

# The Condorcet Paradox Revisited\*

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April 19, 2013

## Abstract

We analyze the Condorcet paradox within a strategic bargaining model with majority voting, exogenous recognition probabilities, and no discounting. Stationary subgame perfect equilibria (SSPE) exist whenever the geometric mean of the players' risk coefficients, ratios of utility differences between alternatives, is at most one. SSPEs ensure agreement within finite expected time. For generic parameter values, SSPEs are unique and exclude Condorcet cycles. In an SSPE, at least two players propose their best alternative and at most one player proposes his middle alternative with positive probability. Players never reject best alternatives, may reject middle alternatives with positive probability, and reject worst alternatives. Recognition probabilities represent bargaining power and drive expected delay. Irrespective of utilities, no delay occurs for suitable distributions of bargaining power, whereas expected delay goes to infinity in the limit where one player holds all bargaining power. Contrary to the case with unanimous approval, a player benefits from an increase in his risk aversion.

KEYWORDS: BARGAINING, CONDORCET PARADOX, STATIONARY SUBGAME PERFECT EQUILIBRIUM, DELAY, RISK AVERSION

JEL CODES: C73, C78, D72

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\***This version: April 19, 2013. First version: March 1, 2010.** The authors thank János Flesch, Eilon Solan, Frans Spinnewyn, Peter Sudhölter, and Walter Trockel for valuable comments.

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# 1 Introduction

Decisions on collective choice problems are often taken by means of majority voting, and the analysis of majority voting is therefore an important topic in political economy. When preferences are such that some alternative beats every other feasible alternative in a pairwise vote, i.e. there is a Condorcet winner, then this will be the outcome reached for a huge variety of games that capture the underlying institution. Such would be the case for instance in models with real-time agenda setting and fixed defaults as in Banks and Duggan (2000), in models with evolving defaults as studied in Bernheim, Rangel and Rayo (2006), as well as in the more traditional social choice approach.

Unfortunately, Condorcet winners may not exist and this gives rise to the Condorcet paradox in which any alternative can be reached from any other by a sequence of alternatives, where each alternative in the sequence beats the previous one by a pairwise majority vote as has been demonstrated in McKelvey (1976, 1979). It has been shown in the literature that the occurrence of the Condorcet paradox is not an artifact. Work by Plott (1967), Rubinstein (1979), Schofield (1983), Cox (1984), and Le Breton (1987) shows that this paradox occurs generically.

The lack of Condorcet winners is also a frequently observed empirical phenomenon. Balinski and Laraki (2010) provide a detailed documentation of the occurrence of the Condorcet paradox in the 1976 Cabernet-Sauvignon wine tasting in Paris, the 1994 general election of the Danish Folketing, and the 2007 French presidential election. Roessler, Shelegia, and Strulovici (2013) explain the underdevelopment of the Roman metro system as a consequence of a Condorcet cycle in the majority preferences over building a metro, preserving antiquities, and not digging.

In its most simple form the paradox features three players, three alternatives, and players' preferences such that a pairwise vote over the alternatives results in a Condorcet cycle: one pair of players prefers the second alternative to the third alternative, another pair of players prefers the first alternative to the second alternative, and a third pair of players prefers the third alternative to the first alternative. Whether and how players reach an agreement in this case is an open issue. It is the main research question addressed in this paper.

We take the strategic bargaining approach to analyze the Condorcet paradox, an approach that is advocated in Baron and Ferejohn (1989) and Banks and Duggan (2000) to study collective decision problems and that extends the seminal work on bargaining by Rubinstein (1982) and Binmore (1987). Such an approach makes explicit how alternatives that are up for voting are selected and how players vote on alternatives, both on and off the equilibrium path.

In every bargaining round, exogenous and positive recognition probabilities select one

player who has the right to propose. This recognized player either proposes one of the three alternatives or gives up the right to propose in which case the bargaining proceeds to the next round. In the former case, the other players publicly vote in a sequential order. Majority voting among three players implies that one vote in favor suffices for acceptance, after which the alternative will be implemented, and players receive their utility. Otherwise, no alternative is implemented and we proceed to the next round where random selection determines the next proposer. Perpetual disagreement leads to a utility of zero for all players.

Our analysis complements the one of Baron and Ferejohn (1989), who use this bargaining protocol to examine the collective decision problem of dividing a surplus, or the more general framework of coalitional bargaining in Chatterjee, Dutta, Ray, and Sengupta (1993), which is the relevant case when the players can make arbitrary side-payments and have utility functions that are linear in the side-payment received. We instead consider the case where collective decision making concerns the choice out of a finite set of alternatives. In many cases side-payments are impossible or prohibited, for instance when a government agency decides on the location of a public facility, chooses what technology to use, and so on, which would make our model the relevant one to consider.

Apart from offering insights in collective choice problems, our model also applies to coalition and network formation, and thereby to marriage and roommate problems. Proposing an alternative corresponds to proposing a coalition in a coalition formation context and to proposing a link in a network formation model. Our model applies to coalition or network formation without side-payments as well as to situations where the coalition or network is formed first, and side-payments are made later. This is for instance the perspective taken in Aumann and Myerson (1988) and Jackson and Wolinsky (1996) in their work on network formation.

Bloch (1996) studies a sequential game of coalition formation when the division of the coalitional surplus is fixed and payoffs are defined relative to the whole coalition structure. Bloch (1996) shows for the rejector-proposes protocol introduced in Selten (1981) that core stable coalition structures can be attained as a stationary subgame perfect equilibrium of the game, but that stationary subgame perfect equilibria in pure strategies may fail to exist when the condition of core stability is violated. When coalitional externalities are absent, one obtains the class of hedonic games studied in Bloch and Diamantoudi (2011). They note that, in roommate problems with odd top rings, equilibria in pure strategies do not exist. When interpreted as a game of coalition formation, our model allows for three non-trivial coalition structures to form, and the Condorcet cycle in our model is equivalent to the absence of a core stable coalition structure and the presence of an odd top ring.

We characterize the set of stationary subgame perfect equilibria (SSPE). A subgame

perfect equilibrium is said to be stationary if the strategy of a player is the same whenever the player faces the same continuation game. In identifying identical continuation games, we follow the approach suggested in Maskin and Tirole (2001) for determining the notion of a stationary strategy. For a foundation of stationary equilibria, we refer to Bhaskar, Mailath, and Morris (2009).

For reasons similar to Binmore, Rubinstein and Wolinsky (1986), we are interested in the case where bargaining occurs relatively fast, so where players do not heavily discount the future. To analyze this case, we derive equilibrium for the limit case where players do not discount the future at all. Since our equilibria will be described as solutions to a finite number of equations in the same number of unknowns, for generic values of our parameters, one can apply the implicit function theorem to derive equilibria nearby the limit equilibrium as a function of the discount factor.

When a player proposes his middle or worst alternative, it will be accepted for sure by the player for whom this is the best alternative. Since proposing his middle alternative strictly dominates proposing his worst alternative, a player will never propose his worst alternative in an SSPE, and the SSPE utility of a player conditional on being the proposer weakly exceeds the utility of his middle alternative. When a player proposes his best alternative, it may or it may not be accepted by the player for whom this is the middle alternative, and it will be rejected by the player for whom this is the worst alternative. A proposing player thereby effectively faces a trade-off between getting the utility of his middle alternative for sure and proposing his best alternative, which may result in a rejection and thereby ultimately in the continuation probability distribution on alternatives.

We show that the continuation utility of a player is at most equal to the utility of his middle alternative, from which it follows that there is an advantage to propose. This implies that, except for degenerate cases, a player is never willing to give up his right to propose. Similarly, a player responding to a proposal consisting of his middle alternative may accept it, thereby securing the utility of his middle alternative, or may reject it, ultimately leading to the continuation probability distribution on all the alternatives.

Essentially a player has to make two decisions: by what probability do I propose my middle alternative and by what probability do I reject my middle alternative when it is offered to me. We define an equilibrium type by the number of players that propose their best alternative for sure, as well as the number of players that accept their middle alternative for sure. We show that across all parameter values seven equilibrium types are possible, three of which occur for a degenerate set of parameter values only, leaving four generic equilibrium types.

We find that in the vast majority of cases, a proposer proposes his best alternative. In two of the generic equilibrium types, all players behave in this way with probability

one, and in the other two generic equilibrium types two out of three players follow this behavior, whereas the third player randomizes between proposing his best and proposing his middle alternative. Rejections of proposals occur more frequently. In two of the generic equilibrium types, two players out of three reject their middle alternative with positive probability, and in only one type of equilibrium none of the players rejects his middle alternative. Still it is the case that in all SSPEs, each proposal is accepted with positive probability and perpetual disagreement does not occur.

