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Structure and Power in Multilateral Negotiations: An Application to French Water Policy

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ABSTRACT

Stakeholder negotiation is an increasingly important policymaking tool. However, relatively little is understood about the relationship between the structure of the negotiating process and the effectiveness with which participating stakeholders can pursue their individual interests. In this paper, we apply the Rausser-Simon multilateral bargaining model to a specific negotiation process, involving water storage capacity and use in the upper part of the Adour Basin in south-western France. In the Rausser-Simon model, the elements of negotiation structure include: the list of participants at the bargaining table; the set of issues being negotiated; the decision rule; political weights ("access"); and the nature of the outcome if agreement cannot be reached. The richness of the data and institutional information available to us provides a realistic environment in which to examine the effect of negotiation structure on participant power. We focus in particular on the three farmer stakeholder groups. Because their interests are aligned but distinct, they form a natural negotiating coalition. We construct experiments that enable us to evaluate the effects of negotiation structure on the effectiveness of this coalition.

Our comparative statics experiments highlight a number of aspects of the relationship between negotiation structure and bargaining power. In addition to the standard indices of bargaining power—the distribution of access and players' utilities in the event that negotiations break down—our analysis identifies a number of other, less obvious, sources of power. First, we show that a coalition member may obtain a better bargaining outcome when his access is reduced, if the redistribution increases the access of another coalition member who has a more favorable "strategic location." Second, we show that the interests of the coalition as a whole will usually, but not always, be advanced if its members cede access to a "spokesman" representing their common interests. However, some coalition members may be adversely affected. Third, we consider the effect on the coalition of restricting the set of proposals that may be placed on the bargaining table. In particular, we impose increasingly tight restrictions on the extent to which coalition members can make bargaining proposals that further their own individual interests at the expense of the interests of other coalition members. We find that usually, but not always, such restrictions harm the coalition as a whole.

1. Introduction

Many areas of public policy are characterized by an increasing emphasis on *devolution*, i.e., direct stakeholder participation in the policy formation process. In some cases, this participation extends to the actual design of the policies that will ultimately be implemented. The trend toward devolution has been particularly significant in the area of water policy design, where the goal is to design policies that are not only environmentally and economically sustainable, but also politically viable. Examples abound, ranging from Armenia to Palestine to the U.S.A. One such collective negotiation among stakeholders, the so-called Three-Way Negotiations which took place in the early 1990s in California, was analyzed in ars. Other, more recent examples of devolution include large-scale rural-urban water transfers in the U.S.-Mexico border region, examined in FrisvoldEmerick06, the San Francisco Estuary Project, and the Sacramento Water Forum. In France, the idea of devolution has been institutionalized in the Water Law promulgated in 1992. This law specifies that specific development plans be set up at the level of each hydrological basin, and that water regulations be negotiated at the smaller, cachment scale. It is required that regulations be negotiated locally between all stakeholders under the supervision of local authorities.[1]

Although stakeholder negotiation is an increasingly important policymaking tool, relatively little is understood about the interactions between the structure of the negotiating process and the interests of the participating stakeholders. How do these considerations influence the negotiated outcome? In this paper we analyze the nature of stakeholder power within a negotiation, focusing on how this power is affected by the structure of the negotiation process and the relationship between the interests of the participants. Understanding these interactions is important for negotiation participants, and for policymakers designing such processes.

[1]Loi #92-3 du 3 janvier 1992, Journal Officiel de la République Française du 4 janvier 1992. See also jiang:93

For our purposes, we define bargaining power as the capacity of a stakeholder to influence the negotiated outcome in order to increase the utility he receives in the equilibrium of the negotiation game. In this paper, we are interested in the bargaining power wielded by a subset of stakeholders, whose interests are sufficiently aligned that they may be thought of as a loose *coalition.* In our case, the coalition consists of farmers who are located at different points along a river. While these farmers compete with each other for water, their interests are more closely aligned with each other than with the other stakeholders at the table, including in particular those representing environmental and other non-agricultural uses of water. We analyze three questions related to the bargaining power of our coalition. First, what are the sources of bargaining power, and how do they interact? Second, is it ever advantageous for some or all of the coalition members to cede their seats at the bargaining table to a "spokesman," charged with the task of representing their joint interests? Third, how does the definition of the bargaining space—i.e., the vector of variables over which negotiations take place, and the restrictions imposed on these variables—affect the bargaining power and resulting utilities of participants? In particular, in some of the bargaining spaces we consider, individual farmers are permitted to pursue their own interests at the expense of the interests of the coalition as a whole, by allocating more water to their own subbasins at lower prices than other farmers pay. Do coalition members benefit when restrictions are imposed on the degree to which they can distinguish their own interests from those of other farmers?

Understanding the factors determining the answers to such questions will facilitate the design of negotiation processes that represent the interests of all stakeholders in an implementable and sustainable fashion. At an intuitive level, stakeholders' power in the negotiation process is measured by their "access" to the decision-making process. Access is a catch-all term for many considerations, including the number of representatives included in the process, the capacity to set agendas, placement on key committees, etc. We demonstrate that the *prima facie* benefits of access can be dominated by other, more subtle kinds of negotiating power, arising from the nature of the interactions between stakeholders and from the structure of the bargaining environment. If a negotiation process is to fairly represent all interests, these interactions must be taken into consideration when policymakers design the negotiation process.

In order to address these questions, we model a specific instance of negotiations over the use and storage of water in the upper Adour basin in south-western France. The upper Adour basin is a water cachment area that extends from the Adour's source in the Pyrenees mountains to its junction with the Midouze River. The upper Adour basin consists of three subbasins, separated by points where minimum water flows are measured by the French government. For our purposes, this negotiation process has a number of advantages as a research topic. First, the negotiation process is well-defined and relatively transparent. The national government clearly specified the rules determining participants, as well as the outcome in the event that the parties are unable to negotiate a solution. Under the specified structure, the participants reached an initial agreement regarding the guiding principles of the negotiation process within a year: they agreed to initiate and fund studies regarding future water needs and supplies, farmers agreed to fund a significant share of management and maintenance costs, and stakeholders agreed on a total water volume for consumptive purposes, which is one of the three critical variables we model. However, the second stage of negotiations deadlocked over the other two critical issues we examine here: allocating water among farmers, and managing limited supplies during droughts **?**. Second, our modeling task is facilitated by the availability of extensive information regarding the scientific and economic relationships that affect stakeholder preferences **??**. The underlying hydrology of the river basin is well-documented **?**. A great deal of information is available regarding the agricultural use of water, in terms of both quantities used and the value of the resulting production. This information provides us with hydrological and economic parameters for our simulation analysis. Third, two types of environmental goals are recognized explicitly by participants: the value of "residual flows"[2] which promote aquatic life, and the scenic costs of dams, which destroy attractive valley landscapes. These two goals compete with each other, and with farmers' use of water for production purposes. Finally, the natural division of farmers by subbasin provides us with a subset of "natural allies," or coalition, consisting of stakeholders whose interests are similar, but not perfectly aligned. The quality of the data and institutional information provides us with a rich and realistic simulation environment for examining the effect of process structure on participant power.

The paper is organized as follows. In section 2, we review the Rausser-Simon multilateral bargaining model (MB), which provides the theoretical basis for this application. Section 3 relates the MB model to the literature on multilateral negotiations. Section 4 introduces the Adour Basin, explains the nature of the negotiations and describes our simulation model of the bargaining problem. Section 5 contains our comparative statics analysis. Section 6 concludes.

2. The Underlying Bargaining Framework

The analytical framework for this paper is the non-cooperative MB model developed in rs1 and applied in ars. In this section, we review the main features of the model, drawing extensively from the presentation in §2 of ars. Complementing the vast theoretical literature on bilateral bargaining spawned by the seminal work of rubinstein:82, the MB framework is designed specifically as an applications tool, to analyze complex multi-issue, multiplayer bargaining problems. It has no closed form solution, and so must be solved using computational techniques.

The specification of a *multilateral bargaining problem* includes a finite set of players, denoted by $I = \{1, \cdots, I\}$ and indexed by i. The players meet together to select a *policy vector*

[2] I.e., total flows net of agricultural usage. See p. 22 for a more complete definition

from some set X of possible alternatives. X is assumed to be a compact, convex subset of n-dimensional Euclidean space, where n is the cardinality of the vector of issues being negotiated. The policy vector $\mathbf{x}$ yields player i a utility of $u_i(\mathbf{x})$, where $u_i(\cdot)$ is assumed to be strictly concave on X. We denote by $\mathbf{u}^0$ the vector of *disagreement* payoffs, i.e., the payoffs players receive if they fail to negotiate an agreement. Throughout this paper, we will assume that decisions are reached by *unanimity*, i.e., an element of X can be selected as the solution to the bargaining problem only if it is accepted by all parties at the bargaining table.

A *bargaining game* is derived from a bargaining problem by superimposing upon it a "negotiation process." We begin by formulating a bargaining game with a finite number, T, of *bargaining rounds*. Under the conditions we assume, each such game has a unique *limit dominance solvable* (LDS) equilibrium.[3] We then define the *solution* to the *limit bargaining game* to be the limit of these finite-round equilibria. At the beginning of the $t \leq T$'th round of the finite game, provided that the game has not already concluded by this round, nature chooses at random some player to be *the proposer* for this round. Nature's choice is governed by an exogenously probability distribution, $\mathbf{w} = (w_i)_{i \in I}$, where $w_i \in [0,1]$—player i is chosen with probability w_i—and $\sum_i w_i = 1$. The vector $\mathbf{w}$ is interpreted as a distribution of *access* to the political system, and w_i is referred to as player i's *access probability*.[4] The player selected by nature makes a *proposal*, which is a policy vector in X, and all players vote on whether or not to accept it. The game concludes in this round if and only if all players vote to accept the proposal; if some player votes against it, play proceeds to the

[3]Limit dominance solvability is a solution concept that extends in an intuitive way the finite-game notion of trembling-hand perfection **?** to extensive form games with a continuum of actions. We prove in rs1 that every bargaining game satisfying the conditions assumed in this paper has a unique LDS equilibrium.

[4]Access probabilities are referred to as "recognition probabilities" in the literature spawned by baronFerejohn:87. While some branches of the political economy literature treat the distribution of political power as endogenous, our paper, along with the other bargaining papers reviewed in §3, treats this distribution as externally determined.

next round. If the T'th round of the game is reached, and if the proposal put forward in this round is rejected, then players receive the vector of disagreement payoffs, $\mathbf{u}^0$. To avoid dealing with degenerate special cases, we will assume throughout that the set X contains a proposal that strictly Pareto dominates $\mathbf{u}^0$.[5]

There is a simple characterization of the unique LDS equilibrium strategies for a game with T rounds of bargaining. This characterization is given by the following, backward inductive construction: a proposal made by player i in period T is accepted if and only if it yields each player $j \neq i$ a utility level at least as great as j's disagreement utility, u_j^0. Similarly, in round $t < T$, a proposal by i is accepted if and only if it yields each j a utility level at least as great as j's *expected* utility from playing the subgame starting from round $t+1$.[6] Thus the game can be solved recursively, starting from the last round: in each round t, player i computes the policy vector that maximizes i's utility, subject to the constraint that for each $j \neq i$, the vector yields player j no less than j's default utility (if $t = T$) or j's expected utility conditional on reaching the next round (if $t < T$). Thus the task for i in each round is to solve a classical non-linear programming problem: maximize a strictly concave function on a convex set.[7] Our conditions ensure that in each round, the unique solution to this problem will yield i greater utility than i's expected utility, conditional on reaching the next round. It follows from this construction that for every finite game there is a unique, stochastic *outcome vector*, consisting of a point in X for each player, which will be proposed by that player if he is chosen in the first round to be the proposer. With probability one, players in round one accept whichever proposal is made. Given a sequence

[5]It should be emphasized that this last assumption is not a necessary one; given our other assumptions, however, it is necessary and sufficient to ensure the existence of a unique negotiated agreement.

[6]In round $t+1$, player i is chosen with probability w_i to be the proposer. Under the conditions we assume in this paper, every proposal that is part of an LDS equilibrium profile is accepted. Therefore, j's expected utility from playing the subgame starting at $t+1$ is the $\mathbf{w}$-weighted sum of the utilities he obtains from all parties' proposals in this round.

[7]The feasible set is convex because it is the intersection of upper contour sets for the other players; these sets are convex because all players' utilities are concave and hence quasi-concave.

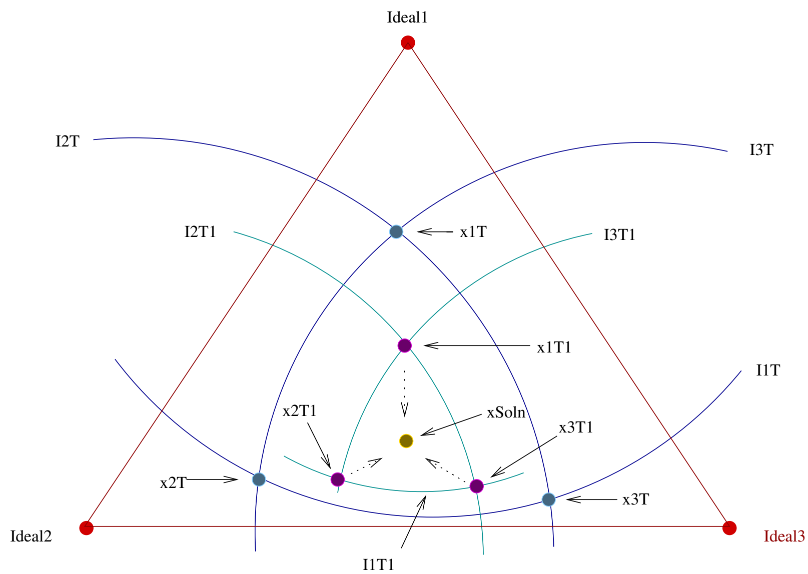

FIGURE 1. An illustration of the Rausser-Simon model (Fig 1. in Adams et. al. (1996))

of finite-round bargaining games, all identical except that the number of bargaining periods increases without bound, any sequence of outcome vectors for these games has a unique, *deterministic* limit in X, i.e., all players' first-round proposals converge to the same point in X. Formal details of this construction are provided in rs1.

We now provide an elementary example, designed to provide some intuition for the basic mechanics of the model. The example, reproduced from ars, belongs to the class of problems known as *spatial problems*, in which the policy space consists of alternative *locations*. Each player has a most preferred location, called her *ideal point*. We assume that the utility derived by a player from a particular location is a decreasing function of the Euclidean distance between this location and the player's ideal point. The example illustrates why a deterministic limit solution must exist.

There are three players. The space of possible locations is represented by a triangle in Figure 1. Players' ideal points are at the vertices of the triangle. Player j's access probability will be denoted by w_j. Consider a game with T rounds of bargaining. For each j, the line $I^{j,T}$ in Figure 1 is the level set corresponding to player j's *reservation utility* in the last round of bargaining: any proposal on this line yields player j a utility level equal to j's *disagreement utility*. This line is the boundary of player j's *participation constraint* on negotiations in round T. Player j's task in this round is to choose the point closest to her ideal point that satisfies both of the other agents' participation constraints.

The outcome conditional on reaching round T is that proposal $\mathbf{x}^j T$ will be agreed upon with probability w_j. Clearly, player j's expected utility conditional on reaching this round is strictly higher than u_i^0, since each of the $\mathbf{x}^j T$'s yields j *at least* u_i^0 while j's own proposal yields her a utility strictly higher than u_i^0. Thus, her participation constraint in round $T-1$ will be strictly "tighter" than in round T. This is illustrated in Fig. 1: the set of proposals for which unanimous agreement can be obtained—i.e., the set bounded by the $I^{j,T-1}$'s—is strictly contained in the set bounded by the $I^{j,T}$'s. Accordingly the distance between players' proposals in round $T-1$ is also smaller than in round T. Clearly, however, it is strictly better for agent j to propose an alternative that will be accepted in the current round, rather than take her chances in the following round. Proceeding by backward induction from round $T-1$ to the first round, this distance between proposals continues to shrink. Thus, if T is sufficiently large, the maximum distance between any two players' proposals in the *first* round of bargaining will be arbitrarily small. This is the intuition for why in the limit as T goes to infinity, the solution to the game is deterministic, i.e., all negotiators propose the same alternative in the first round.

3. Related Literature

Compared with the voluminous literature on bargaining between two players over a single dimension, the literature on multi-player, multi-issue bargaining problems is relatively sparse. We begin with a discussion of the two seminal papers in the former literature—Nash:50 and rubinstein:82—which have strongly influenced the directions in which the latter has evolved. Nash's approach is axiomatic: given a set S of possible utility pairs, and a disagreement outcome (or default payoff) d, Nash identified a unique outcome in S that satisfies four axioms about bargaining outcomes. Extensions of Nash's original paper—the *asymmetric Nash Bargaining Model* (ANBM)—introduce the possibility of asymmetric "bargaining weights," reflecting the two agents' relative bargaining power (see Roth:79).

While the first three of Nash's axioms are innocuous, the fourth, *independence of irrelevant alternatives* (IIA), is highly restrictive. IIA requires that if a given bargaining problem is modified in a way that leaves unchanged the "shape" of the bargaining frontier in any open neighborhood of the solution to the original problem, then the solution to the modified problem must coincide with the solution to the original one. We will argue below (on pp. 10-11) that for many real-world applications, this implication of IIA is highly problematic.

In contrast to Nash's axiomatic approach, Rubinstein's is strategic. In an infinite horizon, discrete-time model, two players make alternating offers to each other concerning the division between them of a "pie." The game has a unique solution, which depends only upon which player makes the first offer, and the relative "impatience" (i.e., discount rates) of the two players. While their frameworks are entirely different, the solutions reached by Nash and Rubinstein are closely linked (see BinmoreEtAl:86 and, for further elaboration, osborne-rubinstein:90): as the time between offers in Rubinstein's discrete time model goes to zero, the solutions to his model converge to the solution to the ANBM with bargaining weights that reflect the Rubinstein agents' relative impatience. In this sense, Nash's axiomatic and Rubinstein's strategic approaches yield "the same" solution to the bargaining problem. It follows that Rubinstein's model also exhibits IIA. Indeed, IIA plays a central role in the vast literature on the strategic approach to bargaining theory that has evolved based on Rubinstein's work. To illustrate, when Rubinstein's model is augmented by providing one of the players with an "outside option"[8], this additional strategic advantage affects the equilibrium outcome of the game *only* if the outside option provides the player with a utility level that strictly exceeds her equilibrium utility in the game without the option.

Both the Nash and the Rubinstein approaches have been extended to a multi-player context. ThomsonLensberg:89 includes an extensive treatment of n-person axiomatic bargaining theory, including Nash Bargaining. KrishnaSerrano:96 [KS] construct a generalization of Rubinstein's game to n players in which the unique solution to the problem of sharing a pie corresponds to the solution of the n-person ANBM. In KS's model, each player can accept or reject the current pie division proposal. Players who accept exit the game and immediately consume their shares of the pie; the remaining players continue to bargain over what remains. Thus unanimity is not required for agreement. The "pie-eating" structure of this setup is clearly restrictive: i's utility from consuming her share is independent of whether or not other players are consuming also, so that the possibility of interpersonal externalities is excluded. KulttiVartiainen:04 have generalized KS's equivalence result to a general context that admits interpersonal externalities.

The Rausser-Simon multilateral bargaining (MB) model applied in the present paper represents a departure from the Nash-Rubinstein tradition in that its solution does not exhibit independence of irrelevant alternatives. In particular, equilibrium outcomes in the MB

[8]This extension was first introduced in shaked-sutton:84b, binmore:85 and binmore-shaked-sutton:89

model depend a great deal on the nature of the offers that are made in the final rounds of negotiations. By contrast, the absolute levels of offers made in the tail of a sequence of Rubinstein offers have no influence on the nature of offers made at the head of the sequence (i.e., the equilibrium offers).[9] This distinction has important implications for the applicability of Rubinstein-type models to the study of certain real-world multilateral bargaining situations. In the context of collective decision-making, an impending deadline can provide a dramatic impetus to compromise: witness the frequency of last-minute resolutions of Congressional deadlocks, and of post-midnight compromises in wage negotiations when strikes are scheduled for the following morning. To the extent that the threats and counter-threats made in these final moments of negotiations involve proposals that are outside of some neighborhood of the ultimate compromise, the solutions of models consistent with Nash's IIA axiom *must* be invariant with respect to the way events unfold at the "eleventh hour." In the MB model, by contrast, these events can have a dramatic impact on equilibrium outcomes.[10] [11]

Of the other multi-player non-cooperative bargaining theoretic papers, most involve some kind of modification of Rubinstein's alternating-offer framework. binmore:85 considers several alternative extensions of Rubinstein's analysis to the problem of "three players and

[9]More precisely, the relationship between equilibrium offers and those made in the final rounds of the finite-horizon games that approximate Rubinstein's model becomes vanishingly small as the time horizon increases **?**.

[10]It should be emphasized at this point that in the *equilibria* of the MB model—and all other complete information bargaining models—agreement is always reached in the first round of bargaining, so that last-minute *equilibrium* agreements never arise. The distinction between Rubinstein's and the MB models arises from *out-of-equilibrium* interactions at the eleventh hour, which, in the latter but not the former, are transmitted via backward induction to be beginning of the game.

[11]Applied economists are generally highly skeptical of arguments that involve long and intricate backward inductive chains. To some extent, this justifiable skepticism may be mitigated when applied to the MB model, because, typically, the basic "shape" of the solution is more or less determined after only a few rounds of backward induction (see §5 below). This fact may also reassure experimentalists, since there is overwhelming evidence that experimental subjects seem unable to backward induct much beyond three periods. (See for example NeelinEtAl:88, SpeigelEtAl:90, BinmoreEtAl:02 and JohnsonEtAl:02.)

three pies:" each pair of players exercises control over the division of a different pie, only one of which can be divided. A result attributed to Shaked[12] shows that in any infinite-horizon, alternating-offer, three-player pure- division problem, if unanimity is required for agreement, and if players are not extremely impatient, then any division of the pie can be implemented by subgame perfect equilibrium strategies.[13]

An interesting n-player variant of the alternating-offer model, called the "Proposal-Making Model," has been advanced by Selten:81. A player is selected by nature to make the first proposal. She proposes a utility vector, a coalition and a "responder." The responder either accepts or rejects. If she rejects, the responder then proposes a new utility vector, a new coalition and a new responder. If she accepts, the responder designates another member of the coalition as the next responder, and so on until all members of a coalition have agreed to some proposal. This model has been studied extensively in ChatterjeeEtAl:87 and by Bennett, writing alone and with various coauthors.[14]

Manzini and Mariotti have studied multilateral bargaining in which an n-member alliance negotiates with another party. In their framework, bargaining proceeds in two stages. The "outer stage" is a standard Rubinstein two-person alternating offer bargaining game. During the "inner stage," alliance members negotiate among themselves over the choice of a proposal; once they have agreed, the proposal is offered to the other party as part of the outer stage. In ManziniMariotti:05, the authors discuss in abstract terms the method by which alliance members decide on a proposal, considering a variety of different "internal procedures." The main finding in this paper is that procedures requiring a unanimous agreement by alliance members result in more aggressive bargaining stances than procedures based

[12]Proposition 3.7 in osborne-rubinstein:90. The result is also discussed in Sutton:86

[13]Sutton:86 and osborne-rubinstein:90 note that Shaked's result can be easily extended to n players.

