A STOCHASTIC MULTIPLE PLAYERS MULTI-ISSUES BARGAINING MODEL FOR THE PIAVE RIVER BASIN

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CESIFO WORKING PAPER NO. 2178
CATEGORY 8: RESOURCES AND ENVIRONMENT
DECEMBER 2007

CESifo *Working Paper No. 2178*

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Abstract

The objective of this paper is to investigate the usefulness of non-cooperative bargaining theory for the analysis of negotiations on water allocation and management. We explore the impacts of different economic incentives, a stochastic environment and varying individual preferences on players' strategies and equilibrium outcomes through numerical simulations of a multilateral, multiple issues, non-cooperative bargaining model of water allocation in the Piave River Basin, in the North East of Italy. Players negotiate in an alternating-offer manner over the sharing of water resources (quantity and quality). Exogenous uncertainty over the size of the negotiated amount of water is introduced to capture the fact that water availability is not known with certainty to negotiating players. We construct the players' objective function with their direct input. We then test the applicability of our multiple players, multi-issues, stochastic framework to a specific water allocation problem and conduct comparative static analyses to assess sources of bargaining power. Finally, we explore the implications of different attitudes and beliefs over water availability.

JEL Code: C61, C71, C78.

Keywords: bargaining, non-cooperative game theory, simulation models, uncertainty.

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First Draft: June 2007. Revised: November 2007
The authors are grateful to Ariel Dinar, Fioravante Patrone and above all Carmen Marchiori for helpful suggestions and discussions. Comments and remarks from Carlo Giupponi, Ignazio Musu and Paolo Rosato are also gratefully acknowledged. All remaining errors are obviously ours.

1. Introduction

The world is experiencing increasing concern over the availability of water resources. Recent publications by international organisations and several academic studies have identified water scarcity as a serious and growing problem, particularly in arid and semiarid areas (see, for instance, Gleick, 2000 and Raskin *et al.*, 1998). Yet, despite the recognition that water is fundamental for life and a major component of current strategies for actions in many areas of national and international policy development[1], water management is still problematic.

In recent years, one of the responses to water scarcity has been to promote collective *negotiated decision-making procedures* for water management, both at the national and at the international level[2]. Through negotiations, proposals to improve water management are put forward by the interested parties, who have both common and conflicting interests (Churchman, 1995). The idea is that negotiated decisions can lead to management choices which are better adapted to local conditions, and can result in easier implementation, less litigation and improved stability of agreements. Examples include the famous 'Three-Way Negotiation', which took place in the early nineties in California between the representatives of urban, agricultural and environmental groups; or, more recently, the San Francisco Estuary Project, and the Sacramento Water Forum.

Even though it has been shown that negotiated policy making can indeed represent a constructive way forward, a model of formal negotiation theory which can deal with both the characteristics of water resources and the processes of strategic negotiation is still lacking. Relatively little is understood about the interactions between the structure and the outcomes of the negotiating process, and most of the analyses of real negotiation processes adopt an empirical, *ad hoc*, approach, without exploring the underpinning theories, or attempting to develop a unified, formal, theory of negotiation (see, e.g., Yoffe *et al.*, 2004). As a result, we are still far from understanding, in a broad enough range of situations, which factors may affect agreements on water allocation, and where and how bargaining processes can be shaped to obtain a more desirable state of affairs with respect to the resource to be shared.

The main objective of this paper is thus to identify which factors are most likely to affect players' strategies during a negotiation process and the resulting agreement – if any is achieved. We will do so by exploring the water allocation problem of the Piave River basin (located in Northern Italy) through the application of a multilateral, multiple issues, non-cooperative negotiation model.

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[1] See, for instance, the UN World Water Development Report (UNESCO, 2003), UNEP's Global Environment Outlook 3 (UNEP, 2003), the numerous reports by the World Water Council (http://www.worldwatercouncil.org), and references therein.

[2] In real-life, there are many examples of international negotiations over other global and regional natural resources, such as atmosphere, the seas, biodiversity, fish stocks, so on and so forth (for some examples, see for instance Breslin, et al., 1992; Breslin, et al., 1990). Similarly, there are many examples of international cooperative efforts to manage shared water resources. One of the oldest attempts is the Baltic Sea agreement, linking environmental quality issues with nations' development policies. Similar attempts can be found in the Aral Sea, and in the Caspian Sea, as summarised in Conca and Dabelko, 2002.

The model applied here has three main distinguishing features. Firstly, it builds upon existing non-cooperative, multilateral, multiple issues bargaining models (e.g. Rausser and Simon, 1992; Simon *et al.*, 2003, 2006; Thoyer *et al.*, 2001), and applies a similar tool to a different reality – both in terms of players and policy space, as well as the underlying geography and economy of the area. The exercise offers a good test case of the model and the robustness of its results – which will ultimately determine its usefulness. Secondly, our model introduces uncertainty in the analysis of negotiated water management: We can thus explore the influence of stochastic variations in water resources on players' strategies, and identify a more robust space of feasible policies for water management. And finally, the involvement of local actors in determining management policies is addressed through the determination of players' preferences and payoffs with their direct input.

The next section will briefly describe the methodological framework used in the analysis of water allocation in the Piave River Basin. For a detailed description of the model and of its formal properties see Carraro and Sgobbi (2007). Section 3 will then describe the context of its application and the process of estimating the parameters of the model. Section 4 will present the main results of our analysis of the Piave River Basin and of the related water allocation problems. Finally, Section 5 concludes this paper by summarising the main results and by drawing some general policy lessons.

2. The bargaining framework

This paper builds upon the multilateral, multiple issue negotiations model developed by Rausser and Simon (1992), in itself an extension of the two-person, one issue Rubinstein-Ståhl model (Rubinstein, 1982; Ståhl, 1972). In this framework, a finite number of players have to select a policy for sharing water resources from some collection of possible alternatives. If the players fail to reach an agreement by an exogenously specified deadline, a disagreement policy is imposed. The disagreement policy is known to all players: it could be an allocation that is enforced by a managing authority; it could be the loss of the possibility to enjoy even part of the negotiated variable; or it could be the continuation of the *status quo*, which is often characterised as inefficient. The constitution of the game as a finite horizon negotiation is justifiable empirically – as consultations over which policies to implement cannot continue forever, but policy makers have the power (if not the interests) to override stakeholders' positions and impose a policy if negotiators fail to agree. In finite horizon strategic negotiation models, it is unavoidable that "11th hour" effects play an important role in determining the equilibrium solution. In fact, last minute agreements are often reported in negotiation.

In our model, unanimity is required for an agreement to be reached. Although this may seem excessively restrictive – in some cases, such as government formation, simple or qualified majority rules may be more realistic – unanimity is justifiable empirically when no cooperation is the *status quo*, when there is no possibility of binding agreements, or enforcement of an agreement is problematic. Unanimity may also be appropriate when a compromise among different perspectives is sought.

Finally, in our formulation of the game, (part of) the players' utility is not known with certainty, as it depends on stochastic realisations of a negotiated variable. Players' strategies will then depend on the expected realisation of future states of the world.

The game is played as follows. At each round of the game, provided no agreement has yet been reached, a player is selected to make a proposal – with the order of moves determined by an exogenously specified vector of access probabilities. Access probabilities can be interpreted as players' ability to influence the process. The proposer will propose a policy package – which specifies the resources' shares for each of the negotiating parties, including himself. Next, all the remaining players respond to the offer in the order specified by the vector of access probabilities. If all players accept the proposal, the game ends. If there is at least one player that rejects the offer, the next period of the game starts. In the next period of the game, the next player in the sequence specified by the vector of access probabilities proposes a policy package, which the remaining players can in turn either accept or reject. The game continues in this fashion until either all players agree to a proposed policy package, or the terminal time is reached, at which point the disagreement policy is implemented.

As shown by Rausser and Simon (1992) and then in subsequent applications of their model (Adams *et al.*, 1996; Simon *et al.*, 2003; Thoyer *et al.*, 2001), the equilibrium strategies of players can be characterised intuitively. If the terminal time is reached, a player will only accept a proposal that yields him at least as much utility as his disagreement payoff. Similarly, at bargaining rounds prior to the deadline, a player will accept a proposal if and only if it yields at least as much utility as the expected continuation payoff – where his expected continuation payoff is defined as the utility he expects to derive from rejecting the offer, and moving on to the next stage of the game. In an offer round, players will make a proposal which belongs to the set of feasible proposals, and that belongs to the set of acceptable proposals of the other players. Furthermore, a player's proposal will maximise his utility.

For multiple issues and multiple players, the model and its stochastic extension have no closed form and must be solved computationally: the numerical solution to the game can nonetheless be quite useful in analysing complex multiple players, multiple issues bargaining problems. Convergence is ensured by the characteristics of the disagreement outcome which is such that, if implemented, it would yield lower utility to all players than any agreement[3]. The player proposing in the last round, therefore, can get his preferred point. Players in the previous rounds anticipate this outcome – and the

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[3] Interestingly, Manzini and Mariotti (2002) show in a two-person, sequential bargaining model that even when the breakdown event is strictly worse than the worst agreement for at least one player (rather than strictly worse than the best agreement for all players), there exists a unique subgame perfect equilibrium. Furthermore, the size of the expected penalty, in itself, cannot determine the bargaining outcome.

game is theoretically solved in the first round of negotiation. A detailed discussion of the properties of the bargaining game and of the algorithm used in this paper is contained in Carraro and Sgobbi (2007).

3. The Piave River Basin and the structure of the game

3.1 Background

The potential usefulness of our multilateral, multiple players, stochastic bargaining model is illustrated in this section. The specific case study on which the model is tested is the Piave River Basin (PRB), which is among the five most important rivers in the North of Italy. Traditionally, in this area water management was primarily aimed at favouring irrigated agriculture and hydroelectric power production. However, the increase of other, non-consumptive, uses of water – such as recreation and tourism in the Dolomite valleys – and the rise in environmental awareness, coupled with variation in the water flow, have led to increasing conflict. Tensions over water management become fierce in the summer season, when the combination of dry months and peaks in demand often lead to local water scarcity situations.