Our main results give a novel perspective on the indeterminacy of the simplest Condorcet paradox when it is embedded in an institutional setting where a recognized player puts up an alternative for majority voting. We discuss our main results pointwise:

*Existence.* We derive a very simple condition that is necessary and sufficient for the existence of an SSPE in mixed strategy profiles. To express this condition, we define a player's risk coefficient as the ratio of the utility difference between his best and middle alternative to the utility difference between his middle and worst alternative. The risk coefficient of a player is less than or equal to one if and only if the player prefers his middle alternative to the fair lottery over his best and worst alternative. Risk coefficients are equal to a particular transformation of the risk limit of Zeuthen (1930) and Harsanyi (1977). The condition for existence states that the geometric mean of the players' risk coefficients should be less than or equal to one. As a side result, we also identify the smaller subclass of preferences for which pure strategy SSPEs exist.

*Agreement within finite time with probability 1.* Every SSPE implies a stochastic equilibrium outcome that can be seen as a lottery over all three alternatives, each with positive probability. More importantly, the probability of perpetual disagreement is zero. Consequently, each player's expected equilibrium utility lies strictly between the utility associated with his worst and best alternative. We also establish the stronger result that each player's expected equilibrium utility is at most the utility level of getting the middle alternative for sure.

*Generic uniqueness.* For generic parameter values, there is a unique SSPE, though in degenerate cases multiple SSPE utilities may exist.

*Delay depends crucially on the division of bargaining power.* In bargaining models a suitable way to express bargaining power is by the choice of recognition probabilities, where more bargaining power corresponds to a higher recognition probability. The division of bargaining power is a key factor to explain expected bargaining delay. For each specification of the agents' utility functions it is possible to divide bargaining power in such a way that no delay occurs at all. At the same time, when almost all the bargaining power goes to a single agent, expected delay goes to infinity.

*Stochastic cycles.* Infinite cycles occur according to the logic of the Condorcet paradox

by assumption. However, within a cooperative game theoretic setting, Chwe (1994) argues that cycles cannot occur when players are farsighted. We study SSPE cycles in the sense of whether there is a positive probability that an equilibrium path can result in which all three alternatives have been proposed and rejected before some alternative is accepted. Generically, such SSPE cycles do not occur, though SSPE cycles are possible in degenerate cases.

*Risk aversion improves the bargaining position.* The general conclusion of the bargaining literature with unanimous approval and side-payments is that risk-aversion undermines a player's bargaining position, see e.g. Roth (1985), Safra, Zhou, and Zilcha (1990), and Kihlstrom, Roth, and Schmeidler (1991). Harrington (1990) shows that without unanimous approval this result no longer holds, and when the preferences of players are not too diverse a higher degree of risk-aversion is beneficial. We investigate changes in risk aversion in our discrete choice model featuring the Condorcet paradox and obtain an unambiguous result where we use the criterion of first-order stochastic dominance. A *less* risk-averse player does *worse* in the sense that the probability of attaining his best alternative weakly decreases, and the probability of attaining his worst alternative weakly increases.

The paper is organized as follows. Section 2 describes the bargaining model and Section 3 presents four characteristic examples. Section 4 introduces the notion of SSPE and characterizes the set of SSPEs as the solutions to a specific system of equations. In that section, we also derive some of the general properties and reduce the complexity of the problem at hand. Then, Section 5 analyzes this system by summarizing the various equilibrium types discussed before. The details of the calculations are relegated to Appendix A. All the other proofs can be found in Appendix B. Section 6 combines all the results of Section 5 and studies the questions of SSPE existence and uniqueness. Section 7 analyzes the potential for delay and cycles and Section 8 the role of risk aversion. Section 9 concludes.

## 2 The Model

Three players, labeled  $i = 1, 2, 3$ , have to decide which out of three possible outcomes,  $x_1$ ,  $x_2$ , and  $x_3$ , should be implemented. The preferences of the players satisfy the following restriction

$$x_1 \succ^{1,3} x_2 \succ^{1,2} x_3 \succ^{2,3} x_1. \tag{2.1}$$

The formulation in (2.1) means that players 1 and 3 prefer the outcome  $x_1$  to  $x_2$ , players 1 and 2 prefer the outcome  $x_2$  to  $x_3$ , and players 2 and 3 prefer the outcome  $x_3$  to  $x_1$ , so the players are involved in a decision problem that gives rise to the Condorcet paradox. A naive approach would lead to the claim that majority voting over the alternatives results in a cycle.

Here we model majority voting over the alternatives by means of an explicit extensive-form game. We take the standard non-cooperative bargaining model from the literature, based on the work by Rubinstein (1982) and in particular Binmore (1987). The same bargaining protocol has been advocated in Banks and Duggan (2000) to analyze collective choice problems, and has been used in their work on bargaining in legislatures by Baron and Ferejohn (1989).

We assume that in each period  $t$  some player, say player  $i$ , is selected randomly according to an a priori specified probability distribution. Player  $i$  then decides either to make a proposal to the other two players, i.e. he proposes some outcome  $x_j$ , or he decides not to make a proposal, and the players reach period  $t + 1$ . In the latter case, we say that player  $i$  makes proposal  $x_0$ . In the former case, the other two players vote sequentially.<sup>1</sup> To avoid inessential multiplicity of equilibria, we assume that the player who ranks the outcome highest, is the first one to vote.<sup>2</sup>

Table 1 illustrates the order in which players vote given a proposal by some player, where in the table  $(x_j, i)$  means that proposal  $x_j$  is made by player  $i$ . If player 1 proposes  $x_1$ , then we assume that first player 3 votes and next, conditional on a vote against by player 3, player 2. After player  $i$  makes proposal  $x_j$ , the first player to respond is denoted by  $f_{ji}$ , the second by  $s_{ji}$ .

Proposal	Sequence	Proposal	Sequence	Proposal	Sequence
$(x_1, 1)$	$(3,2)$	$(x_1, 2)$	$(1,3)$	$(x_1, 3)$	$(1,2)$
$(x_2, 1)$	$(2,3)$	$(x_2, 2)$	$(1,3)$	$(x_2, 3)$	$(2,1)$
$(x_3, 1)$	$(3,2)$	$(x_3, 2)$	$(3,1)$	$(x_3, 3)$	$(2,1)$

Table 1: The order of voting.

A voter casts a vote either in favor or against  $x_j$ . If the first voter casts a vote in favor of  $x_j$ , then together with the proposer he forms a majority in favor of  $x_j$ , the outcome  $x_j$  is accepted, and bargaining ends. If the first voter votes against  $x_j$ , then the second voter is allowed to vote. If the second voter casts a vote in favor of  $x_j$ , then again a majority is in favor of  $x_j$ , the outcome  $x_j$  is accepted, and bargaining ends. Otherwise, period  $t + 1$  is

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<sup>1</sup>Simultaneous voting may lead to undesirable equilibria due to coordination failures. For instance, the case where all players vote in favor of all proposals leads to an equilibrium, as there is no player who can gain by deviating. To avoid this problem, it is standard to assume either sequential voting or simultaneous voting with players use stage-undominated voting strategies.

<sup>2</sup>Suppose player 1 proposes  $x_2$ , the best outcome for player 2, and suppose that player 3 votes before player 2. The outcome  $x_2$  is the worst outcome for player 3. Player 3 may nevertheless decide to vote in favor of  $x_2$  since he knows that the proposal will be accepted anyhow by player 2 next and is therefore indifferent as far as his own voting behavior is concerned.

reached. In period  $t + 1$  a new proposer is selected, and the entire procedure is repeated.

We assume that the probability of being recognized as a proposer is given by  $\rho = (\rho_1, \rho_2, \rho_3)$  in each period  $t$ , where  $\rho_1 + \rho_2 + \rho_3 = 1$  and  $\rho_i > 0$  is the probability that player  $i$  is recognized.

The preferences of the players are represented by von-Neumann Morgenstern utility functions. We normalize utilities in such a way that the utility of disagreement forever is 0 for all players.

