best response is to choose g_1 to maximise π_1 given g_2 and vice versa. Solving the first order conditions of the maximisation problem with respect to g_i gives the following best response functions:[4]

$$g_1 = \frac{\sqrt{c_1(c_1 + c_2 - 1)g_2(e_1 + g_2)}}{c_1} - g_2, \tag{9}$$

$$g_2 = \frac{\sqrt{c_2(c_1 + c_2 - 1)g_1(e_2 + g_1)}}{c_2} - g_1. \tag{10}$$

Note that α_1 and α_2 do not appear in the best response functions. Differences in productivity do not affect equilibrium levels of fighting. Also note that the best responses do not depend on the other country's resource endowment, only on the portion of this endowment that is used for fighting.

Symmetric countries In the special case where the countries have equal claims and resource endowments (i.e. $c_1 = c_2 = c > \frac{1}{2}$ and $e_1 = e_2 = e$), countries have equal fighting inputs $g_1 = g_2 = g$. To determine the natural distribution, the system of two equations (9)–(10) can be easily solved for g:

$$g^\star = \left(\frac{2c - 1}{2c + 1}\right)e \tag{11}$$

Equilibrium levels of fighting (denoted by *) are increasing and linear in resource endowments and increasing and concave in claims. Because of symmetry, water

[4]A logarithmic production function of the form $y(x_i, w_i) = \ln \alpha_i(x_i w_i + 1)$ yields similar best response functions.

is divided equally in the natural distribution: $w^\star = \frac{1}{2}$. Payoffs can be determined by combining (7) with (11):

$$\pi^\star = \left(\frac{e}{2c+1}\right)^\alpha \tag{12}$$

Equilibrium payoffs are increasing and concave in resource endowments and decreasing and convex in claims.

When resource endowments increase, there is more fighting. Although increasing inputs to fighting are costly, payoffs increase with resource endowments. When claims increase, there is also more fighting. Given constant resource endowments, this increase in fighting reduces the countries' payoffs. Clearly, the larger the share of contested water, the less efficient is the natural distribution.

Asymmetric countries In the general case, without assuming symmetry, calculation of the equilibrium is more complex. Solving the system of two equations (9)–(10) for g_1 and g_2 gives polynomials of degree three. Using Cardano's formula, equilibrium values of $g_i^\star$ can be expressed as a function of c_1, c_2, e_1, and e_2.[5] This function is analytically not tractable and, therefore, we resort to numerical simulations over a wide range of parameter values. Our results show that equilibrium fighting efforts, water allocation, and payoffs are well-behaved (see figures 7–8 in the Appendix) and that the qualitative results of the symmetric outcome also hold for asymmetric countries, as is demonstrated in section 4. Again, increasing resource endowments causes an increase in fighting and payoffs. Increasing claims causes an increase in fighting but a decrease in payoffs.

It is possible to determine the ratio of both fighting inputs and water use in the natural distribution. Rearranging the response functions (9)–(10) gives

$$(g_1 + g_2)^2 = \frac{(c_1 + c_2 - 1)g_2(e_1 + g_2)}{c_1}, \tag{13}$$

$$(g_1 + g_2)^2 = \frac{(c_1 + c_2 - 1)g_1(e_2 + g_1)}{c_2}. \tag{14}$$

By substitution and rearranging, the ratio of g_1 to g_2 in equilibrium (denoted by $\star$)

[5]This function is available from the authors upon request. See e.g. Sydsaeter et al. (2000) for Cardano's formula, who advise against its use. The polynomials have at least one real root in the relevant range. It can be shown that there is a unique interior solution such that $0 < g_i^\star < e_i$. This proof is also available from the authors upon request. We thank Rudi Weikard for mathematical advice.

is

$$\frac{g_1^\star}{g_2^\star} = \frac{c_2(e_1 + g_2^\star)}{c_1(e_2 + g_1^\star)}. \tag{15}$$

Hence, $g_1^\star > g_2^\star$ if and only if $c_2(e_1 + g_2^\star) > c_1(e_2 + g_1^\star)$. In equilibrium, the ratio of inputs to fighting between country 1 and country 2 is a function of their claims and endowments. A larger endowment gives a higher ratio of inputs to fighting. A larger claim, however, gives a lower ratio of inputs to fighting, because having a larger claim corresponds to the other country having a smaller uncontested water claim, which will increase its inputs to fighting. These results are illustrated in section 4.

With equilibrium levels of fighting determined, we can turn our attention to water use in the natural distribution. Substituting and rearranging (5) and (6) gives us the ratio of p_1 to p_2:

$$\frac{p_1}{p_2} = \frac{w_1 + c_2 - 1}{w_2 + c_1 - 1}. \tag{16}$$

Because (3) and (4) imply that $g_1/g_2 = p_1/p_2$, the right hand sides of (15) and (16) are equal. The relation between w_1 and w_2 in the natural distribution is

$$\frac{w_1^\star + c_2 - 1}{w_2^\star + c_1 - 1} = \frac{c_2(e_1 + g_2^\star)}{c_1(e_2 + g_1^\star)}. \tag{17}$$

Because we normalise river water W to unity, we have $w_1 + w_2 = 1$. By substitution and rearranging we obtain the natural distribution of water:

$$w_1^\star = \frac{c_1[c_2(e_1 + g_2^\star) + (1 - c_2)(e_2 + g_1^\star)]}{c_1(e_2 + g_1^\star) + c_2(e_1 + g_2^\star)}, \tag{18}$$

$$w_2^\star = \frac{c_2[c_1(e_2 + g_1^\star) + (1 - c_1)(e_1 + g_2^\star)]}{c_1(e_2 + g_1^\star) + c_2(e_1 + g_2^\star)}. \tag{19}$$

In the natural distribution, water use is a function of the countries' claims, endowments and inputs to fighting. Note that equilibrium water use depends on equilibrium values of fighting, of which we only know the ratio in equilibrium, see (15). Hence, this system cannot be solved analytically, but results are easy to compute for any specification of parameters.