[14]Bennett:91a, Bennett:91b, BennettHouba:87, BennettVanDamme:91

on majority rule. In ManziniMariotti:03, the model is applied to the problem of negotiations between an alliance of polluting firms and a regulator. Using a unanimity procedure, they find that the outcome of negotiations is entirely determined by the preferences of the "toughest" alliance member.

One advantage of Manzini-Mariotti's framework relative to many others in the multilateral bargaining literature is that it delivers a unique solution to the bargaining problem, even when decision-making within the alliance is governed by majority rule. This advantage, however, has a significant cost. Technically, the result is obtained by separating into distinct rounds the multilateral bargaining within the alliance and the (bilateral) bargaining between the alliance, acting as a unit, and the other party. This structure, however, limits the applicability of their framework. In many bargaining situations, such as the one we study in this paper, the distinction between an alliance and "the other side" is far from clearcut, and "alliance" members interact with each other within plenary negotiating sessions, without ever constituting themselves as a distinct group with a unitary "voice."

Cai:03 also studies bargaining between a single, "active" player against an (implicit) alliance of many "passive" players, who exhibit different degrees of toughness (see also Cai:00). In Cai's model, the active player negotiates with each of the passive players in turn, in an exogenously specified order. If an agreement is reached with a passive player, that player leaves the game, with a contingent commitment that will be honored by the active player. Provided players' common discount factor exceeds a prespecified value $\bar{\bar{\delta}} < 1$, Cai's game has one efficient, and multiple inefficient, Markov equilibria. The source of inefficiency (necessarily) is that agreement is not reached in the first round. In the inefficient equilibria, the passive players have different strategies. In the three-player version of this game, the active player proposes to the tougher of the two passive players, and agreement is not reached. The second passive player is now obliged to accept a bad deal rather than wait for another round of bargaining. As the discount factor goes to unity, the tougher passive and the active players receive essentially equal shares, and the weaker passive player receives a smaller share.

The models discussed above were all developed by economists. Models of multilateral bargaining and negotiations have also been developed within other disciplines, especially political science, psychology and management science. Of these, perhaps the most influential has been the framework [BF] introduced in baronFerejohn:87, baronFerejohn:89a and baronFerejohn:89b. BF consider a problem in which n identical players must divide up a pie, using majority rule. One variant of BF is strikingly similar to the MB model, yet draws quite different conclusions; players propose divisions of the pie in odd-numbered rounds; nature chooses one of the proposals at random and voting follows in even-numbered rounds. In the two-round version of this model, each proposer keeps slightly more than half of the pie for herself, and distributes a small portion to enough others to obtain a majority vote. In the infinite-horizon version of the game, as usual, virtually any division can be supported as an equilibrium. The two-period outcome, however, is identified as the unique outcome that can be supported by "stationary" or Markov perfect strategies. These are strategies that can only depend on "current and immediate future" conditions, such as the set of available strategies in the current round, the parties that are bidding in the next round, etc. Strategies involving punishments for past deviations from the equilibrium path are thus excluded. Also excluded, however, are strategies that exploit impending deadlines, since a player's strategy cannot depend on the number of remaining bargaining rounds. Because of this choice of solution concept, the BF and MB models have strikingly different properties, in spite of their very similar extensive forms.

BF's model has spawned a very large literature. We mention here only a small selection. Eraslan:02 and EraslanMcLennan:05 have shown that a unique stationary equilibrium exists for the BF model under quite general conditions. JacksonMoselle:02 extend the bargaining space of BF's model to two dimensions, an ideological and a distributive dimension, and study the stationary equilibria of this model. Players' preferences are separable across the two dimensions. Along the distributive dimension, each bargainer prefers the largest possible share, and is indifferent with respect to the distribution of the share that he does not receive. Along the ideological dimension, each player has single-peaked preference, as in the standard uni-dimensional voting model. While proposals may be linked or decoupled, equilibrium proposals are always linked.

Norman:02 focuses on the finite-horizon version of the BF game. When all players have identical discount rates, he establishes that when there are at least five bargainers ($n \geq 5$) who are sufficiently patient, any division of the pie in which each player receives a positive share can be supported as an equilibrium when the time horizon is sufficiently long. The proof of this multiplicity result involves an argument quite different from the one used to establish multiplicity in an infinite horizon game: it depends critically on the fact that proposers are indifferent with respect to the compositions of the coalitions that support their proposals, and so can be modeled as selecting coalitions in ways that support the punishment of deviations from the equilibrium path. On the other hand, when players' discount rates differ, he shows that except for a measure zero set of discount rate vectors, there is a unique vector of subgame perfect equilibrium payoffs for each finite horizon game when $n \geq 5$. While Norman's generic eradication of the multiplicity problem is potentially encouraging, it exhibits the unsatisfactory property that equilibrium outcomes fluctuate dramatically with respect to the time horizon of the game: players who have the lowest equilibrium payoffs in the T-period game will be the cheapest ones to bribe in the first round of the T+1-period game, hence will be selected by all proposers in that round, and will have the highest equilibrium payoffs in that game. In this sense, this model, while interesting, has essentially no predictive power because the outcome is so sensitive to perturbations in T. This oscillatory property appears to be an unavoidable consequence of assuming decision-making by majority rule. It is precisely to avoid such oscillations that we assume in the current application of the MB model that proposals must be accepted unanimously.

We complete this review of the bargaining theory literature with a brief discussion of some other papers developed by non-economists. In DoronSened:95 and DoronSened:01, the political bargaining process is characterized as distinct from economic bargaining in several dimensions: it is usually more complex; it often involves numerous actors who are endowed with unequal skills, leverage and information; it is typically dynamic, and tends to yield non-unique outcomes; the participants are rarely of equal status; they often act on behalf of an undefined "public interest," or in the name of the uninformed population of voters and supporters. The resources allocated are a mix of tangible and intangible goods which often cannot be ascribed fixed prices or comparable values. Political commodities such as sovereignty, independence, equality or legitimacy are all unlikely to have a market determined value. They must be provided to the public through institutionalized and non-voluntary mechanisms.

StokmanOosten:94 develop an exchange model of policy networks, which assumes that players reach collective decisions after using threats and conflict. deMesquita:85 and deMesquita:90 model political decision makers as expected utility maximizers. Each actor will calculate the utility it will attain from making different offers and from possible offers made by the other actors, and selects the route that will result in the highest expected utility. The bargaining process can be then viewed as a search by the actors among different alternatives, according to their perceptions of what the outcome will be in each situation. Druckman:94 conducts a meta-analysis of the literature on bargaining experiments to identify which variables have the strongest effect on compromising behavior and time-to-resolution in bargaining; his findings suggest that the initial distance between positions, time pressure and the negotiator's orientation are among the strongest determinants of the outcome.

The economic literature applying bargaining theory and game theory to negotiations over water scarcity has grown as such negotiations have become more common. One strand of this literature has focused on the application of cooperative game theory to water negotiations. DinarRatnerYaron92 provide an extensive survey of work in this area, and ParrachinoDinarPatrone06 summarize more recent developments. DinarEtAl06 compare the cooperative approach to a negotiated approach utilizing interactions between analysts and stakeholders for allocating water in the Kat basin in South Africa. They find that results are similar, and that cooperative game theoretic modeling may complement an interactive stakeholder negotiation approach.

CarraroEtAl:06 is an extensive examination of the applications of negotiation theory to problems involving water management. After surveying the literature on standard theoretical models, and noting that the predictions of these models are often not realized in real negotiation processes, attention is turned to the relatively new field of research on Negotiation Support System (NSS) tools. These tools, developed by computer scientists, political scientists and engineers to assist negotiators, are essentially computer models that support the negotiation process by performing constrained optimization with multiple objectives and multiple issues. The survey reports on a number of studies which address topics closely related to the one analyzed in this paper. BecuEtAl:03 developed a Multi-Agent System to facilitate water management in Thailand. The model includes a biophysical module and a social module and and is designed to simulate different water management scenarios. BarreteauEtAl:03 develop an Agent-Based Simulation tool to support negotiations over water allocation among farmers in the Drome valley in France. Computer models assess the collective consequences of alternative water allocation scenarios under different assumptions about water availability. The results are presented to stakeholders in the negotiations and the issue space is modified according to their reactions. Other support system tools are designed to be used interactively. For example, ThiesseEtAl:98 created the Interactive

Computer-Assisted Negotiation Support System to provide real-time assistance to parties on all sides of the negotiating process, facilitating the selection of a mutually beneficial agreement. Negotiators are presented with different alternatives that emerge from their preferences on the issue space and the physical constraints. The effectiveness of this tool was tested in controlled experiments with two parties and up to seven issues. A limitation of the approach is that equity issues cannot be incorporated; also the system relies heavily on truthful revelation by participants about their rankings over alternatives.

4. Adour River Negotiations

We will apply the model introduced in §2 to a specific negotiation in Southern France over water use, water storage capacity, and user prices. Our analysis is based on extensive background research regarding the hydrology, agriculture and political economy of the upstream part of the Adour river basin in southwestern France, from its origin in the Pyrenees to its junction with the Midouze river. A detailed discussion of the institutional background is provided in adour1. See faysse:98, faysse-morardet:99, noauthor:94 and gleyses-morardet:97 for additional information regarding institutions, and extensive discussions of technical, agricultural and hydrological parameters, stakeholder groups and preferences.

4.1. **Background.** Under the national French water law passed in 1992, water is a national resource, and stakeholders are assigned responsibility for designing the regulations governing its use, subject to the overall guideline that these regulations will balance the needs of water users against environmental considerations. The national law requires that specific water development plans be formulated for each hydrological basin and that the regulations to implement these plans must be designed and enforced at the cachment level. The Adour basin is one such cachment area. At this more localized level, regulations must be negotiated among all stakeholders under conditions defined by the relevant government authorities.

Use of the river water from the Adour basin for irrigation has increased substantially over the past twenty years, and is now its most important use by volume, accounting for roughly two-thirds of total water use. Agriculture uses water primarily in the dry summer months of July and August, when the river flow is low. Corn is the most important irrigated agricultural crop, followed by soybeans. Increased irrigation has led to a water shortage in the basin equal to roughly a fifth of annual agricultural use. Several environmental groups have been concerned over the effect of irrigation-induced reductions in river flows on the welfare of aquatic life. One proposed solution to these concerns has been to construct one or more dams that would capture water during the wet months, and then release it in July and August. Other environmental groups have opposed this proposal, because of the expected impact of dam construction on the natural landscape. To resolve the issue, a negotiation has been initiated, to be conducted according to a process mandated by the national government.

The water development plan for the Adour basin required stakeholders to consider whether or not to build one or more dams, and how the operating costs of these dams would be allocated among users. The variables to be negotiated included river flow requirements (and hence irrigation quotas) and quota prices. Specifically, Adour basin stakeholders were charged with determining the amount of water that should be allocated to irrigation, how this water should be allocated among agricultural users, and the price that users should pay for this water. The parties at the negotiating table included: elected representatives of agricultural producers; environmental interests; a group representing the interests of all non-agricultural water users in the basin, including urban and recreational users downstream from our study area; representatives of agricultural and environmental agencies from local and central governments; representatives of elected local governments; and the manager of the semi-public Adour Basin water authority that maintains infrastructure, delivers water, and monitors river flow.

4.2. **Model.** Applying the MB framework reviewed in 2, we developed a stylized computer simulation model of the negotiation problem described in §4.1, the results of which are presented in §5. In this subsection we describe the components of the simulation model. Many of the details, suppressed here to save space, are available elsewhere (**?**, **?**).

<u>Structure of the Problem</u>: The Adour Basin consists of three subbasins (see Fig. 2), separated by flow points. The label inside each circle indicates the number of hectares (in thousands) under irrigation in each subbasin. We will label these by U, M and D, for "upstream," "midstream" and "downstream." The upstream subbasin is above Estirac. The midstream subbasin is below Estirac and above Aire sur Adour. The downstream subbasin is below Aire sur Adour and above Audon, where the Midouze joins the Adour. As Fig. 2 indicates, the sizes of the three subbasins differ substantially. In particular, Fu's subbasin is larger than the other two. We assume that corresponding to each subbasin there is a single *representative farmer*, labeled, respectively, Fu, Fm and Fd. The pattern of agricultural activity differs across subbasins.

Farmers in each subbasin negotiate over the quota allocation they will receive. The negotiated quota allocation determines the maximum amount of water that a farmer is entitled to use, per eligible hectare farmed.[15] The quota does not depend on technical parameters, such as the crops a farmer intends to grow, or the on-farm technical efficiency of water use. Quotas may, however, vary by subbasin, because farmers' needs and the externalities resulting from water use are significantly different across subbasins.

Farmers are required to pay a fixed unit price for each quota unit at the time it is allocated. After-tax operating revenue from quota sales—the inner product of prices and the quota

[15] In practice, the actual water used during the two-month period modeled is between 64% and 70% of the quota allocation. Generally, water is scarce enough that farmers use their entire purchased allocation over the entire growing season.

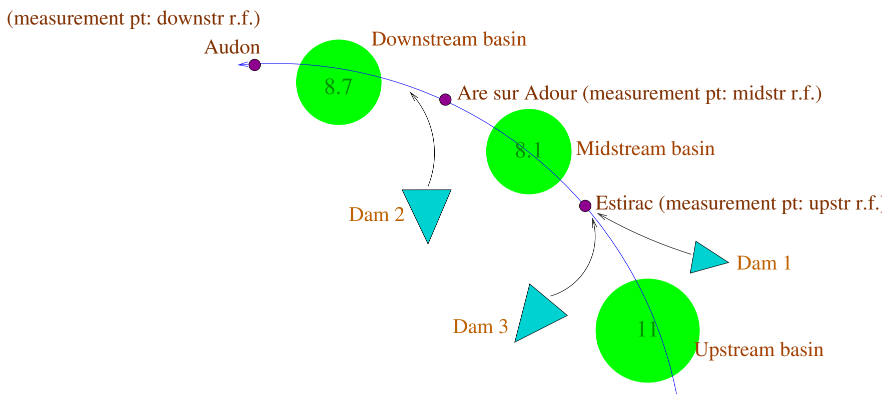

FIGURE 2. A schematic of the Adour Basin

allocation—accrues to the *water manager*, to offset his operating costs.[16] The level of quota sales is related to the minimum level of quota prices by the *administrative budget constraint (ABC)*. The ABC requires that after-tax operating revenues from water management cover operating costs, which are an affine function of aggregate dam capacity.

Quota sales are limited by *hydrology constraints*, which specify minimum *residual flows* of water downstream of each subbasin. The residual flow at a measurement point is calculated as the total volume of water that flows into the subbasin immediately above the point, including releases from existing and proposed new upstream dams, minus the total volume of water used by farmers within that subbasin. In the absence of dams, these flows would be determined by the *natural flows* of water, after deducting quotas allocated to farmers. The Adour-Garonne Water Development Plan proposed that the natural flows should be supplemented by building as many as three dams, provided stakeholders could negotiate an agreement regarding the size of each dam, subject to capacity limits determined by technical considerations (see Fig. 2 for proposed dam locations and the measurement points at which

[16]Note that the manager's revenue depends on the quota *allocation*, not on the amount of water actually applied by farmers. Even if a farmer uses less than his quota allocation, he must pay the tax on the entire allocation.

flows are monitored.[17]) The dams, if constructed, would have different implications for water flows: as Fig. 2 indicates, dam #2 would increase flows at the measurement point downstream of subbasin D only, while dams #1 and #3 would each increase flows at all three measurement points. Farmers would be required to finance the operating costs of the dams, but not the capital costs. Local government entities would share responsibility for the capital costs with the national agricultural and environmental ministries **?**.

Dam construction is controversial. The advantages are that new dams would increase the residual flows of water. Such residual flow increases would benefit users who are downstream of the subbasins, promoting aquatic life, and relaxing the hydrological constraints on farmers. The disadvantages are that dams are costly and degrade the quality of the rural landscape.[18]

We now explain the hydrology constraints in more detail. For each subbasin, the residual flow of water cannot fall short of a minimum level (called *flow objective*), which was set in the Adour-Garonne Water Development Plan (SDAGE), in order to protect aquatic life in the river **?**. Two of the three classes of variables being negotiated will directly affect the hydrology constraints: dam capacities, which affect water inflows, and quotas, which determine water outflows. The other class of variables—quota prices—interact with hydrology constraints through the administrative budget constraint. When dam capacities increase, administrative operating costs increase also. Holding quota levels constant, then quota prices must rise in order to keep the administrator's budget constraint in balance.

<u>The Bargaining Space</u>: There are three classes of negotiated variables: prices, quotas and dam capacities. There are three proposed dams, and three price-quota pairs, one for each

[17] Dam #1's maximum capacity is one quarter the maximum capacity of either of the other two dams.

[18] In general, it is by no means obvious that dams would benefit downstream aquatic life. In this paper, we model the benefits reported by stakeholders **?**. We are indebted to an anonymous referee for emphasizing this point.

subbasin. In the bargaining games we simulate, we distinguish between three bargaining *regimes*, identified as CPCQ, CPIQ and IPCQ. The regimes differ in the flexibility they provide a representative from one subbasin to differentiate that subbasin's treatment under the bargaining outcome from the treatment that the other subbasins receive. In regime CPCQ (common prices, common quotas), the bargaining space is restricted so that a common price and a common quota applies to all subbasins. In regime CPIQ (common prices, individual quotas), the price remains common but bargainers are allowed to specify distinct quota levels for each subbasin. In regime IPCQ (individual prices, common quotas), prices are common and quotas are distinct. In both CPIQ and IPCQ, we impose (and, in §5.3 vary) a *heterogeneity bound* on the degree to which subbasin-specific negotiated variables can be differentiated from each other.[19] In the absence of such a bound, each subbasin representative would attempt to acquire for his own subbasin the highest possible quota at the lowest possible price, offloading the entire scarcity (in CPIQ) or cost (in IPCQ) burden onto the other subbasins to the maximum extent allowed by their participation constraints. By varying these bounds continuously, we can conduct comparative statics experiments on the impact of restricting players' flexibility within the bargaining space.

Analyzing these three distinct regimes enables us to explore the effect on bargaining performance of different institutional specifications of the bargaining space. In particular, we test the natural conjecture that if farmers are limited by institutional constraints on the extent to which they can pursue their own interests at the expense of their "coalition partners," then their performance as a group will be enhanced.

Each regime is examined under both *normal* and *drought* conditions. Historically, in eight out of ten years, rainfall in the Adour Basin has been sufficient to provide farmers with adequate water without violating the hydrology constraints. We refer to conditions in these

[19] Specifically, in regime CPIQ (IPCQ), we impose a bound on the *variance* of the three quotas (prices) announced in a given proposal.

years as "normal" and calibrate our model so that under normal conditions, the hydrology constraints are not binding in equilibrium (although they may bind off the equilibrium path). By contrast, our calibration of "drought conditions" ensures that at least one of the hydrology constraints binds in equilibrium. These two scenarios represent alternative operating assumptions on which negotiations might be based: rational stakeholders would adopt quota proposals consistent with binding flow constraints if and only if they collectively acknowledged the possibility of drought conditions.[20] As will become apparent below, the negotiating environment—and hence the comparative statics properties of our model—will be quite sensitive to this critical assumption.

<u>Bargaining Participants and their payoff functions</u>: There are seven "players," each one representing either a single stakeholder or a composite of stakeholders. Because the distribution of political power among these stakeholders is not a primary consideration in this study, we specify exogenously that each player in our benchmark model has the same access probability. (This assumption is standard in the literature, cf. baronFerejohn:87 and the large literature that it spawned).

Each player has a strictly concave utility (or payoff) function defined on the space of bargaining proposals. In multilateral, multi-issue bargaining contexts such as ours, *weak* concavity would be a more natural assumption, since many dimensions of the bargaining space, though of critical importance to some negotiators, will have no impact at all on others. However, strict concavity is required in the MB model if we are to obtain unique

[20]In the actual negotiation procedure on which this study was based, no provision was made for assigning quotas conditional on rainfall levels. As a result, the agreed-upon total consumptive use would result, under drought conditions, in unsustainable levels of water usage, reducing residual flows to below government-defined crisis flow levels. In such an event, the water manager would be authorized to halt all irrigation. This rigidity in the negotiating procedure has an obvious and unfortunate consequence: if the assumptions on which farmers base their negotiating positions are too conservative, they will deprive themselves of available water under normal conditions; if the assumptions are not conservative enough, farmers risk the possibility of catastrophic shut-downs under drought conditions. In turn, this rigidity contributed to the deadlocking of the negotiations.

solutions and hence meaningful comparative statics. The problem with weak concavity is that decisions which have a significant impact on one party may be determined by an arbitrary resolution of indifference by another.[21] Indeed, in a computational model such as ours, the numerical solution algorithm may resolve indifference in a significantly different way in response to an insignificant change in parameter specifications, generating a comparative statics effect that appears to be dramatic but is in fact completely artificial.

When we impose strict concavity on a problem involving the allocation of a burden (or benefit) among multiple parties, we encounter two distinct kinds of problems. The first is a general one, common to all multi-issue problems: typically, not every negotiator necessarily cares about each one of the variables being negotiated. The second is special to allocation problems: when the burden is being shared among a some or all of the negotiating parties, the most parsimonious assumptions are: an individual who bears a portion of the burden cares about the size of her share, but is indifferent between alternative distributions of the remaining share; for an individual who bears none of the burden, the *aggregate* size of the burden may matter, but how the burden is allocated is of no consequence.