The highly political and strategic nature of the problem has led to what is called "the battle of the Piave", with the problem of exploitation of water resources at the centre of the debate, especially in relation to the requirements of the tourism industry in the Dolomite valleys, and the needs for agricultural water uptake downstream (Baruffi *et al.*, 2002). We can thus identify three major areas of conflict with respect to water management in the Piave River Basin:

<u>Hydroelectric vs. environment</u>: even though hydroelectric power generation does not consume water *per se*, its storing and realises patterns have a significant impact on water availability for other uses – water temporarily stored for power generation is not available downstream. Furthermore, part of the water used for hydroelectric power generation is diverted away from the Piave River to the neighbouring Livenza River (about 40m^3/s).

<u>Agriculture vs. environment</u>: irrigation needs condition the management of lakes and reservoirs, managed as to guarantee enough water for irrigation. As a consequence, much of the river flow in the middle part of the basin is reduced significantly for large part of the year: many of the river inlets, and the main river bed itself, are completely dry for long stretches.

<u>Tourism development vs. consumptive water uses</u>: With the current level of water abstraction permits, only the release of water stored in reservoirs can guarantee meeting the demand for water downstream, with important negative impacts on the socio-economic development of the upstream area, where the water reservoirs are located.

It is now widely accepted that the current exploitation regime for the Piave River Basin is not sustainable, as it has significant negative impacts on the river balances and ecological functioning, with consequent risks for the safety of local communities and economic activities (Franzin *et al.*, 2000). Dalla Valle and Saccardo estimate an average water deficit of 3.4 million m^3 and, in dry years, this deficit can reach 75.5 million m^3, as it happened in 1996 (Dalla Valle and Saccardo, 1996).

The current situation with respect to water users and management plans in the Piave River Basin represents a good test case for the proposed non-cooperative, multilateral bargaining model: the planning authority (the River Basin Authority of Alto Adriatico) intends to take into account the interests and needs of all major stakeholders in planning for water use, yet its initial attempt has encountered their opposition. Exploring the key issues of conflicts in allocating water in the Piave River Basin within the proposed framework may highlight management strategies which are good compromises among different users, thus helping reduce conflicts over the resource and promoting its sustainable development.

The model is necessarily a simplified representation of the existing problems with managing water resources in the Piave River Basin, but the substantial contribution of local actors in identifying the key negotiation variables and in calibrating players' utility functions make it nonetheless useful for starting exploring the problem more formally and suggesting some policy entry point for conflict management. The process of transposing reality into a simplified model, and determining players' utilities and preferences, is intrinsically subjective: to avoid as much as possible introducing biases in the estimates, a suite of tools has been used in this research. The framework approach adopted is inspired by the NetSyMoD[4] approach (Network Analysis, Creative System Modelling and Decision Support). The problem itself, the information, the choice set and the judgement are defined with the contribution of different actors, who may be various experts in the disciplines relevant for the solution of a certain problem, or they may be the actors and decision makers that are formally or informally involved in the participatory process of decision-making, for instance during the definition of a local development plan (Giupponi *et al.*, 2006).

3.2 Players and issues

The management problems of the Piave River Basin are complex, involving a multitude of actors at different levels, and issues of different urgency. After reviewing the literature on the subject area, a series of interviews were held with the main actors – both at the individual and at the institutional level[5]. The existing conflicts of interests among the Province of Belluno on the one hand, and the agricultural water users in the Province of Treviso on the other, was thus singled out as the most important aspect of controversy of the Piave River. The downstream water users for irrigation are

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[4] NetSyMoD is the result of several years of experience in the field of participatory modelling and planning within the Natural Resource Management Programme at FEEM. NetSyMoD has been designed as flexible and comprehensive methodological framework, using a combination of methods and support tools, and aimed at facilitating the involvement of actors or experts in decision-making processes. For further information, see www.netsymod.eu.

[5] The field work benefited from the EC funded project ISIIMM (Institutional and Social Innovations in Irrigation Mediterranean Management). See http://www.isiimm.agropolis.org/. Interactions with local actors took two main forms: either individual, face to face interviews or group decision making processes, and had the main objective of validating and fine-tuning the preliminary findings, allowing for a more precise specification of the model constitutional structure. This included the identification of key players and key issues, as well as the information necessary to construct their preference functions, and the constraints in the Piave River basin. A full report on the project's results for the PRB can be found in Sgobbi *et al.*, 2007.

represented by the two major Land Reclamation and Irrigation Boards (LRB), the LRB of Destra Piave and the LRB of Pedemontano Brentella. These are the institutions mandated with managing irrigation infrastructure and water distribution. The role played by ENEL – the electricity production company – also appeared as important, in determining water availability in the area. Finally, a municipality representative of all the municipalities in the lower part of the Piave River was also included, as defending environmental interests of the river downstream of Nervesa.

Players negotiate over two main issues, namely the abstraction permits for consumptive uses of water in the summer (dry) months and in the winter (wet) months. Water allocations in winter and summer are considered as two variables as the needs are very different in the two periods of the years, and so is water availability. For both the winter and summer periods we use the average (m^3/s) flow, and players negotiate over the *share* of the total resource that they can abstract for their own use.

We assume that the Province of Belluno negotiates to prevent water release from the reservoirs, as it is in its interests to maintain them relatively full, given their landscape and tourist uses. We only consider ENEL's water diversions at a specific point in the electricity producing system, namely the Fadalto power plant system, directly linked to one of the major water reservoirs in the mountainous part of the river. The rationale for this choice is that virtually all the water diverted at the Fadalto system is not returned to the Piave River, but transferred to the Livenza River. Water use for power production at this point of the system can thus be effectively considered consumptive use.

It must be highlighted that, given the wealth of studies and political processes aimed at finding a compromise solution to the "battle of the Piave", our players can be assumed to have common knowledge over their opponents' utility functions. Because of this, players will not be able to behave strategically in the sense of trying to deceive their opponents, presenting themselves as having different preferences over the negotiated variables.

It should also be pointed out that the River Basin Authority is not included explicitly as a player in the game. The Authority is interested in exploring the conflicts and potential solutions to tailor its management plan accordingly, thus identifying policies and allocation patterns which may represent a good compromise among competing water users. For our purposes, the River Basin Authority is assumed to establish the rules of the negotiation, as well as the default policy to be implemented in case of no agreement.

3.3 Estimating players' utility functions

We define our model in the class of spatial problems, where players' utility is a declining function of the distance between the (proposed or implemented) policy package and their ideal point, weighted by the relative importance of the negotiated variables. These preferences are translated into utility functions with "good" mathematical properties and realistic parameters estimates[6] with the direct inputs of players.

We adopt this perspective for three reasons: firstly, this approach is less data intensive; secondly, it is better suited to our aim of calibrating players' utility functions with the direct input of players themselves. For designated players such as environmentalists or irrigation boards, which, by legislations, provide a service of social utility and cannot aim at profit making, adopting a more traditional approach of equating players' preferences with their production or profit function was not deemed appropriate, contrary to the profit function approach used in Adams *et al*. (1996), Simon *et al.* (2003, 2006) and Thoyer *et al*. (2001). Finally, in negotiation process often perceptions are more influential than "hard facts" in determining the equilibrium agreement, if any.

Interviews[7] were thus conducted, with the main objective of identifying players' ideal and cut-off points with respect to the policy dimensions to be negotiated, thus delimiting the bargaining area were the final policy agreement will need to lie. In addition, players' *status quo* bargaining power was to be identified.

Players' utility functions are described as follows:

[1] $$U_i(\mathbf{x}) = q * [\gamma - \mathbf{d}(\mathbf{x}, \boldsymbol{\alpha}_\mathbf{i})]^{1-\rho_i}$$

where $U_i(\mathbf{x})$ is the utility player i obtains from the implementation of policy package $\mathbf{x}$; γ and q are scaling parameters, equal for all players: the first is needed to ensure a positive value within the brackets; the second, on the other hand, is included for computational purposes, as the programme used to solve the game performs better when the vale of the objective function is close to 0; $\rho_i \in (0,1)$ is players' risk aversion coefficient, and $\mathbf{d}(\mathbf{x}, \boldsymbol{\alpha}_\mathbf{i})$ is the matrix of the distances between the proposed allocation and players' ideal point, $\boldsymbol{\alpha}_\mathbf{i}$. In this application, ideal points are represented by a 2-dimensional vector. The distance between players' ideal policy and the proposed/implemented one is defined as:

[2] $$\mathbf{d}(\mathbf{x}_\mathbf{i}, \boldsymbol{\alpha}_\mathbf{i}) = \sqrt{\psi + \sum_{k=1}^{K} \eta_{i,k} * (x_{i,k} - \alpha_{i,k})^2}$$

Where ψ is a scaling parameter ensuring that the number inside the square root is always positive (for computational purposes), but not affecting the results of the model. Players' preferences

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[6] It should be stressed that at no stage during the bargaining game do players compare their utility with that of the other players: at each round, each player only compares his utility with the utility he can expect at the following round. Utility functions thus do not need to be comparable. Furthermore, only local preferences are required, so that players' preferences need not be completely described.

[7] In order to reduce potential interview biases and an excessively subjective and mediated preference elicitation process, the interviews were structured around a questionnaire, with a mix of open-ended and close-ended questions: the former are particularly useful in interviews, as they leave space for the respondent to freely describe his experience with respect to the issue. Close ended questions, on the other hand, are less problematic both analytically, and psychologically, as they minimise biases in responses. A mix of the two is therefore likely to provide more information, with in-built reliability check and balances.

towards the two negotiated variables are not symmetric, and the relative weights assigned to each variable are denoted by $\eta_{i,k}$.