Because resources are spent on fighting, the natural distribution is not efficient. Total payoffs will increase if countries are able to prevent conflict. As explained in the introduction, we analyse this possibility in a bargaining game where the natural distribution serves as the disagreement point. The interesting issue is how countries' incentives to bargain depend on the possibility of third party intervention. This is the topic of the following section.

3 Bargaining or intervention?

In this section we analyse whether countries are successful in bargaining over the property rights to water. Instead of bargaining, they may leave the bargaining table and ask for third party intervention. We include this possibility as an "outside option", as discussed below. Countries bargain over the allocation of contested river water. If bargaining succeeds, the Nash bargaining solution is used to determine the allocation of water, and the game is finished. If one of the countries leaves the bargaining table and opts out, third party intervention will be successful with probability q, which settles the conflict. With probability $(1-q)$ conflict results and the natural distribution emerges.

First, we discuss bargaining in more depth. Countries can prevent the inefficient conflict equilibrium by defining property rights to water in a bargaining game.[6] This game can be modelled as a non-cooperative alternating-offers bargaining game in the spirit of Rubinstein (1982). An obvious solution concept for this bargaining game is the limit case, where the non-cooperative bargaining solution approaches the axiomatic Nash bargaining solution (Binmore et al., 1986). In the Nash bargaining solution, the choice of the disagreement point drives the outcome. The natural distribution is used as the disagreement point (D in figure 1), as it is the outcome under conflict when bargaining would break down (cf. Muthoo, 1999, chapter 4). The Nash bargaining solution, denoted by $\left(\pi_1^N, \pi_2^N\right)$ is obtained by maximising the product of the countries' gains in payoff compared with their payoffs at the disagreement point (denoted by *):

$$\left(\pi_1^N, \pi_2^N\right) = \max_{(w_1,w_2)} \left[\left(e_1 w_1\right)^{\alpha_1} - \left((e_1 - g_1^\star) w_1^\star\right)^{\alpha_1}\right]\left[\left(e_2 w_2\right)^{\alpha_2} - \left((e_2 - g_2^\star) w_2^\star\right)^{\alpha_2}\right], \quad (20)$$

[6] Buchanan (1975) argues that the resource allocation when moving away from (or, in our case, preventing) conflict, is equal to the allocation in the natural distribution. The only difference is that countries disarm (or do not arm), which increases total payoffs. We do not see why countries would choose this specific allocation of water as a basis for the definition of property rights (cf. Houba and Weikard, 1995).

subject to rationality constraints. The payoff frontier f is concave, see figure 1:

$$f = \left(\frac{e_1 \left(e_2 - \pi_2^{1/\alpha_2} \right)}{e_2} \right)^{\alpha_1}. \tag{21}$$

The Nash water allocation (w_1^N, w_2^N) can be computed by solving the following system of equations (Muthoo, 1999):

$$\frac{\pi_1^N(0, w_1^N) - \pi_1(g_1^\star, w_1^\star)}{\pi_2^N(0, w_2^N) - \pi_2(g_2^\star, w_2^\star)} = -f'(\pi_2) = \frac{\alpha_1 \pi_2^{1/\alpha_2 - 1} \left(e_1 \left(e_2 - \pi_2^{1/\alpha_2} \right) / e_2 \right)^{\alpha_1}}{\alpha_2 \left(e_2 - \pi_2^{1/\alpha_2} \right)}, \tag{22}$$

$$w_1^N = 1 - w_2^N. \tag{23}$$

Note that for the case of symmetric countries, discussed in section 2.2, $w^N = \frac{1}{2}$, and $\pi^N = \left(\frac{1}{2}e\right)^\alpha$.

This establishes the outcome of the Nash bargaining solution, denoted N in figure 1. This outcome is self-enforcing as any deviation (i.e. investing in g to secure more water) would imply a shift to the natural distribution, which is worse for both countries in terms of payoff. In this respect, our model is different from conventional conflict models where enforcement of a negotiated outcome is necessary to prevent open conflict (see Anbarci et al., 2002 and Skaperdas, 2006 for discussions on how enforcement costs depend on the bargaining solution used).

Alternatively, instead of bargaining over the property rights to water, a country can decide to leave the bargaining table and engage in conflict, anticipating an intervention by a third party. Such an intervention may be requested by any of the two countries, for instance by submitting a case to the International Court of Justice. Three examples illustrate the effectiveness of third party intervention.