It is relatively easy to resolve the first, general problem: we model each agent as having non-degenerate preferences over all "aggregate" variables in the bargaining space, but, to sharpen our analysis, we weight variables that are less important for that agent by negligibly small coefficients. For example, each farmer in our model is primarily concerned about the price and quota she negotiates for herself, but also has a negligible preference for larger over smaller dams. To resolve the second, special problem, we assume, without particularly strong foundations, that negotiators have an extremely mild, "second-order" preference for "equity"; that is, we assume that each agent obtains a vanishingly small increment in utility

[21] A precisely analogous problem is endemic in extensive form game-theory, though it arises in a quite different context: decisions made by one agent at "off-the-equilibrium-path" decision nodes are of no consequence to that agent, but will in general have a significant impact on the set of opportunities available to other agents.

from a symmetric allocation of a given residual burden (i.e., excluding her own share) relative to an asymmetric allocation of the same residual. To implement this second idea, we add to each player's "real," or *first order* utility function a second, almost flat, function that is strictly concave in the variables being allocated—prices and quotas. The net result of our adaptions is that each agent's utility function will have indifference surfaces with significant curvature along the dimensions that really matter to that agent, and barely perceptible curvature along the dimensions that don't.[22] As the discussions of our results that follow will demonstrate, these second-order preferences for equity affect none of our results in a significant way.

We now introduce our seven agents and their preferences.[23]

i) three representative *farmers*, one from each subbasin, labeled Fu, Fm and Fd. Fi denotes the generic farmer. Fi's objective is to maximize profits from farming in

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[22]The idea here is very similar in spirit to the notion of "trembling-hand perfection" introduced in selten:75. The difference is that while Selten represented second order preferences by sequences of arbitrarily small trembles, we cannot work with infinitesimals; our second-order preferences make a small but finite contribution to agents' overall preferences.

[23] To each agent's u term defined below, we add the corresponding v term, representing the agent's "second order" preferences for equitable distributions of burdens and benefits. The γ's are very small in absolute value, with signs that match agents' preferences for the corresponding "first-order" variables; e.g, farmers prefer higher quotas and lower prices, both for them selves and for other farmers, while negotiators on the "other side" have the reverse preferences.

i) *farmer groups*: $v_i = \gamma_i^p \sqrt{\sum_{\iota\in\{\mathrm{U\ M\ D}\}} p_\iota^2} + \gamma_i^q \prod_{\iota\in\{\mathrm{U\ M\ D}\}} q_\iota^{1/3}$, where $\gamma_i^p < 0$ and $\gamma_i^q > 0$.

ii) *the manager*: $v_{\mathsf{Mg}} = \gamma_{\mathsf{Mg}}^p \prod_{\iota\in\{\mathrm{U\ M\ D}\}} p_\iota^2 + \gamma_{\mathsf{Mg}}^q \prod_{\iota\in\{\mathrm{U\ M\ D}\}} q_\iota^2$, where $\gamma_{\mathsf{Mg}}^p, \gamma_{\mathsf{Mg}}^q > 0$.

iii) *other players*: $v_m = \gamma_m^p \prod_{\iota\in\{\mathrm{U\ M\ D}\}} p_\iota^2 + \gamma_m^q \sqrt{\sum_{\iota\in\{\mathrm{U\ M\ D}\}} q_\iota^2}$, where $\gamma_m^p > 0$ and $\gamma_m^q < 0$.

The effect of adding the v's to the u's is that whenever a decision "really matters" to an agent, the choice that the agent makes will be determined, effectively, by that agent's u and not by her v. For example, if the participation constraints (see p. 8) of farmers Fm and Fd are binding when farmer Fu makes a decision, then how Fu allocates benefits and costs between Fm and Fd will be determined (except for an very small error term) by the lagrangians on those constraints. When neither participation constraint is binding, however, the effects of farmer Fu's choice on Fm and Fd will be determined by Fu's v function.

the i'th subbasin. Profits increase with quota levels and decrease with quota prices. Because of differences in agricultural patterns at the subbasin level, farmers differ in their willingness to pay for quotas—for a given quota, Fm's willingness is greatest, then Fu, then Fd. To ensure that farmers' preferences depend to some degree on all the variables being negotiated, we assume that farmers have a slight preference for larger rather than smaller dams, but that this preference is very weak. (Note that while dam capacities are not significant *direct* contributors to farmers' utilities, they do have an important, indirect effect through the model's constraint structure.)

Formally, Fi's first order utility is translog in his quota price p_i and quota level q_i:

$$\begin{aligned}
\ln\Big(u_i(p_i, q_i, \mathbf{d})\Big) &= a_i^0 + \sum_{k=1}^{5} a_i^k x_i^k(p_i, q_i) + \sum_{j=1}^{3} b_i^j \ln(1 + d_j), \text{ where} \\
\mathbf{x}_i(p_i, q_i) &= \Big(\ln(1 + p_i) \;\ln(1 + p_i^2) \;\ln(1 + q_i) \;\ln(1 + q_i^2) \;\ln((1 + p_i)(1 + q_i))\Big).
\end{aligned}$$

The vector $\mathbf{a}_i \in \mathbb{R}^6$ is estimated from linear programming simulations based on microeconomic farm models **?**; the vector $\mathbf{d} = (d_j)_{j=1}^3$, where d_j is the capacity of the j'th dam, expressed as a fraction of its maximum feasible capacity. The b_i^j's are only negligibly larger than zero. It should be noted that the arguments of Fi's utility are not the regular inputs and output of an agricultural production function. Rather, once quotas have been negotiated, the maximum quota level available to Fi, q_i will be a constraint on production. Moreover, since Fi must pay for the quota level he has agreed to, regardless of his actual production level, he will view $p_i q_i$ as a sunk cost.

ii) an *environmentalist* (Ev). This stakeholder, a composite of diverse environmental interests, is primarily concerned about the quality of the rural landscape, and secondarily about maintaining adequate river flow rates. Since the rural landscape is negatively impacted by dam construction, Ev's CES utility function is decreasing in the vector $\mathbf{d}$ and increasing in the vector $\mathbf{r}$: d_j is the capacity of the j'th dam, expressed as a fraction of its maximum feasible capacity; r_i is the residual flow of water in the i'th subbasin, again expressed as a fraction of the maximum feasible residual flow.[24] (Note that players do not explicitly *propose* values for the residual flow vector, $\mathbf{r}$; rather, each proposal implies a unique value for $\mathbf{r}$, which increases with proposed dam capacities and decreases with proposed quotas.) Clearly, Ev's two goals can be reconciled only by reducing the water used by farmers.

In our specification of nonfarmers' utilities, the capacities of dams #1 and #2 are viewed as virtually perfect substitutes for one another, and imperfect substitutes for the capacity of dam #3. (The qualifier "virtually" is required to ensure strict rather than weak preference concavity.) Dam #3 is treated specially because its construction would have a particularly significant negative impact on the landscape—it is located in the mountains in a very scenic valley. Also residual flows in subbasins U and Mas virtually perfect substitutes for one another, and imperfect substitutes for residual flows below subbasin D. Flows below subbasin D are tread specially because they are considered particularly important for maintaining aquatic life and recreational activities.

We assume that Ev has a very weak preference for higher rather than lower levels of total revenue from quota sales, $\sum_{i=1}^{3} p_i q_i$; local authorities tax these sales at a proportional rate, and utilize the tax receipts for maintaining the river; Ev obtains some utility from these tax-financed government services. In symbols, let $\phi(\mathbf{x})$ and $\psi(\mathbf{x})$ denote, respectively, strictly concave and strictly convex functions that are both arbitrarily close to the function $\sum_{j=1}^{n} x_j$. Now define $u_{\mathsf{Ev}}(\mathbf{d},\mathbf{r}) = \left(a_i^0 \sum_{k=1}^{5} a_{\mathsf{Ev}}^k \left(x_{\mathsf{Ev}}^k(\mathbf{d},\mathbf{r})\right)^{\rho_{\mathsf{Ev}}}\right)^{1/\rho_{\mathsf{Ev}}}$, where

[24] This maximum is attained when dams are built to their maximum capacity and farmers use no water.

$\mathbf{x}_{\mathsf{Ev}}(\mathbf{d},\mathbf{r}) = \Big(\phi(r_{\rm U}, r_{\rm M}), \quad r_{\rm D}, \quad (2-\psi(d_1,d_2)), \quad (1-d_3), \quad \sum_{i=1}^{3} p_i q_i\Big)$ and $\mathbf{a}_{\mathsf{Ev}} \in \mathbb{R}^5_{++}$ with $a^5_{\mathsf{Ev}} \ll a^1_{\mathsf{Ev}}, a^2_{\mathsf{Ev}} \ll a^3_{\mathsf{Ev}}, a^4_{\mathsf{Ev}}$ and $a^5_{\mathsf{Ev}} \approx 0$. Note that increases in proposed dam capacities affect utility positively through the first two arguments of u_{Ev}, and negatively through the third and fourth. When a dam is small, its *net* effect on u_{Ev} is positive, but there may exist a critical size beyond which its net effect becomes negative.

Lacking quantitative data data from which to estimate Ev's preferences, we assign values to the weights $\mathbf{a}_{\mathsf{Ev}}$ which reflect in a qualitative way the relative importance that Ev assigns to different concerns, as elicited from stakeholder interviews **?**. We proceed in the same way for the remaining three players described below.

iii) a *downstream user* (Ds). There are stakeholders in the Adour basin that are primarily concerned with minimizing demands on water flows in the three subbasins. These include downstream water users, recreational users of the river and environmentalists concerned with downstream aquatic wildlife. We combine these stakeholders into a composite "downstream user," Ds. While Ds's utility has the same functional form as Ev's, he ranks water flows as significantly more important than preserving the rural landscape. (Recall that Ev, by contrast, was significantly more concerned about rural landscape.) Specifically, we assume that $a^1_{\mathsf{Ds}}, a^2_{\mathsf{Ds}} \gg a^3_{\mathsf{Ds}}, a^4_{\mathsf{Ds}} \gg a^5_{\mathsf{Ds}}$, with $a^5_{\mathsf{Ds}} \approx 0$. Since Ds has a higher "willingness-to-pay" for residual flows in terms of larger dams, the *net* effect of a unit increase in dam capacity for u_{Ds} is either more positive or less negative than for u_{Ev}.

iv) a *manager* (Mg). Mg administers the distribution of water in the district. For statutory reasons, he is equally concerned with avoiding budget deficits and budget surpluses. Further, he derives utility from increasing the scope of the water system he administers. That is, he prefers a larger operation, and therefore higher dam capacities. Mg's CES utility is $u_{\mathsf{Mg}}(\mathbf{p},\mathbf{q},\mathbf{d}) = \left(a^0_{\mathsf{Mg}} \sum_{k=1}^{2} a^k_{\mathsf{Mg}} \left(x^k_{\mathsf{Mg}}(\mathbf{d},\mathbf{p},\mathbf{q})\right)^{\rho_{\mathsf{Mg}}}\right)^{1/\rho_{\mathsf{Mg}}}$ where $\mathbf{a}_{\mathsf{Mg}} \in \mathbb{R}^2_+$, $\mathbf{x}^1_{\mathsf{Mg}} = \phi(\mathbf{d})$ and $\mathbf{x}^2_{\mathsf{Mg}}$ decreases in the distance between the manager's realized and his target return on operations. Note that in addition to his role as a player, Mg impacts the bargaining through the administrative budget constraint (see p. 21).

v) the *taxpayer* (Tp). The taxpayer in our model represents interests that are primarily non-local and non-agricultural.[25] This player's goals are to minimize the burden on French taxpayers, by limiting expenditures on local dams, and to maximize benefits to non-farm users, by increasing residual flows. Like Ev and Ds, Tp has a very weak positive preference for higher rather than local local tax revenues. Formally, Tp's CES utility is $u_{\mathsf{Tp}}(\mathbf{r},\mathbf{c}) = \left(a^0_{\mathsf{Tp}} \sum_{k=1}^{4} a^k_{\mathsf{Tp}} \left(x^k_{\mathsf{Tp}}(\mathbf{r},\mathbf{c})\right)^{\rho_{\mathsf{Tp}}}\right)^{1/\rho_{\mathsf{Tp}}}$ where $\mathbf{x}_{\mathsf{Tp}}(\mathbf{r},\mathbf{c}) = \left((\phi(r_{\mathrm{U}}, r_{\mathrm{M}}), \quad r_{\mathrm{D}}, \quad (3-\psi(\mathbf{c})), \quad \sum_{i=1}^{3} p_i q_i\right)$, where c_j is the construction cost of the j'th dam, expressed as a fraction of the cost of constructing to their maximum admissible capacity, and $\mathbf{a}_{\mathsf{Tp}} \in \mathbb{R}^4_{++}$ with $a^4_{\mathsf{Tp}} \ll a^1_{\mathsf{Tp}}, a^2_{\mathsf{Tp}} \ll a^3_{\mathsf{Tp}}$ and $a^4_{\mathsf{Tp}} \approx 0$.

Note that under this specification, all players have non-degenerate preferences over all classes of variables, with the qualifications that farmers care only about the quotas that affect their own subbasins, and non-farm players care only about the inner-product of quota prices and and quantities. With the addition of second-order preferences (footnote 23) to these "first-order" preferences, each player's preferences are strictly concave in all variables.

The preference profile specified above gives rise to a clear-cut conflict between farmers on the one hand, and Ev, Ds and Tp on the other. (For this reason, we shall sometimes refer to the latter group of three players as the *anti-farmer group*). Farmers prefer higher quotas,

[25] In actual negotiations, these interests might be represented by a bureaucrat from Paris, charged with ensuring that the negotiation process is not captured by either farmers or by local political interests.

and, when the hydrology constraints are binding, prefer greater dam capacity to less. Ev, Ds and Tp prefer lower quotas, because quotas and residual flows are negatively related, and less dam capacity, either to preserve the rural landscape or to lower the tax burden. The relationship between the manager and the farmers is more complex. Like the farmers, the manager prefers higher quotas and more dam capacity, but, in contrast to the farmers, he also prefers higher prices.

Projecting Preferences onto price-quota space: Because the dimensionality of our bargaining space is so large ($\mathbb{R}^7$), it is difficult to obtain much intuition by studying players' full-dimensional proposals directly. Fortunately, one can gain a great deal of intuition for the comparative statics results discussed in §5 by projecting players' preferences onto price-quota space. (This simplification does, however, obscure some interesting subtleties.) The projection is immediate for farmers, at least in regime CPCQ, and quite simple for Tp and Mg. For Ds and Ev, however, it is obtained indirectly through the constraint system, since these players derive first-order utility from residual flows and landscape quality, caring barely at all about prices.

In order to understand how Ds and Ev's preferences are projected, consider regime CPCQ and assume that the ABC is binding.[26] Letting i denote either Ds or Ev, player i's concerns can be mapped into preferences over prices and quotas as follows. Starting from a given utility level $\bar{u}_i$, a unit increase in the common quota reduces residual flows; hence i's utility declines, and the only variables on the bargaining table that can perhaps increase it back up to $\bar{u}_i$ are dam capacities. (Recall from p. 29 that, *holding quotas constant*, if the initial capacity of dams is sufficiently small, the net effect of dam capacity increases on u_i is positive.) Now consider a unit increase in quotas, an increase in dam capacity that exactly offsets the resulting loss in residual flows would leave i's utility below its initial level $\bar{u}_i$, since i dislikes dams. So dams must be increased by more than this level, to the point that

[26] See p. 21. The ABC is almost always binding when farmers make proposals.

the resulting *net increase* in residual flows is sufficient to compensate i for his utility loss due to larger dams. Since administrative operating costs increase with dam capacity, and the ABC is binding, larger dams require higher quota prices. Thus, the ABC, together with the technological relationships between quotas, dams and residual flows, induce utility levels for i in price-quota space which decrease with quotas and, *provided that the derivative of* u_i *with respect to some dam capacity is positive*, increase with prices (that is, i's indifference curves in price-quota space are positively sloped). If, however, dam sizes reach levels such that i's utility declines with any further increase in their sizes, then farmers cannot "purchase" from i any further increase in quota levels at *any* price.

The shape of i's induced preferences in price-quota space depend on his relative preference for residual flows and rural landscape. It follows from our comparison of Ds and Ev on p. 29 that a unit increase in quotas hurts Ds less than Ev, while, holding quotas constant, a unit increase in dam capacity benefits Ds more. Therefore, the range of dam sizes for which Ev's indifference curves in price-quota space will be positively sloped is smaller than the range for Ds, and they will be more steeply sloped whenever they are positive. To summarize the preceding discussion, while there is no *economic* marketplace in which farmers can "buy" quotas from either Ds or Ev, there is, in effect, a *political* marketplace in which quotas can be "purchased" from either of these "suppliers," by increasing dam size (and residual flows), and a range of dam sizes for which the "political supply schedule" for quotas is upward sloping. Having made this distinction, we can now proceed *as if* farmers were buyers of quotas, and non-farmers were sellers.

The slope of the political supply schedule may become considerably steeper when hydrology constraints are binding, which in drought conditions is usually the case. For example, on p. 52 below, we discuss in some detail the predicament facing farmers in regime IPCQ under drought conditions: (a) at the proposed quota and dam levels, the residual flow below either subbasin M or U is at its minimal admissible level; (b) player Ds's participation constraint is binding; (c) dams #1 and #3 are so large that Ds's utility declines with a further increase in either; (d) an increase in dam #2 increases Ds's utility. In this situation, the only way a farmer can induce Ds to agree to "supply" still more quotas is to offer to expand the size of dam #2. However, an increase in the common quota decreases residual flows below *each* of the subbasins, while the expansion in dam #2 increases only the flow below subbasin D (see Fig. 2). Consequently, to restore the flows below the other subbasins to their minimal admissible levels, either dam #1 or dam #3 must be increased as well. But by (c), these secondary increases negatively impact Ds's utility, so that dam #2 must be increased still further to compensate him. That is, because of the hydrology constraints, a unit increase in quotas requires three "rounds" of dam increases rather than the single one that would be required under normal conditions. Because each additional increase in dam size raises operating costs, and part of each increase in dam capacity must be "bought" by devoting part of the capacity increase to increasing residual flows, three rounds of quota price increases are required as well. In this way, the hydrology constraints steepen the slope of the "political supply schedule" facing farmers.

5. Comparative Statics Analysis

In this section, the institutional setting described in §4 provides a context within which we explore a number of questions relating to bargaining power. To obtain the results reported in this section, we solved our computer simulation model for a variety of benchmark specifications, then successively increased one parameter (e.g., some player's access probability) and re-solved the model to obtain numerical comparative statics properties. We will summarize the results of three *simulation experiments*, each one consisting of a large number of individual simulations. Our primary objective in this paper is to provide intuitions for our key findings. Accordingly, we will suppress all but essential details of our numerical results, and focus almost exclusively on the effect of perturbing certain parameters on the final rounds of bargaining. (Many of these suppressed details are documented in the papers cited on p. 20.) In §5.1, we introduce our method of analysis with a stripped down model in which only three players participate. In §5.2, we compare the performance of the farmer coalition when farmers participate independently in the bargaining process, versus when the coalition is represented by a spokesman, charged with maximizing the joint interests of all farmers. Finally, in §5.3, we consider how the specification of the bargaining space affects player utilities. In particular, we examine whether farmers' bargaining power is increased if the maximum permissible degree of heterogeneity across water prices or quotas is restricted.

5.1. **Shifting Access: an heuristic example.** To introduce our method of analysis, we begin with a simple example. The example serves an heuristic purpose, but also makes a substantive point. As an instructive device, the example illustrates in a simplified context how comparative statics exercises are conducted and analyzed in this paper. In particular, it illustrates the role that backward induction plays in the MB model, and demonstrates how effects in the last rounds of the game "build on each other," creating a "snowball effect" that become magnified as we move backwards through the game tree. The substantive contribution is to highlight a striking characteristic of the Rausser-Simon model, which distinguishes it from axiomatic models of bargaining such as the Nash bargaining model, and strategic models such as Rubinstein's that implement the "Nash program" **?**. In all of those models, there is a monotone increasing relationship between a player's equilibrium payoffs and his traditional, exogenously specified measures of bargaining power: his bargaining weight and his "default payoff," i.e., the payoff he receives if the bargaining phase ends without an agreement being reached. In the MB model, there are additional, less transparent, sources of bargaining advantage, so that the relationship between payoffs and traditional measures of power is more delicate. In particular, the relationship between payoffs and power as traditionally measured need no longer be monotone.

The example in this subsection compares the equilibria of two games which are identical except for the players' access probabilities. In both games, farmers as a group have the same aggregate access, but in the second, the distribution among them is shifted in favor of a farmer who has a strategic advantage relative to the others, arising from his "location" in preference space. To reduce the problem to its barest essentials, we strip down our model by excluding four of our seven players from the bargaining process, leaving only Fu, Fm and Ds. Assume also that there is only one dam (#1) whose size is being negotiated. The comparative statics experiment we consider is a shift in access from Fu to Fm in the CPCQ regime.[27] (Recall that access probabilities were introduced on p. 5. and that regime CPCQ is defined by the condition that prices and quotas must be equal across subbasins.) To further simplify the exposition, we project all players' preferences onto price-quota space, in the manner described on pp. 31-33. Intuitively, one would expect that a shift in access from Fu to Fm would increase Fm's utility while decreasing Fu's. In fact, the outcome is that *both* Fm and Fu benefit from the shift! The key to the argument is that Fm's participation

[27]The reader should be advised that we use the word "shift" for expositional convenience: we are not suggesting that the access probability vector is a variable over which farmers have some control. The exercise considered here is a routine comparative statics one, in which one exogenous parameter of the model—the distribution of power between farmers—is varied.

in the negotiations generates, in effect, a positive externality for Fu. When Fm gains access at the expense of Fu, there are, in all but the last round of bargaining, multiple effects on Fu's payoff. In all rounds of bargaining, there is a "direct" effect, which reduces it. In round T-1, there is an "indirect" effect—the externality—that increases it. In rounds T-2 and earlier, there are multiple indirect effects, which further increase Fu's payoff. Under certain conditions, the indirect effects dominate, resulting in an inverse relationship between Fu's equilibrium payoff and his access probability.

First consider the impact of an access shift from Fu to Fm in the final round of bargaining. In this round, players' proposals depend only on default payoffs, and hence are independent of access probabilities. Hence the *only* impact of the change in access is what we call the "direct" one: Fu strictly prefers his own proposal to Fm's, and the latter is now more heavily weighted, so that Fu's expected utility, conditional on reaching the final round, is negatively impacted.