One specification is needed. According to the standard theory of non-cooperative bargaining, discounting imposes a cost on the negotiation processes, as delays in the achievement of the agreement cause a loss in the utility players can derive from the equilibrium outcome. In this model, we assume that players do not discount their payoffs – convergence of the result can still be obtained because there is a deadline, after which negotiations cease and a disagreement policy is implemented; and the disagreement policy – which is common knowledge to all players – is strictly worse off for all players than any agreement[8].

Players maximise their utility in [1], subject to exogenous constraints given by:

[3] $$x_{i,k} + epsilon \leq 1, [\forall i, \forall_k]$$

That is, the share of the resource that players *individually* propose to consume in either season plus a small positive disturbance term to ensure that all players get some positive allocation, must not exceed the total quantity of water available for use.

And subject to their offer being in the acceptance region of other players, that is, subject to other players' expected utility constraint.

[4] $$EU_j(\mathbf{x}_i) = \sum_i \omega_i U_j(x_i)$$

Stating that the expected utility (or acceptance set) is equal to the sum of all the possible payoffs he could get in the next stage of the game, determined by the proposal of all the remaining players including himself, weighted by the proposer's access probability, ω_i.

An additional constraint is needed, to reflect the fact that players may have a threshold level below which they would not accept a compromise:

[5] $$U_i(\mathbf{x}_i) \geq U_i(\mathbf{x}_i^{\min})$$

Where $U(\mathbf{x}_i^{\min})$ is the utility that player i derives from the minimum acceptable allocation level, $\mathbf{x}_i^{\min}$.

We thus estimate players' ideal points, inferring them directly from players' stated preferences. It clearly emerges from the interviews that players have conflicting preferences: the two

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[8] Rausser and Simon (1992) show that, if players have positive time-discount factors, a deterministic solution may not be guaranteed, but the existence of an "almost deterministic" still is.

Land Reclamation Boards prefer more water in the summer as opposed to the winter season, as agriculture requires more irrigation during this period. On the other hand, ENEL, the electricity company, would rather release water from the reservoirs in the winter for hydroelectric production, when demand for energy is higher. The remaining two players have more or less symmetrical preferences – even though they require different amounts of water.

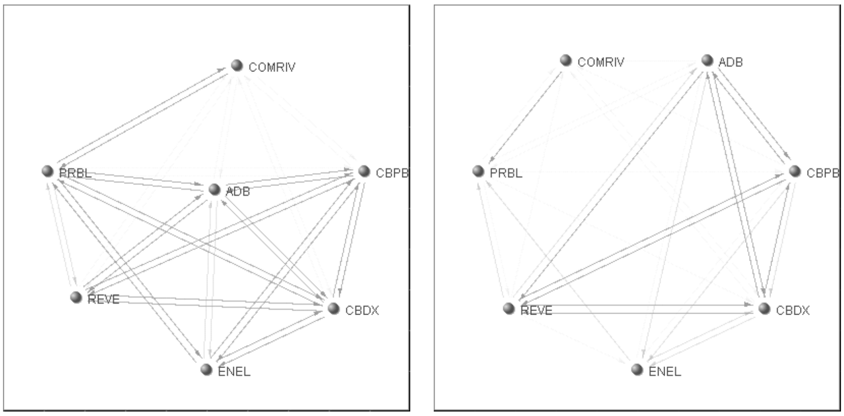
We infer players' minimum acceptable allocation, which may be determined by technical reasons (as in the case of agriculture or hydroelectric power generation), economic purposes (as in the case of the Province of Belluno and tourism in the reservoirs) or biological considerations (as in the case of the minimum water flow). For the two LRBs, the minimum allocation is inferred from players' interviews. For the Province of Belluno, we assume a minimum allocation of zero – that is, we assume that the reservoirs are managed at the minimum regulatory level, releasing all the volume of water usable for hydroelectric power generation and irrigation downstream. This assumption may seem extreme, but it reflects the relatively low bargaining power of the Province of Belluno with respect to the daily operation decisions for the three reservoirs. For the riverside communities we assume that the minimum flow they are ready to accept is the flow established by law in years of medium drought. Finally, for ENEL, we derive the minimum water needs at the point of diversion from observed diversion patterns.

We elicit the intensity of players' preferences (the real value of parameter $\eta_{i,n}$ in equation [2]), asking them to rank the relative importance of the two negotiated variables – and water price. The weights attributed to the two variables by the five players are a reflection of the underlying demand for water: for tourist and environmental purposes, water demand is constant throughout the year; for irrigation purposes, water is crucial in the summer; for hydroelectric power generation, on the other hand, demand is higher in the winter months, when the price for electricity is higher, and so water in the winter is more important.

We estimate players' access probability, ω_i, which represents the bargaining power of players, and is determined exogenously: the higher the political weight, the higher the probability of the player to "seize the initiative" in the negotiation. The process of estimating ω_i warrants a more detailed discussion: when studying the negotiation process within a non-cooperative bargaining theory framework, the political weight plays a critical role in determining the equilibrium outcome. In the literature, players' access probability is approximated by a random variable with a well-specified probability distribution, or its value is assumed *ad hoc* (as in the applications of the Rausser and Simon's model, see Adams *et al.*, 1996; Simon *et al.*, 2003, 2006; Thoyer *et al.*, 2001). In this latter case it is easier to see how access probabilities can be considered as a proxy for players' relative power[9]. In this paper, we adopt a different approach and estimate players' access probability, based on players' stated behaviour. More specifically, we characterise players' political power on the basis of two elements: on the one hand, the influence of each actor will be partly determined by the policy priorities set by the dispositions of Italian legislation on matters related to water management and local development (Law 36/1994). On the other hand, players' influence will depend on their role within the social network of institutions operating in the area – with more active and central actors being more able to influence the opinion and behaviour of others. This latter component is estimated using Social Network Analysis[10] techniques (SNA). Analysing patterns of social and institutional relations, various elements characterising actors as embedded in a social structure can be inferred.

In our application, the component of players' bargaining power related to their embedding in the local institutional network is given by in-degree centrality as a measure of actors' influence, estimated in terms of actors' planning cooperation with the institutional decision makers for the area – namely, the River Basin Authority and the Veneto Region. The network constituted by our four actors – and other actors of relevance for policy making – is visualised in Figure 1, where actors are represented by points (nodes), and relational ties by lines – or arcs – connecting the nodes. On the left hand side, players' relations are represented, while the cooperation in the planning stage is represented on the right hand side. In both cases, thicker lines represent more frequent (stronger) relations.

Figure 1: Players' relational network



Presence of institutional interactions

Interactions in planning

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[9] Although in reality players may decide to invest in their bargaining power – and hence the vector of access probability would be determined endogenously in the game – in this model we will not consider this possibility.

[10] Wetherell *et al.* (1994) provide a useful definition of SNA: "Most broadly, social network analysis (1) conceptualises social structures as a network with ties connecting members and channelling resources, (2) focuses on the characteristics of ties rather than on the characteristics of the individual members, and (3) views communities as 'personal communities', that is, as networks of individual relations that people foster, maintain, and use in the course of their daily lives." (p. 645). For a more detailed review of SNA and its techniques, see Wasserman and Faust (1994).

Finally[11], we assume players have a risk aversion coefficient of 0.5; in the stochastic simulations, we explore the impact of players' risk attitudes through their beliefs about the availability of water in the summer months, and how changes in the underlying probability distributions affect players' negotiation behaviour.

Table 1: Summary of players' utility function parameters

	Ideal winter allocation (m^3/s)	Ideal summer allocation (m^3/s)	Relative importance of winter water	Relative importance of summer water	Access probability
LRB of Pedemontanto Brentella (CBPB)	28	44.4	0.2	0.8	0.30
LRB of Destra Piave (CBDX)	16.5	34.45	0.3	0.7	0.30
ENEL	42.7	42.7	0.7	0.3	0.17
Province of Belluno (PRBL)	46.8	64.3	0.6	0.4	0.15
Riverside communities (COMRIV)	20	20	0.5	0.5	0.08

3.4 Estimating the exogenous constraint

Exogenous constraints in the current formulation of the model refer to the hydrological balance of the Piave River system. At the general level, water available can be described by the following equation:

$$\overline{X}_k = flow_k + \sum_d release_k - MWF_k \tag{6}$$

Where the total quantity of water available for consumptive use in each period k ($k=1$ is summer, and $k=2$, $\overline{X}_k$, is determined by the natural flow of the river, $flow_k$; MWF_k is the MWF constraint; and $release_k$ is the total volume of water that can be released by upstream reservoirs, d, in each period. Releases will in turn depend on the quantity of water stored in the reservoirs, which is a function of the amount of rainfall and storage capacity of the reservoirs. Thus, the residual flow in each sub-basin is calculated as the difference between the total volume of water that flows into the sub-basin, including releases from existing dams, and the total volume of water used within the sub-basin.

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[11] With the resources available for this study, it was not possible to design a system to estimate players' risk attitude, and we have thus relied on existing literature on the subject. In this application, players are therefore assumed to have the same degree of aversion to risk, which is constant and independent of the space variables (Romer, 1996).

In the first part of our application, we will assume that the supply of water is equal the amount available for consumption[12], since, as illustrated in the paper by Rausser and Simon (1992), the problem reduces to individual maximisations, subject to feasibility constraints and individual rationality constraints.

Depending on the allocation rule used, several examples exist in practice on how water available for consumptive uses is determined in sharing agreements. For instance, the US Compact for river sharing among Colorado, Kansas and Nebraska, which is based on a proportional rule, uses an estimate of annual virgin water supply – with adjustment made to the shares if the supply varies by more than 10% (Bennet and Howe, 1998).

Under fixed allocation rule, the water flow constraints could theoretically differ for the players, as water flows from upstream to downstream, and availability to downstream users is influenced by the decisions of upstream users[13]. In this application, we consider a proportional allocation which does not give *a priori* priority to some players to the detriment of others. We are thus able to simplify the problem, by assuming that all players face the same constraint.

To estimate the water constraint, we consider three factors: the average (virtual) water flows at the closing sections of the river basin, as reported by in ADB (1998); the theoretical maximum releases from the reservoirs, as derived from the release curves of the main reservoirs (Carlini and Sulis, 2000); finally, to the above, we subtract the MWF set by legislation – which varies between summer and winter months (ADB, 1998).