The first example is the 1953 US intervention on water allocation in the Jordan river basin. This intervention occurred after a period in which the dispute on Jordan river water became more and more tense. The following Johnston negotiations resulted in an allocation of water that was originally based on the area of irrigated land in each country. Although the Johnston Accord was never ratified, its allocation has been used in agreements between Israel and Jordan (1994) and Israel and the Palestinian authorities (1995), in which property rights to water were finally established (Wolf, 1999). The second example is the 1951 intervention by the World Bank in the dispute between India and Pakistan on the Indus river basin. In 1948, India diverted water away from Pakistan's irrigation canals, breaking the 1947 Standstill Agreement. The World Bank successfully allocated the contested water by assigning the three eastern rivers of the basin to India and the three western rivers to Pakistan, which formed the basis of the 1960 Indus Waters Treaty (Alam, 2002). The third example concerns the Euphrates basin, where Iraq called for intervention by the Arab League in 1974 after it claimed that Syria diverted too much water at the Tabqa dam. Although this intervention failed and military threats increased, mediation by Saudi Arabia in 1975 was successful. Beach et al. (2000) report that ultimately 40% of the Euphrates water was allocated to Syria and 60% to Iraq.

Note that (successful) intervention cannot be expected with certainty. The examples above illustrate that interventions in water negotiations usually concern the proposal of an allocation of water that is beneficial to all parties involved, and includes some notion of "equity". Equitable water allocation may be based on pragmatic principles such as population, irrigation needs, catchment size, or historic use (Wolf, 1999; Van der Zaag et al., 2002). Alternatively, principles of international water law such as "reasonable and equitable use" and "no significant harm" can be applied, as summarised in the Helsinki Rules, the UN Watercourses Convention, and the Berlin Rules (Salman, 2007). We assume that the third party proposes an allocation of water, based on any of these principles, that satisfies two requirements. First, the equitable allocation yields higher payoffs to both countries compared to the natural distribution. Second, the equitable allocation is efficient. Denote this equitable allocation by w_i^E. An appealing example is an allocation of water that is proportional to the countries' water claims:

$$w_1^E = \frac{c_1}{c_1 + c_2}, \tag{24}$$

$$w_2^E = \frac{c_2}{c_1 + c_2}. \tag{25}$$

In the remainder of this paper, we use this functional form for w_i^E. Furthermore, we assume that the equitable allocation is enforced by the third party.

In choosing between bargaining property rights or opting out, hoping for a possible settlement of claims through third party intervention, countries will compare the associated payoffs. Stylised payoffs for the disagreement point (the natural distribution) D, the Nash bargaining solution N, and the equitable allocation E are shown in figure 1. Note that N is located on h, the highest rectangular hyperbola relative to axes through D that has a point in common with f. Because f is continuously decreasing, and both N and E are on f (no resources

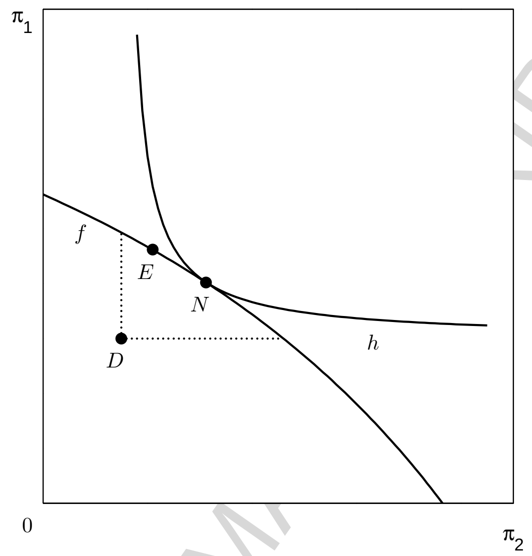

Figure 1: A stylised payoff space for countries 1 and 2. D denotes the disagreement point (the natural distribution), N denotes the Nash bargaining solution, E denotes the equitable allocation, f is the payoff frontier, and h is a rectangular hyperbola relative to axes through D.

are spent on fighting), if N is preferred by one country, then E is preferred by the other.

When defining property rights using the Nash bargaining solution, country i's payoff is according to (20). When opting out, hoping for intervention, country i's payoff depends on the subjective probability $q_i \in (0, 1)$ that third party intervention occurs.[7] Its payoff is the probability weighted sum of the payoffs at the equitable allocation $\pi_i^E(0, w_i^E)$ and the natural distribution $\pi_i(g_i^\star, w_i^\star)$. Consequently, country i will prefer to define property rights in a bargaining game rather than call for intervention, and vice versa, if

$$\pi_i^N(0, w_i^N) \geq q_i \pi_i^E(0, w_i^E) + (1 - q_i)\pi_i(g_i^\star, w_i^\star). \tag{26}$$

The presence of possible third party intervention can be interpreted as an

[7]Perceptions of the likelihood of third party intervention and the probability of its success may differ across countries. Note that we do not explicitly model the third party's decision to intervene as is done, for instance, by Chang et al. (2007). The parameters q_i therefore capture all relevant information on the expectation and success of intervention by a third party.

"outside option" (Muthoo, 1999).[8] If (26) is violated for country i, waiting for third party intervention is a credible outside option. In figure 1, this may be an attractive possibility for country 1. The outside option payoffs are on a straight line connecting D and E (using probabilities q_i and $1 - q_i$), as reflected by (26). In figure 1, country 2 will always prefer a bargain. However, for a sufficiently large q_1, the outside option is attractive enough for country 1 to leave the bargaining table; country 1 will not agree on the Nash bargaining solution N, but hope for third party intervention to obtain E.