Matters become more complex as we move backwards through the game tree. We explain the argument underlying the result with the aid of figures 3 and 4 below, which represent, respectively, rounds T-1 and T-2 of the bargaining in a T-round game. In each figure the shaded area highlights the region of the bargaining space that is relevant for that round; curves outside the shaded region are relevant for the round that follows. We begin with Fig. 3. The left panel represents the bargaining for our benchmark vector of access probabilities. The three solid thick curves (labelled u_r^0) outside the shaded region represent the three players' participation constraints in the round T of bargaining, i.e., any price-quota pair on u_r^0 yields player r the same payoff as the disagreement outcome. Note that Fm's constraint is steeper than Fu's, reflecting Fm's higher willingness-to-pay for the marginal quota (for the reason explained on p. 27). The players' T-round proposals are indicated by the $\mathbf{x}_r^T$'s. The large dot in the center of the left panel denotes the weighted average, $E\mathbf{x}^T$, of these proposals, where the weights are the players' access probabilities. The three

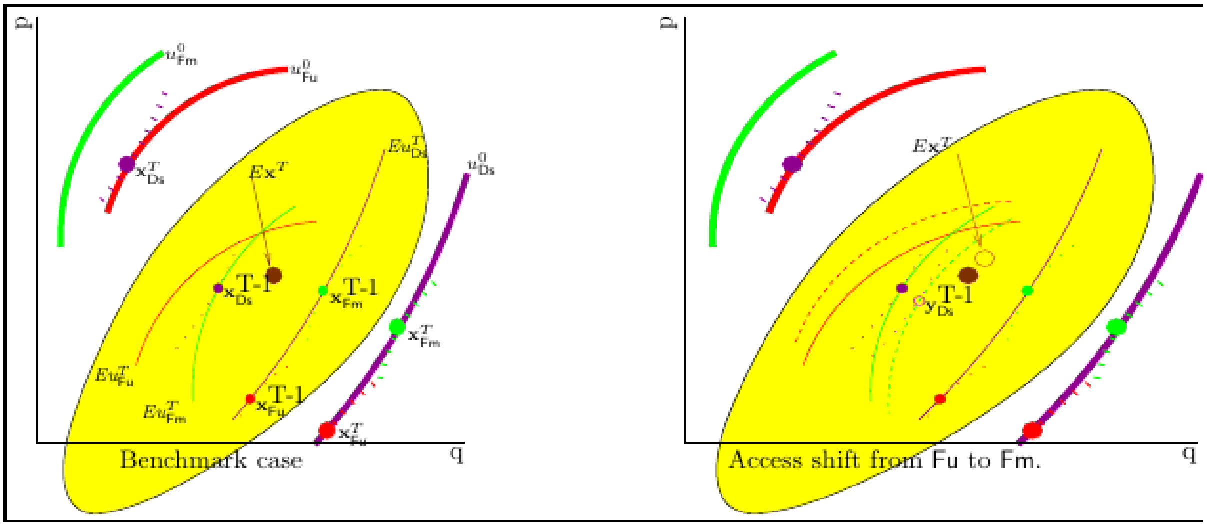

FIGURE 3. Access shift tightens Fm's participation constraint in round T-1

solid thin curves (labelled Eu_r^T) in the left panel represent participation constraints in round T-1, i.e., any price-quota pair on Eu_r^T yields player r the same payoff as r's expected payoff from the lottery in round T generated by the $\mathbf{x}_r^T$'s. Note in particular that while the relative locations of u^0_{Fm} and u^0_{Fu} are determined by the exogenously specified disagreement payoffs, the locations of the curves $\mathsf{Eu}^T_{\mathsf{Fm}}$ and $\mathsf{Eu}^T_{\mathsf{Fu}}$ relative to point $E\mathbf{x}^T$ depend on agents' risk aversion. The more risk-averse is agent r, the greater will be the *minimum* distance between $E\mathbf{x}^T$ and the curve Eu_r^T. Unless Fm is significantly more risk averse than Fu, Fm's participation constraint in round T-1 must lie, as it does in the figure, to the south-east of Fu's in the region of the figure to the south of $E\mathbf{x}^T$. The level sets of Ds's payoff function are relatively steep, in fact they are almost vertical. (This means that if the size of dam #1 is increased by one unit, the resulting increment in water flows *holding quotas constant* raises Ds's utility by an amount only barely greater than the amount by which Ds's utility declines because dams despoil the landscape. The gap between these two amounts is the "surplus utility" generated by the dam increase, which can be "soaked up" by an increase in quota allocation, leaving Ds indifferent. In this instance, the surplus amount is tiny.)

Now, since Fm's level sets are steeper than Fu's, Fm's participation constraint must be binding on Ds, while Fu's must be slack. It follows that Ds's proposal in round T-1 will be independent of the precise location of Fu's participation constraint in round T ($\mathsf{Eu}^{T}_{\mathsf{Fu}}$), but will be affected by any small change in the location of Fm's ($\mathsf{Eu}^{T}_{\mathsf{Fm}}$).

The right panel of Fig. 3 indicates schematically the effect of a shift in access from Fu to Fm on the bargaining in round T-1. The expected price-quota pair in round T shifts to the north-east (i.e., from the solid dot to the open dot), reflecting Fm's relative preference, now more heavily weighted, for higher quotas at higher prices. To reduce clutter in this panel, we have omitted the labels on the lines representing participation constraints. The *dashed* lines parallel to the two farmers' thin solid lines represent their participation constraints after the access shift: necessarily, Fm's constraint tightens while Fu's slackens. The widely spaced dotted curves represent the proposers' indifference curves through their respective optimal proposals. Since Ds is bound by Fm's constraint and unaffected by Fu's, the effect of the access shift is that Ds now proposes the open dot $\mathbf{y}^{\text{T-1}}_{\mathsf{Ds}}$ rather than the (unlabeled) solid dot representing $\mathbf{x}^{\text{T-1}}_{\mathsf{Ds}}$. Thus, relative to the benchmark case, the lottery now facing players, conditional on reaching round T-1, is unambiguously more favorable for Fm, and less favorable for Ds. For Fu, the net effect is indeterminate. Once again, the direct effect of the access shift is negative: Fu prefers his own proposal to Fm's, and weight initially assigned to the former is now assigned to the latter. But in this round, there is an additional, "indirect" effect, associated with the shift in Ds's proposal. Because the perturbed proposal is preferred by Fu to Ds's original proposal, this effect benefits Fm. These changes in round T-1 impact the locations of players' participation constraints in round T-2. Fig. 4 depicts the bargaining in this round; we include the participation constraints for round T-1 as well for reference. The left panel represents the benchmark case; the participation constraint for player r in round T-2 is represented by the thick curve Eu^{T-1}_{r}. The right panel indicates the cumulative effect of the access shift by round T-2. As in the right panel of Fig. 3,

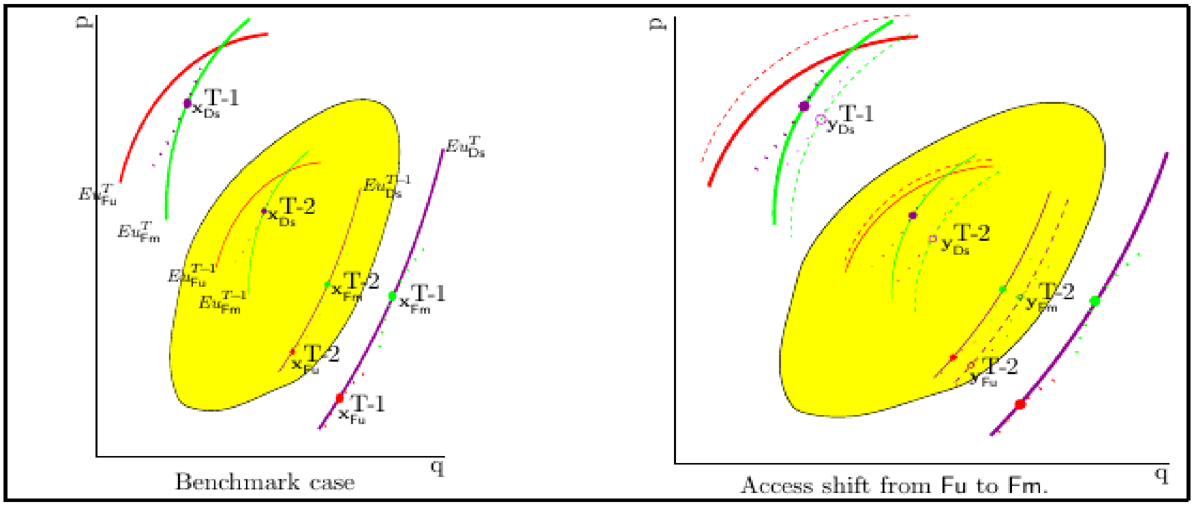

FIGURE 4. Additional effects in round T-2

participation constraints in the benchmark case are represented by solid lines; those after the access shift by dashed lines. Once again, each widely spaced dotted curve represents the indifference curve through some player's optimal proposal. Reflecting the remarks above, Ds's participation constraint is slacker than in the benchmark case, while Fm's is tighter. As we have noted, Fu's constraint could be slacker or tighter than in the benchmark; for this illustration, we have drawn it as slightly slacker, i.e., we have assumed that in round T-1, the loss to Fu resulting from the access shift dominates the gain to Fu due to Ds's weaker performance.

In this round, there are additional indirect effects that have no counterpart in round T-1: as in round T-1, $\mathbf{y}^{\text{T-2}}_{\mathsf{Ds}}$ is southeast of the unlabeled solid dot $\mathbf{x}^{\text{T-2}}_{\mathsf{Ds}}$. But in this round, so too are $\mathbf{y}^{\text{T-2}}_{\mathsf{Fm}}$ and $\mathbf{y}^{\text{T-2}}_{\mathsf{Fu}}$, relative to the unlabeled solid dots $\mathbf{x}^{\text{T-2}}_{\mathsf{Fm}}$ and $\mathbf{x}^{\text{T-2}}_{\mathsf{Fu}}$ (cf., in Fig. 3, $\mathbf{y}^{\text{T-1}}_{\mathsf{Fm}}$ and $\mathbf{y}^{\text{T-1}}_{\mathsf{Fu}}$ were in the same locations as $\mathbf{x}^{\text{T-1}}_{\mathsf{Fm}}$ and $\mathbf{x}^{\text{T-1}}_{\mathsf{Fu}}$). As a result, Ds's participation constraint in round T-3 is further slackened relative to the original case, since in this round, *all three* proposals now yield him less utility. On the other hand, each farmer benefits, relative to the original case, from these movements, so that, other things equal, each farmer's participation constraint in round T-3 will tighten. Once again, of course, these positive effects on Fu's participation constraint are offset by the usual, negative direct effect of the access shift.

It will now be apparent how the "snowball" we have been describing builds momentum as we induct backwards through the game tree. The impact of the access shift on Fm's *equilibrium* payoff is the limit, as T increases without bound, of the impacts on Fm's participation constraints in the first round of the bargaining in the game with T rounds. Without additional restrictions on parameters, given our functional form specifications we cannot *guarantee* that these constraints will all tighten; however, our simulation results confirm that this property is extremely robust over a wide range of parameters.

5.2. **Combining Forces: impact of a common spokesman for farmers.** In §5.2 and §5.3, we return to the complete specification of our model. We consider the effect on farm coalition performance of introducing a *spokesman* charged with the role of representing farmers' collective interests. The spokesman is similar to other players in that he has a non-zero access probability; he differs in that his approval is not required in order for a proposal to be accepted. Formally, there is no participation constraint associated with the spokesman. (Think of him as an attorney, hired to represent the interests of his clients: ultimately, the clients themselves, not the attorney, must decide whether or not to accept any proposed deal.) The utility function that the spokesman maximizes is defined as the simple average of the three farmers' utility functions. We shall refer to this as the *average farmer utility function*. In this subsection, we consider the effect of transferring access from farmers to the spokesman, holding constant the absolute access vector for non-farmer parties and the individual access probabilities of farmers *relative to each other*.

Our goal here is to explore the natural conjecture that farmers will negotiate more effectively as a group, the more they can present a "united front" at the bargaining table. When an individual farmer makes a proposal, his objective is to advance his own interests, typically at the expense of other members of the farmer coalition. When farmers' proposals are weighted according to their access probabilities, farmers collectively suffer because each farmer fails to take account of other farmers' interests. The spokesman, on the other hand, will internalize any externalities that result from farmers' pursuit of their individual self-interest, subject to his objective function's equal weighting of the three farmers' utilities. We would expect, therefore, that the equilibrium value of the average farmer utility function will increase with the spokesman's access.

A number of questions arise in the context of our particular model: Does the spokesman always improve coalition performance? Under what conditions will the spokesman's contributions have the greatest impact? Which farmers benefit from the spokesman's participation, which, if any, lose, and why? The "why" question is, in our view, particularly interesting, because it focuses attention on the precise nature of the externalities that are internalized by the spokesman, how these externalities differentially affect the different members of the farmer coalition and, most importantly, how they impact the bargaining performance of the farmer coalition.

We address these questions for six specifications, varying both the issue space (CPCQ, CPIQ, IPCQ) and hydrological conditions (normal vs. drought). Throughout §5.2 (and §5.3 as well), we focus on the case in which Ds is *default strong*, across all six specifications. (We say that a member of the anti-farmer group (as defined on p. 30) is default strong if his participation constraint is binding on all farmers and the spokesman in the final round of negotiations.[28]) The results of our simulation experiments are summarized below. Most striking is the counter-intuitive result that in regime IPCQ under normal conditions, all farmers' utilities actually decline as the spokesman gains access! Our other results are:

[28]Surprisingly, we find that changing the identity of the default strong player has little impact on our results.

(i) comparing his effect on farmer coalition performance in regime CPCQ relative to the other two regimes, the spokesman has a negligible effect under normal conditions, and no effect whatever under drought conditions. As the spokesman gains access in regimes IPCQ and CPIQ; (ii) Fu's equilibrium utility always declines; (iii) Fm's, Fd's and the average farmer's equilibrium utilities increase *except* in regime IPCQ, normal conditions; and (iv) equilibrium utilities for all members of the anti-farmer group move in the opposite direction from the change in the average farmer's utility.

One can obtain intuition for each of these results through a detailed study of players' final round proposals. Once these final round details are well understood, most of the equilibrium comparative statics properties can be deduced readily by applying the usual backward induction logic, taking into account the "snowball" effects illustrated in §5.1. To illustrate how this logic works, we shall see that in the final round (round T), the spokesman discriminates against Fu to the benefit of other farmers, so that Fu's participation constraint in round T-1 becomes slacker as the spokesman gains access. In the penultimate round, typically, the spokesman again discriminates against Fu, and for the same reason. (The degree of discrimination will typically be less dramatic in round T-1 than in T, because participation constraints become tighter as we move backward through the inductive chain, leaving the spokesman with less room to maneuver.) Thus in round T-1 there will be *two* reinforcing effects—his slacker participation constraint and the discrimination against him by the spokesman—that contribute to a weaker performance by Fu. Typically, this weakness will compound as we work back through the inductive chain to the solution: the result, typically, will be that as the spokesman gains access, Fu's expected solution payoff will decline. We emphasize the qualification "typically" because for some parameter values, countervailing effects can reverse the impact of the last round effects. Since no such reversals arise in the experiments reported in this paper, the details we overlook by focusing on the final round, though interesting, are not critical.

Regime CPCQ: In this regime under normal conditions, the farmer coalition's welfare increases. with the spokesman's involvement. Under drought conditions, it makes no difference whatsoever. The explanation for this difference is as follows. In the absence of hydrology constraints, farmers maximize their utilities subject to a common "political supply schedule" for quotas (see pp. 31-33). Because farmers have different optimal locations along this schedule, their proposals will differ. If hydrology constraints bind sufficiently tightly, however, the lowest quota level on the schedule that will satisfy these constraints will exceed even the level that would be optimal for Fm, who has the highest willingness to pay for quotas. Under these circumstances, all preference differences between farmers will be suppressed at the bargaining table, since all farmers will be obliged to propose the same, super-optimal quota level. When the spokesman participates, he will be subject to exactly the same constraints; hence his proposal will be indistinguishable from the common proposal offered by farmers. For this reason, if the drought is sufficiently intense, the transfer of access to the spokesman will have no impact at all. (For the same reason, the bargaining outcome will also be independent of the distribution of access across farmers)

Under normal conditions, when the hydrology constraints do not bind, the preference variation between farmers is no longer suppressed, and the spokesman can make a difference. Not surprisingly, however, his role in regime CPCQ is relatively insignificant since farmers in this regime are *constrained* to treat themselves and other farmers equally; there are, simply, no opportunities for self-promotion at the expense of the group. The spokesman's role is limited to merely reducing risk. As noted above, in the absence of hydrology constraints, farmers' final round proposals will differ in accordance with their willingness-to-pay: Fm proposes the highest quotas, prices and dam capacity levels, and Fd the lowest. When the spokesman's access increases, farmers' expected utilities increase somewhat because their risk exposure is reduced: their utilities from the spokesman's proposal exceeds average of their utilities from all three farmers' proposals. For the model specifications we consider, this reduction in risk translates into an increase in farmers' solution payoffs. We should not expect, however, that this property will be robust across a wide range of parameter specifications, since other parties at the bargaining table also benefit from the spokesman's participation: as his access increases, the variance of farmers' proposals decreases to the benefit of all risk averse parties. Had the other negotiators been significantly more risk averse than the farmers, their gain from the reduction in risk might have exceeded the farmers' gain, inducing, possibly, a *decline* in farmers' solution payoffs as the spokesman's access increased.

In contrast to CPCQ, each farmer in regime CPIQ or IPCQ has ample opportunity to pursue his own interests at the expense of other farmers. He does so by proposing either low quotas (in CPIQ) or high prices (in IPCQ) for other farmers, and either a high quota or a low price for himself. We refer to this individually rational pursuit of self-interest as *beggar-thy-neighbor* behavior. Its implications, explored below, are subtle and diverse, and vary depending on the regime and hydrological conditions. As noted earlier, much can be learned by comparing the spokesman's proposal in the final round of bargaining to the average of farmers' individual proposals in that round.

In the discussion of regime CPIQ that follows, we will consider three kinds of averages. For a given *farmer*, we consider the mean of the three subbasin quota proposals made by that farmer, and refer to this the *farmer's mean quota*. For a given *subbasin*, we will examine the average of the three farmers' quota proposals *for that basin* and refer to this to as an *average subbasin quota proposal*. Each average subbasin proposal will be compared to the spokesman's proposal for that basin. Finally, we will examine the average of these subbasin averages, and refer to this as the farmers' *the overall average* quota proposal. This last scalar will be compared to the average of the quotas that the spokesman proposes for the three basins.

Regime CPIQ: In regime CPIQ, we shall focus exclusively on normal conditions, since in this regime, the spokesman's role is independent of hydrological conditions. In each case, the overall average quota proposal in the final round is inefficient from a coalition perspective, because the differences between the average subbasin proposals do not efficiently reflect the different costs that quotas in different subbasins impose on the environment. To illuminate this inefficiency, Fig. 5 compares the proposals made by farmers and the spokesman in the final round of bargaining, under normal conditions. The upper panel of figure Fig. 5

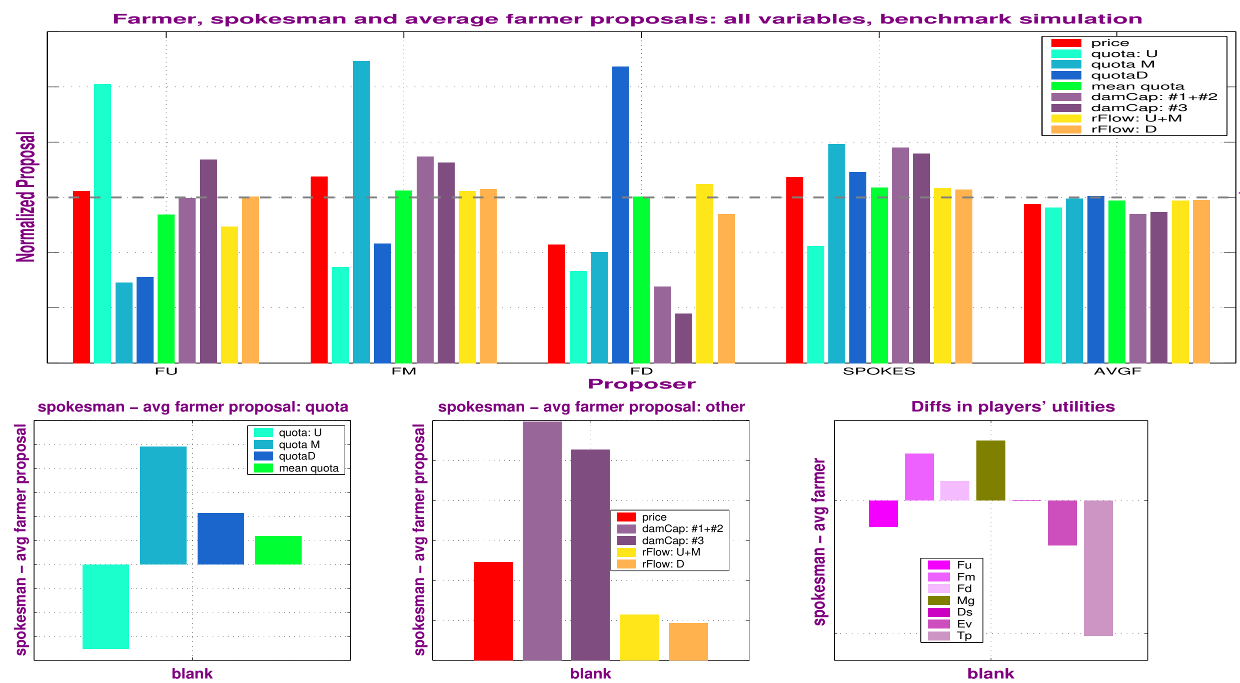

FIGURE 5. Farmer proposals: regime CPIQ, normal conditions, final round

depicts graphically, from left to right, the final round proposals made by each of the three farmers, the spokesman's proposal, and the average of the three proposals by farmers. The bar heights are normalized so that the height of each class of variable represents the player's proposal *relative* to the average of four proposals, consisting of the three proposals by individual farmers and one by the spokesman; e.g., farmer i's quota for his own subbasin is represented as his proposal divided by the mean of all quota proposals by either farmers or the spokesman. Thus a proposal is above (below) average if the corresponding bar is taller (shorter) than 1. From left to right, each cluster of nine bars represents: the common price; three subbasin quota levels; the mean farmer quota; the average capacities for dam #1 and #2; the capacity of dam #3; the average of up- and mid-stream residual flows; downstream residual flows. (Recall that while players do not explicitly propose residual flow levels, they are implied by the variables that are proposed.) Utility levels for Ds and Ev are determined, at least to a first-order approximation, by the right-most four bars in each cluster.

The lower left and middle panels of Fig. 5 depict the difference between the spokesman's proposal and the average of the three farmers' proposals. In the lower left panel, the right-most bar compares the average of the quotas proposed by the spokesman to the farmers' overall average quota proposal. Each of the other bars compares the spokesman's proposal for some subbasin to the corresponding farmers' average subbasin proposal. The lower middle panel reports the differences for the remaining variables. The lower right panel reports the difference between players' payoffs from the spokesman's proposal and the average of their payoffs from the farmers' proposals. Since the experiment involves a shift in access away from farmers towards the spokesman, a player's participation constraint in the penultimate round will tighten (slacken) if and only if the player's bar in this panel is positive (negative).