An increasing body of literature is developing to address the issue of uncertain water availability and its impact on the efficiency and stability of allocation agreements. Within the second part of this application, uncertainty in summer water availability is introduced, thus implicitly assuming water available in winter can be predicted with reasonable accuracy. Although this simplification may not seem realistic, it can be justified empirically, since water consumption patterns are relatively stable in the winter months. Thus, the choice is to focus on summer variations, as the summer period is clearly more critical, and weather conditions make accurate predictions more difficult[14].

Uncertainty over the availability of water will not be resolved before agreement can be reached, since players negotiate an allocation agreement that remains valid for a fixed period of time, during which water availability will be subject to random variations.

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[12] This is necessarily a simplification, but our interest here is in exploring how the consideration of stochastic variations in water availability affects players' strategies through a simulation exercise.

[13] Note that it is not necessarily the case that upstream users have an advantage over downstream users: in fact, with fixed downstream allocation, it is downstream users whose needs are to be covered first, with the (estimated) remaining water available for consumption upstream. This indeed seems to be the case in the PRB, as agricultural users are prioritised with respect to the needs of the mountain communities.

[14] Note however that the availability of water in the summer period will necessarily depend on winter use, through the regulation of the water reservoirs, and the accumulation of water in the reservoirs themselves – a function of rainfall level, as well as water release patterns. To simplify matters, we will assume that these variations are captured by the stochastic variability of X_2.

One way to model this form of uncertainty is to assume that players have prior beliefs over water variability, which are fixed, and cannot be adjusted during the course of the bargaining. In the stochastic model, the hydrological constraint for the summer period can thus be represented by:

[7] $$MWF_2 \geq flow_2 + \sum_d release_2 - MWF_2 + \tilde{k}_i$$

Where $\tilde{k}_i$, is a random element influencing water availability. The realisation of X_2 is thus defined by the probability density function over $\tilde{k}_2$, and it is assumed to vary following an exogenously specified probability distribution. According to the literature on probabilistic hydrological forecasting, the most commonly used probability distribution is the gamma distribution (Bobee and Ashkar, 1991, Markovic, 1965). We thus fit a gamma distribution to observed values of water flow in the Piave River, and estimate the distributions' parameters.

4. Negotiated water management in the Piave River Basin

The bargaining game briefly described in Section 1 and analysed in Carraro and Sgobbi (2007) is solved computationally by using the estimated payoff functions and constraints described in the previous section. We first solve the game with the deterministic constraint, and explore the impact of different constitutional features on players' strategies and equilibrium payoffs. We then introduce uncertainty in water availability, and observe how players' strategies change – both when players have the same attitude to risk, and when attitude to risk differs. Finally, we carry out some policy-relevant exercises, comparing *ex post* different players' strategies and their individual and overall welfare implications.

Formally, the game is solved by backward induction. In the last period of the bargaining game – the first period of the computable model – the proponent will select a set of policy which maximises his utility. The other players will have to accept this proposal, because it is better for them than the disagreement policy by assumption. The optimal action of the next-to-last bargaining round is then determined, taking the last round's action as given. In this round, a player will be selected to make a proposal according to the vector of access probability, and the proposal will be such that his utility is maximised, and it yields to all other players a utility higher than their expected utility for the round. The process continues in this way backwards in time until the proposals made by all players converge.

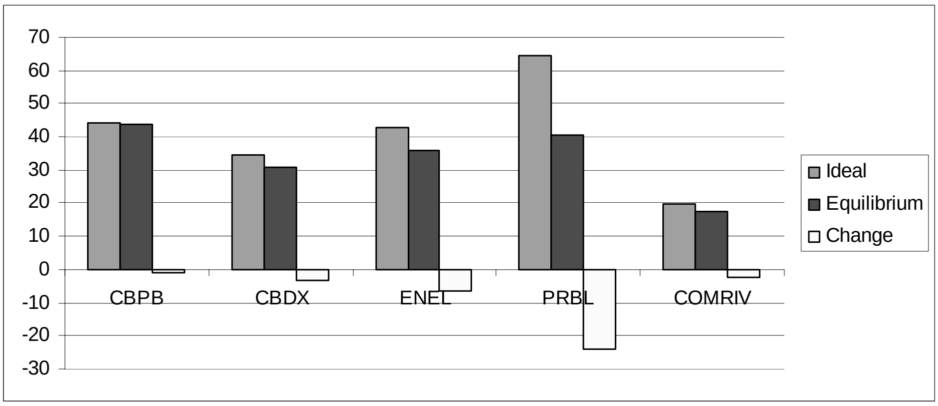
The computational model is solved recursively, by computing a series of single-person decision problems, until an acceptable degree of convergence is achieved. For the simulation, we use GAMS – General Algebraic Modelling System (McCarl, 2004). GAMS is a high-level modelling system for mathematical programming problems. It is designed to provide a convenient tool to represent large and complex model in algebraic form, allowing a simple updating of the model and flexibility in representation, and modular construction[15].

4.1 The deterministic case

The results of the baseline deterministic analysis show that, if the last round is reached (the first round of the computational model), when selected to be a proposer, each player would propose his ideal allocation, which would be accepted by the others. In fact, in the final round of the negotiation, players would attain their highest payoff, should they be selected to be proposers. As we move backwards in the game, the expected utility constraints of all players become increasingly binding.

The value of the deterministic numerical solution of the negotiation model is not in the quantitative results but, rather, in the qualitative intuition that can be derived. It is therefore instructive to look at the equilibrium quantities more in detail. Figure 2 reports the difference between the ideal allocation for the summer and the equilibrium allocation, resulting from the simulation of the non-cooperative negotiation process. It is clear that the $PRBL$ ends up with a much lower allocation with respect to its ideal than the other players (about -37%), while the other players are more or less experiencing the same reduction. The exception is $CBPB$, which ends up with approximately its ideal allocation. What can be driving these results? The issue will be discussed more in detail in the following sections, when we explore the effects of shifting access power on the resulting agreement.

Figure 2: Difference in allocation – ideal and equilibrium (x_2)



4.1.1 Varying access probability

In line with intuition and the results of existing applications, we expect players' access probabilities to influence to a significant extent the resulting equilibrium allocation and expected utilities. We thus begin our analysis by shifting access probability from $CBPB$ to $CBDX$, keeping

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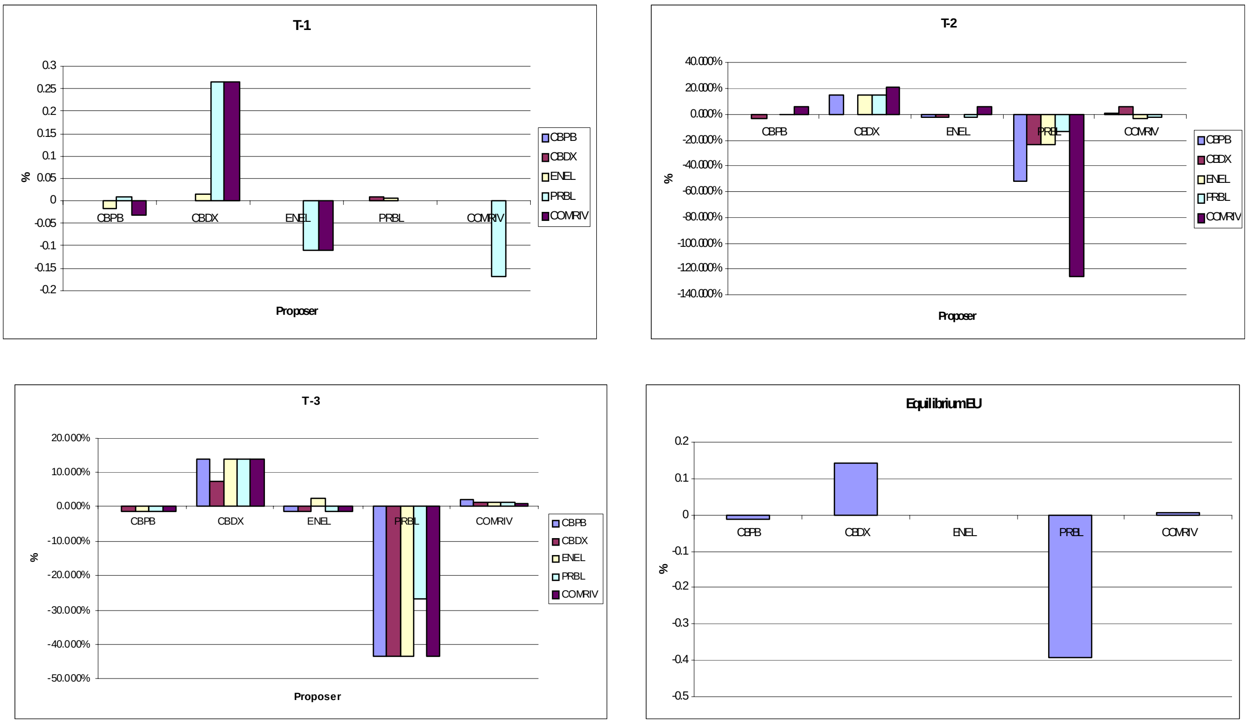
[15] In the GAMS code, a solution is found when $\varepsilon \leq 0.001$ – where ε is the difference between two consecutive solutions.

the other players' political influence constant. One would expect the equilibrium allocation to be more favourable to $CBDX$ with respect to the baseline case.

The effect of shifting access probabilities in round T is to tighten the expected utility constraint of $CBDX$, as this player strictly prefers his own proposal to the proposals of other players. Figure 3 traces back these impacts through the inductive chain: the top left panel shows the changes in players' utilities for the different proposers in round $T-1$, and similarly the other panels show the changes in players' utilities from their opponents' proposals as access power is shifted from $CBPB$ to $CBDX$. It appears clear that $CBDX$ gains substantially if the final round of the negotiation is reached, as this player has a higher probability that his preferred proposal will be drawn in that round. As we move backwards toward the beginning of the game, however, this advantage decreases, while the relative disadvantage experienced by other players levels off.