The presence of an outside option as such does not obstruct an efficient and immediate bargaining outcome. The country with an outside option has a strategic advantage in the bargaining procedure. Consequently, its payoff in a bargaining solution must be at least as high as its outside option payoff (Muthoo, 1999).

Without loss of generality, let country 1 have an outside option, as in figure 1. Furthermore, let $\tilde{q}_1$ denote the level of q_1 for which (26) holds with equality. When $q_1 < \tilde{q}_1$, the outside option is not credible and countries will bargain to reach N. When $q_1 \geq \tilde{q}_1$, the outside option is credible, leading to one of two outcomes. Either $q_2 \geq q_1$, then countries will bargain and country 1 receives its outside option payoff as explained above. Or $q_2 < q_1$, then country 2 is not willing to give in to country 1's outside option—as it considers country 1 to overstate its subjective probability of third party intervention—leading to emerging conflict with possibly third party intervention. Clearly then, what can obstruct a bargaining outcome is a difference in the countries' perceptions of the probability of third party intervention.[9]

As shown, the bargaining solution depends on the perceived probability of third party intervention in two ways. First, the probability of third party intervention may influence the payoffs of the countries in the bargaining outcome, as discussed above. Second, when the probability of third party intervention is sufficiently large, it may cause a country to use its outside option.

[8] Conventionally, outside options have a time constraint. In this model, there is no time constraint, but a probability constraint, see Muthoo (1999).

[9] Note that, alternatively we could model different perceptions of the location of E, possibly determined as the expected values of two different probability density functions. Such differences in the perception of the location of E may be attributed, for instance, to a "self-serving bias" (cf. Babcock and Loewenstein, 1997). An alternative reason why countries would not bargain an efficient outcome is a "long shadow of the future". In a dynamic setting, initial conflict may permanently increase future payoffs, for instance by eliminating the adversary (Garfinkel and Skaperdas, 2000). In the context of this paper, however, this does not seem to be a plausible argument.

4 Numerical example

For asymmetric countries, payoffs and water use in both the natural distribution and the Nash bargaining solution cannot be determined analytically. Therefore, and to provide further insights and illustrations we present a numerical example. Throughout this example we keep the parameters of country 2 constant at $c_2 = 0.7$ and $e_2 = 1.5$, while varying the parameters of country 1. Also, productivity parameters are constant at $\alpha_1 = \alpha_2 = \frac{1}{4}$.

Figure 2 shows the best response functions (9)–(10) for the symmetric case where $c_1 = c_2 = 0.7$ and $e_1 = e_2 = 1.5$. Equilibrium values for the natural distribution are $g_1^\star = g_2^\star = 0.25$ and $w_1^\star = w_2^\star = 0.5$. A second equilibrium where both countries do not fight at all ($g_1 = g_2 = 0$) is not stable because a very small increase in fighting by one of the countries would cause a shift to the other equilibrium. This instability can also be derived from the specification of the contest success function in (3) and (4), given that resource endowments e_i are not too asymmetric. The figure shows that inputs to fighting are concave in inputs to fighting by the other country.[10]

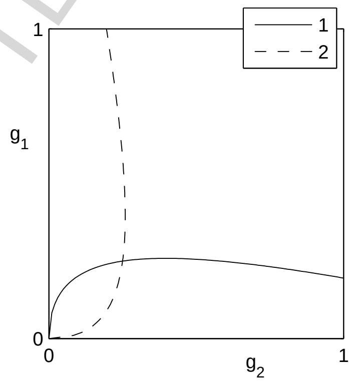

Figure 2: Best response functions of country 1 and 2 for the symmetric case where $c_1 = c_2 = 0.7$ and $e_1 = e_2 = 1.5$.

Figure 3 shows the equilibrium values for $g_i^\star$, $w_i^\star$, and $\pi_i^\star$ in the natural distribution as a function of c_1. Clearly, increasing claims lead to higher inputs to fighting by both countries. Having a higher claim increases a country's water use and payoffs. Due to the production foregone because of fighting, total payoffs decrease with increasing claims.

[10] Figure 6 in the Appendix provides a more general picture and shows the best response functions for nine different combinations of c_i and e_1.

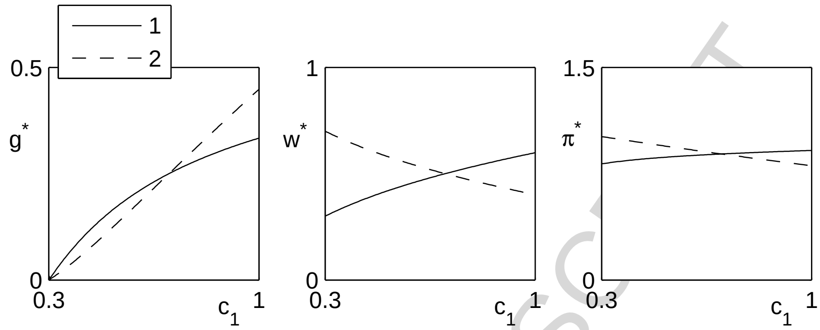

Figure 3: Natural distribution equilibrium values for $g_i^\star$, $w_i^\star$, and $\pi_i^\star$ as a function of c_1 with $e_1 = 1.5$ and $c_2 = 0.7$.