Figure 5 illustrates a number of significant points. First, Fd's proposal is much more "efficient" than Fu's, and somewhat more efficient than Fm's, in terms of its impact on dam capacities and hence prices. Specifically, while Fd's mean quota proposal is almost as high as Fm's and much higher than Fu's, the residual flows implied by Fd's proposal are roughly comparable with those implied by the other farmers' proposals; moreover Fd's proposed dam capacities and, consequently, proposed common price are *much* lower. These differences arise because whenever residual flows are reduced at some location along the river, flows at every measurement point downstream from that point are reduced as well. Thus, flow reductions from subbasin U imply matching reductions in subbasins M and D, while reductions from subbasin D have no impact on the flows through subbasins further upstream. For this reason, a unit of quota assigned to Fd has, very roughly, one-third the total environmental impact of a unit assigned to Fu. Consequently, Fd can "acquire" for his subbasin essentially the same total level of quotas as can the other two farmers, but with much less dam capacity, and hence, since prices rise with dam capacity, a much lower price as well. The remaining three points illustrated by Figure 5 are all closely related to the point just discussed.

Second, comparing the spokesman's proposal to the average of the farmers' proposals, observe that Fu is the clear loser: the spokesman's price is higher than the average price, while the spokesman allocates a quota to Fu that is much lower than the farmers' average subbasin U quota proposal. This difference can be traced to the relative environmental cost considerations noted above: quotas assigned to subbasin U are the most environmentally costly of all quotas.

Third, note from the top panel of Figure 5 that the spokesman can induce Ds to accept a higher overall average quota level than that proposed by the farmers, and at a slightly lower price. The spokesman can accomplish this because he allocates quotas across subbasins more efficiently than do the farmers. In particular, he discriminates against player Fu, so that under his proposal, residual flows below the environmentally sensitive subbasin D are higher than under Fm's proposal. Fourth, while each farmer proposes a much larger quota for his own subbasin, there is little variation between the farmers' three average subbasin proposals. On the other hand, while the spokesman's quota allocation is more evenly distributed across farmers than is any individual farmer's, it is much less evenly distributed than the average subbasin proposals. Once again, this reflects the fact that the spokesman's proposal efficiently balances the relative environmental costs of assigning quotas to different farmers against the relative benefits that farmers derive from them.

The question arises: why don't individual farmers take into account at least the relative environmental costs of assigning quotas to *other* farmers? For example, why does Fm assign roughly equal quota levels to Fu and Fd? The explanation can be traced to "beggar-thy-neighbor" behavior: unlike the spokesman, each individual farmer assigns to himself the highest possible quota; as a result, the heterogeneity bound on individual proposals (p. 23) prevents him from optimally differentiating the quotas assigned to the other two farmers.

Our final observation relates to the lower middle and right panels of the figure. Relative to the farmers' average proposal, the spokesman negotiates significantly higher levels of dam capacities, in exchange for slightly higher levels of residual flows. This tradeoff leaves Ds indifferent, because his participation constraint is binding in the final round, but negatively impacts Ev who, relative to Ds, is concerned more about dam capacities and less about residual flows. Similarly, while Tp derives some benefit under the spokesman's proposal from the increase in residual flows, his primary concern is to reduce the tax burden; consequently, this benefit is more than offset by the negative tax implications of the increase in dam construction under the spokesman's proposal.

The end result of all these considerations is that as the spokesman's access increases, there is an increase in Fm's and Fd's expected utilities conditional on reaching the final round of bargaining. Mg's expected utility increases also, because of the additional dam construction under the spokesman's proposal. Ds is unaffected in this round by the participation of the spokesman, because his participation constraint is binding on the spokesman as well as all farmers. (In earlier rounds, however, his utility declines.) Ev's, Tp's and Fu's expected utilities decline. Under normal conditions, these qualitative effects are all reinforced as we move backward up the inductive chain to the solution of the game. Under drought conditions, the effect of the spokesman's participation on the solution is comparable, except for a couple of relatively insignificant differences.

Regime IPCQ: In our discussion of regime IPCQ, we again refer to several different averages. We will maintain a parallel terminological convention to the previous one, distinguishing this time between the average subbasin price, the farmer mean price and the overall average price. We shall also compare the average common quota proposed by farmers to the common quota proposed by the spokesman.

In contrast to regime CPIQ, the qualitative impact of the spokesman in this regime depends very much on hydrological conditions. The similarities and differences are once again revealed by an examination of the final round of bargaining. The details of the discussion below can be summarized as follows. Under both drought and normal conditions, individual farmers pursue collectively inefficient beggar-thy-neighbor strategies, proposing low prices for themselves and high prices for others. In both scenarios, the spokesman's participation mitigates this inefficiency. There is, however, a second impact of the spokesman's involvement. In normal conditions, it is a negative one for farmers, which dominates the benefit of the first impact. Specifically, the spokesman's common quota proposal in drought conditions is greater than the farmers' average common quota, while in normal conditions, his proposal is less than this average. Since Ds's constraint is binding on all farmers and the spokesman, and he dislikes the marginal quotas less than either Ev or Tp, these latter players are made worse off by the spokesman's participation in drought conditions, and better off by his participation in normal conditions. Moreover, the farmer Fm, who is strategically important in the sense we discussed in §5.1, prefers the spokesman's proposal to the average of farmers' proposals in drought conditions, while in normal conditions, this preference is reversed. In each hydrological scenario, these attitudes toward the spokesman's involvement reinforce each other, and initiate inductive chains that lead, ultimately, to diametrically opposite comparative statics effects for drought vs normal conditions.

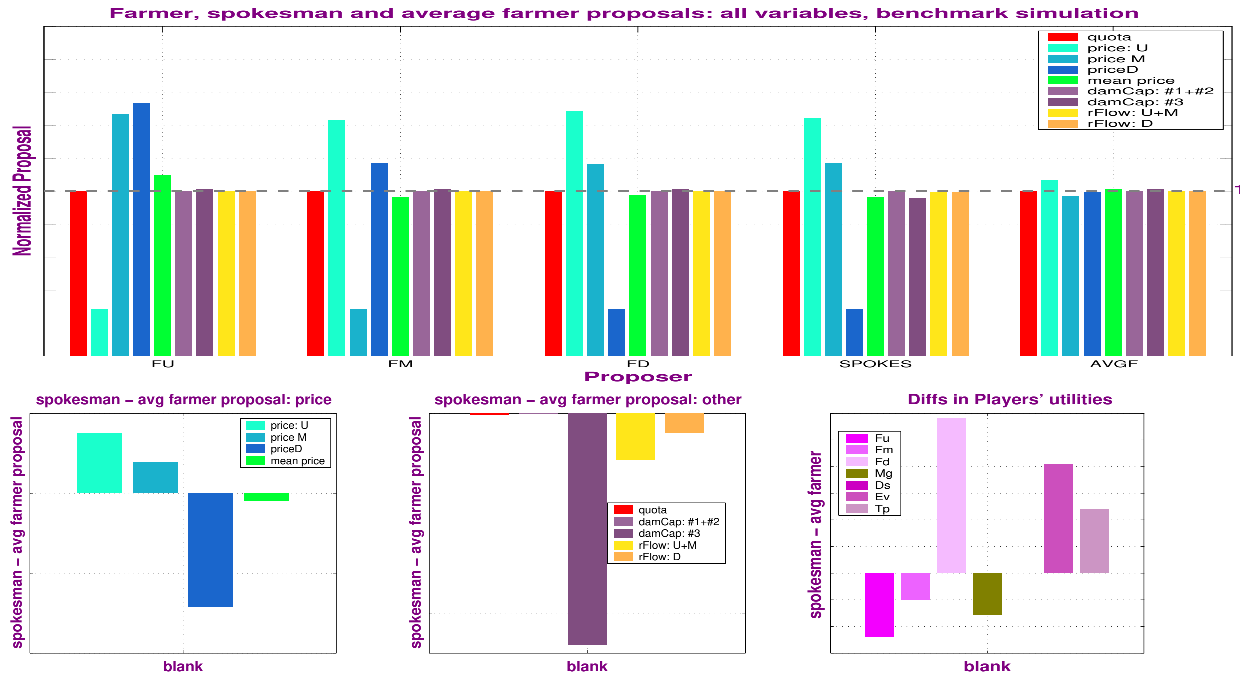

FIGURE 6. Farmer proposals: regime IPCQ, normal conditions, final round

To understand in more detail the differences between normal and drought conditions, compare Fig. 6 with Fig. 8 on p.53 below. The two figures have the same structure as Fig. 5, except that the locations of prices and quotas are exchanged. The bottom left panels of the two figures are qualitatively similar, except for the price paid by farmer Fm. In both cases, the farmers' overall average price proposal is higher than the spokesman's average price. On the other hand, the two bottom middle panels of Figs. 6 & 8 are diametrically different. These panels depict the difference between the spokesman's and the average farmer's final round proposals for quotas, dam capacities and implied residual flows. Under normal conditions, the spokesman proposes lower levels for all of these variables; under drought conditions, his proposals are higher.

Our explanation of this difference begins with a detailed consideration of normal conditions (Fig. 6). The difference between the average price proposed by the spokesman and the overall average price proposed by farmers can be attributed to "beggar-thy-neighbor" behavior by farmers. As discussed in §5.1, farmers face an upward sloping "political supply schedule" for quotas. As the top panels of the two figures indicate, each farmer assigns very high prices to others and proposes a common quota level that is individually optimal for that farmer, to a first-order approximation,[29] given the low price that he himself is required to pay. This behavior, while individually rational, creates negative externalities: since each farmer is more likely to be required to pay the high price assigned to him by some other farmer than the low price he has assigned to himself, he is *on average* trading quotas for prices at a rate that he would consider unacceptable if he were required to pay this rate with certainty. The spokesman internalizes this externality and purchases slightly fewer quotas. The qualitative properties of the lower middle panel now follow from the familiar linkage between quotas and prices: when quotas are reduced, the capacity of dam #3 can be reduced as well, so that budget balance can be maintained with lower prices.

The comparison between the spokesman's proposal and the farmers' is illustrated by Fig. 7 which depicts the level set, $LS(u_{\mathrm{AF}})$ of the average farmer utility function passing through the overall average farmer proposal, labeled as $\mathbf{x}^T_{\mathrm{AF}}$. Reflecting the fact that on average, farmers are over-paying for the marginal quota, this level set is less steeply sloped at $\mathbf{x}^T_{\mathrm{AF}}$ than the induced level set in price-quota space (see pp. 31-33) for Ds, whose participation constraint binds on farmer proposals in the final round. As it turns out, each farmer proposes the dam configuration that is globally optimal from Ds's perspective, given the common quota level, so that Ds's participation constraint, denoted by $u^0_{\mathrm{Ds}}(\mathrm{AF})$, is vertical at the overall average farmer proposal.

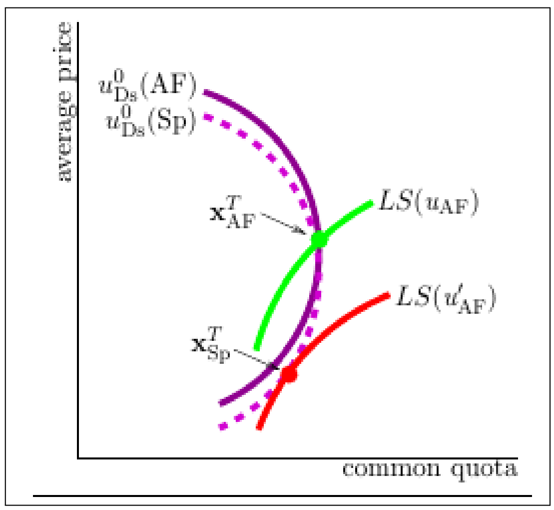

FIGURE 7: *IPCQ, normal conditions*

[29]A farmer does derive disutility from other farmers paying high prices. However, this disutility only arises as part of his second-order utility term. The results of this simulation demonstrate that the second-order utility term does not have a substantial effect.

Relative to the average farmer, the spokesman obtains efficiency gains in two respects. First, he rationalizes the distribution of prices across farmers: efficiency dictates a shift in the price burden towards Fu, who has the most irrigated area and hence the greatest revenue leverage, and Fm, who has the highest willingness-to-pay. With this adjustment, a given quota level can be achieved at a lower average price, so that Ds's induced participation constraint in price-quota space, $u^0_{\mathrm{Ds}}(\mathrm{Sp})$, shifts downwards relative to $u^0_{\mathrm{Ds}}(\mathrm{AF})$. Second, he internalizes the externality that farmers were imposing on each other by beggaring their neighbors, equating Ds's marginal rate of substitution of prices for quotas with that of the average farmer. The net effect of these changes is that the spokesman proposes the vector $\mathbf{x}^T_{\mathrm{Sp}}$ and thus obtains the higher utility level, u'_{AF}, for the average farmer.

The utility implications of these differences for each player are reflected in the bottom right panel of Fig. 6. While farmers benefit *on average* from the spokesman's involvement (a slightly lower quota at a significantly lower overall average price), the distribution of benefits is highly skewed: Fd benefits hugely from the spokesman's redistribution of prices, while both Fu and Fm are negatively impacted. Mg's budget is unaffected by the spokesman's involvement (since his budget constraint binds), but his utility is negatively impacted because he prefers larger dams to smaller. Apart from Fd, the other beneficiaries from the spokesman's participation are Ev and Tp. Relative to the overall average farmer proposal, the spokesman reduces dam size (and hence lowers prices) in exchange for lower residual flows, at an exchange rate that leaves Ds indifferent. Compared to Ds, however, Ev and Tp have a relative preference for smaller dams (steeper induced MRS's in quota-price space), so that at the exchange rate that leaves Ds indifferent, both Ev and Tp benefit from the trade.

We now turn to drought conditions (Fig. 8). Once again, farmers Fu and Fd beggar their neighbors. In this case, however, Fm's capacity to beggar *his* neighbors is limited by hydrological and technological constraints. As explained on p. 33, farmers can acquire quotas in

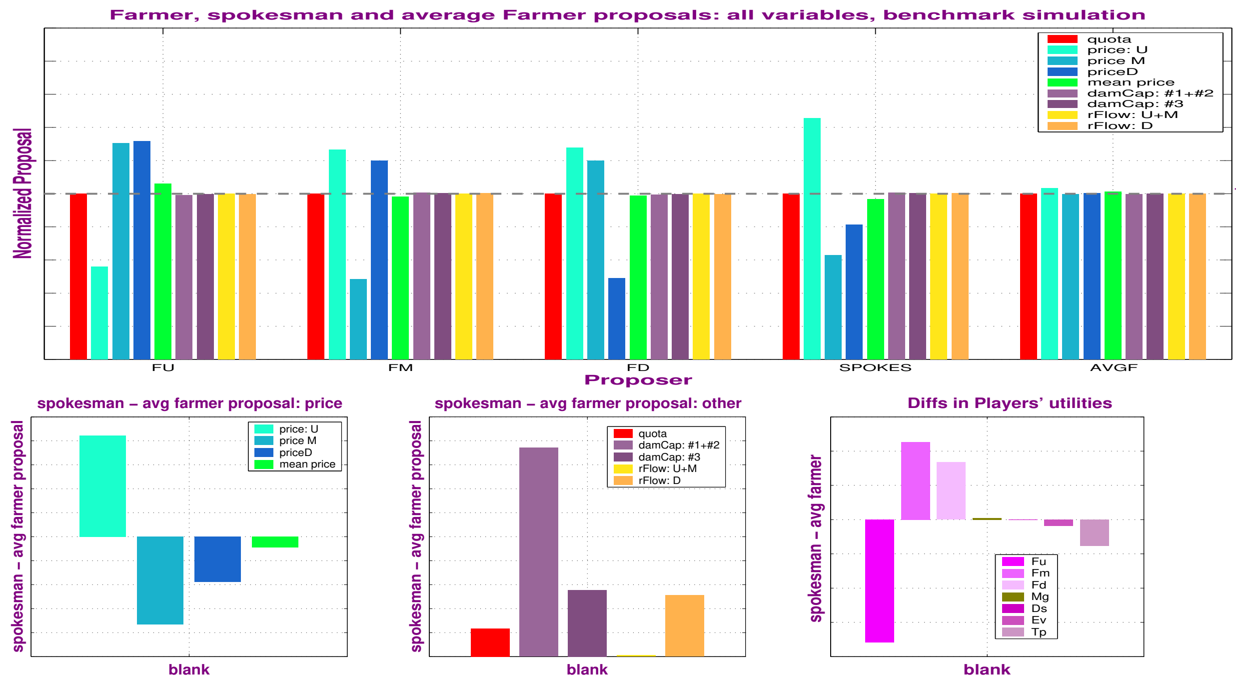

FIGURE 8. Farmer proposals: regime IPCQ, drought conditions, final round

this regime under drought conditions *only* by increasing the size of dam #2; moreover, the "cost" of quota increases in terms of dam increases is significantly higher when the hydrology constraint on subbasin M binds. As a result, farmer Fm, who has the highest willingness to pay for quotas, is obliged to propose the maximum feasible size for dam #2, in order to satisfy the hydrology constraint, and is unable to achieve the quota level that is optimal for him when he beggars his neighbors, subject only to the heterogeneity constraint. Even though the other two farmers, who are not capacity constrained, over-spend on quotas in the way we would anticipate, the capacity constraint on Fm binds sufficiently tightly that the farmers' overall average quota proposal is actually *suboptimal* from the average farmer's perspective.

The result is that in contrast to normal conditions, the indifference curve of the average farmer utility function passing through the overall average farmer proposal is *steeper* at this point than Ds's participation constraint. That is, because of Fm's technological constraint, the *average* farmer would in this instance choose to buy *more* quotas than he is purchasing under the overall average farmer proposal (see Fig. 9). Once again, the spokesman achieves two kinds of efficiency gains, relative to the average farmer. As in normal conditions, he rationalizes the distribution of prices across farmers, so that a given quota level can be acquired at a lower average price. But in contrast to normal conditions, he now proposes slightly *more* quotas than the average farmer.[30] The implications of these differences are reflected in the bottom-right panel of Fig. 8. In all critical respects (Fd and Fu are not critical), the signs are the reverse of those in Fig. 6: Fm in this case prefers the spokesman's proposal to the average farmer's; Ds is unaffected by the spokesman's involvement because his participation constraint binds; because quotas increase rather than decrease, Ev and Tp are negatively rather than positively impacted; Mg's budget remains in balance, but benefits from the increase in dam capacity.

Now compare the implications of the bottom-right panels of Figs. 6 & 8 for the penultimate and earlier rounds of bargaining. We begin with normal conditions. Except for player Fd,[31] whose strategic role is minimal in this scenario, the qualitative effects reported above on all of the players are reinforced by secondary effects in the penultimate round: Tp's participation constraint,

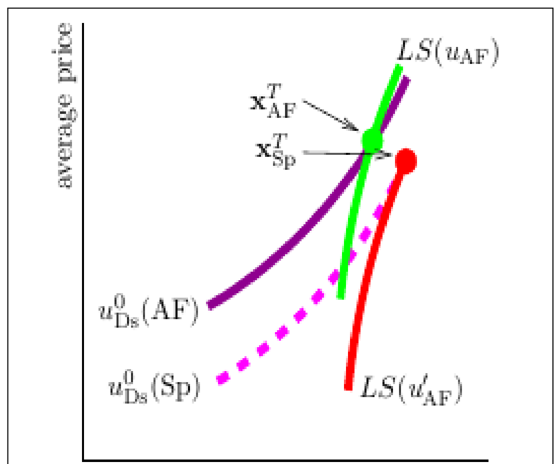

FIGURE 9: *IPCQ, drought conditions*

[30]Like Fm, Sp is unable to achieve a tangency with Ds's participation constraint, because he has pushed dam #2 to its maximum feasible size.

[31]Fd is negatively impacted by the all of the changes in participation constraints; however, his benefit from the spokesman's rationalization of prices relative to the overall average farmer proposal is large enough to dominate all these negative effects. But since Fd's participation constraint is never binding in the critical final rounds of bargaining, these effects do not impact the outcome of the bargaining.

which is binding on all farmers in this round,

becomes tighter with the spokesman's involvement and this weakens all farmers' proposals. The constraints that bind Mg are Ev's and Tp's, so his proposal is weaker as well. Fm's constraint, which is binding on all non-farmers, becomes slacker as the spokesman's access increases, and this strengthens all non-farmers' proposals. These qualitative penultimate round net effects are all transmitted back to the solution of the game: as the spokesman's access probability increases, all non-farmers gain, while Mg and all farmers except Fd lose.

Under drought conditions, Fm's and Mg's penultimate round participation constraints become tighter as the spokesman's access increases; since both players' constraints are binding on the anti-farmer group, this group does worse in the penultimate round as the spokesman's access increases. On the other hand, Ev's constraint becomes slacker while Ds's is unchanged, and this benefits all farmers. For Fm and Fd, this effect reinforces the positive effects that occurred in the final round, and occur in this round as well. For Fu, however, the negative impact of the redistribution of the price burden dominates the benefit from Ev's slacker constraint, and the net effect of the spokesman on this player is negative. These effects are transmitted backwards through the inductive chain, so that in the solution to the game, all members of the anti-farmer group are negatively impacted by the spokesman's involvement, while Fm and Fd benefit. Fu is negatively impacted. Because subbasin U has the largest irrigated area, the spokesman "sacrifices" Fu by assigning him a very high quota price.

<u>Summary and Discussion</u>: The qualitative comparative statics results we obtain in this experiment reveal that in negotiations where there is significant scope for divergent behavior among coalition members (i.e. our regimes IPCQ and CPIQ), the intervention of a spokesman will usually, but not necessarily, benefit the coalition as a group. In the experiments we consider, the impact of the spokesman's participation on the coalition's equilibrium payoff depends, basically, on two factors: his impact on the expected quota

proposal and on Fm's expected utility conditional on reaching the final round of bargaining. The expected quota proposal is important because it impacts, through its effect on dam capacities and residual flows, the wellbeing of the non-farmer players Ev and Tp, whose participation constraints are slack in the final round, but bind in all earlier rounds. Any proposal that leaves Dsindifferent makes these two players better off. Fm's conditional expected utility plays a pivotal role for precisely the reason that we identified in the stripped down context of §5.1: because Fm's constraint is binding on the anti-farmer group in the penultimate round of bargaining, Fm's performance in the final round is a primary determinant of all farmers' expected performance in the penultimate and earlier rounds. In all the experiments we report here, these two effects reinforce each other. For other parameterizations, however, this need not be the case, in which case our analysis of the spokesman's impact would require much more delicacy.