In equilibrium, $CBDX$ gains significantly from the increased access, as shown in the bottom right panel of Figure 3. While most of the players seem to lose relatively little to the increase of power of $CBDX$, $PRBL$ loses out substantially.

Figure 3: Changes in utilities – shifting access



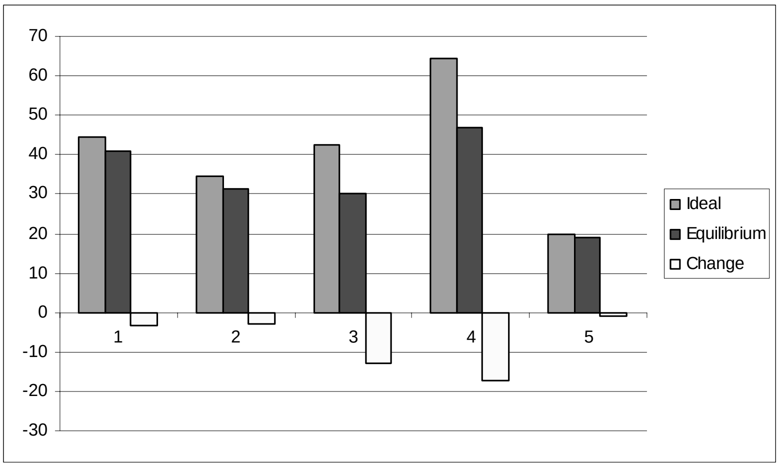
What is the reason determining this build-up effect that progressively worsens the situation of this player, while leaving substantially unchanged the outcome for the player whom we have weakened by construction? Unlike the experiments of the Rausser and Simon model (Simon *et al.*, 2003, 2006), we cannot explain this outcome by the similarity of players' ideal points, since we are dealing with a situation of pure conflict. The driving force behind this effect is likely to be players' participation constraint and the complex interactions among different sources of bargaining power, which are explored in the next comparative statics exercises. This result brings us to the hypothesis that access probability is not the only source of bargaining power for players. Players' acceptance set may be playing an important role in determining equilibrium allocation. This hypothesis is explored in the next section.

4.1.2 Varying players' acceptance set

In this simulation, we return to our baseline data, with the exception of players' minimum acceptable utility level, below which they would be leaving the negotiation table. In particular, we will assume that the minimum compromise for $PRBL$ increases, and we look at the resulting equilibrium allocation. The effect of increasing the compromise level for one of the players is to restrict the zone of agreement. We would therefore expect to see, under some circumstances, a smaller space for agreement. Such an outcome could emerge in situation of extreme water scarcity, for instance, when the minimum water allocation to the players cannot be met: it is thus a direct consequence of restricting the zone of feasible compromise.

Some qualitative considerations can be made on the convergence path of players' offers. The convergence process takes longer than in the baseline case: the increased difficulty is likely to be the results in restricting the space of acceptable agreements, and several iterations are needed to reach an agreement. Furthermore, convergence of the offers is more complex than in the baseline case, as the participation constraint of $PRBL$ becomes binding on some players, contrary to the baseline case.

Figure 4: Difference in allocation – ideal and equilibrium (changed agreement zone, x_2)



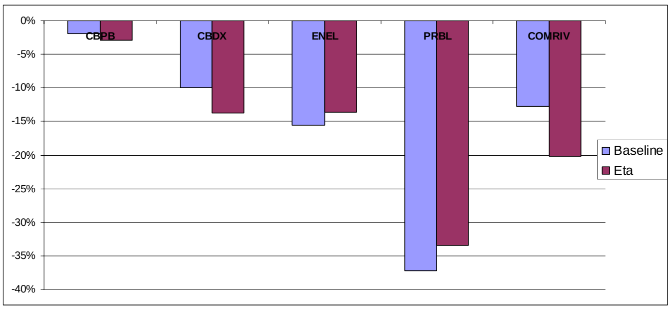
Players' acceptance set is confirmed as playing a very important role in determining the equilibrium shares. Figure 4 shows the changes in the agreed allocations for water during the summer months, as compared to the ideal allocation. $PRBL$ is still suffering from a larger reduction, both in absolute value and in percentage terms: however, this reduction is much smaller than in the baseline case (27% compared to 37%), while the other players suffer a substantially increased relative reduction (-7.5% for $CBPB$; -9% for $CBDX$; -30% for $ENEL$).

4.1.3 Varying the relative importance of the negotiated variables

An important results of the theory on multiple issue bargaining – and of the related theory on issue linkage (see, for instance, the pioneering contributions of Folmer *et al.*, 1993; Cesar and De Zeeuw, 1996; Barrett, 1997; Carraro and Siniscalco, 1997; Katsoulacos, 1997 and, more recently, Alesina *et al.*, 2001) – is that there are gains to be made when the negotiating parties are able to trade-off different variables. So, for instance, the Land Reclamation Boards may increase their utility by lowering their demands on their winter share in exchange for a higher summer share, as they prefer to be closer to their ideal allocation in summer. But what are the impacts of reducing this in-built flexibility? In this section we attempt to answer this question. We could, for instance, imagine a situation in which the summer months become increasingly hot, thus leading to a higher electricity demand for air conditioning and cooling systems. Under such circumstances, it is reasonable to expect that the player $ENEL$ would not give much more importance to satisfying his ideal water demand in the winter period, but rather would prefer to satisfy his needs in the hot months of the year.

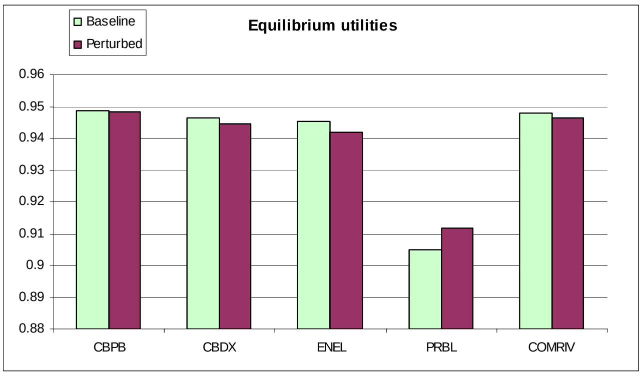
In equilibrium, $ENEL$ is able to attain a higher share of the resource in the summer – which is now the period in which he needs water most. This is shown in Figure 5, which compares the distance between equilibrium and ideal summer quantities in the baseline case and under this scenario.

Figure 5: Distance (%) between equilibrium and ideal allocation (summer quantities)



Yet, this does not necessarily mean that this player is better off. Intuitively, if the weight assigned to one variable relative to the other is much higher, the remaining distance between a player's ideal allocation and the agreed allocation may still decrease equilibrium payoffs. This is shown in Figure 6, which compares the utilities that players derive from the equilibrium allocations in the baseline case and in the case where the preferences of $ENEL$ are more similar to those of the other players. Another interesting result seem to emerge from Figure 6: most of the players are worse off under this scenario with the restricted scope for trade.

Figure 6: Equilibrium utilities – comparing baseline and eta scenarios



Even though these results are sensitive to the choice of parameters, they do nonetheless have an important value, in that they provide formal support to the empirical evidence that, when players have similar preferences, the scope for gains from trade is reduced, and the allocation process in a purely competitive bargaining situation is generally more difficult. As a consequence, players are likely to be worse off in this situation, as the distance between their ideal allocation and the allocation agreed upon is, on average, larger.

4.2 Negotiations in a stochastic environment

In this section, to explore the impact of introducing uncertainty over the realisation of "summer water", we solve the game computationally 300 times. In each simulation, the games are identical with the exception of the realised quantity of water available for consumption in the summer period. We compare the equilibrium agreement with the baseline case, in which players do not take into account in their strategic choices the possibility of uncertain realisation of X_2.

4.2.1 Same attitude to risk

Intuitively, we would expect players to adopt different strategies, when accounting in an explicit way for the possibility that X_2 is not known with certainty. More specifically, we would expect them to attempt extracting a higher share of the resource to hedge against possible states of the world in which water is scarce in the summer months. As in the previous sections, we restrict our attention to water in the dry periods of the year.

First of all, when uncertainty over the availability of water in the summer is introduced in the model, the negotiation game may not have a deterministic solution[16]. Figure 7 summarises the results of the simulation runs: the left column reports the frequency of exact equilibria, while the remaining columns represent the frequency with which approximate equilibria are calculated for each of the indicated degrees of accuracy.

Almost all the equilibria are exact, but there are instances when the difference between players' proposals in the convergence round is relatively large: this result can be interpreted as the failure to reach an agreement. These are the solution vectors for which the largest difference between players' proposals and the average proposal in the equilibrium round is larger than the chosen degree of accuracy, and occur in 15% of the simulation experiments. Interestingly, this situation is observed in two opposite cases: either the realised X_2 is too small to satisfy the minimum requirements of all players; or there is sufficient water during the summer months that all players' can achieve their ideal solution. When we are on this end of the spectrum, of course, there is no conflict among players, and the non-cooperative bargaining model is not needed.