Figure 4 shows the equilibrium values for $g_i^\star$, $w_i^\star$, and $\pi_i^\star$ in the natural distribution as a function of e_1. Increasing resource endowments leads to higher inputs to fighting by the country with the higher endowment (not necessarily by both countries as can be seen in figure 8 in the Appendix). Having a higher resource endowment increases a country's water use and payoffs. Notwithstanding the production foregone because of fighting, total payoffs increase with increasing resource endowments.

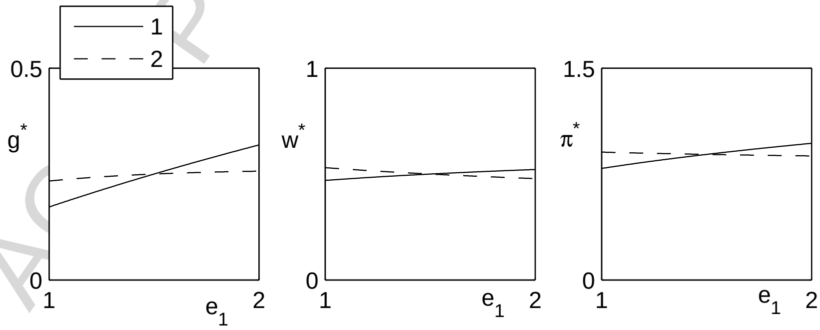

Figure 4: Equilibrium values for $g_i^\star$, $w_i^\star$, and $\pi_i^\star$ as a function of e_1 with $c_1 = c_2 = 0.7$ and $e_2 = 1.5$.

Three additional model features for the natural distribution are obtained using a range of simulations (see figures 7–8 in the Appendix); they are partly illustrated by figures 3 and 4. First, inputs to fighting, water use, and payoffs are increasing at a decreasing rate in a country's own claim, see figure 3. Second, despite the opportunity costs of fighting, a country's payoff increases with both its claims and its endowments, irrespective of the other country's claims or endowments, see figures 7 and 8 in the Appendix. Third, just having a high claim, or just having high endowments does not necessarily make a country better off than its opponent in terms of payoffs. Claims and endowments appear to be substitutes. This can be seen in the bottom-left panels of figures 7 and 8 in the Appendix, where country 1's payoff curves are below country 2's payoff curves.

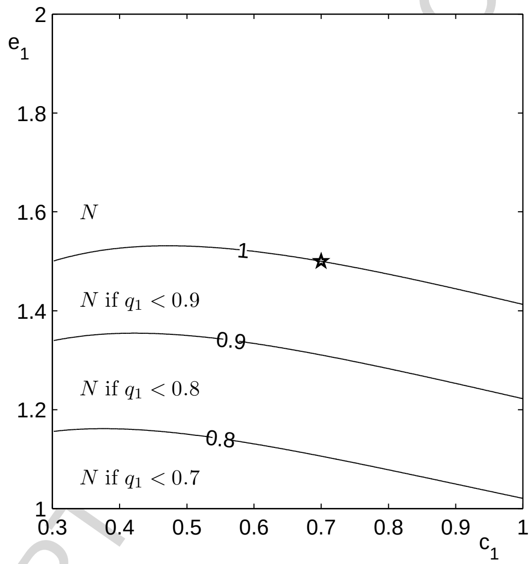

Figure 5: Preference of country 1 for N (bargaining) or E (waiting), as a function of c_1 and e_1. Isolines indicate threshold values of q_1 for which country 1 is indifferent between N and E. Note that $c_2 = 0.7$ and $e_2 = 1.5$.

Parameter combinations of c_1 and e_1 determine the locations of the Nash bargaining solution N and the equitable allocation E on the payoff frontier as illustrated in figure 1. A comparison of payoffs in choosing between bargaining and leaving the bargaining table hoping for third party intervention, is shown for country 1 in figure 5. The figure shows isolines for threshold values of q_1 such that (26) holds with equality as a function of parameter combinations of c_1 and e_1. Recall that when (26) holds with equality, country 1 is indifferent between bargaining property rights and opting out. As explained in section 3, when N is preferred by one country, then E is preferred by the other. This implies that the $q_1 = 1$ isoline, where country 1 is indifferent between bargaining and opting out, coincides with the $q_2 = 1$ isoline. This is the case, for instance, at the symmetric point where countries have equal claims and endowments, indicated by $\star$ in figure 5. In the upper part of the figure where country 1 prefers to bargain to reach N, country 2 will—for certain levels of q_2—prefer to opt out and hope for third party intervention. This implies that, given q_1 and q_2, bargaining is more likely for parameter combinations of c_1 and e_1 close to the $q_1 = q_2 = 1$ isoline.

In this numerical example claims have almost no impact on the country's preference for bargaining. Note that even with a tiny overlapping claim (c_1 close to 0.3), there is a possibility that only one country prefers to bargain, leading eventually to conflict. Endowments, however, have a high impact. The more equal the distribution of resources endowments, the more likely it is that countries bargain property rights to reach N.