We are interested in the case where bargaining occurs relatively fast, so players do not heavily discount the future. To analyze this case, we derive equilibrium for the limit case where players do not discount the future at all. For generic values of our parameters, one can apply the implicit function theorem to derive equilibria nearby the limit equilibrium as a function of the discount factor. Player  $i$ 's utility of acceptance of proposal  $x_j$  in period  $t$  is equal to  $u^i(x_j)$ . To satisfy (2.1), we have that

$$u^1(x_1) > u^1(x_2) > u^1(x_3) \geq 0, \tag{2.2}$$

$$u^2(x_2) > u^2(x_3) > u^2(x_1) \geq 0, \tag{2.3}$$

$$u^3(x_3) > u^3(x_1) > u^3(x_2) \geq 0. \tag{2.4}$$

For  $i = 1, 2, 3$ , and  $j = 0, 1, 2, 3$ , we define  $u_j^i = u^i(x_j)$ ,  $u_j = (u_j^1, u_j^2, u_j^3)$ ,  $u^i = (u_0^i, u_1^i, u_2^i, u_3^i)^\top$ , and  $u = (u^1, u^2, u^3)$ . For  $i = 1, 2, 3$ , we define  $b_i, m_i$ , and  $w_i$  as the number of the alternative related to the best, middle, and worst outcome for player  $i$ . For instance, we have  $b_1 = 1$ ,  $m_2 = 3$ , and  $w_3 = 2$ .

Each sequence of proposers, proposals, and votes defines a history. A pure behavioral strategy of a player assigns an action to each history where he has to take a decision, and mixed behavioral strategies are defined in the usual way. Every strategy implies a probability distribution  $(\pi_0, \pi_1, \pi_2, \pi_3)$  over the four possible final outcomes, being perpetual disagreement, agreement on  $x_1$ , agreement on  $x_2$ , and agreement on  $x_3$ . Any mixed strategy therefore implies expected payoffs that are a weighted average of  $u_j$ ,  $j = 0, 1, 2, 3$ , with weights  $\pi_j$ . Note that  $\pi_0 > 0$  implies a positive probability of the players' worst possible outcome of perpetual disagreement.

Utility functions  $u$  and recognition probabilities  $\rho$  satisfying (2.2)–(2.4) determine a game  $G = (u, \rho)$  in extensive form. The class of all such games is denoted  $\mathcal{G}$ .

### 3 Four Characteristic Examples

In this section we present four examples that give rise to the four equilibrium types that occur across generic parameter values. We will show in Section 5 that up to degeneracies, the four examples represent all the possible cases.

Assume players use strategies that are time and history independent. We use  $p_{b_i}^i$ ,  $p_{m_i}^i$ , and  $p_{w_i}^i$  to denote the probability that player  $i$  proposes his best, middle, and worst alternative, respectively. In this section we ignore the possibility that player  $i$  proposes  $x_0$ , i.e. gives up the right to propose, so  $p_{b_i}^i + p_{m_i}^i + p_{w_i}^i = 1$ . Similarly, we use  $a_{b_i}^i$ ,  $a_{m_i}^i$ , and  $a_{w_i}^i$  to denote the probability that player  $i$  accepts his best, middle, and worst alternative, respectively, when offered to him, so  $0 \leq a_{b_i} \leq 1$ ,  $0 \leq a_{m_i} \leq 1$ , and  $0 \leq a_{w_i} \leq 1$ .

For all the examples in this section, we assume that recognition probabilities are uniform, i.e. every player is recognized with probability  $1/3$  to be the proposer. Table 2 presents Example 3.1, a typical case where the Condorcet paradox applies.

	$u^1$	$u^2$	$u^3$	$p^1$	$p^2$	$p^3$	$a^1$	$a^2$	$a^3$
$x_1$	3	0	2	1	0	0	1	0	1
$x_2$	2	3	0	0	1	0	1	1	0
$x_3$	0	2	3	0	0	1	0	1	1

Table 2: Parameter values and equilibrium strategies in Example 3.1.

In Example 3.1, if a player  $i$  proposes his middle alternative, he is sure it will be accepted by the player for whom this is the best alternative. It follows that conditional on being the proposer, his payoff is at least  $u_{m_i}^i$ . It is then clear that no player would like to propose his worst alternative, since it would be accepted by the player for whom this is the best alternative, leading to a payoff  $u_{w_i}^i$ . On the other hand, it is not a priori clear what happens if a player proposes his best alternative. For sure it will be rejected by the player for whom this is the worst alternative. However, the player for whom this is the middle alternative may or may not accept it.

Consider for Example 3.1 the pure strategy combination illustrated in Table 2 where every player proposes his best alternative for sure and always accepts his middle and best alternative when offered to him. At this strategy combination there is immediate agreement and all outcomes occur with probability  $1/3$ .

We claim, and prove formally later on in Theorem A.4.4, that such a strategy combination is an equilibrium. The intuition following from the consideration of one-stage deviations is as follows. When a player is selected as a proposer, he obtains a utility of 3 and clearly has no incentive to deviate. When a player has to vote on his middle alternative he gets a utility of 2 when he follows the equilibrium strategy. A one-shot deviation to a rejection leads to a uniform probability distribution on each outcome, giving rise to an expected utility of  $5/3$ , and is therefore not attractive.

Table 3 presents Example 3.2. The only modification in this example when compared to Example 3.1 is that the utility of the middle alternative of player 2 has dropped from

	$u^1$	$u^2$	$u^3$	$p^1$	$p^2$	$p^3$	$a^1$	$a^2$	$a^3$
$x_1$	3	0	2	1	0	0	1	0	1
$x_2$	2	3	0	0	1	0	1/2	1	0
$x_3$	0	1	3	0	0	1	0	1/2	1

Table 3: Parameter values and equilibrium strategies in Example 3.2.

2 to 1. The pure strategy combination of Example 3.1 is no longer an equilibrium. The reason is that player 2 no longer has an incentive to accept when the middle alternative is offered to him. Indeed, accepting leads to a utility of 1, whereas a one-shot deviation to rejection gives rise to the uniform probability distribution on all alternatives, and an expected utility of  $4/3$ . The problem, in a sense, is that the continuation utility is too favorable for player 2. In order to make him accept his middle alternative, he should be disciplined by rejections of his proposal  $x_2$  by player 1. Indeed, if player 1 rejects an offer of  $x_2$  with probability  $1/2$ , the ex ante probabilities  $\pi_1$  and  $\pi_2$  of outcomes  $x_1$  and  $x_2$  are proportional to  $(2/3, 1/3)$ , so the continuation utility of player 2 following a rejection is 1, as desired to make player 2 indifferent between accepting and rejecting  $x_3$ .

If player 2 would accept  $x_3$  for sure, then player 1 has no incentives to reject  $x_2$  with probability  $1/2$ . Indeed, following a rejection the expected continuation utility of player 1 is below 2 since the outcomes  $x_1$  and  $x_3$  are occurring with equal probability. To improve upon the continuation utility of player 1, player 2 should reject  $x_3$  with probability  $1/2$  when offered to him, making outcomes  $x_1$  and  $x_3$  occur with probability proportional to  $(2/3, 1/3)$ , making player 1 indifferent between accepting and rejecting  $x_2$ . The equilibrium strategy combination is given in Table 3. It is formally proved to be an equilibrium in Theorem A.4.2. In this case there is agreement with probability  $2/3$  per bargaining round and the players reach an agreement within finite time with probability 1. It is impossible that cycles across players occur because the proposal  $x_3$  by player 3 is accepted for sure by player 1.

We turn next to Example 3.3, which is illustrated in Table 4. It has a similar structure as Example 3.2, except that the ratio of the utility differences between best and middle, and middle and worst, have gone down for players 1 and 3 from  $1/3$  to  $1/4$ , and for player 2 from 2 to  $5/4$ . These ratios will be formally defined in Section 4 and are called risk coefficients. Risk coefficients are a crucial tool to understand the strategic situation of the players involved in the bargaining process. One of our main results is for instance that equilibria exist if and only if the product of the risk coefficients, or equivalently, their geometric mean, is less than or equal to 1, a property that is readily verified for the examples of this section.

	$u^1$	$u^2$	$u^3$	$p^1$	$p^2$	$p^3$	$a^1$	$a^2$	$a^3$
$x_1$	5	0	4	1	0	1/4	1	0	1
$x_2$	4	9	0	0	1	0	1	1	0
$x_3$	0	4	5	0	0	3/4	0	4/7	1

Table 4: Parameter values and equilibrium strategies in Example 3.3.