Figure 7: Histograms for the solution vectors

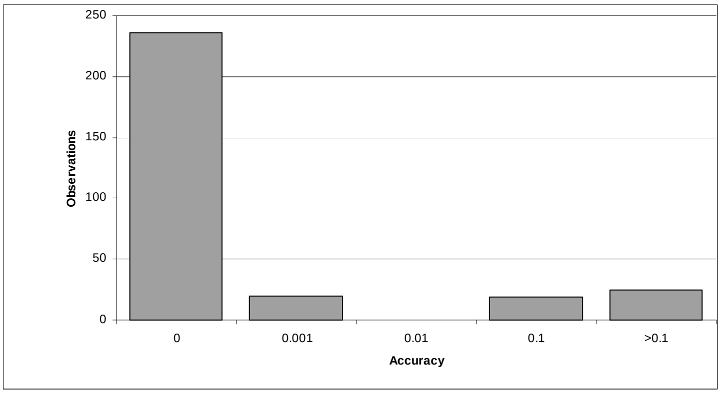


Figure 8 compares the shares proposed under the deterministic and stochastic strategies in several rounds of the game. In the first three quadrants of the figure, each bar represents the difference between the stochastic and the deterministic shares for the players, while the horizontal axis reports the proposers of the policy vectors. The top left panel compares the offers in the final round of the negotiation: it is clear that all players, when being the proposers, ask for a higher share of the resource under their stochastic strategies as compared to the deterministic case, while offering lower shares to their opponents. As we move backwards towards the beginning of the negotiation, however, the interaction among players' offers and counteroffers decreases individual advantages, as the

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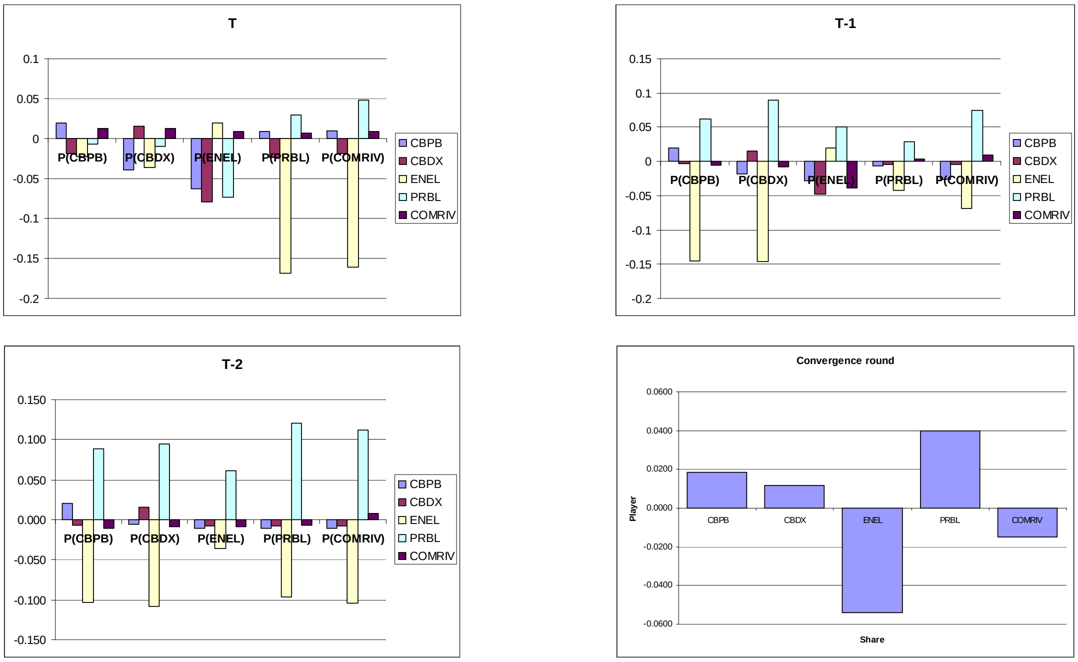
[16] A solution is called deterministic when all the elements of players' proposals vectors are the same – on the other hand, when the equilibrium vectors are almost identical across players, a solution is called approximate.

participation constraints of all players is tighter in the stochastic case as opposed to the deterministic case in round T of the negotiation, and this effect builds up as we proceed backwards.

Figure 8: Comparison of proposed summer shares



Of course, as players are constrained by the fact that, in equilibrium, the sum of their proposals cannot be larger than 100% of the total quantity available, in the convergence round some players will be able to retain a stronger negotiation stance and attain a higher share of the resource, while other players will suffer an equal loss of equilibrium share. This effect is shown in the bottom right panel of Figure 8. In the convergence round, some players benefit more than others from the snowball effect of their more aggressive strategy in the last bargaining round: in particular, the $PRBL$ is able to extract a much higher surplus even when it is the other players' turn to make a proposal, while $ENEL$ is more penalised. These results would seem against intuition, as both the access probability and the default strength of $ENEL$ are higher than those of $PRBL$. As stressed in several occasions, the relation between players' bargaining power and their equilibrium payoff is not obvious within this framework. Intuitively, the observed result could be driven, as the deterministic case, by the participation constraint of the fourth player in the final rounds of negotiation.

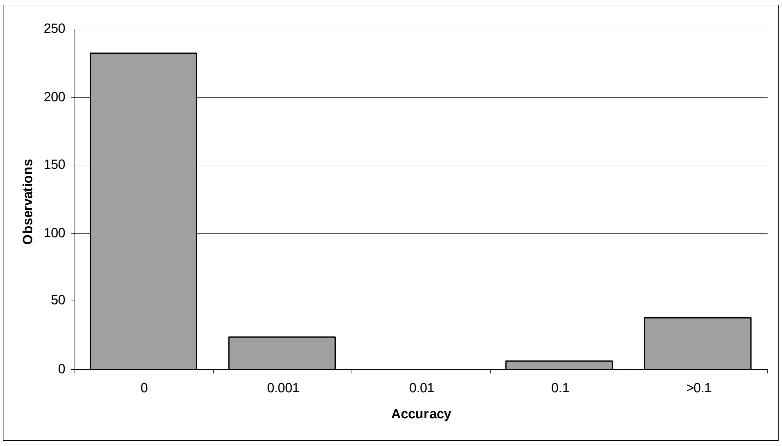
4.2.2 Comparative statics: "optimistic" vs. "pessimistic" players

What happens when a player is more pessimistic than the others? The experiment addressing this question may serve three purposes: on the one hand, it enables us to explore individual behaviour in the face of uncertainty, that is, individual attitudes towards risks and how these affect individual strategies and, in turn, build on the interactions among all the players. On the other hand, it can also tell us the value of information (that is, reducing uncertainty over the realisation of X_2) through an *ex post* assessment exercise. Finally, it is also interesting as it enables us to assess whether players' strategies may change as a response to climate change, which is expected to increase river flow variability and change (possible reduce) mean river flow.

To explore the impact of different risk attitudes, we assume that one player, $ENEL$, has different beliefs over the possible realisations of water availability. We thus change the underlying probability distribution for summer water in such a way as to maintain the same variability as in the baseline case, but reduce the average water flow (this is in line with the literature, see for instance Mendhelson and Bennet, 1997).

First of all, let us look at what happens to the equilibrium solution of the simulation when one player has different beliefs about the quantity of water available, which will affect both his proposals and his acceptance set. We will then compare the limit results in the two stochastic cases, and look at how the behaviour of our target player changes. Figure 9 summarises the results of the simulation exercise: it is clear, by comparing it with Figure 7, that the incidence of non-exact equilibria is higher in this case – the height of the second column. Similarly, there are more cases in which, for our purpose, no equilibrium agreement can be found, as players' proposals do not converge to (almost) the same vector (18%). This result is in line with intuition: when one player has a more pessimistic view of the world than the other players, he will consistently ask for a higher *share* of the resource in order to remain as close as possible to his ideal *quantity*, consequently offering lower shares for the others.

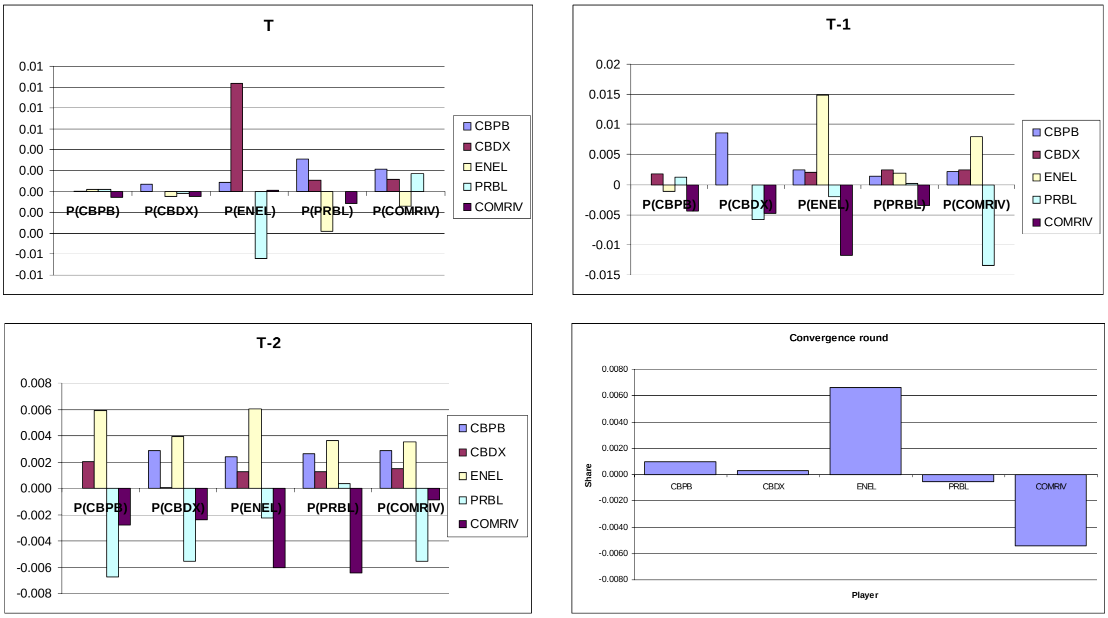
Figure 9: Histograms for the solution vectors with a "pessimistic" player



The number of rounds needed to reach an agreement is slightly higher under this scenario as well, indicating the difficulties encountered in building consensus when players have different beliefs about the state of the world: the weighted average is 6.8 in the baseline case, compared to 7.1 in the case in which a player has different beliefs over the realisation of X_2. However, the number of instances in which the maximum time to reach an agreement is needed (9 iterations) increases.