It is significant that when the coalition does benefit from the spokesman's participation, it does so only because he can discriminate against one of the coalition members. As we have observed, Fu is always the target of discrimination by the spokesman, since the constraints that bind him will be relaxed by a mean-preserving perturbation in subbasin prices (quotas) involving an increase (decrease) in Fu's price (quota): in IPCQ, a unit increase in Fu's price raises more revenue than a unit increase in either one of the other farmers' prices; in CPIQ, a unit increase in Fu's quota requires a larger increase in dam capacity than a unit increase in either one of the other farmers' quotas. Hence the spokesman, whose task is to maximize the sum of farmers' utilities, assigns a higher price and lower quota to Fu. Anticipating this discrimination, we would expect that Fu would not agree to the appointment of a spokesman of the kind we model. (Of course, whenever the farmer group does better on average with the spokesman, Fu could in principle be sufficiently compensated with side-payments that all coalition members would benefit from the spokesman's participation.)

Our spokesman experiment illustrates dramatically the extreme sensitivity of our results to factors whose importance one would not necessarily anticipate in the absence of a computational model. We observed that all of our comparative statics results are reversed in regime IPCQ when hydrological conditions change from normal to drought. We traced this reversal to the apparently inconsequential fact that in the final round of bargaining under drought conditions, Fm proposes the maximum feasible capacity level for dam #2. This single technological constraint limits the extent to which Fm can squander the other farmers' money, and a chain of significant consequences follow.

We emphasize this example because it highlights the complex, delicate and highly nonlinear nature of player interactions when they negotiate with each other in a environment such as the present one, characterized by high dimensionality and multiple "sharp edges." This environment contrasts sharply with the smooth, low-dimensional, stylized characterizations of the world that one is obliged to construct in order to generate analytical comparative statics results. While environments of the latter kind are more elegant and transparent than ours, and more likely to yield robust results, in many instances the cost of these positive attributes is that the simpler models fail to reflect the full richness of economic actors' interactions either with each other or with the institutional contexts within which they must operate. In the experiment we have just discussed, a technological constraint that might have been assumed away in order to construct a simplified model with analytical comparative statics results proved to be an important determinant of the negotiated outcome.

Finally, our results in regime IPCQ provide a counter-example to the intuitively self-evident conjecture we proposed on p. 40 that the spokesman's participation will always benefit the farmer coalition. It is true that when members of this coalition pursue their individual self-interests, the expected result of their activities will generally be sub-optimal from the perspective of the coalition as a whole. For example, each farmer in IPCQ proposes a higher quota level than he would have proposed if he were required to pay his fair share of quota costs.[32] The conjecture mentioned above is intuitively obvious precisely because we would expect the spokesman always to internalize any negative externalities arising from beggar-thy-neighbor behavior by individual farmers. Indeed, the spokesman does exactly this. Our conjecture fails in regime IPCQ, however, in part[33] because the externality that is negative in this narrow sense turns out to be positive in a broader sense—beggar-thy-neighbor behavior hurts Ds, Ev and Tp more than it hurts the farmers, and in fact *benefits* the manager—so that when the spokesman internalizes it, the farmer coalition's equilibrium performance actually declines. On reflection, this result should not be at all surprising: a fundamental lesson from game theory is that behavior which is suboptimal by decision-theoretic criteria can in a game-theoretic context increase a player's equilibrium payoff relative to behavior that is decision-theoretically optimal.[34]

5.3. **Limiting dissention: reducing the degree of proposal heterogeneity.** As we observed in §5.2, the spokesman's role was essentially negligible in regime CPCQ, but significant in the other two regimes. It seems probable, therefore that in regimes IPCQ and CPIQ, reducing the degree of permissible heterogeneity among player proposals will have similar effects. As we have noted above (page 23), players in our base-case scenarios for regimes IPCQ and CPIQ are constrained in the extent to which they can pursue their own subbasins' interests at the expense of other subbasins. Specifically, in regime CPIQ (IPCQ), the specification of the bargaining space includes an upper bound on the standard deviation of the three quotas (prices) proposed by any player. In this subsection, we explore the impact of successively relaxing these bounds, again restricting our attention to the case

[32]We reiterate (cf p. 51) that it is the *political* supply schedule for quotas that is upward sloping.

[33]A second factor is that while the spokesman enhances *average* farmer utility, in normal conditions he reduces Fm's utility, and it is this utility rather than farmers' average that matters in the final round of the game. Cf section §5.1

[34]See for example, the vast literature on reputation building beginning with krepsWilson:82 and milgromRoberts:82.

in which, in the final round of bargaining, Ds's constraint is binding on all farmers and on Mg.

A natural conjecture arising from §5.2 is that farmers' utilities will increase or decrease on average as these restrictions become tighter, depending on whether the average farmer benefits from the participation of the spokesman. In regime CPIQ, for example, we observed from the spokesman experiment that self-interested, beggar-thy-neighbor behavior by individual farmers served to weaken the performance of the farmer coalition. In the present experiment, we test the conjecture that when we successively tighten our bound on the extent of heterogeneity among proposals, and thus increasingly proscribe this kind of behavior, farmers will on average do better in equilibrium. It is less straightforward to make predictions for regime IPCQ, since in this case the impact of the spokesman turned out to be counter-intuitive, at least under normal conditions. Even so, it still seems intuitive that when we limit the extent to which each farmer can favor his own subbasin at the expense of the others, farmers will again do better on average.

Except for one of the four scenarios we discuss in this subsection—CPIQ, normal conditions—these conjectures are not supported by our simulation experiments. In regime CPIQ, farmers benefit on average when the heterogeneity bound is tightened under normal conditions, but do worse when it is tightened in drought conditions. In regime IPCQ under both normal and drought conditions, the average farmer does monotonically worse as the bound tightens. Moreover, an analysis of our simulation results reveals that the forces driving our comparative statics results are quite different from the ones we anticipated.

Why in regime CPIQ are farmers positively impacted by a tighter bound in normal conditions, but negatively impacted in drought conditions? To answer this question, we focus as usual on the final round of negotiations. We restrict our attention to farmer Fd, for whom the effect of hydrological conditions is most dramatic. In the discussion which follows, it is important to keep in mind the topography of the Adour Basin (see Fig. 2 on p. 20), noting in particular that both Fd's quota allocation and the capacity of dam #2 affect residual flows only below subbasin D.

On pp. 31-33 of §4, we discussed how to project players' preferences onto price-quota space in regime CPCQ. We now extend this discussion to the more complex situation that arises in regime CPIQ. Fig. 10 collapses Fd's optimization problem down to two dimensions. The curve labeled "water supply function" maps the proposed capacity of dam #2 (on the vertical axis) to water flows *gross of farm quotas* below subbasin D (on the horizontal axis). Non-farmers care about *residual* water flows, which are gross flows minus any quotas allocated to farmers. The curve labeled "Ds's participation constraint" is the level set of Ds's utility function at his default utility, representing his willingness to trade off dam size against residual flow. The slope of Ds's level set is steeper than the slope of the "supply function" if and only if the increase in residual flows resulting from an expansion of the dam's size increases Ds's utility at a faster rate than the rate at which Ds's utility declines because he dislikes dams. For any given capacity for dam #2, farmer Fd can assign quotas that sum to the horizontal distance between Ds's level set and the water supply function. The heterogeneity constraint restricts the fraction of this distance that Fd can assign to his own subbasin. In Fig. 10, the heterogeneity bound determines the lengths of the solid, horizontal, double-ended arrows (Fd's quota) *relative to* the lengths of the dotted arrows (Fm and Fu's quotas). As the constraint tightens, this fraction shrinks. The key point to note here is that since each farmer, naturally, assigns the largest fraction of total quotas to his own subbasin, a tightening of the heterogeneity bound means that *aggregate* quotas must be increased in order to deliver to a given farmer the same quota level he was receiving initially. It necessarily follows that as the heterogeneity bound tightens, there is an increase in the tension between farmers and those stakeholders who value residual flows.

Since *ceteris paribus* (c.p), the capacity of dam #2 determines the common quota price through the administrative budget constraint, we can reinterpret Fig. 10 to represent the tradeoff facing farmer Fd, which is, essentially, between quota and price. When considering Fd's options, mentally relabel the vertical axis as the quota price implied by the given dam capacity, and the horizontal axis as quotas, then interpret all curves associated with Fd as either opportunity sets or indifference curves in price-quota space. Assuming that from Fd's perspective, quotas are optimally divided among farmers Fu and Fm, we can trace out the frontier of the choice set available to Fd. For our baseline case, this is indicated by the solid line labeled "Fd's feasible set: loose constraint;" when the constraint tightens the feasible set contracts, as indicated by the dashed line labeled "Fd's feasible set: tight constraint." Note that the feasible set is "backward-bending" if and only if at the margin, Ds's dislike of dam #2 exceeds his fondness for residual flows. The solid and dashed lines labeled "Fd's indifference curve" indicate the indifference curves determining the location of Fd's optimal proposals, both before and after the heterogeneity constraint tightens. The tangency points, indicated by oval-shaped dots, are characterized by the property that the marginal cost to Fd—incurred because the common quota price must increase to satisfy the administrator's budget constraint—of a further increase in the dam's size just offsets the marginal benefit to Fd from proposing additional quotas for his own subbasin, taking into account the increases in Fm's and Fu's quotas that he must also propose in order to satisfy the heterogeneity constraint. When the constraint tightens, Fd pays a higher unit price for fewer quotas, reflecting the fact that both quotas and the residual numeraire are normal goods.

It should be emphasized that the two-dimensional Fig. 10 is only an partial representation of the problem being modeled. In particular, the location of Ds's participation constraint is *not* independent of the allocation of quotas among farmers, and hence depends on the heterogeneity bound. Specifically, note in Fig. 10 that pressure on upstream residual flows increases with the lengths of the horizontal dashed arrows, but is independent of the lengths of the solid arrows. This implies that when the constraint tightens, holding everything else in the figure constant, the line labeled "Ds's participation constraint" now represents a lower level of utility, because Ds cares also about upstream flows. In other words, Ds's actual constraint moves to the right as the bound shrinks. Note also that if farmer Fd were replaced in the figure by Fu, then the relationship between the heterogeneity bound and Ds's constraint would be reversed: in this case, a tightening of the bound would shift Ds's constraint to the left.

We say that "drought conditions" apply when at least one of the hydrology constraints are binding. In our benchmark simulation of drought conditions, the hydrology constraints bind at the mid- and down-stream measurement points; the up-stream constraint is slack. When the heterogeneity bound tightens under these circumstances, farmer Fd is in an especially difficult position: to satisfy a tighter

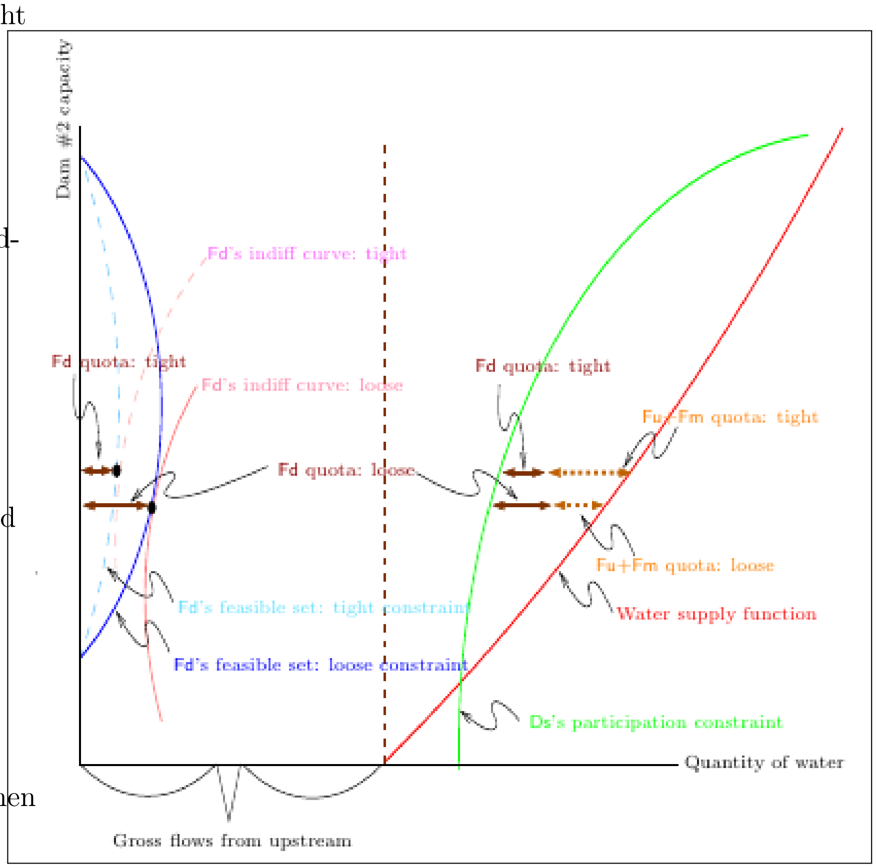

FIGURE 10: *Farmer* Fd*'s problem, normal conditions*

heterogeneity bound, he must reduce the quotas he assigns to himself and increase the quotas he assigns to upstream farmers. As we have noted above, a one-to-one transfer of quotas upstream either doubles or triples the burden of satisfying residual flow requirements. Moreover, in our simulation, dam #1 is already at full capacity, while dam #3 is already so large that the net marginal benefit to user Ds of increasing it still further is negative. Since dam #2 services only the down-stream basin, farmer Fd cannot increase the supply of water to the up- and mid-stream basins without *reducing* Ds's utility (cf. in normal conditions, an increase in dam #3 created a net surplus utility for Ds, which gave Fd room to maneuver.) Since Ds's participation constraint is binding, he must be compensated somehow for this loss. By a process of elimination, the only feasible way that Fd can provide this compensation is to reduce the mean quota allocation he proposes and to reduce the size of dam #2.

To summarize, Fd's response in normal conditions is to buy fewer quotas for his own sub-basin, at a higher price, and to increase the size of dam #3 to accommodate the increased pressure on residual flows induced by the forced reallocation of the quotas he proposes. In drought conditions, he has less room to maneuver, and is obliged to *reduce* the size of dam #2. As we have discussed many times, when a farmer adjusts dam sizes and residual flows, he does it on terms that leave user Ds indifferent. But Ev and Tp dislike dams more than Ds—if they had been included in Fig. 10, their participation constraints would be flatter than Ds's—so that they benefit (suffer) whenever a farmer reduces (increases) a dam size.

We now broaden our discussion to include the other players, considering each scenario in turn. For the four cases we consider, the effects of the heterogeneity restriction in the final round of bargaining are summarized in Figures 11-15. The information conveyed of these figures parallels the information conveyed by the corresponding figures in §5.2. The difference is that instead of comparing farmer proposals to the spokesman's, we compare farmers' proposals when we move from the tightest to the loosest specification of the heterogeneity bound.

The final round of bargaining: regime CPIQ, normal conditions: Observe from the bottom left panel of Fig. 11 that the overall average quota proposal declines as the bound tightens, although farmer Fu's mean quota proposal increases. From the lower middle panel, the mean common price proposal increases, and there are increases in the means of farmers' proposed levels of both the capacity of dam #3 and and the residual flow into the downstream subbasin. (In fact, Fu's proposed price declines, while Fm's and Fd's increase, but

FIGURE 11. Farmer proposals: CPIQ, normal conditions, final round

these details are not apparent from the figure.) The utility comparisons are noteworthy: Farmer Fu benefits significantly, Fu moderately, and Fm slightly from the tightening of the constraint, while both Ev and Tp are negatively impacted. That is, each of the parties for whom the heterogeneity constraint binds actually benefits from a tightening of this constraint!

Why are farmers affected so differently by a tightening of the heterogeneity bound? The source of the difference has been alluded to above (pp. 60-62). When any farmer reduces the quota that he proposes for himself, residual flows increase at every monitoring point *downstream* of that farmer. Thus, when Fu is the proposer, a unit decrease in his own proposed quota generates, very roughly, three times the increase in residual flows that a corresponding decrease made by Fd would generate. Consequently, it is much less costly for Fu to satisfy the tightening heterogeneity bound than it is for either Fm of Fd. Indeed, it would be technologically feasible for Fu to satisfy the tighter constraint even leaving proposed dam capacities unchanged: he could do so by slightly reducing his own quota and significantly increasing the other two, thereby increasing residual flows at the upstream and midstream monitoring points, and only slightly reducing the flow at the downstream point. Moreover, because this adjustment would increase the *aggregate* number of quotas, the administrator's budget constraint could be satisfied at a *lower* common price. However, even this relatively minor adjustment is suboptimal for Fu: it is better for him to reduce his quota by a lesser amount, increase the other quotas by more, and offset the loss in residual flows relative to the previously discussed adjustment by slightly increasing the capacity of dam #3. For Fd, on the other hand, a quota adjustment exactly comparable to the optimal adjustment for Fu would result in very large losses in residual flows, and hence would be infeasible. Fd must, therefore, significantly shrink his own quota, increase other quotas by much smaller amounts, and, to satisfy the budget constraint, increase the common price. Like Fu, Fd chooses to increase slightly the capacity of dam #3, which reduces slightly the amount by which he must shrink his quota, at the cost of an increase in the common price.

We now turn to the bottom right panel of Fig. 11. Farmers benefit in expectation as the heterogeneity bound tightens, because, as expected, they are *forced* to act in a less self-interested fashion. Each farmer fares worse from his own proposal, but better from other farmers' proposals. The impact for a farmer is more favorable, the further upstream is his subbasin, for the reason explained in the preceding paragraph. It is difficult to infer either from the figure or from general principles why even farmer Fd should do better in expectation, when the price he expects to pays increases and the quota he expects to receives decreases. We merely observe at this point that each farmer is negatively impacted by the tighter bound when he is selected to be the proposer, but is positively impacted when another farmer is selected, and that because farmers are risk averse, the gains are weighted more heavily than the loss.

Since the tighter bound increases the average proposed size of dam #3 and residual flows below subbasin D, both Ev and Tp are negatively impacted, for the usual reason. Thus, all of the effects observed in the final round reinforce each other as we move backward along the inductive chain, so that in the solution to the game, all farmers do better, while all non-farmers do worse, as the bound tightens.

<u>The final round of bargaining: regime CPIQ, drought conditions</u>: Comparing the bottom left panel of Fig. 12 with the corresponding panel of Fig. 11, note that the average subbasin quota proposal increases by less under drought than under normal conditions. The reason is that under drought conditions, the tangency points represented by the dots in Fig. 10 are now associated with impermissibly low residual flows. To satisfy the hydrological constraints in the benchmark case, the required dam capacities must be so high that even Ds derives negative marginal utility from further increases. When the heterogeneity bound tightens, the mitigation option that was available under normal conditions—expand dams to accommodate Ds's residual flow requirement, thereby limiting the required reduction in mean quotas—is no longer such a readily available option for all farmers; in fact, as we have previewed above (pp. 62-63), Fd has no choice but to reduce his proposed size of dam #2 in order to satisfy Ds's participation constraint. The bottom right panel of Fig. 12 reports the net effect of these changes on players' utilities, which are much less clearcut than in the other cases we have considered. The key points to note are that all farmers' utility

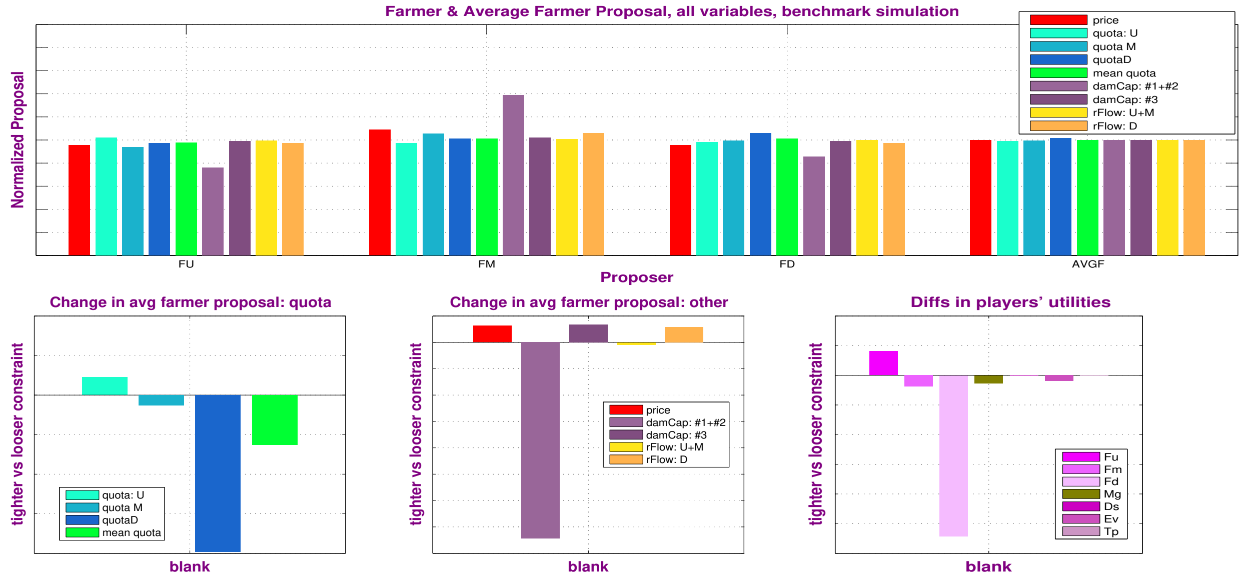

FIGURE 12. Farmer proposals: CPIQ, drought, final round

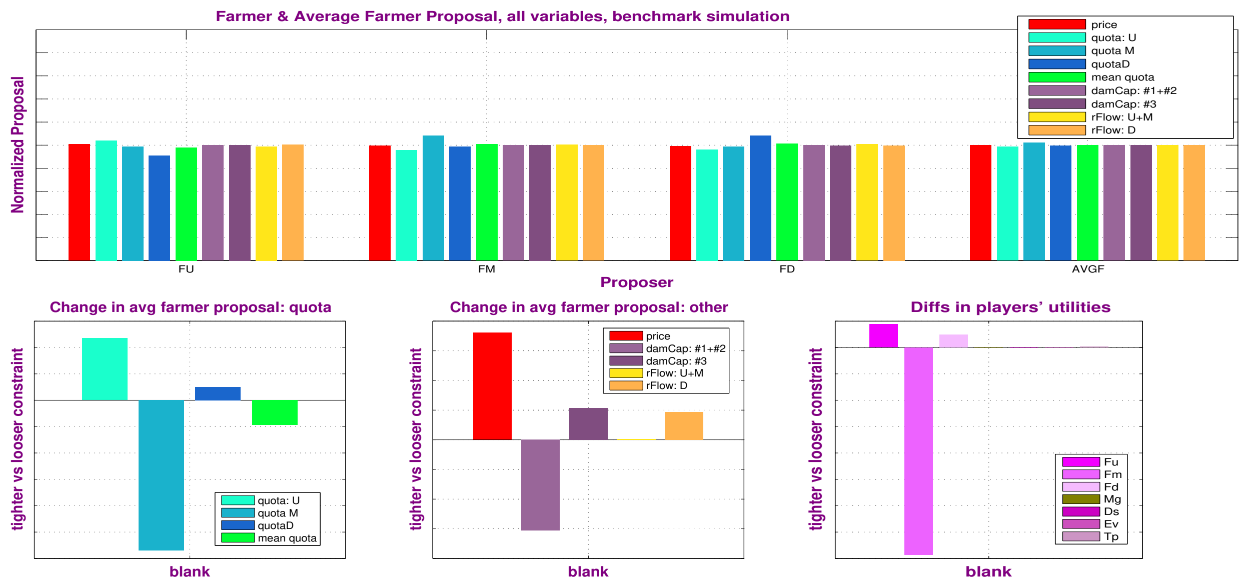

FIGURE 13. Farmer proposals: CPIQ, drought, third-to-last round

are affected less positively (or more negatively) than under normal conditions (Fig. 11), while the impact on non-farmers is less negative. In this scenario, the comparative statics impact of the change are indeterminate even in the penultimate round; by the third to last round, however, they are resolved (see Fig. 13). The key characteristics of Fig. 13 are that the overall average quota proposed by farmers is significantly lower, and the common price significantly higher when the bound tightens. Both the capacity of dam #3 and the residual flow in the downstream basin increase, while the size of dam #2 is significantly smaller. Farmer Fm, who is is strategically important in the sense we discussed in §5.1, is significantly negatively impacted.