Suppose we had the same equilibrium type as in Example 3.2. As before Player 2 has to be disciplined in order to accept  $x_3$ . If player 1 rejects  $x_2$  with probability  $1/5$ , we have  $\pi_1 : \pi_2 = 5/9 : 4/9$ , which leads to an expected continuation utility of 4 for player 2 following a rejection, which makes him indifferent between accepting and rejecting  $x_2$ , as desired. To make player 1 willing to reject  $x_2$ , his continuation utility following a rejection should be brought up to 4, which can be achieved by having player 2 reject  $x_3$  with probability  $3/4$ . The resulting strategy profile results in  $(\pi_1, \pi_2, \pi_3) = (20/41, 16/41, 5/41)$ . However, now player 3 is no longer willing to propose  $x_3$ . Proposing  $x_3$  leads to acceptance and utility 5 with probability  $1/4$ , but to rejection and utility  $105/41$  with probability  $3/4$ . The expected utility is then below 4, which player 3 could obtain by proposing  $x_1$ .

The alternative to make player 2 accept  $x_3$  is to have player 3 randomize between proposing  $x_1$  and  $x_3$ . Indeed, if player 3 proposes  $x_1$  with probability  $1/4$  and  $x_3$  with probability  $3/4$ , we have  $\pi_1 : \pi_2 = 5/9 : 4/9$ , which makes player 2 indifferent between accepting and rejecting  $x_3$ . To make player 3 willing to randomize between proposing  $x_1$  and proposing  $x_3$ , his proposal  $x_3$  should be rejected by player 2 with probability  $3/7$ . We then have  $(\pi_1, \pi_2, \pi_3) = (35/75, 28/75, 12/75)$ , and player 3 is indeed indifferent between proposing  $x_1$  and getting utility 4 for sure, or proposing  $x_3$ , getting an acceptance and a utility of 5 with probability  $4/7$ , and getting a rejection and an expected utility of  $8/3$  with probability  $3/7$ . We have derived the strategy profile presented in Table 4. It is proved to be an equilibrium in Theorem A.3.2. We can make similar observations as in Example 3.2. An agreement is reached in finite time with probability 1 and Condorcet cycles do not occur.

We finally turn to Example 3.4. It is identical to Example 3.3, except that the risk coefficient of player 2 has gone up from  $5/4$  to 2. Suppose we had the same equilibrium type as in Example 3.3, so we have player 3 mix between proposing  $x_1$  and  $x_3$ .

To make player 2 indifferent between accepting and rejecting  $x_3$ , player 3 should propose  $x_1$  with probability 1. However, since now  $\pi_3 = 0$ , player 1 will only accept the proposal  $x_2$  by player 2 if  $\pi_1 = 0$ , which is not possible, since player 3 proposes  $x_1$  with probability 1.

To make player 2 indifferent between accepting and rejecting  $x_3$ , we need a combination of player 3 randomizing between proposing  $x_1$  and  $x_3$ , and by having player 1 rejecting

	$u^1$	$u^2$	$u^3$	$p^1$	$p^2$	$p^3$	$a^1$	$a^2$	$a^3$
$x_1$	5	0	4	1	0	1/3	1	0	1
$x_2$	4	3	0	0	1	0	2/3	1	0
$x_3$	0	1	5	0	0	2/3	0	1/2	1

Table 5: Parameter values and equilibrium strategies in Example 3.4.

$x_2$  with positive probability. Moreover, to make player 3 willing to propose  $x_1$ , we need player 2 to reject  $x_3$  with positive probability. Solving the resulting system of equations, leads to the equilibrium strategy in Table 5. This strategy profile is proved to be an equilibrium in Theorem A.3.1. Also in this example, the Condorcet paradox is resolved.

We will show in Section 5 that up to degeneracies, the four examples represent all the possible cases, even when recognition probabilities are not required to be uniform. Except for degenerate cases, it holds that the equilibrium either has the structure of Example 3.1 with all players proposing their best alternative and accepting their middle alternative for sure, or the structure of Example 3.2 with all players proposing their best alternative, one player accepting his middle alternative for sure and two players randomizing between acceptance and rejection of their middle alternative, or the structure of Example 3.3 with one player randomizing between proposing his best and middle alternative, and a positive chance of a rejection when he chooses to propose his best alternative, or the structure of Example 3.4 with one player randomizing between proposing his best and middle alternative, and the other two players randomizing between accepting and rejecting their middle alternative.

We see that players propose their best alternative in the vast majority of cases, either since we are in a situation like Example 3.1 or 3.2 where all players propose their best alternative for sure, or since we are in a situation like Example 3.3 or 3.4 where two out of three players propose their best alternative for sure and the third player proposes his best alternative with positive probability. It is also clear that a player who proposes his middle alternative with positive probability, expects rejections with positive probability when he proposes his best alternative. Such a player will never reject when his middle alternative is proposed to him. Also, as Example 3.2 demonstrates, even if everybody proposes his best alternative, rejections can occur, but there is at most one player who considers to do so. Finally, when a player proposes his best alternative, it is never rejected for sure, but there is always a positive probability that it be accepted.

We will show in Section 6 that for generic parameter values equilibria are unique. The equilibrium strategies exhibited in the examples are the only equilibrium strategies.

## 4 Stationary Subgame Perfect Equilibria

We analyze the extensive-form game of Section 2 by examining its stationary subgame perfect equilibria. Suppose a player has to take an action at two subgames that are isomorphic. Then stationarity requires that the player take the same probability mix over actions in both subgames. In defining two subgames to be isomorphic, we follow the approach of Maskin and Tirole (2001), which corresponds to the coarsest way of doing so. A subgame perfect equilibrium in stationary strategies is called a *stationary subgame perfect equilibrium* (SSPE).

Since the continuation game following the selection of a proposer is history independent, we can restrict ourselves to strategies where the proposal is history independent. We denote by  $p_j^i$  the probability that player  $i$  proposes  $x_j$  when he is recognized as proposer. Since the continuation game following a proposal by some player depends only on the proposal made and the identity of the proposer, the rejection probability may only depend on the identity of the proposer and the proposal made, but not on any other aspect of the history. The continuation game starting with the last responder to a proposal depends on the proposal made, but does not depend on the identity of the proposer. We therefore require the response of the last responder to be independent of the identity of the proposer.

The probability that player  $i$  rejects a proposal  $x_j$  by player  $h$  is denoted  $r_{jh}^i$ . As explained in the previous paragraph, the notion of a stationary strategy imposes the requirement  $r_{32}^1 = r_{33}^1$ ,  $r_{11}^2 = r_{13}^2$ , and  $r_{21}^3 = r_{22}^3$ . For notational simplicity, we define  $r_{0h}^i = 1$ . We define the set  $P$  of admissible proposals by  $P = P^1 \times P^2 \times P^3$ , where

$$P^i = \{p^i \in \mathbb{R}_+^4 \mid \sum_{j=0,1,2,3} p_j^i = 1\}, \quad i = 1, 2, 3,$$

and the set  $R$  of admissible rejection probabilities by  $R = R^1 \times R^2 \times R^3$ , where

$$R^i = \{r^i \in [0, 1]^{4 \times 2} \mid \text{for } h, h' \neq i, r_{0h}^i = 1 \text{ and } r_{w_i h}^i = r_{w_i h'}^i\}.$$

Given stationary strategies, we can compute the expected utilities of the players. It will be useful to do so conditional on the identity of the proposer. The expected utility of player  $i$  conditional on the proposer being player  $h$  is denoted by  $v_h^i$ . Unconditional expected utility of player  $i$  is  $z^i$  and satisfies  $z^i = \sum_{h=1}^3 \rho_h v_h^i$ .

Stationarity of the strategies implies that the following recursive system holds,

$$v_h^i = \sum_{j=0}^3 p_j^h (1 - r_{jh}^{h-1} r_{jh}^{h+1}) u_j^i + \sum_{j=0}^3 p_j^h r_{jh}^{h-1} r_{jh}^{h+1} z^i, \quad i = 1, 2, 3, \quad h = 1, 2, 3, \quad (4.1)$$

$$z^i = \sum_{h=1}^3 \rho_h v_h^i, \quad i = 1, 2, 3. \quad (4.2)$$

In the definition of rejection probabilities above, we identify player 0 with player 3, and player 4 with player 1. Equation (4.1) expresses that the expected utility of player  $i$  conditional on the proposer being player  $h$  is equal to the sum over all proposals of the probability that player  $h$  makes this proposal and that it is accepted by the other players times the utility of the proposal plus the probability that player  $h$  makes a proposal that is rejected times the continuation utility  $z^i$ .