In the convergence round of the computational model – our limit solution – $ENEL$ is indeed able to extract a higher share of the resource – this is shown in the bottom right panel of Figure 10. As in the case of bargaining power, however, a player's belief over the total availability of the resource is not monotonically related to his – or to others' – equilibrium outcome. More in detail, two players – namely $CBDP$ and $CBDX$ – do not seem to bear a significant share of the burden of $ENEL$'s increased pessimism, which leads him to bargain harder. Intuitively, it is the players' relatively high political effectiveness that affords them to maintain a tight participation constraint on all the other players. In fact, if we look at how the advantage of $ENEL$ builds up as we move backwards through the game, we can observe that this player's participation constraint is not binding in round T (top left panel of Figure 10), but becomes so starting from the second round of the computational model: in round $T-1$, $PRBL$ and $COMRIV$ are forced to concede, and thus $ENEL$ is offered a higher share of the resource than in the baseline stochastic case. On the other hand, neither $CBPB$ nor $CBDX$ are significantly affected by $ENEL$'s strategy until round $T-2$ is reached. At the same time, the strength of $CBPB$ and $CBDX$ is likely to be constraining on $ENEL$, and the player is forced to seek a higher share by offering lower shares to the remaining two players. This intuition is in line with the observations in the baseline, deterministic case.

Figure 10: Comparison of proposed summer shares – "pessimistic" player



4.3 Assessing players’ strategies and allocation rules in the face of uncertainty

The value added of the proposed approach to explore water allocation problem lies in its ability to provide useful information to policy makers. In this section, we will thus explore two aspects that may be of interest: the individual efficiency of accounting for uncertainty in negotiating water policy; and the individual and overall welfare implications of different sharing rules, when players are left to negotiate among themselves. These issues are of particular relevance in the face of climate change, which is expected to increase uncertainty over water availability.

Let us compare the deterministic and stochastic strategies and equilibrium shares, and assess ex post their efficiency. We expect that, for water-poor years, players do better following a strategy which accounts for uncertainty; but, when there are years of abundant water, hedging excessively against water fluctuations may cause them to lose out.

4.3.1 Ex post efficiency

What happens to players’ utility level, when they follow a deterministic vs. a stochastic bargaining strategy, in the face of a certain realisation of water availability? We assume that uncertainty over the quantity of water available in the summer is resolved after an agreement over water allocation has been achieved, and we compute players’ utilities as derived from their equilibrium agreement shares under both the deterministic and the stochastic strategies. We assume three realisations of the resource: low, medium, and high, compute players’ quantities and the resulting utility.

The relation between players’ equilibrium shares under the two bargaining strategies differs across players: although all players begin by asking for a larger share of the resource under their stochastic strategies, to hedge against possible shortfalls, not all of them are able to maintain the advantage to the limit outcome of the game. In particular, players with higher access probability, larger default strength, and lower ideal points are able to benefit from their stronger bargaining in round T of the game.

Table 2 summarises the results of the *ex post* comparison of players’ strategies. The three columns report the qualitative changes in players’ utility under three realisations of winter water: low, when water is scarce; medium, when summer water constraint is still binding, but not as tight as in the previous case; and high, when the summer water constraint would not binding on players.

The results of our simulations suggest that uncertainty will not affect players’ strategies and their payoffs in the same manner. Stronger players will, on average, benefit by explicitly taking into account uncertain water supply in their negotiation strategies in a wide range of situations and, in particular, when water is scarce and there are likely to be acute conflicts. On the other hand, players with a lower bargaining effectiveness will be worse off in these situations, as the more aggressive bargaining strategies of the stronger players lead to an equilibrium outcome that is unfavourable to them. Interestingly, the results are robust for a wide range of values for X_2, indicating that accounting for uncertainty is a winning bargaining strategy for the stronger players.

Table 2: Summary of results – ex post assessment

	Change in utilities		
	Low	**Medium**	**High**
CBPB	++	++	---
CBDX	++	++	--
ENEL	--	---	+
PRBL	+++	+++	++
COMRIV	-	--	+

Only when the summer water constraint is not binding would the more aggressive players suffer a lower utility level than in the deterministic case. However, this result is likely to be strongly driven by the chosen functional form of players' payoffs: by construction, players suffer a loss of utility from allocations which are above their ideal point. In real life, an agreed water share above the ideal point of a player is unlikely to negatively impact his utility, as the excess water can simply be left in the river – benefiting, in addition, downstream players. This is true for a quantity of water below a critical value, after which floods and related damages may occur.

Figure 11: Comparison of distances between players' ideal allocation (summer) and players' realised allocation

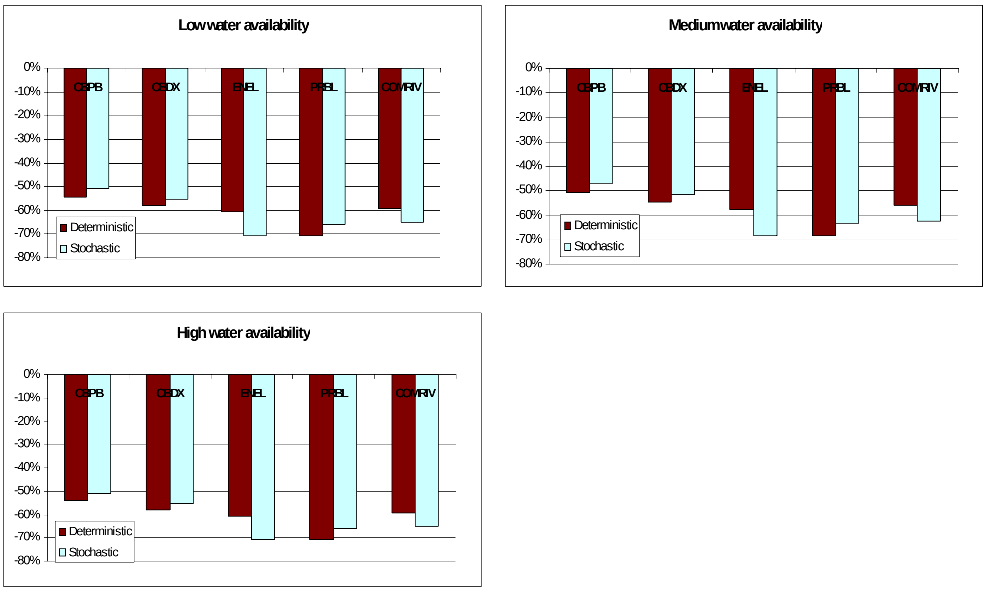


Figure 11 shows graphically the (percentage) distance between players' ideal quantity of water for the summer months, and the realised quantity – that is, the allocation which results as an equilibrium agreement. It is clear that, under low and medium drought conditions, $CBPB$, $CBDX$ and, to a lower extent, $PRBL$ are better off when accounting for uncertainty in their negotiation strategies.

In conclusion, and with all the necessary caveats, the results of our numerical experiments seem to indicate that accounting for uncertainty in water availability when bargaining over how to share the resource does influence to a significant extent players' strategies. The sharing agreement that emerges as an equilibrium of the non-cooperative bargaining model will be even more skewed in favour of the players with stronger political influence: thus, if the observed trend in decreasing river water will continue in the future, we can expect the weaker players to bear a larger share of the burden of water scarcity.

4.3.2 Proportional vs. fixed share allocation

A final exercise, which may be of interest for policymaking, is the comparison between fixed and proportional allocation rules. A fixed rule allocates a fixed quantity of water to players, in an exogenously specified order: thus, the needs of the priority user are satisfied first, and the residual water is allocated to other uses. Fixed upstream distribution gives priority to the upstream users, while fixed downstream distribution prioritises downstream users. On the other hand, proportional rule allocates a share of the resource to the users, which however need not be the same.

In this section, we will compute the utilities of individual players and the overall welfare (in a utilitarian sense, this will be computed as the sum of players' utilities) under the two different sharing rules: fixed (downstream) and proportional allocation, when players account for uncertainty in water supply.

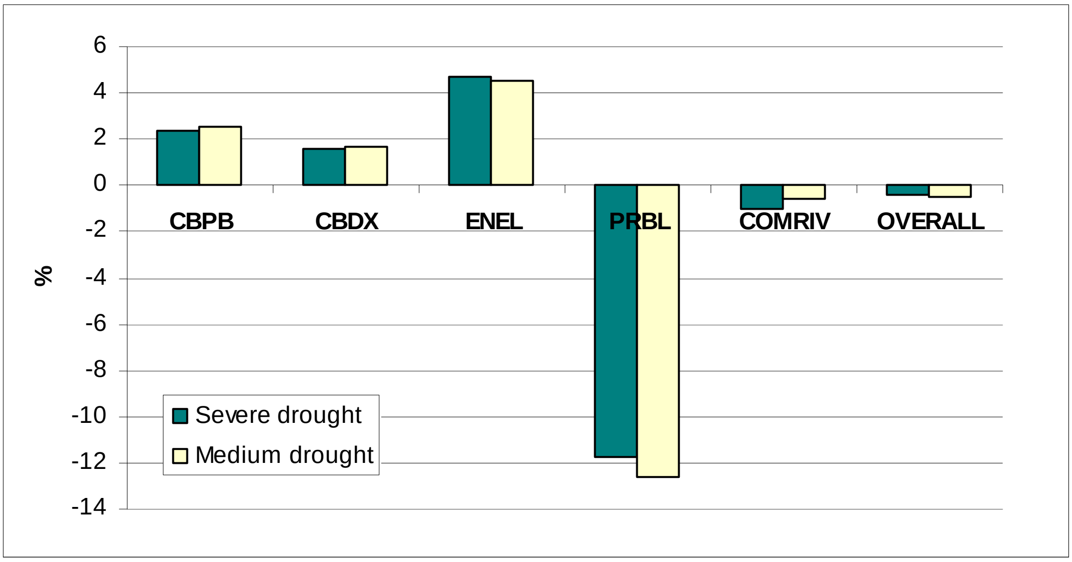
In particular, we use the multilateral bargaining model to mimic a negotiation process in which the five players haggle over how to allocate a fixed quantity of resource. The underlying parameters of the model are the same as the baseline stochastic simulation exercise discussed in Section 0. We then assume, as in the previous exercise, three realisations of water availability, and we compute the utilities that each player derives from the equilibrium allocation agreement under the two scenarios. For conditions of severe and medium drought, when the equilibrium quantities under the fixed sharing rule exceed the total quantity of water available, we assume a reduction in players' quantities as implemented in reality by the ADB (and as detailed in the River Basin Authority's Decision 4/2001). Key to our result is the assumption of fixed downstream allocation: it is in fact the case that, in cases of water shortage, all the water reservoirs are managed by ENEL in such a way as to ensure that downstream (agricultural) needs are satisfied. We thus assume that the Province of Belluno loses all of its allocation. Furthermore, we reduce the allocation to the downstream municipalities (the residual flow) to the emergency minimum water flow (ADB, 2001).