The impact of claims on the preference for bargaining seems counter-intuitive: starting in the symmetric point, when c_1 increases, country 1 prefers to bargain. One would expect that when c_1 increases, E moves in a north-western direction along the payoff frontier because water allocation in E is determined proportional to claims, see (24). This would make E more attractive relative to N, as illustrated in figure 1. A shift in relative claims, however, also affects the position of D and thereby the position of N. When c_1 increases, the position of D changes such that N moves even further than E in the same direction along the payoff frontier. Country 1's payoff at N increases more than its payoff at E. Hence we find the preference of country 1 for bargaining to reach N instead of hoping for third party intervention E.

Note that for symmetric countries, N and E coincide and countries will always bargain property rights. In figure 5, the difference between payoffs for N and E are smaller the closer we get to the centre of the figure (where countries are symmetric). This implies that for more symmetric countries, the threshold level of q_i to not bargain property rights becomes higher. In other words, conflict between countries is more likely the larger the differences between them.

5 Discussion and conclusion

This paper develops a theory of how conflict over river water may emerge through contested water rights. Formal property rights to water are not necessarily established; one country may prefer not to bargain an efficient allocation. Instead, it may prefer to engage in conflict, hoping for third party intervention. This result is illustrated using a numerical example in which, for certain parameter combinations, conflict in the natural distribution is an equilibrium outcome. Apparently, the resolution of water disputes and resulting trade in water is not necessarily an attractive option.

The Coase theorem applied to water resources implies that the efficient use of water does not depend on the distribution of water rights. Transaction costs, arising from uncertainty and contract enforcement, can obviously obstruct the bargaining process over water (Richards and Singh, 2001). This paper shows that there is another potentially important obstruction to Coasean bargaining: the presence of overlapping claims to water, making water a contested resource for which property rights are disputed. The presence of claims has severe implications for the efficiency of water use, because claims determine both the equilibrium water use in the natural distribution, and consequently, the possibilities to bargain a more efficient allocation of water. Clearly, claims combined with subjective probabilities of third party intervention render the Coase theorem inapplicable in the case of river water resources. Conflict is possible, with countries hoping for a third party to intervene. This obstructs water trade because property rights to water fail to emerge.

Intervention by a third party in a conflict is not always desirable (cf. Chang et al., 2007). Our model shows that the mere possibility of third party intervention may cause an inefficient equilibrium of water use through investments in fighting. This illustrates the problematic position of organisations whose aim is to mediate or resolve international conflicts, such as the World Bank or the United Nations. The existence of organisations that facilitate conflict resolution may actually generate conflict. In other words, the prospect of conflict mediation may crowd out the capacity of conflicting parties to resolve the conflict themselves. Our results also highlight the problem created by conflicting principles of international law in water allocation (Salman, 2007). Conflicting principles may cause countries to have different perceptions of what is an equitable allocation which, in turn, may obstruct a bargaining solution; see footnote 9.

The model developed in this paper describes a situation in which countries may end up in an inefficient equilibrium, instead of bargaining an efficient outcome. Overlapping claims to productive resources and the presence of an information asymmetry cause this inefficiency. The model results depend on parameter combinations of countries' resource endowments and claims, which are presumed to be exogenous. It seems attractive to endogenise the claims. Given best response functions (9) and (10), and because claims have no cost, this implies that in the natural distribution both countries would claim 100% of the water. These extremely high claims would cause high inputs to fighting (see figure 3) and consequently, low payoffs. In practice, however, claims are never this high; countries generally do not invoke 100% claims (Wolf, 1999).[11] Instead, they base claims on an observable criterion, such as irrigation needs or historic use. In addition, 100% claims would not be credible to a third party that would have to settle claims. Hence, endogenous claims are not a logical feature of this model.

In this paper, we have studied the case of two countries sharing a river. Although our model is general enough for other applications, it can capture the upstream-downstream character of a shared river. The geographical advantage of the upstream country can be reflected by assigning it a higher claim. A model of this type is relevant for other bargaining situations too, where claims are overlapping and with the possibility of third party intervention. Possible applications are: (i) countries' claims to the control of a fishing area or a shared aquifer; (ii) disputed territory; and (iii) partners' claims to common property in a divorce, where a court may settle the division of the property.

We see two logical extensions to the model described in this paper. First, instead of modelling the outcome of third party intervention proportional to the countries' water claims, it could be impacted by lobbying at the third party. Second, repeated interaction between the countries may increase cooperation (cf. Wolf, 1998) or induce conflict (cf. Garfinkel and Skaperdas, 2000). A dynamic version of the model presented in this paper may treat x_i and g_i as flows of input to stocks of goods and weapons. These extensions, however, are left for future work.

Acknowledgement

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[11] A 100% claim by an upstream country reflects the principle of absolute territorial sovereignty, a 100% claim by a downstream country reflects the principle of absolute territorial integrity.