For the remainder of this section, let  $(p, r)$  be an SSPE inducing continuation utilities  $v$  and  $z$ . No player has a profitable deviation at any decision node, so in particular, no player has a profitable one-shot deviation at any decision node. The absence of a profitable one-shot deviation is equivalent to the following set of implications, where in (4.3) it holds that  $i \in \{1, 2, 3\}$  and  $j \in \{0, 1, 2, 3\}$ ,

$$p_j^i > 0 \Rightarrow (1 - r_{ji}^{i-1} r_{ji}^{i+1}) u_j^i + r_{ji}^{i-1} r_{ji}^{i+1} z^i = \max_{k \in \{0, 1, 2, 3\}} (1 - r_{ki}^{i-1} r_{ki}^{i+1}) u_k^i + r_{ki}^{i-1} r_{ki}^{i+1} z^i, \quad (4.3)$$

$$r_{jh}^i > 0 \Rightarrow z^i \geq u_j^i \text{ or } r_{jh}^{i'} = 0, \quad j = 1, 2, 3, \quad h = 1, 2, 3, \quad i = f_{jh}, \quad i' = s_{jh}, \quad (4.4)$$

$$r_{jh}^i < 1 \Rightarrow z^i \leq u_j^i \text{ or } r_{jh}^{i'} = 0, \quad j = 1, 2, 3, \quad h = 1, 2, 3, \quad i = f_{jh}, \quad i' = s_{jh}, \quad (4.5)$$

$$r_{jh}^i > 0 \Rightarrow z^i \geq u_j^i, \quad j = 1, 2, 3, \quad h = 1, 2, 3, \quad i = s_{jh}, \quad (4.6)$$

$$r_{jh}^i < 1 \Rightarrow z^i \leq u_j^i, \quad j = 1, 2, 3, \quad h = 1, 2, 3, \quad i = s_{jh}. \quad (4.7)$$

Equality (4.3) expresses that a proposal that is made with positive probability maximizes the sum of instantaneous and continuation utility. We obtain (4.4) by observing that  $r_{jh}^i > 0$  implies  $(1 - r_{jh}^{i'}) u_j^i + r_{jh}^{i'} z^i \geq u_j^i$ ; the utility to player  $i$  of rejecting proposal  $j$  by player  $h$  should weakly exceed the utility of acceptance. This inequality is equivalent to  $z^i \geq u_j^i$  or  $r_{jh}^{i'} = 0$ . The derivation of (4.5)–(4.7) is analogous. Observe that (4.4)–(4.5) correspond to the cases where player  $i$  is the first voter to accept or reject a proposal, and (4.6)–(4.7) to the cases where player  $i$  is the second voter to make such a decision.

We now derive several properties of SSPEs, thereby reducing (4.3)–(4.7) to a considerably simpler system. The first property states that forever delay with probability 1 is not an SSPE. Indeed, forever delay with probability 1 implies, for every  $i$ ,  $z^i = 0$  and  $v^i = 0$ . By (4.3), player 1 should obtain expected utility 0 from proposing  $x_1$ , which can only be the case if  $r_{11}^2 = r_{11}^3 = 1$ . By (4.4),  $r_{11}^3 = 1$  implies  $z^3 \geq u_1^3$  or  $r_{11}^2 = 0$ . This leads to a contradiction as  $z^3 = 0 < u_1^3$  and  $r_{11}^2 = 1$ . It follows that forever delay with probability 1 is not an SSPE.

We have derived that some player makes with positive probability a proposal that is accepted with positive probability. Since such a player is recognized with positive probability, the probability that negotiations have not terminated at period  $t$  goes to zero as  $t$  goes to infinity. In other words, at any SSPE there is an agreement in finite time with probability 1. In SSPE, even perfectly patient players do not cycle forever with positive probability.

**THEOREM 4.1** *It holds that  $\pi_0 = 0$ , every SSPE leads to agreement in finite time with probability 1.*

Since  $\pi_0 = 0$ , each  $z^i$  is therefore a weighted average of  $u_j^i$ ,  $j = 1, 2, 3$ , with  $\pi_j \in [0, 1]$  such that  $\pi_1 + \pi_2 + \pi_3 = 1$  independent of  $i$ . It holds in particular that  $\pi_j > 0$  for some  $j = 1, 2, 3$  and  $(z^1, z^2, z^3) \neq 0$ .

This result shows that bargaining under exogenous recognition probabilities is a road map to overcome the Condorcet paradox. Given the indeterminacy of many cooperative theories about the Condorcet paradox, this result already suggests a great potential in further elaborating the bargaining approach.

Conditions (4.1)–(4.7) are necessary conditions for an SSPE. For games with discounting, these necessary conditions are also sufficient. Since we abstain from discounting, we need the slightly stronger necessary and sufficient conditions as presented in Theorem 4.2.

**THEOREM 4.2** *The strategy profile  $(p, r) \in P \times R$  is an SSPE if and only if there is  $h$  such that  $\sum_{j=0}^3 p_j^h r_{jh}^{h-1} r_{jh}^{h+1} < 1$  and there is  $v \in \mathbb{R}^{3 \times 3}$  and  $z \in \mathbb{R}^3$  such that (4.1)–(4.7) hold.*

In the next step, we use the characterization of SSPE given in Theorem 4.2 to derive a number of intuitive properties that equilibria should satisfy.

**THEOREM 4.3** *Let the strategy profile  $(p, r)$  be an SSPE with continuation utilities  $z$  and outcome probability distribution  $\pi$ . Then*

$$p_{w_i}^i = 0, \quad i = 1, 2, 3, \quad (4.8)$$

$$r_{w_i h}^i = 1, \quad i = 1, 2, 3, \quad h \neq i, \quad (4.9)$$

$$r_{21}^2 = r_{32}^3 = r_{13}^1 = 0, \quad (4.10)$$

$$r_{31}^2 r_{31}^3 = r_{12}^1 r_{12}^3 = r_{23}^1 r_{23}^2 = 0, \quad (4.11)$$

$$z^i > u_{w_i}^i, \quad i = 1, 2, 3, \quad (4.12)$$

$$z^i < u_{b_i}^i, \quad i = 1, 2, 3, \quad (4.13)$$

$$\pi_1, \pi_2, \pi_3 > 0. \quad (4.14)$$

According to (4.12), each player  $i$  has  $z^i$  strictly exceeding the utility  $u_{w_i}^i$  of his worst outcome and, according to (4.13), has  $z^i$  strictly lower than the utility of his best outcome,  $u_{b_i}^i$ . It then follows that any voter rejects his worst alternative for sure as expressed in (4.9). It follows from (4.10) that the middle alternative is accepted by the player for whom this is the best alternative, whereas (4.11) claims that proposing the worst alternative leads to an acceptance. The recognized player can therefore always conclude the bargaining for

sure by proposing his worst or his middle alternative. As a corollary, a recognized player will never propose his worst alternative, because he can do strictly better by proposing his middle alternative, and (4.8) follows. Finally, (4.14) states that, ex ante, every alternative is accepted with strictly positive probability.

The next result claims that there is no loss of generality in restricting the analysis to proposer-independent rejection probabilities.

**THEOREM 4.4** *If  $(p, r) \in P \times R$  is an SSPE inducing utilities  $v$  and  $z$ , then there is also an SSPE  $(p, \bar{r}) \in P \times R$  inducing utilities  $v$  and  $z$  such that  $\bar{r}$  is proposer-independent, i.e.  $\bar{r}_{jh}^i = \bar{r}_{jh'}^i$  for all  $i, j, h$ , and  $h'$ . Moreover,  $\bar{r}$  can be defined by setting, for  $i = 1, 2, 3$ ,  $\bar{r}_{b_{i+1}}^i = 0$ ,  $\bar{r}_{m_{i-1}}^i = r_{m_{i+1}}^i$ , and  $\bar{r}_{jh}^i = r_{jh}^i$ , otherwise.*