The results indicate that, under fixed downstream allocation, the downstream players who have priority – namely $CBPB$, $CBDX$, and $ENEL$ are able to preserve a high welfare compared to the equilibrium agreement under proportional allocation rule. The welfare gains of these two players, however, come at the expenses of the weaker players: the upstream player, $PRBL$, whose allocation is sacrificed under the fixed downstream proportional rule; and the $COMRIV$, who defend the interest of the river, but find that the MWF is further reduced to guarantee sufficient water for consumptive uses. These results are represented graphically in Figure 12, where each bar represents the change in players' welfare under fixed vs. proportional sharing rule, for two drought conditions.

Figure 12 shows us another insight: the utility gains enjoyed by the three stronger players are not sufficient to offset the loss of utility suffered by the upstream player and the downstream, weak player. That is, overall welfare is higher, under uncertain water supply, under a proportional vs. fixed quantity allocation rule.

These results are in line with previous findings, and reflect the fact that, under a proportional allocation, the risks of water shortage are shared equally among players. they are robust for a wide range of parameters for the underlying probability distribution – both in terms of changing means and spread.

Figure 12: Change in utility – fixed vs. proportional allocation rule



5. Conclusions and policy implications

The scarce application of game theory to water management issues may be partly explained by the complexities involved in the negotiation processes themselves: negotiation outcomes over water may be influenced in more or less subtle ways by the socio-economic and political situation in which the negotiation takes place, as well as by other, seemingly unrelated, issues. In theory, formal models of bargaining can integrate these exogenous factors, hence exploring their impacts on the negotiated outcome, but their identification, quantification, and introduction may be difficult from a practical point of view. This paper is an attempt to propose an analytical tool that can combine rigorous formal properties and careful empirical foundations. It shows how formal models, aided by computer simulation tools, can provide useful insights to policy makers for improving water resources management.

The results of our numerical experiments conform to both intuition and previous results in the literature: with certain water supply, players' access probability – which can be interpreted as their political effectiveness – is an important source of bargaining power. However, the relation between players' access probability and the equilibrium agreement, resulting from non-cooperative bargaining among players, is not straightforward: increasing the strength of one player does not only improve his position, but may also improve the relative position of other players. In the formulation of this game, such advantage is not the result of players having similar preferred position, as we are dealing with a purely competitive bargaining. It is rather the result of the position of the player who indirectly benefits from the improved strength of another player vs. this very player.

Access probability is not the only source of bargaining power: in fact, the size of players' acceptance region – that is, the set of negotiated variables that they are ready to accept, before rejecting any offer – does influence to a significant extent the equilibrium agreement. Players who have a smaller acceptance set are able to extract a larger share of the pie than otherwise: by construction, the other players are forced to concede more, as they all prefer any agreement to no agreement, and are thus keen to find a compromise. This result is akin to the observation that players' default strength – that is, the level of utility players gain from non-agreement – influences to their favour the equilibrium result: intuitively, the higher is the disagreement payoff relative to that of the others, the stronger is the negotiators' bargaining position (Richards and Singh, 1996, Adams *et al.*, 1996; Simon *et al.*, 2003, 2006). Players' acceptance region is embedded in the structure of the game: It is therefore important to understand that players' bargaining strength – and, thus, the equilibrium agreement – is determined not only by their political influence, but also by this parameter. Furthermore, if the managing authority can credibly threaten to impose a default policy in case the parties reach no agreement, it may be able to influence players' strategies and, as a consequence, the equilibrium agreement. In particular, if the default policy yields differentiated advantages to a sub-set of players, the resulting equilibrium agreement will favour this sub-set.

When players take into account the fact that water availability cannot be predicted with certainty, their bargaining strategies are significantly affected: all players bargain harder under their stochastic strategy as compared to their deterministic strategy in the final round of the negotiation game since they attempt to secure themselves a higher share of the resource to hedge against water scarcity conditions. However, as in equilibrium the sharing agreement must satisfy the total quantity constraint, the emerging agreement favours only some players – generally those who are stronger. Interestingly, these more effective bargainers are better off in a wide range of situations as compared to the deterministic strategies: only when the quantity of water available is above the observed average, and the availability constraint is not binding, would these players experience a reduction in utility. As this result is likely to be in part driven by the specific form chosen for the utility functions, we can conclude that the explicit account for uncertainty in bargaining strategies has an asymmetric effect: players who are more effective bargainers are better off, while the weaker negotiators bear most of the risk.

The explicit introduction of uncertainty in players' strategies does have an additional cost, which affects all players: on average, it is more difficult for an equilibrium agreement to emerge. Players' offers do not always converge to an exact equilibrium and, for the purpose of this application, in several occasions no agreement is found. This problem is exacerbated when players have different risk attitudes: in this case, not only is agreement more difficult to achieve, but also more pessimistic players bargain much harder to extract a larger share of the resource, and weaker players bear even more the burden of risk.

Therefore, there seems to be a value in investing to reduce uncertainty in water availability to all players – perhaps through more targeted reservoir management, or through the building of additional reservoirs to hedge against water flow fluctuations. This is indeed in line with the finding of Tsur, Zemel and Grahm-Tomasi (Tsur, 1990; Tsur and Grahm-Tomasi, 1991; Tsur and Zemel, 1995) on the stabilisation role of groundwater. Secondly, the value of information is increased when it is disseminated evenly: when players have a common knowledge over water availability, an agreement is easier to attain. The role of information and knowledge dissemination is even more important when we consider climate change, which is expected to have important implications for water variability.

Finally, our simulation results indicate that proportional allocation rules are welfare improving as opposed to the current system of fixed downstream allocation, in particular when there is uncertainty over water supply. Furthermore, under proportional allocation, the risk of water shortage is spread evenly across players, and the allocation may thus be seen as fairer. Yet, a switch from fixed downstream to proportional allocation necessarily implies a significant change in individual welfare allocation, with the players who benefit from the current system incurring losses to the benefit of the currently weaker players. A policy to induce the players who would be worse off to accept the change for the benefit of society as a whole would therefore be needed: financial resources for upgrading irrigation infrastructure could be made available, extension services to encourage farmers switching to less water-intensive crops, or funds for building additional water reservoirs.

In conclusion, the results of the simulation exercise conform with intuition, and provide some useful insights, based on formal models, as to which factors influence to a significant extent players' strategies and, as a consequence, the resulting equilibrium agreement. Our simulations support the findings of similar applications of non-cooperative, multilateral, multiple issues bargaining models – and thus strengthen the argument for the potential usefulness of this approach in exploring allocation problems. The benefits deriving from implementing similar simulation models are primarily in a new ability to predict negotiation strategies and outcomes, and alter the rules, incentives and structures in such a way as to obtain a more desirable agreement – be it a "fairer" or a more efficient one, and in the ability of the approach to help finding politically and socially acceptable compromise.

Several improvements of our analysis are possible and will be the object of future research efforts. First of all, water availability is estimated in a static manner, abstracting from the complex hydrological system of the PRB. As a consequence, our exercise should not be used to provide guidance as to the quantity of water that should be allocated to different water users. Rather, the qualitative behaviour of the system and of players, given changes in the rules of the game, can provide policy directions and compare different policy options that the managing authority can implement to manage existing conflicts.

Secondly, the functional form of players' utilities is symmetric, and implies an equal utility loss for positive and negative divergences from players' ideal point. Water excess and shortage may have different, non-linear effects on players' utilities. Excess water, for instance, may not cause any harm to players up to a threshold level, after which it causes flooding and, thus, a significant utility loss. On the other hand, even small water shortages may cause irreparable damages to, for instance, production processes. The choice of representing players' preferences as distances from an ideal allocation was dictated by one of our primary aims in this research: the usefulness of game theory – and formal models in general – can only be ensured if the underlying parameters truly reflect players' perceptions, which significantly influence their behaviour. We thus wanted to test an approach that combines formal game theory with more "soft" methodologies, such as interviews and social network analysis. A utility function which is minimal in terms of data requirements was thus selected.

Finally, fairness concerns can play an important role in determining the outcome of negotiations. Importantly, alternating offer games attenuate, to some extent, procedural unfairness: when roles as proposers and respondents alternate, players may perceive the negotiation as more fair than, for instance, constant roles (Guth *et al.*, forthcoming). It could nonetheless be interesting to extend the model by considering a situation in which players are not only concerned with their own payoff, but also with the payoffs of the others relative to their own. Simon *et al*. (2006) address the issue of fairness by assuming that negotiators have a mild "second order" preference for equity, thus preferring a more equal distribution of water (excluding their own share) relative to an asymmetric allocation. The inclusion of these second order preferences, however, does not alter the results in any significant way (Simon *et al.*, 2006, p. 23). Perhaps a more robust extension of the model would be to follow the approach by Fehr and Schmidt (1999), in which “fairness” concerns are modelled as self-centred aversion to inequality, whereby the utility function of players includes players’ aversion to disadvantageous and advantageous inequality, where the first causes a decrease in the utility of a player as his own allocation is lower than each of the other player; and the latter represents players’ aversion to advantageous inequality in allocation.

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