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Appendix

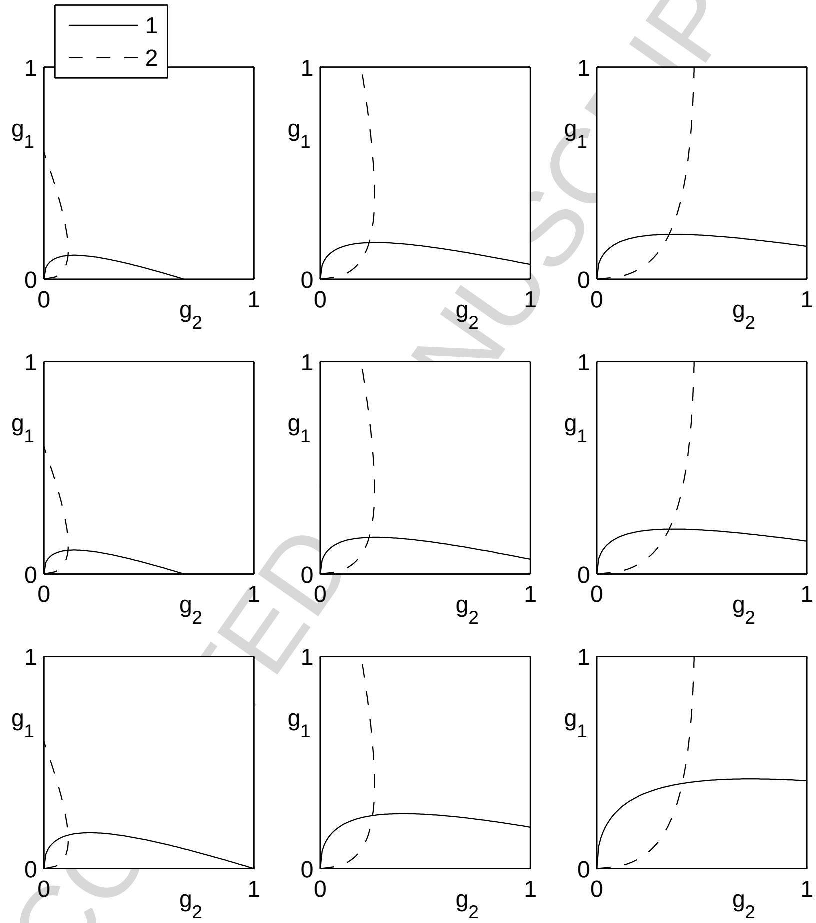

Figure 6: Best response functions of country 1 and 2, with c_1 increasing in the columns (0.5, 0.7, and 0.9), and e_1 increasing in the rows (1, 1.5, and 2). Parameter values of country 2 are constant at c_2 = 0.7 and e_2 = 1.5.

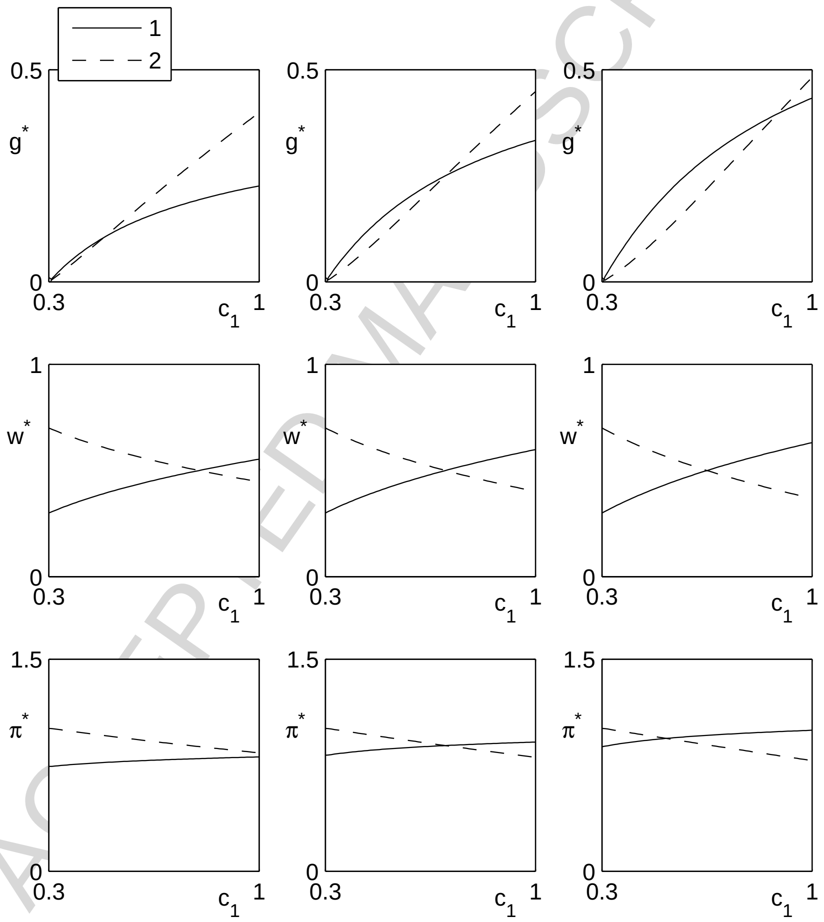

Figure 7: Natural distribution equilibrium values for $g_i^\star$, $w_i^\star$, and $\pi_i^\star$ as a function of c_1, with e_1 increasing in the columns (1, 1.5, and 2). Parameter values of country 2 are constant at $c_2 = 0.7$ and $e_2 = 1.5$.