By virtue of Theorem 4.4, we may drop the subscript indicating the proposer from the notation of a rejection probability. It is also more convenient now to express all equations in terms of acceptance probabilities rather than rejection probabilities. The set of proposer-independent acceptance probabilities is  $A = A^1 \times A^2 \times A^3$ , where

$$A^i = \{a^i \in [0, 1]^4 \mid a_0^i = 0\}.$$

It follows from Theorem 4.3 that at an SSPE  $(p, \bar{a}) \in P \times A$ , for every player  $i$ ,  $p_{w_i}^i = 0$ ,  $\bar{a}_{w_i}^i = 0$ , and  $\bar{a}_{b_i}^i = 1$ . The only variables that have not yet been determined are  $p_0^i$ ,  $p_{m_i}^i$ ,  $p_{b_i}^i$ , and  $\bar{a}_{m_i}^i$ . It seems intuitive that the recognized player is better off making some proposal instead of not making a proposal, so  $p_0^i$  should be equal to 0. As we will show in Section A.1, for some parameter values we can have  $p_0^i > 0$  for some  $i$ . In such cases, however, there also exists an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_0^i = 0$  for all players  $i$  that yields exactly the same utilities. This implies that in characterizing the set of SSPEs, we may first search for SSPEs  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_0^i = 0$  for all players  $i$ . Indeed, if  $(p, \bar{a})$  is an SSPE with  $p_0^i \neq 0$  for some  $i$ , then  $(\bar{p}, \bar{a})$  is also an SSPE, where  $\bar{p}_{b_i}^i = p_{b_i}^i + p_0^i$ ,  $\bar{p}_0^i = 0$ , and  $\bar{p}_j^i = p_j^i$  for  $j \neq 0, b_i$ . By the definition of SSPE it should not be profitable to propose  $x_{b_i}$  instead of  $x_0$ . This means that either  $x_{b_i}$  is rejected with probability 1 when proposed or  $z^i = u_{b_i}^i$ . The latter case contradicts (4.13), so we only have to consider the former case. Since we are considering SSPEs, the change in strategy from not making a proposal to proposing one's best outcome, which is rejected with probability 1, is not affecting the payoffs of anyone, and is also an SSPE.

The next proposition gives an easy characterization of SSPEs  $(\bar{p}, \bar{a}) \in P \times A$  where no player gives up the right to make a proposal, i.e.  $\bar{p}_0^i = 0$  for all players  $i$ .

**THEOREM 4.5** *The strategy profile  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE where all players make a proposal with probability one if and only if for  $i = 1, 2, 3$ ,  $\bar{p}_0^i = \bar{p}_{w_i}^i = 0$ ,  $\bar{a}_{b_i}^i = 1$ ,  $\bar{a}_{w_i}^i = 0$ ,*

and there is  $\bar{\pi} \in \mathbb{R}_{++}^3$  and  $\bar{z} \in \mathbb{R}^3$  such that

$$\bar{p}_{m_i}^i > 0 \Rightarrow u_{m_i}^i \geq \bar{a}_{m_{i-1}}^{i-1} u_{b_i}^i + (1 - \bar{a}_{m_{i-1}}^{i-1}) \bar{z}^i, \quad i = 1, 2, 3, \quad (4.15)$$

$$\bar{p}_{b_i}^i > 0 \Rightarrow \bar{a}_{m_{i-1}}^{i-1} u_{b_i}^i + (1 - \bar{a}_{m_{i-1}}^{i-1}) \bar{z}^i \geq u_{m_i}^i, \quad i = 1, 2, 3, \quad (4.16)$$

$$\bar{a}_{m_i}^i < 1 \Rightarrow \bar{z}^i \geq u_{m_i}^i, \quad i = 1, 2, 3, \quad (4.17)$$

$$\bar{a}_{m_i}^i > 0 \Rightarrow \bar{z}^i \leq u_{m_i}^i, \quad i = 1, 2, 3, \quad (4.18)$$

$$\bar{\pi}_1 u_1^i + \bar{\pi}_2 u_2^i + \bar{\pi}_3 u_3^i = \bar{z}^i, \quad i = 1, 2, 3, \quad (4.19)$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1, \quad (4.20)$$

$$\bar{\pi}_1 : \bar{\pi}_2 = \rho_1 \bar{p}_{b_1}^1 \bar{a}_1^3 + \rho_3 \bar{p}_{m_3}^3 : \rho_2 \bar{p}_{b_2}^2 \bar{a}_2^1 + \rho_1 \bar{p}_{m_1}^1, \quad (4.21)$$

$$\bar{\pi}_2 : \bar{\pi}_3 = \rho_2 \bar{p}_{b_2}^2 \bar{a}_2^1 + \rho_1 \bar{p}_{m_1}^1 : \rho_3 \bar{p}_{b_3}^3 \bar{a}_3^2 + \rho_2 \bar{p}_{m_2}^2. \quad (4.22)$$

## 5 Equilibrium Types

The results of the previous section show that player  $i$  faces two dilemmas. First, by what probability  $p_{m_i}^i$  will I propose my middle alternative  $x_{m_i}$  knowing it will be accepted for sure instead of taking the risk involved in proposing my best alternative. Second, by what probability  $a_{m_i}^i$  will I accept my middle alternative  $x_{m_i}$  when offered to me knowing that rejecting it leads to a gamble over my top three alternatives including my worst. These dilemmas concern the SSPE values of  $p_{m_i}^i$  and  $a_{m_i}^i$  that also pin down  $p_{b_i}^i = 1 - p_{m_i}^i$ .

The answer to the first dilemma results in four possible types of equilibrium. The first one is where all players  $i$  have a positive  $\bar{p}_{m_i}^i$ . This case is analyzed in Appendix A.1. The other types of equilibria are characterized by two, one, and none of the players having a positive  $\bar{p}_{m_i}^i$  and are treated in Appendix A.2, A.3, and A.4, respectively. The answer to the second dilemma is intimately related to the value of the equilibrium continuation utility  $\bar{z}^i$ . We will show that all SSPEs have the property that  $\bar{z}^i \leq u_{m_i}^i$ . Then it follows that  $\bar{a}_{m_i}^i = 1$  if  $\bar{z}^i < u_{m_i}^i$ , whereas values for  $\bar{a}_{m_i}^i$  strictly below 1 are admitted when  $\bar{z}^i = u_{m_i}^i$ .

Theorem A.1 collects the conditions under which an SSPE with three players having a positive  $\bar{p}_{m_i}^i$  exists. These conditions hold in degenerate cases only. Moreover, in any such SSPE it holds that  $\bar{z}^i = u_{m_i}^i$  for all players  $i$ . We show that SSPEs with two players having a positive  $\bar{p}_{m_i}^i$  do not exist. For the case with one of the players having a positive  $\bar{p}_{m_i}^i$  there exist two equilibrium subtypes, depending on the number of players with  $\bar{z}^i = u_{m_i}^i$ . These subtypes are treated in the subsections A.3.1, when there is one such player, and A.3.2, when there are two such players. Theorem A.3.1 and A.3.2 provide conditions under which such SSPEs exist. For the case with none of the players having a positive  $\bar{p}_{m_i}^i$  there exist four equilibrium subtypes, again depending on the number of players with  $\bar{z}^i = u_{m_i}^i$ .

Theorem	Example	Proposals	Utilities	Occurrence
A.1		$\bar{p}_2^1 > 0$ $\bar{p}_3^2 > 0$ $\bar{p}_1^3 > 0$	$\bar{z}^1 = u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 = u_1^3$	Degenerate
A.3.1	3.4	$\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 > 0$ $\bar{p}_2^1 = 0$ $\bar{p}_3^2 > 0$ $\bar{p}_1^3 = 0$ $\bar{p}_2^1 > 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$	$\bar{z}^1 = u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 < u_1^3$ $\bar{z}^1 = u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 = u_1^3$ $\bar{z}^1 < u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 = u_1^3$	
A.3.2	3.3	$\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 > 0$ $\bar{p}_2^1 = 0$ $\bar{p}_3^2 > 0$ $\bar{p}_1^3 = 0$ $\bar{p}_2^1 > 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$	$\bar{z}^1 < u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 < u_1^3$ $\bar{z}^1 = u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 < u_1^3$ $\bar{z}^1 < u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 = u_1^3$	
A.4.1		$\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$	$\bar{z}^1 = u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 = u_1^3$	Degenerate
A.4.2	3.2	$\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$ $\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$ $\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$	$\bar{z}^1 = u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 < u_1^3$ $\bar{z}^1 = u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 = u_1^3$ $\bar{z}^1 < u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 = u_1^3$	
A.4.3		$\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$ $\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$ $\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$	$\bar{z}^1 = u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 < u_1^3$ $\bar{z}^1 < u_2^1$ $\bar{z}^2 = u_3^2$ $\bar{z}^3 < u_1^3$ $\bar{z}^1 < u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 = u_1^3$	Degenerate Degenerate Degenerate
A.4.4	3.1	$\bar{p}_2^1 = 0$ $\bar{p}_3^2 = 0$ $\bar{p}_1^3 = 0$	$\bar{z}^1 < u_2^1$ $\bar{z}^2 < u_3^2$ $\bar{z}^3 < u_1^3$	

Table 6: Characteristics of the various types of equilibrium.