The final round of bargaining: regime IPCQ, normal conditions: It is interesting to compare the panels of Fig. 14 to the panels of Fig. 6, which summarizes the corresponding scenario in the spokesman experiment. The lower middle panels of both figures are virtually identical. In both figures, the common quota level, dam capacities and residual flows all decline, reflecting the fact that as the extent of beggar-thy-neighbor behavior is limited, either endogenously by the spokesman's behavior, or exogenously by the tighter heterogeneity bound, farmers internalize to a greater extent the true cost of buying quotas. On the other hand, the overall average price declines in the lower left panel of Fig. 6 while it increases in Fig. 14. The reason for this difference is that, in contrast to the spokesman, each farmer is once again constrained by the heterogeneity bound from allocating prices efficiently even between the other two farmers (cf. the discussion on p. 48). In spite of this qualitative difference in the price effects, the effect on players' utilities (the bottom right panel of Fig. 14) is qualitatively similar to the effect of the spokesman (Fig. 6) in all respects except strategically unimportant ones. As the bound tightens, the strategically important farmer Fm pays a higher price on average for a lower quota level, and so is negatively impacted. Note also that because dams and residual follows are reduced at a rate that leaves Ds indifferent, both Ev and Tp, who dislike dams more than Ds, once again benefit from these reductions. These effects all reinforce each other, and are transmitted back to the initial round of the game. In the equilibrium, all members of the non-farmer

FIGURE 14. Farmer proposals: regime IPCQ, normal conditions, final round

group benefit monotonically from the tightening of the heterogeneity bound. Farmer Fu, whose mean quota price declines significantly, benefits monotonically also, while Fm, whose demand for quotas is the highest, and Fd both suffer monotonically. The *average* farmer's equilibrium welfare declines also.

To summarize, the comparative statics impact of tightening the heterogeneity bound in regime CPIQ depends on hydrological conditions. Ultimately the decisive factor is the level of dam capacity in the benchmark case. Under drought conditions, significantly higher levels are required to meet hydrological constraints, to the point that Ds's aversion to dams at the margin dominates his appetite for residual flows. Consequently, when the heterogeneity constraint tightens in drought conditions, and farmers are obliged to transfer quotas to their neighbors, the possibility of mitigating the impact by increasing dam size is no longer available. So dam sizes contract rather than increase, as in normal conditions, with the usual consequences. As we shall see below, the role of the heterogeneity bound is quite different in regime IPCQ.

The final round of bargaining: regime IPCQ, drought conditions: The effect of the heterogeneity restriction under drought conditions is qualitatively similar to the effect under normal conditions. It is summarized in Fig. 15, which is similar in many respects to Fig. 14. One significant difference is that under normal conditions, there is an slight increase in the overall average price proposed by farmers, while under drought conditions, this price declines. Another is that both dam capacities and quotas fall much more substantially under drought conditions than under normal conditions. These differences, however, do not affect the end result: as in normal conditions, when beggar-thy-neighbor behavior is mitigated, the key beneficiaries are Ev and Tp, who benefit substantially from the reduction in dam sizes. The effects of these benefits are transmitted up the inductive chain, and the solution impacts are the same as under normal conditions: all non-farmers do better in equilibrium,

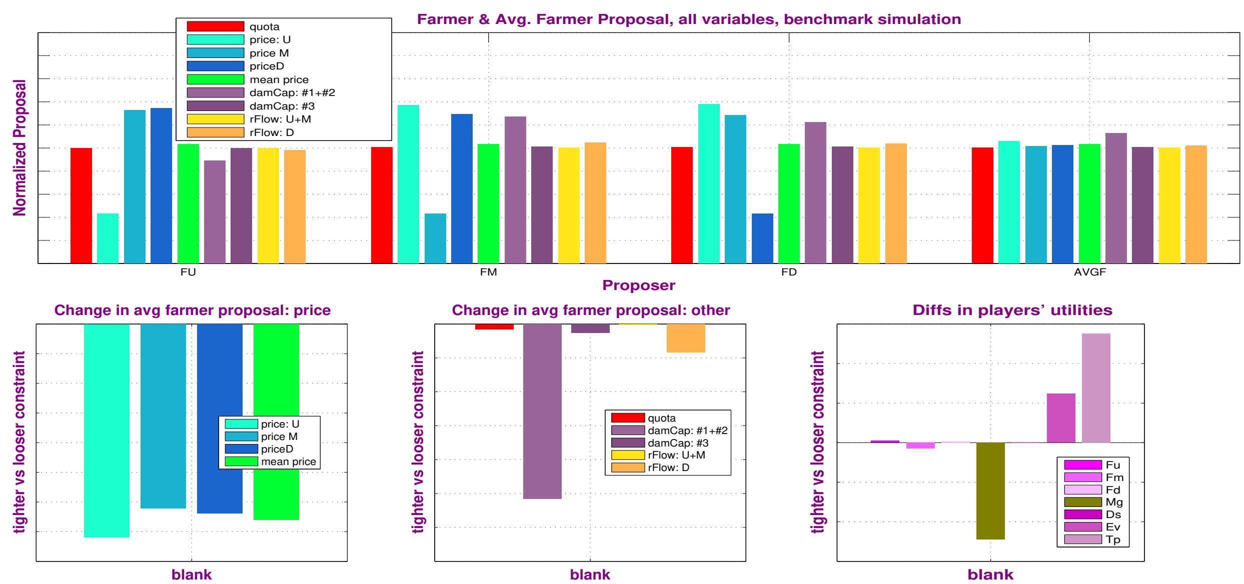

FIGURE 15. Farmer proposals: regime IPCQ, drought conditions, final round

which all farmers except Fd, including the average farmer, do worse.

The equilibrium comparative statics in this case are the reverse of the ones we obtained in the corresponding experiment involving the spokesman (see pp. 52-54, esp. Fig. 8). In the current experiment, the primary impact of the tightening heterogeneity bound is to mitigate beggar-thy-neighbor activity, and Fu and Fd both benefit from this. However, Ev and Tp both benefit also, and to a considerably greater extent. By contrast, the spokesman not only mitigates beggar-thy-neighbor activity, but also rationalizes the assignment of prices relative to the farmers' average assignment, and as a result can obtain more quotas for less total expenditure, as well as an increase in dam size. Though farmer Fu is sacrificed in the process, the strategically important farmer Fm benefits, and Ev and Tp are both hurt.

Summary: There are quite striking, and unanticipated, differences between the comparative statics results in §5.2 and §5.3. We had expected the results in both subsections to be driven by the factor common to both: the changes we introduced were each designed to mitigate, in expectation, the divisive tendency of each farmer to pursue his own self interest at the expense of the farmer coalition. This objective was indeed accomplished in all of the experiments we considered: on average in the final round of bargaining, the gap narrowed, at least in expectation, between the marginal benefit of acquiring an additional quota and the marginal cost of obtaining it. However, the equilibrium impacts of this accomplishment were quite different in the two subsections. In all cases but one in §5.2, the equilibrium payoff for the average farmer increased with the participation of the spokesman, while those of non-farmers decreased, providing a tentative confirmation of our conjecture that beggar-thy-neighbor activity would be a significant negative contributor to coalition performance.

The results of the experiment reported in the current subsection, however, suggests that determinants of bargaining success are in fact more subtle. When we tightened the heterogeneity bound, beggar-thy-neighbor activity was once again mitigated on average, yet in all but one case, the average farmer's equilibrium payoff declined. Our comparison of the two subsections revealed that the more significant contribution made by the spokesman was to rationalize the average allocation of quotas and prices across subbasins, so that residual flows could be increased even as dam capacities were expanded. These increases in the final round proved to be important determinant of equilibrium improvement for the average farmer. Specifically, when both dam capacities and residual flows increased, the rates of increase were determined by Ds's preferences, since by construction Ds's participation constraint was binding on all farmers in the final round. But rates of increase that leave Ds indifferent have a net negative impact on Ev and Tp, weakening the bargaining position of the non-farmer coalition in the penultimate and earlier rounds.

6. Conclusion

This paper reports on a computational application of the Rausser-Simon multilateral bargaining framework to a rich environment that includes economics, hydrological, and strategic considerations. We used the model to explore the interactions between the structure of the bargaining process and the effective power of bargaining participants. Our results indicate a number of ways in which the structure of the negotiation process can be an important determinant of negotiation outcomes. For participants, there are a number of sources of bargaining power. The two direct sources are "access," modeled as the probability of being chosen to make a proposal, and "default strength," or how well the participant will fare if the negotiation does not result in an agreement. Our analysis identified a number of less direct sources of power, including "strategic location." In §5.1, we showed in a stripped-down context that under certain circumstances, a coalition member's equilibrium performance is not necessarily monotone increasing in his access: there are circumstances in which a player can actually benefit in equilibrium when his access is transferred to another player whose strategic location is more favorable.

Our "spokesman" experiment demonstrated that the welfare of farmers as a whole typically increased when they were represented by a spokesman charged with the objective of maximizing farmers' average welfare. The spokesman improved average farmer welfare in three out of four scenarios. We identified two main reasons for this improvement.

First, the spokesman mitigated, in an expected sense, the tendency of individual farmers to adopt beggar-thy-neighbor bargaining strategies: in our baseline parameterization for regime IPCQ, each farmer in effect purchased quotas with other farmers' money, and consequently purchased more than he would have done had he been obliged to use his own money; in regime CPIQ, each farmer kept for himself a disproportionate share of the total number of quotas, thus lowering for himself the per unit cost of quotas and raising it for others. Second, the spokesman rationalized the allocation of prices and quotas across subbasins. There were, however, winners and losers from this rationalization, so that the spokesman's successes were always obtained at the expense of one of the farmers. This suggests that in order to obtain the coalition's unanimous endorsement of a spokesman's participation, side payments would typically be required in order to compensate the losers.

Our "heterogeneity bound" experiment was designed to mimic the impact of the spokesman by limiting exogenously the extent to which farmers could engage in beggar-thy-neighbor behavior. Our exogenous restriction did indeed limit this behavior; however, the equilibrium consequences of doing so were unexpected. We found that in three out of four scenarios, farmers' equilibrium welfare actually declined as farmers were forced to act in a less selfish manner. The unanticipated lesson from this experiment was that, while farmers might collectively benefit from a restriction that obliged them to act less selfishly, "the opposition" might benefit even more so. (Recall that "acting less selfishly" meant purchasing fewer quotas, and this benefited both Ev and Tp, while leaving Ds indifferent.)

We conclude that the decisive contribution made by the spokesman was that he was more effective at distributing prices and quotas efficiently across subbasins than farmers were when they acted as self-interested individuals. A careful reading of §5 suggests, however, that the implications for coalition performance of even this contribution are unlikely to be very robust. As we observed in §5.2, farmer Fm was, typically, a beneficiary of the spokesman's efficiency improvements, while Fu was typically a loser. Fortunately for the farmers, it was Fm rather than Fu who was strategically important in the sense we identified in section §5.1. Had the interrelationship between hydrological and agricultural conditions been different, Fu might have been the strategically important farmer, in which case the spokesman's participation might have had the opposite effect on equilibrium payoffs.

Linking our analysis to the real-world negotiation process it models, we can identify some potential reasons for the deadlock in the second stage of negotiations, and some recommendations for altering the structure of the negotiation process in order to increase the probability of its success. First, given that the interests of farmers are imperfectly allied, the selection of specific negotiation participants is an important consideration. However, the lack of robustness regarding the effects of the spokesman's participation on farmers' welfare does not provide firm recommendations regarding the selection process, and the appropriate level of aggregation for farmers' heterogeneous interests. On the other hand, the results of the spokesman experiment suggest that the negotiation process should be expanded to allow for side payments among participants in order to increase efficiency while maintaining unanimity regarding the negotiation outcome. Second, an explicit specification of the permissible range of outcomes may facilitate agreement about allocating water across farmers in a manner acceptable to non-farmer stakeholders; no such specification existed in the real negotiation process. Third, the only tool the water management agency can use in the real world to allocate limited water during a drought is to shut water off completely. This enforces consistency across farmers regarding their water use during a drought, and likely was the primary cause of the failure to come to agreement regarding how to allocate limited supplies during a drought. If all irrigation was stopped in order to protect in-stream flows, the costs would vary widely across farmers, making it difficult for them to agree on any proposal that would simultaneously satisfy the other stakeholders. Our analysis illustrated the value of negotiating explicitly over quotas and prices for drought conditions separately from normal conditions. Doing so allows the farmers' quotas and prices to reflect the marginal value of the water in production they each have, while simultaneously meeting hydrological constraints and satisfying the other stakeholders.

Overall, our analysis suggests that indirect sources of bargaining power may critically influence the outcome of a negotiation process. Comparing our results to the stalled Adour negotiation suggests that when designing a negotiation process, policymakers must pay attention to the structural details that interact with these indirect sources of bargaining power in order to ensure that the structure will guide the stakeholders to an agreement.

The formal model: There is a set $\mathbb{I}$ of n players, interpreted as the set of stakeholders for a bargaining problem. Let X be a convex, compact, non-empty set, representing the space of bargaining *proposals*. Let $\mathbf{u} = (u_1, ...u_n)$, where $u_i : X \to \mathbb{R}$, denote the mapping from proposals to *utilities* for each player. We assume that for each j, u_i is continuous and strictly concave on X. Let $\mathbf{u}^0 \in \mathbb{R}^n$ denote the *disagreement payoff* that players receive if they do not adopt whichever proposal is proposed in the last round of bargaining. For convenience, we define a "disagreement proposal" $\mathbf{x}^0$—that need not necessarily belong to X—which generates for players the disagreement payoff vector $\mathbf{u}^0$.

For each $T \in \mathbb{N}$ we consider a bargaining game with a set $\mathbb{T} = \{1, ..., T\}$ rounds of negotiation. In the first round, a player is chosen at random, according to a strictly positive vector of *access probabilities* $\boldsymbol{\omega} = (\omega_1, ..., \omega_n)$, to make a proposal. Players then vote on the proposal. If all players accept the proposal $\mathbf{x}$, the proposal is adopted, the game ends and players receive the payoff vector $\mathbf{u}(\mathbf{x})$, otherwise players proceed to the next round and the process is repeated. If proposal is not adopted after T rounds, all players receive the payoff $\mathbf{u}^0$.

We now formally define strategies for the game. In general, strategies depend on history; however, as will become apparent below, the solution concept we will invoke eliminates from consideration all strategies that depend non-trivially on history, including the identity of the proposer. Accordingly, to reduce notation, we will specify a family of history-independent strategies. A *strategy for player* i is a collection, $\left(\mathbf{x}^{i,t}, v^{i,t}\right)_{t\in\mathbb{T}}$, where $\mathbf{x}^{i,t} \in X$, and $v^{i,t} : X \to \{Y, N\}$; $\mathbf{x}^{i,t}$ is the proposal that i would make in round t if chosen to be the proposer in that round and $v^{i,t}(\mathbf{x})$ is i's yes/no vote on proposal $\mathbf{x}$ if it is tabled in round t. Given a profile of strategies, $\mathbf{s} = \left(\mathbf{x}^{i,t}, v^{i,t}\right)_{t\in\mathbb{T}}$, let $X(\mathbf{s}) = \{\mathbf{x}^{j,t} : \prod_{r\in\mathbb{I}} v^{r,t}(\mathbf{x}^{r,t}) = Y\}$; $X(\mathbf{s})$ is the set consisting of all of the proposals which would, under the strategy profile $\mathbf{s}$, be proposed by some player in some round, if that round were ever reached, and, if proposed, would be adopted. Now define the mapping $A(\mathbf{s}) : \mathbb{I} \times \mathbb{T} \to \{0, 1\}$, by $A^{j,t}(\mathbf{s}) = \begin{cases} 1 & \text{if } x_{j,t} \in X(\mathbf{s}) \\ 0 & \text{otherwise} \end{cases}$. $A^{j,t}(\mathbf{s})$ is one if j's proposal in round t is adopted, otherwise it is zero. Next, define the *ex ante* probability that the outcome $\mathbf{x}^{j,t} \in X(\mathbf{s})$ will be proposed (and then adopted) as $\mu(\mathbf{x}^{j,t}|\mathbf{s}) = \begin{cases} \omega_j & \text{if t = 1} \\ \prod_{t'=1}^{t-1}\left(1 - \sum_{r\in\mathbb{I}} \omega_r A^{r,t'}(\mathbf{s})\right)\omega_j & \text{if } t > 1 \end{cases}$. In words, $\mu(\mathbf{x}^{j,t}|\mathbf{s})$ is the probability that no agreement is reached in any round prior to t, times the conditional probability that player j is chosen as the proposer in round t, given that this period is reached. Let $\mu(\mathbf{x}^0|\mathbf{s}) = 1 - \sum_{\mathbf{x}\in X(\mathbf{s})} \mu(\mathbf{x}|\mathbf{s})$ denote the probability that no proposal is ever adopted. For a T-period multilateral bargaining game, we can now define the *payoff function* mapping strategy profiles to expected payoff vectors by

$$\mathbf{P}(\mathbf{s}) \quad = \quad \sum_{x\in X(\mathbf{s})\cup\{\mathbf{x}^0\}} \mathbf{u}(\mathbf{x})\mu(\mathbf{x}|\mathbf{s})$$

A *Nash Equilibrium* is a strategy profile $\mathbf{s}$ such that for each j and each strategy s'_j for j, $P_j(\mathbf{s}) \geq P_j(s'_j, \mathbf{s}_{\neg j})$. The standard solution concept for games of this kind is subgame perfection. A strategy profile is a *subgame perfect equilibrium* if the strategies form a Nash equilibrium, starting from any subgame of the game.

In the present context, sub-game perfection is an inadequate solution concept. To see this, note that in any T-round MB game with at least three players, there is a subgame perfect equilibrium which implements the default outcome, regardless of the possible Pareto gains to bargaining. One such equilibrium is the profile in which all players reject all proposals; since at least two acceptances are required before a proposal can be adopted, no individual player can benefit by accepting any proposal. Similarly, for any proposal $\mathbf{x}$ such that $\mathbf{u}(\mathbf{x}) \geq \mathbf{u}^0$, and any $t \in \mathbb{T}$, there is a subgame perfect equilibrium in which $\mathbf{x}$ is adopted in round t.

Intuitively, almost none of these subgame perfect equilibria would be robust to "trembles" in the sense of "trembling hand perfection" (THP). For continuous action games, however, the known sufficient conditions for existence of THP equilibria are not satisfied by games of the kind we are considering **?**. Accordingly, we propose a new, quite stringent equilibrium refinement—we call it "limit dominance solvability"—which reflects the intuition underlying THP, and isolates a unique bargaining outcome. This concept extends to games with an infinite number of strategies the solution concept for finite games known as "dominance solvability."

In finite games, the idea of reducing the set of equilibria by iterated elimination of weakly dominated strategies[35] is well established. In general, this procedure yields indeterminate results, because the *order* in which strategies are eliminated may affect the outcome of the procedure. On the other hand, a game with finitely many actions is said to be *dominance solvable* "if all players are indifferent between all outcomes that survive the iterative procedure in which *all* the weakly dominated actions of each player are eliminated at each stage."[36] That is, in a dominance solvable game, the order in which weakly dominated strategies are eliminated is immaterial. We will refer to an outcome that survives such a

[35] A strategy s_j is *weakly dominated* by s'_j if $P(s_j, s_{-j}) \leq P(s'_j, s_{-j})$, for all $s_{-j} \in S_{-j}$, and, for some s_{-j} $\in$ S_{-j}, $P(s_j, s_{-j}) < P(s'_j, s_{-j})$

[36] The concept of dominance solvability was first proposed by Moulin:79. The quote is from **?**

procedure as a *dominance solvable outcome* and the payoffs associated with such an outcome as a *dominance solvable payoff vector*.

To our knowledge, the concept of dominance solvability for infinite games has not been systematically explored. However, the following extension of the finite concept to our particular infinite game is very natural. For each T, we will consider sequences of bargaining games that are identical to our original specification, except that proposers are restricted to choose from increasingly large, but *finite* proposal spaces, which converge to our original proposal space X in the sense of Hausdorff.[37] Dominance solvability is a well-defined concept for these approximating games, since they have finite strategy sets. Of course, not all approximating games are dominance solvable. However, we provide a simple inductive construction for constructing dominance solvable approximations. We then say that a T-round MB game is *limit dominance solvable* if there exists a unique payoff vector that is the limit of dominance solvable payoff vectors for *any* sequence of dominance solvable approximating games.