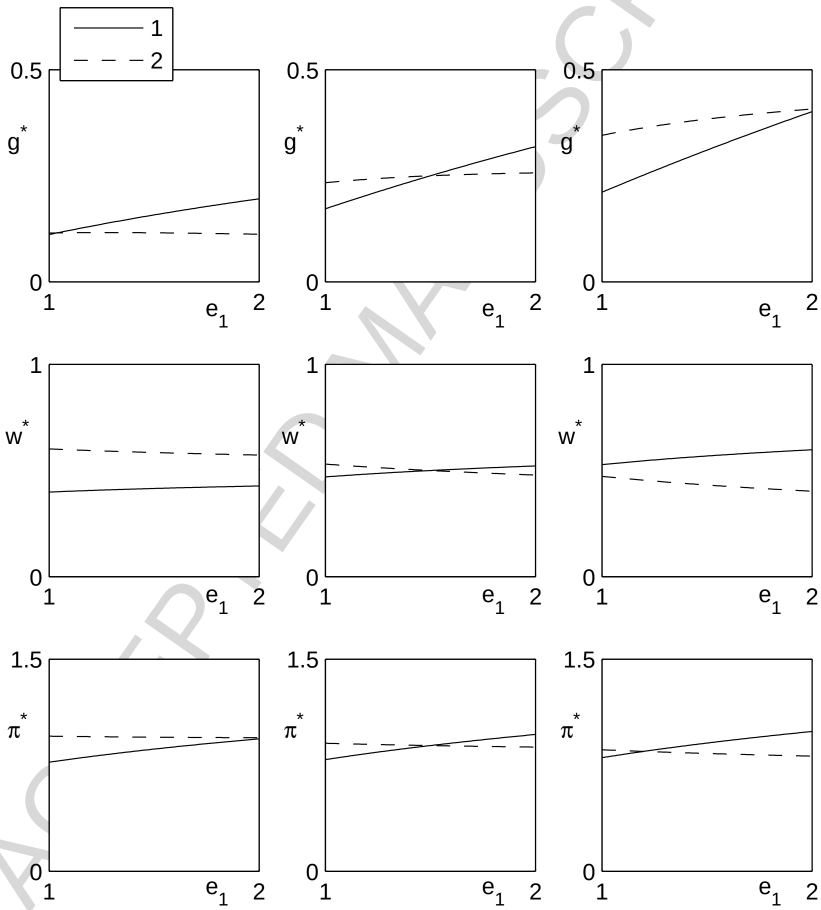

Figure 8: Natural distribution equilibrium values for $g_i^\star$, $w_i^\star$, and $\pi_i^\star$ as a function of e_1, with c_1 increasing in the columns (0.5, 0.7, and 0.9). Parameter values of country 2 are constant at $c_2 = 0.7$ and $e_2 = 1.5$.

Table 1: Agreements on water allocation with payment details.

Basin (year) and agreement name	Side payment details
Indus (1892): Amended terms of agreement between the British Government and the State of Jind, for regulating the supply of water for irrigation from the Western Jumana Canal.	Jind (India) made a fixed annual payment to Great Britain for the delivery of water for the irrigation of 50,000 acres through newly constructed distribution works.
Gulf of Aden drainage basin (1910): Convention regarding the water supply of Aden between Great Britain and the Sultan of Abdali.	Great Britain agreed to make monthly payments to the Sultan of Lahej for extracting groundwater.
Gash (1925): Exchange of notes between the United Kingdom and Italy respecting the regulation of the utilisation of the waters of the River Gash.	Sudan (the United Kingdom) agreed to pay a share of its income from irrigated agriculture to Eritrea (Italy) for passing through the necessary water.
Näätämo (1951): Agreement between the Government of Finland and Norway on the transfer from the course of the Näätämo (Neiden) river to the course of the Gandvik river.	Norway receives water from the Näätämo basin to be used for power generation and compensates Finland for lost water power through a lump-sum payment of NKR 15,000.
Isonzo (1957): Agreement between the government of the Italian Republic and the government of the Federal People's Republic of Yugoslavia concerning the water supply of the town of Gorizia.	Italy pays 58 million lira annually to Yugoslavia for receiving 4.5 million MCM/year, which equals 85% of the total river flow in the Isonzo.
Colorado (1966): Exchange of notes constituting an agreement concerning the loan of waters of the Colorado river for irrigation of lands in the Mexicali valley.	Mexico reimburses losses in power generation to the USA for releasing 50 MCM in the fall of 1966 for irrigation purposes (on top of its allocation according to the 1944 Water Treaty).
Roya (1967): Franco-Italian convention concerning the supply of water to the Commune of Menton.	France made a one-time ITL 10 million payment for diverting water from the Roya to supply the village of Menton, while agreeing to pass through a fixed share of its diversion to the Italian village of Ventimiglia.
Helmand (1973): Helmand River Water Treaty.	On top of its original allocation of 22 cubic metres per second, Iran was to purchase an additional four cubic metres per second from Afghanistan.
Orange (1986): Treaty on the Lesotho Highlands Water Project between the Government of the Republic of South Africa and the Government of the Kingdom of Lesotho.	South Africa agreed to make annual payments to Lesotho for water transfers, increasing from EUR 14 million in 1998, when actual water deliveries started, to EUR 24 million in 2004.

Sources: Compiled from Beach et al. (2000); Wolf (1999); Dinar (2006) and the International Freshwater Treaties Database, available at `http://www.transboundarywaters.orst.edu/`.

Note: The table lists only those agreements where payments are explicitly coupled to water delivery. Therefore, agreements such as the 1926 Cunene Agreement and the 1960 Indus Waters Treaty are not included.