These subtypes are treated in the Subsections A.4.1, A.4.2, A.4.3, and A.4.4 of Appendix A.4, where Subsection A.4. $k$  treats the case when there are  $k - 1$  players with  $\bar{z}^i = u_{m_i}^i$ . Theorem A.4.1, A.4.2, A.4.3, and A.4.4 collect the conditions under which such SSPEs exist.

Table 6 summarizes the characteristics of the SSPEs as found in the Appendix. The equilibrium types and subtypes lead to a total of seven cases, with three cases being degenerate. The cases A.3.1, A.3.2, A.4.1, and A.4.2 have three rows, corresponding to permutations of the players' roles. Four cases, A.3.1, A.3.2, A.4.2, and A.4.4, are robust in the sense of having positive Lebesgue measure in the parameter space. Case A.4.4 corresponds to an SSPE in pure strategies.

Table 7 shows the conditions for which particular types of equilibria exist. To explain these conditions, it is instructive to define the *risk coefficient*  $\alpha_i$  of player  $i$  by

$$\alpha_i = \frac{u_{b_i}^i - u_{m_i}^i}{u_{m_i}^i - u_{w_i}^i}, \quad i = 1, 2, 3.$$

Moreover, for notational convenience, we define

$$\beta_1 = \frac{1 - \alpha_1 \alpha_2 \alpha_3}{\alpha_1 + \alpha_1 \alpha_3 + \alpha_1 \alpha_2 \alpha_3}, \quad \beta_2 = \frac{1 - \alpha_1 \alpha_2 \alpha_3}{\alpha_2 + \alpha_1 \alpha_2 + \alpha_1 \alpha_2 \alpha_3}, \quad \text{and} \quad \beta_3 = \frac{1 - \alpha_1 \alpha_2 \alpha_3}{\alpha_3 + \alpha_2 \alpha_3 + \alpha_1 \alpha_2 \alpha_3}.$$

Theorem	Example	Conditions on $\alpha$	Conditions on $\rho$	Occurrence
A.1		$\alpha_1\alpha_2\alpha_3 = 1$		Degenerate
A.3.1	3.4	$\alpha_1\alpha_2\alpha_3 < 1$	$\frac{\rho_1}{\rho_3} < \beta_1$ $\rho_2 \geq \alpha_3\beta_3$ $\frac{\rho_3}{\rho_2} < \beta_3$ $\rho_1 \geq \alpha_2\beta_2$ $\frac{\rho_2}{\rho_1} < \beta_2$ $\rho_3 \geq \alpha_1\beta_1$	
A.3.2	3.3	$\alpha_1\alpha_2\alpha_3 < 1$	$\frac{\rho_1}{\rho_2} < \alpha_2$ $\rho_2 < \alpha_3\beta_3$ $\frac{\rho_3}{\rho_1} < \alpha_1$ $\rho_1 < \alpha_2\beta_2$ $\frac{\rho_2}{\rho_3} < \alpha_3$ $\rho_3 < \alpha_1\beta_1$	
A.4.1		$\alpha_1\alpha_2\alpha_3 = 1$		Degenerate
A.4.2	3.2	$\alpha_1\alpha_2\alpha_3 < 1$	$\frac{\rho_1}{\rho_3} \geq \beta_1$ $\frac{\rho_1}{\rho_2} \leq \alpha_2$ $\frac{\rho_3}{\rho_1} \geq \alpha_1$ $\frac{\rho_3}{\rho_2} \geq \beta_3$ $\frac{\rho_3}{\rho_1} \leq \alpha_1$ $\frac{\rho_2}{\rho_3} \geq \alpha_3$ $\frac{\rho_2}{\rho_1} \geq \beta_2$ $\frac{\rho_2}{\rho_3} \leq \alpha_3$ $\frac{\rho_1}{\rho_2} \geq \alpha_2$	
A.4.3		$\alpha_1\alpha_2\alpha_3 < 1$	$\frac{\rho_3}{\rho_1} = \alpha_1$ $\rho_1 < \frac{1}{1+\alpha_1+\alpha_1\alpha_3}$ $\frac{\rho_1}{\rho_2} = \alpha_2$ $\rho_2 < \frac{1}{1+\alpha_2+\alpha_1\alpha_2}$ $\frac{\rho_2}{\rho_3} = \alpha_3$ $\rho_3 < \frac{1}{1+\alpha_3+\alpha_2\alpha_3}$	Degenerate Degenerate Degenerate
A.4.4	3.1	$\alpha_1\alpha_2\alpha_3 < 1$	$\frac{\rho_1}{\rho_2} > \alpha_2$ $\frac{\rho_2}{\rho_3} > \alpha_3$ $\frac{\rho_3}{\rho_1} > \alpha_1$	

Table 7: Conditions under which various types of equilibria exist.

Table 7 demonstrates that the conditions for SSPE existence can be formulated in terms of the players' risk coefficients (since also  $\beta_i$  can be expressed in terms of  $\alpha_1$ ,  $\alpha_2$ , and  $\alpha_3$ ) and the recognition probability vector  $\rho$  only.

The risk coefficient is closely related to the concept of *risk limit* as introduced in Zeuthen (1930) and further developed in Harsanyi (1977). The risk limit is defined in a setting with two players and three outcomes. There is the outcome proposed by the player himself, say  $y_1$ , the outcome proposed by his opponent, say  $y_2$ , and the disagreement outcome, say  $y_0$ . The risk limit of a player is then defined as the probability on the disagreement outcome for which he would be indifferent between getting the disagreement outcome with that probability and  $y_1$  with the remaining probability, and getting outcome  $y_2$  for sure. In a formula the risk limit  $\ell$  is given by

$$\ell = \frac{u(y_1) - u(y_2)}{u(y_1) - u(y_0)}.$$

This paper involves three players and four alternatives (we now count the disagreement outcome as one alternative), so the risk limit is not directly applicable. However, if we define  $y_1$  as the best alternative  $x_{b_i}$  for player  $i$ ,  $y_2$  as his middle alternative  $x_{m_i}$ , and  $y_0$  as

his worst alternative  $x_{w_i}$ , then a straightforward calculation reveals that

$$\ell_i = \frac{\alpha_i}{1 + \alpha_i}.$$

Alternatively, we can write  $\alpha_i = \ell_i/(1 - \ell_i)$ .

A player  $i$  who is indifferent between getting  $x_{m_i}$  for sure and a fair lottery on  $x_{b_i}$  and  $x_{w_i}$  has a risk coefficient of 1. A player with a risk coefficient above 1 prefers the lottery, a player with a risk coefficient below 1 prefers getting his middle outcome for sure. It is immediate from Table 7 that the a necessary condition for SSPE existence is  $\alpha_1\alpha_2\alpha_3 \leq 1$ , or equivalently,  $\sqrt[3]{\alpha_1\alpha_2\alpha_3} \leq 1$ . In words this condition expresses that the geometric mean of the players' risk coefficients is less than or equal to 1. In the next section this condition is also shown to be sufficient for SSPE existence.

The robust cases have the following defining characteristics: First, conditional on being recognized, at most one player randomizes between his best and middle alternative, and the other players always propose their best alternative for sure. To put it differently, at most one player proposes cautiously and the others aggressively. Second, the number of players who propose their best alternative and get it accepted for sure can be any number ranging from one to three, but it cannot be zero. Third, at the start of any bargaining round during ongoing negotiations, all players can realize, in expectation, an SSPE utility that is at most the utility of the middle alternative, so  $\bar{z}^i \leq u_{m_i}^i$ . In case the inequality is strict, player  $i$  accepts his middle alternative for sure, whenever it is on the table. In any SSPE, this will provoke player  $i + 1$ , for whom  $m_i$  is the best alternative, to propose aggressively whenever he is recognized. Fourth, conditional on being recognized, a player realizes a utility weakly exceeding the utility of his middle alternative, so  $\bar{v}_i^i \geq u_{m_i}^i$ . Moreover, it can be shown that there is a strict advantage in being recognized, so  $\bar{v}_i^i > \bar{z}^i$ .

## 6 Existence and Uniqueness of SSPEs

Table 7 shows that SSPEs can only exist if the geometric mean of the risk coefficients is less than or equal to 1. The next result states that this condition is not only necessary, but also sufficient for the existence of SSPEs.