Our interest is in the outcomes of games with arbitrarily large numbers of bargaining rounds. Accordingly, we define a *solution to the MB model* to be a limit, as T goes to infinity, of dominance solvable payoff vectors from a sequence of T-round, limit dominance solvable bargaining games. We will prove below that under the assumptions we impose, each MB model has a unique, deterministic solution: if there is no proposal that weakly Pareto dominates the disagreement payoff vector $\mathbf{u}^0$, then each round ends with disagreement, and $\mathbf{u}^0$ is realized with certainty; otherwise, there is a unique element $\mathbf{x}^*$ of X, which each player proposes, and all others accept, in the first round of bargaining. The solution to the MB model is then the payoff vector $\mathbf{u}(\mathbf{x}^*)$.

[37]Given two sets Y_1 and Y_2 and a metric d on both of them, the Hausdorff distance between these sets less than δ if for $i = 12$, and any element $y \in Y_i$ there is some point $y' \in Y_{3-i}$ such that $d(y, y') < \delta$.

We establish the existence of the unique solution vector $\mathbf{x}^*$ in three steps. Each step specifies an inductive algorithm. Our first algorithm identifies the proposal $\mathbf{x}^*$, without using any game-theoretic concepts. Second, we demonstrate the existence of a sequence of dominance solvable finite games that approximate, increasingly closely, our original infinite game. Third, we show that any sequence of dominance solvable outcomes for these approximating games indeed converges to the solution vector $\mathbf{x}^*$.

In contrast to the formal specification on pp. 75-76, the time index in the algorithm below runs backwards. To emphasize the distinction we index time with the symbol τ rather than t.

Step I: An algorithm for identifying the solution vector $\mathbf{x}^*$:

In this subsection, we presume that there exists some proposal $\mathbf{x} \in X$ such that $\mathbf{u}(\mathbf{x}) \geq \mathbf{u}^0$, the disagreement payoff vector, and specify an inductive algorithm which selects a unique proposal $\mathbf{x}^*$ from X. Later we will show that $\mathbf{u}(\mathbf{x}^*)$ is the unique solution to the MB model.

First, some preliminaries. Let $\mathsf{Eu}^0 = \mathbf{u}^0$ and let $G^1 = \cap_{r=1}^n \{\mathbf{x} \in X : u_r(\mathbf{x}) \geq \mathsf{Eu}_r^0\}$. By assumption, G^1 is nonempty. Moreover, since the u_r's are concave and hence quasi-concave, the upper contour sets of each u_r are convex. Hence G^1 is the intersection of convex sets and hence convex. Now, for $\tau \in \mathbb{N}$, assume that both $\mathsf{Eu}^{\tau-1}$ and G^τ have been defined and that G^τ is non-empty. This assumption is certainly satisfied for $\tau = 1$. $\mathsf{Eu}^{\tau-1}$ will be interpreted as the *participation constraint vector*, and G^τ as the *adoptable proposal set*, in the τ'th from last round of negotiations. For each player j, let $\mathbf{x}^{j,\tau}$ maximize $u_j(\cdot)$ on G^τ. Since each $u_r(\cdot)$ is strictly concave, G^τ is a convex set; moreover, since $u_j(\cdot)$ is strictly concave, $\mathbf{x}^{j,\tau}$ is uniquely defined. If there exists $\mathbf{x}^* \in G^\tau$ such that $\mathbf{x}^{r,\tau} = \mathbf{x}^*$, for each r, then $\mathbf{x}^*$ will be the solution to the bargaining model. From now on, we assume that this condition is *not* satisfied, i.e., that at least two players' optimal choices differ. We will define both Eu^τ and $G^{\tau+1}$, and establish that $G^{\tau+1}$ is non-empty.

Define $\mathsf{Eu}^\tau = \sum_{r=1}^n \omega_r \mathbf{u}(\mathbf{x}^{r,\tau})$ and let $G^{\tau+1} = \cap_{r=1}^n \{\mathbf{x} \in X : u_r(\mathbf{x}) \geq \mathsf{Eu}_r^\tau\}$. Note that since X is convex, $\mathbf{Ex}^\tau = \sum_{r=1}^n \omega_r \mathbf{x}^{r,\tau} \in X$ and that since each $u_j(\cdot)$ is strictly concave, $\mathbf{u}(\mathbf{Ex}^\tau) > \sum_{r=1}^n \omega_r \mathbf{u}(\mathbf{x}^{r,\tau}) = \mathsf{Eu}^\tau$. It follows, therefore, that $\mathbf{Ex}^\tau \in G^{\tau+1}$, i.e., $G^{\tau+1}$ is nonempty. Thus, provided that G^1 is nonempty, we have defined an infinite sequence of subsets, $\{G^\tau\}$, of X and an infinite sequence of expected payoff vectors, $\{\mathsf{Eu}^\tau\}$. Next note that for each j and τ, $u_j(\mathbf{x}^{j,\tau}) \geq u_j(\mathbf{Ex}^\tau) > \mathsf{Eu}_j^{\tau-1}$. Hence $\{\mathsf{Eu}^\tau\}$ is a strictly increasing sequence. Moreover, since X is compact and $\mathbf{u}(\cdot)$ is continuous, the sequence $\{\mathsf{Eu}^\tau\}$ is bounded above. It now follows from the Monotone Convergence Theorem that $\{\mathsf{Eu}^\tau\}$ converges to a vector $\mathsf{Eu}^* \in \mathbb{R}^n$. Moreover, for each τ and each j, $\mathsf{Eu}_j^\tau \geq \omega_i \left(u_i(\mathbf{x}^{j,\tau}) - \mathsf{Eu}_j^{\tau-1} \right) + \mathsf{Eu}_j^{\tau-1}$. Since $\{\mathsf{Eu}^\tau\}$ converges, it follows that $\lim_\tau \left(u_i(\mathbf{x}^{j,\tau}) - \mathsf{Eu}_j^{\tau-1} \right) = 0$. Next, note that for each τ, $G^{\tau+1} \subsetneq G^\tau$. It now follows that there exists $\mathbf{x}^* \in X$ such that $\cap_{\tau=1}^\infty G^\tau = \mathbf{x}^*$. (Suppose to the contrary that $\cap_{\tau=1}^\infty G^\tau$ contains two distinct points $\mathbf{x}$ and $\mathbf{x}'$. In this case, since $u_j(\cdot)$ is strictly concave, there exists $\epsilon > 0$ s.t. for each j and τ,

$$u_j^\tau(\mathbf{x}^{j,\tau}) \quad \geq \quad u_j(0.5(\mathbf{x}+\mathbf{x}')) - \epsilon \quad \geq \quad \min(u_j(\mathbf{x}), u_j(\mathbf{x}')) \quad \geq \quad \mathsf{Eu}_j^* \quad \geq \quad \mathsf{Eu}_j^{\tau-1}.$$

But this is impossible, since we have established that $\lim_\tau \left(u_i(\mathbf{x}^{j,\tau}) - \mathsf{Eu}_j^{\tau-1} \right) = 0$.) We will establish below that as the number of bargaining rounds increases without bound, in any equilibrium of our bargaining game, each player in the first round makes some proposal arbitrarily close to $\mathbf{x}^*$, and this proposal is adopted immediately.

<u>Step II: An algorithm for constructing a dominance solvable finite game</u>:

For an arbitrary finite game, Rochet:80 shows that condition (R) below is sufficient for dominance solvability.

$$\text{for all } \mathbf{s}, \mathbf{s}' \in S, \text{ for all } i, \text{ if } P_i(\mathbf{s}) = P_i(\mathbf{s}') \text{ then } \mathbf{P}(\mathbf{s}) = \mathbf{P}(\mathbf{s}') \tag{R}$$

Condition R states that if the vectors of payoffs associated with two strategy profiles differ in one component, then they differ in all components. We now provide an algorithm for constructing a finite game with a property which is slightly stronger than (R). Recalling the definition of $\mu(\cdot|\mathbf{s})$ from page 76, the condition is:

$$\text{for all } \mathbf{s}, \mathbf{s}' \in S, \quad \mu(\cdot|\mathbf{s}) \neq \mu(\cdot|\mathbf{s}') \text{ implies that} \qquad (R')$$

$$\text{each element of } \mathbf{P}(\mathbf{s}) \text{ differs from the corresponding element of } \mathbf{P}(\mathbf{s}')$$

To see that (R') implies (R), observe that if (R') is satisfied, then $P_i(\mathbf{s}) = P_i(\mathbf{s}')$ implies $\mu(\cdot|\mathbf{s}) = \mu(\cdot|\mathbf{s}')$, in which case $\mathbf{P}(\mathbf{s}) = \mathbf{P}(\mathbf{s}')$.

We first specify some notation for T-round multi-lateral bargaining games in which proposers are restricted to select from a finite set of proposals. Given a finite subset Y of X, let $S_{|Y} \subset S$ denote the (finite) set of strategies with the property that all proposers in all periods choose proposals from Y. A game in which proposers are so restricted will be called *a bargaining game played on* Y. Now let $M_{|Y}$ denote the set of all probability measures on $X \cup \{\mathbf{x}^0\}$ that can be generated by some profile of strategies in $S_{|Y}$. (Recall that $\mathbf{x}^0$ is the "disagreement proposal" defined on p 75.) Necessarily, $M_{|Y}$ is a finite set. If $Y \cup \{\mathbf{x}^0\}$ is enumerated as $\{\mathbf{x}^1, ..., \mathbf{x}^{\#Y}, \mathbf{x}^0\}$, then each element $\mu \in M_{|Y}$ uniquely defines a vector $\boldsymbol{\sigma}^\mu \in \Delta^{\#Y}$, the $\#Y$-dimensional unit simplex, with the property that for $\eta = 1, ..., \#Y$, $\sigma^\mu_\eta = \mu(\mathbf{x}^\eta)$. Finally, define the expected payoff mapping $\mathbf{\Pi}(\cdot|Y) : M_{|Y} \to \mathbb{R}^n$ by

$$\mathbf{\Pi}(\mu|Y) \quad = \quad \sum_{x \in Y \cup \{\mathbf{x}^0\}} \mathbf{u}(\mathbf{x})\mu(\mathbf{x}) \quad = \quad \sum_{\eta=1}^{\#Y+1} \mathbf{u}(\mathbf{x}^\eta)\sigma^\mu_\eta$$

Note that the *image* of $\mathbf{\Pi}(\cdot|Y)$ is identically equal to the image of $\mathbf{P}(\cdot)$; the difference between the two mappings is that the argument of $\mathbf{P}$ is a strategy profile, while the argument of $\mathbf{\Pi}(\cdot|Y)$ is a probability measure generated by a strategy profile. Note also that if Y' is a perburbation of the set Y with the same number of elements, then the set of all probability measures on $X \cup \{\mathbf{x}^0\}$ that can be generated by some profile of strategies in $S_{|Y'}$ can be recovered from the set $\{\boldsymbol{\sigma}^\mu : \mu \in M_{|Y}\}$.

We now provide an inductive construction that will result in a finite set $Y \subset X$ with the property that any bargaining game played on Y exhibits property (R'). First, select a finite subset X_0 of X and a scalar $\epsilon_0 > 0$ with the following properties.

i) $\mathbf{x} \neq \mathbf{x}' \in X_0$ and $j \in \mathbb{I}$ implies $u_j(\mathbf{x}) \neq u_j(\mathbf{x}')$.

ii) for all $j \in \mathbb{I}$ and all $\mu, \mu' \in M_{|X_0}$, $\Pi_j(\mu) \neq \Pi_j(\mu')$ implies $|\Pi_j(\mu) - \Pi_j(\mu')| > \epsilon_0$ (ϵ_0 exists because $M_{|X_0}$ is a finite set).

Let $\mathbb{M}$ denote the subset of $M_{|X_0} \times M_{|X_0}$ consisting of pairs $\boldsymbol{\mu} = \{\mu^v, \mu^w\}$, $v < w$. Enumerate the distinct elements of $\mathbb{M}$ as $\{\boldsymbol{\mu}^1, ..., \boldsymbol{\mu}^{\#\mathbb{M}}\}$. Now fix $m \in \{1, ..., \#\mathbb{M}\}$ and assume that

i) $\epsilon_{m-1} > 0$ and X_{m-1} have been defined.

ii) for each $1 \leq m' < m$, each j and pair $\boldsymbol{\mu}^{m'} = (\mu^{v'}, \mu^{w'})$, $\left|\Pi_j(\mu^{v'}|X_{m-1}) - \Pi_j(\mu^{w'}|X_{m-1})\right| > \epsilon_{m-1}$

For $m = 1$, the first condition is clearly satisfied, while the second condition is satisfied vacuously. We'll now define $\epsilon_m > 0$ and X_m such that $\#X_m = \#X_{m-1}$ and

$$\text{for each } 1 \leq m' \leq m, \text{ each } j \text{ and each pair } \boldsymbol{\mu}^{m'} = (\mu^{v'}, \mu^{w'}), \qquad (1)$$
$$\left|\Pi_j(\mu^{v'}|X_m) - \Pi_j(\mu^{w'}|X_m)\right| > \epsilon_m.$$

First, write $\boldsymbol{\mu}^m$ as (μ^v, μ^w). Now pick $\gamma \leq \epsilon_{m-1}$ such that $\Pi_j(\mu^v|X_{m-1}) \neq \Pi_j(\mu^w|X_{m-1})$ implies
$\left| \Pi_j(\mu^v|X_{m-1}) - \Pi_j(\mu^w|X_{m-1})\right| > 2\gamma$. There are now two cases to consider.

Case A: $\Pi_j(\mu^v|X_{m-1}) \neq \Pi_j(\mu^w|X_{m-1})$ for all j;

Case B: there exists j such that $\Pi_j(\mu^v|X_{m-1}) = \Pi_j(\mu^w|X_{m-1})$;

In Case A, define $\epsilon_m = \gamma$, $X_m = X_{m-1}$. Now suppose that Case B obtains. In this case, pick $\mathbf{x} \in X_{m-1}$ such that $\mu^v(\mathbf{x}) \neq \mu^w(\mathbf{x})$. Since μ^v is distinct from μ^w, such an $\mathbf{x}$ necessarily exists. Choose $\mathbf{x}'$ near $\mathbf{x}$ such that for all $j \in \mathbb{I}$, $0 < |u_j(\mathbf{x}') - u_j(\mathbf{x})| < \gamma$. Define

X_m to be equal to X_{m-1} except that $\mathbf{x}'$ replaces $\mathbf{x}$. Now observe that for all j such that $\Pi_j(\mu^v|X_{m-1}) = \Pi_j(\mu^w|X_{m-1})$,

$$\begin{aligned} \Pi_j(\mu^v|X_m) &= \Pi_j(\mu^v|X_{m-1}) + \mu^v(\mathbf{x})(u_j(\mathbf{x}') - u_j(\mathbf{x})) \\ &\neq \Pi_j(\mu^w|X_{m-1}) + \mu^w(\mathbf{x})(u_j(\mathbf{x}') - u_j(\mathbf{x})) \quad = \quad \Pi_j(\mu^w|X_m) \end{aligned}$$

while for all j such that $\Pi_j(\mu^v|X_{m-1}) \neq \Pi_j(\mu^w|X_{m-1})$,

$$\begin{aligned} & \Pi_j(\mu^v|X_m) - \Pi_j(\mu^w|X_m) \\ = \quad & \Pi_j(\mu^v|X_{m-1}) - \Pi_j(\mu^w|X_{m-1}) + (\mu^v(\mathbf{x}) - \mu^w(\mathbf{x}))(u_j(\mathbf{x}') - u_j(\mathbf{x})) \\ > \quad & 2\gamma - \gamma \quad > \quad 0 \end{aligned}$$

Finally pick $\epsilon_m \leq \gamma$ such that for all j, $|\Pi_j(\mu^v|X_m) - \Pi_j(\mu^w|X_m)| > \epsilon_m$ and observe that since $\epsilon_m \leq \epsilon_{m-1}$, condition (1) is indeed satisfied for both Cases A and B above. To complete the inductive construction, define $Y = X_{\#\mathbb{M}}$, and note that condition (R') is satisfied for the game played on Y. Since our starting set X_0 was an arbitrary finite subset of X, we can use the above construction to build a sequence of finite games that converge to X in the sense of Hausdorff.

Step III: Existence of a unique limit of limit dominance solvable payoff vectors:

Fix T and consider a sequence X^k of finite subsets of X that Hausdorff converge to X. Assume for convenience that for each $k \in \mathbb{N}$, there exists $\mathbf{x} \in X^k$ such that $\mathbf{u}(\mathbf{x}) \geq \mathbf{u}^0 = \mathsf{\mathbf{Eu}}^0$. Assume also that for each $k \in \mathbb{N}$, the T-period MB game played on X^k is dominance solvable. (Step II established the existence of such a game.) We will show that the sequence of dominance solvable payoff vectors for these approximating games converges to $\mathsf{\mathbf{Eu}}^T$, which is the T'th element of the sequence $\{\mathsf{\mathbf{Eu}}^\tau\}$ of vectors uniquely identified by the algorithm constructed in Step I. The notation we use in this section will parallel the notation used on pp. 79-80, with the addition of "k" superscripts to index the finite approximating proposal spaces.

For each $k \in \mathbb{N}$, set $\mathsf{Eu}^{0,k}$ equal to the disagreement payoff Eu^{0}. Let $\tau \in \{1, ..., T-1\}$ denote the τ'th-from-last round of negotiations (i.e., $\tau = 1$ denotes the final round of negotiations in a T-period game). Now assume that for the game played on X^k, after $2(\tau-1)$ rounds of elimination of weakly dominated strategies, the following is true for any profile of strategies that has survived these elimination rounds (henceforth referred to as "surviving strategy profiles"): (a) if a proposal is not adopted in this round, the continuation payoff vector is $\mathsf{Eu}^{\tau-1,k}$; (b) $\left\{\mathsf{Eu}^{\tau-1,k}\right\} \to_k \mathsf{Eu}^{\tau-1}$, where $\mathsf{Eu}^{\tau-1}$ was defined on p. 80. Both these assumptions are certainly satisfied for $\tau = 1$. We will now define, for each $k \in \mathbb{N}$, the vector $\mathsf{Eu}^{\tau,k}$ with the property that for the game played on X^k, after $2t$ rounds of elimination of weakly dominated strategies, the following is true for any surviving strategy profile: (a) if a proposal is not adopted in the $\tau+1$'th-from-last round of bargaining, the continuation payoff is $\mathsf{Eu}^{\tau,k}$; (b) $\left\{\mathsf{Eu}^{\tau,k}\right\} \to_k \mathsf{Eu}^{\tau}$.

First, define $G^{\tau,k} = \cap_{r=1}^{n}\{\mathbf{x} \in X^k : u_r(\mathbf{x}) > \mathsf{Eu}_r^{\tau-1,k}\}$. Let $S_N^{\tau,k}$ denote the set of all surviving strategies in $S_{|X^k}$ which vote "N" in the τ'th-from-last round on some proposal $\mathbf{x} \in G^{\tau,k}$. Clearly, each strategy $s_r \in S_N^{\tau,k}$ is weakly dominated for player r by the surviving strategy that is identical to s_r, except that it votes "Y" on every $\mathbf{x} \in G^{\tau,k}$ in the τ'th-from last round. Similarly, let $S_{r,Y}^{\tau,k}$ denote the set of surviving strategies that votes "Y" in the τ'th-from-last round on a proposal $\mathbf{x} \in X^k$ such that $u_r(\mathbf{x}) < \mathsf{Eu}_r^{\tau-1,k}$. Once again, each strategy $s_r \in S_{r,Y}^{\tau,k}$ is weakly dominated for player r by the surviving strategy that is identical to s_r, but in this round votes "N" on $\{\mathbf{x} \in X^k : u_r(\mathbf{x}) < \mathsf{Eu}_r^{\tau-1,k}\}$. Now, for each player r, eliminate all strategies in $S_N^{\tau,k} \cup S_{r,Y}^{\tau,k}$. Call this the $(\tau, 1)$'th round of elimination. After the $(\tau, 1)$'th round of elimination, a proposal $\mathbf{x}$ by j in the τ'th-from-last round will be adopted if $\mathbf{x} \in G^{\tau,k}$ and rejected by at least one player if $\mathbf{x} \in \cup_{r=1}^{n}\{\mathbf{x} \in X^k : u_r(\mathbf{x}) < \mathsf{Eu}_r^{\tau-1,k}\}$. It now follows that a necessary condition for a strategy s_j to be undominated after the

$(\tau, 1)$'th round of elimination is that

j's proposal $\mathbf{x}$ in the τ'th-from-last round satisfies:

$$\mathbf{u}(\mathbf{x}) \geq \mathsf{Eu}^{\tau-1,k} \qquad and \qquad u_j(\mathbf{x}) \geq u_j(\mathbf{x}'), \text{ for all } \mathbf{x}' \in G^{\tau,k}. \tag{2}$$

Now eliminate all strategies for player j that fail to satisfy condition (2); call this the $(\tau, 2)$'th round of elimination.

For each $k \in \mathbb{N}$, consider a strategy s_j that survives the $(\tau, 2)'th$ round of elimination and let $\mathbf{x}^{j,\tau,k}$ denote the proposal specified by s_j for presentation in the τ'th-from-last round. We will argue that $\{\mathbf{x}^{j,\tau,k}\} \to_k \mathbf{x}^{j,\tau}$, where $\mathbf{x}^{j,\tau}$ was defined on p. 79. Suppose to the contrary that there exists $\epsilon > 0$ and a subsequence, again indexed by k, such that for all k, $||\mathbf{x}^{j,\tau,k} - \mathbf{x}^{j,\tau}|| > \epsilon$. Since X is compact, this sequence contains a convergent subsequence: let $\mathbf{y}^{j,\tau}$ denote its limit. Now from the definition of G^{τ} (p. 79), since the X^k's converge to X and, by assumption, $\left\{\mathsf{Eu}^{\tau-1,k}\right\} \to_k \mathsf{Eu}^{\tau-1}$, we have $\mathrm{cl}\left(\cup_k G^{\tau,k}\right) = G^{\tau}$. It follows, therefore, that $\mathbf{y}^{j,\tau} \in G^{\tau}$, and $u_j(\mathbf{y}^{j,\tau}) \geq u_j(\mathbf{x}')$, for all $\mathbf{x}' \in G^{\tau}$. However, by definition, the same properties hold for $\mathbf{x}^{j,\tau}$. But this is a contradiction because, since $u_j(\cdot)$ is strictly concave, it has a unique maximizer on G^{τ}.

This completes the inductive argument: we have proved that for all $\epsilon > 0$, there exists $\bar{\tau}$ and a sequence $\{K_\tau\}$ such that for $\tau > \bar{\tau}$ and $k > K_\tau$, $||\mathsf{Eu}^* - \mathsf{Eu}^{\tau,k}|| < \epsilon$. This establishes that the T-round MB game is limit dominance solvable, and that the sequence of limit dominance solvable payoff vectors converges to Eu^*.