**THEOREM 6.1** *There exists an SSPE if and only if  $\alpha_1\alpha_2\alpha_3 \leq 1$ .*

The necessary and sufficient condition for SSPE existence requires risk coefficients to be sufficiently low on average. It allows for one or two risk coefficients that are larger than one, but then at least one player's risk coefficient should be sufficiently below one. A player with a low risk coefficient prefers his middle outcome over a lottery involving his

worst and best outcome, and is therefore more inclined to accept proposals offering his middle outcome. The uncertainty over outcomes resulting from the rejection of a proposal helps to avoid the Condorcet paradox and leads to equilibrium existence.

What can be said when  $\alpha_1\alpha_2\alpha_3 > 1$ ? An SSPE does not exist by Theorem 6.1. Nevertheless, it is conceivable that weaker versions of equilibrium do exist. Suppose that we change the utilities in the game in the following way. Whenever an agreement is reached, players receive the payoff related to this agreement in every period following the agreement and the utility of a player is determined by the average reward criterion. The resulting game thereby falls into the class of average reward stochastic games. Since the game also belongs to the subclass of three-player absorbing games, it follows from Solan (1999) that an  $\varepsilon$ -equilibrium payoff exists for every  $\varepsilon > 0$ . Since our game also belongs to the class of perfect information stochastic games, the existence of a Nash equilibrium follows from the results of Thuijsman and Raghavan (1997). Finally, our game is also a recursive perfect information game with non-negative payoffs, a class for which Flesch, Kuipers, Schoenmakers, and Vrieze (2010) demonstrate the existence of a subgame-perfect  $\varepsilon$ -equilibrium for every  $\varepsilon > 0$ .

In our model, SSPE may not be unique and there might be infinitely many SSPE utilities. This occurs under the conditions of Theorem A.4.3. The following result demonstrates that such examples are degenerate in the sense that this set of games has a closure with Lebesgue measure zero. To compute the Lebesgue measure of a set of games, we consider a game  $(u, \rho)$  as an element of  $\mathbb{R}^9 \times \mathbb{R}^2$ , where we identify  $\rho$  by its first two coordinates. To require the zero Lebesgue measure property for the closure of a set of games, evidently implies this property for the set of games itself, but not vice versa, as for instance illustrated by the set of rational numbers.

**THEOREM 6.2** *Consider the set of games  $(u, \rho) \in \mathcal{G}$  such that  $\alpha_1\alpha_2\alpha_3 \leq 1$ . Except for a subset of games whose closure has Lebesgue measure zero, there is a unique SSPE.*

The generic uniqueness of SSPEs enables us to carry out meaningful comparative statics exercises, the subject of the next two sections.

## 7 Delay and Cycles

We analyze the extent to which there can be delay in the SSPE. If the probability of delay in a single bargaining round is  $\delta$ , then the expected delay is equal to  $\delta/(1-\delta)$  periods. Using the results of the Appendix, it is a straightforward exercise to compute the probability of delay in a single bargaining round. Table 8 gives an overview of the delay probabilities.

Theorem	Example	Delay probability	Occurrence
A.1		$[1 - (1 + \alpha_2 + \alpha_1\alpha_2) \min\{\rho_1, \frac{\rho_2}{\alpha_1\alpha_2}, \frac{\rho_3}{\alpha_2}\}, 1)$	Degenerate
A.3.1	2.4	$\rho_2 + (\alpha_1\alpha_2\alpha_3(1 + \beta_2) - \beta_2)(1 - \rho_2)$ $\rho_1 + (\alpha_1\alpha_2\alpha_3(1 + \beta_1) - \beta_1)(1 - \rho_1)$ $\rho_3 + (\alpha_1\alpha_2\alpha_3(1 + \beta_3) - \beta_3)(1 - \rho_3)$	
A.3.2	2.3	$\frac{\alpha_3 - (1 + \alpha_2)\alpha_3\rho_2}{\alpha_3 + \rho_2}$ $\frac{\alpha_2 - (1 + \alpha_1)\alpha_2\rho_1}{\alpha_2 + \rho_1}$ $\frac{\alpha_1 - (1 + \alpha_3)\alpha_1\rho_3}{\alpha_1 + \rho_3}$	
A.4.1		$1 - (1 + \alpha_2 + \alpha_1\alpha_2) \min\{\frac{\rho_1}{\alpha_2}, \rho_2, \frac{\rho_3}{\alpha_1\alpha_2}\}$	Degenerate
A.4.2	2.2	$1 - \frac{1 + \alpha_2 + \alpha_1\alpha_2}{\alpha_2} \rho_1$ $1 - \frac{1 + \alpha_1 + \alpha_1\alpha_3}{\alpha_1} \rho_3$ $1 - \frac{1 + \alpha_3 + \alpha_2\alpha_3}{\alpha_3} \rho_2$	
A.4.3		$D_1$ $D_2$ $D_3$	Degenerate Degenerate Degenerate
A.4.4	2.1	0	
		$D_1 = [\max\{0, 1 - \frac{1 + \alpha_2 + \alpha_1\alpha_2\rho_1}{\alpha_2}\}, 1 - \frac{1 + \alpha_2 + \alpha_1\alpha_2}{\alpha_2 + \rho_1} \rho_1] \cap [\max\{0, 1 - \frac{1 + \alpha_2 + \alpha_1\alpha_2\rho_1}{\alpha_2}\}, 1 - (1 + \alpha_1 + \alpha_1\alpha_3)\rho_1)$	
		$D_2 = [\max\{0, 1 - \frac{1 + \alpha_3 + \alpha_2\alpha_3\rho_2}{\alpha_3}\}, 1 - \frac{1 + \alpha_3 + \alpha_2\alpha_3}{\alpha_3 + \rho_2} \rho_2] \cap [\max\{0, 1 - \frac{1 + \alpha_3 + \alpha_2\alpha_3\rho_2}{\alpha_3}\}, 1 - (1 + \alpha_2 + \alpha_1\alpha_2)\rho_2)$	
		$D_3 = [\max\{0, 1 - \frac{1 + \alpha_1 + \alpha_1\alpha_3\rho_3}{\alpha_1}\}, 1 - \frac{1 + \alpha_1 + \alpha_1\alpha_3}{\alpha_1 + \rho_3} \rho_3] \cap [\max\{0, 1 - \frac{1 + \alpha_1 + \alpha_1\alpha_3\rho_3}{\alpha_1}\}, 1 - (1 + \alpha_3 + \alpha_2\alpha_3)\rho_3)$	

Table 8: Delay probabilities.

In the case of Theorem A.1 and A.4.3 the delay probability is given by an interval. This means that for every value of delay in the interval, there is an SSPE with that probability of delay.

An important question is whether there always exists some vector of recognition probabilities  $\rho$  such that the corresponding SSPE does not involve delay.

**THEOREM 7.1** *Let  $u$  be such that  $\alpha_1\alpha_2\alpha_3 \leq 1$ . Then there is a  $\rho$  such that the game  $(u, \rho)$  has an SSPE without delay.*

If we think of the parameters  $\rho_i$  as a measure of bargaining power, then Theorem 7.1 makes clear that irrespective of the players' utility functions, delay in bargaining can be avoided under an appropriate distribution of bargaining power.

The intuition behind Theorem 7.1 is the following. Suppose that every player proposes his best outcome with probability 1, meaning that outcomes are implemented according to probability vector  $\rho$ . Under the condition  $\alpha_1\alpha_2\alpha_3 \leq 1$  it is always possible to choose

$\rho$  in such a way that every player  $i$ 's continuation payoff is less than or equal to  $u_{m_i}^i$ . In particular, this means that players with high risk coefficients should have low recognition probabilities. Given a continuation payoff below  $u_{m_i}^i$ , player  $i$  accepts outcome  $x_{m_i}$  with probability 1, which in turn makes it optimal for every player to propose his best outcome with probability 1.

The next result shows that the expected delay in bargaining goes to infinity when one player has almost all the bargaining power. We model this by taking a sequence of recognition probability vectors that converges to a unit vector and show that the limit of the SSPE delay probability is equal to 1.

**THEOREM 7.2** *Let  $u$  be such that  $\alpha_1\alpha_2\alpha_3 \leq 1$ . Consider a sequence of recognition probability vectors  $(\rho^n)_{n \in \mathbb{N}}$  which converges to  $e^i$ , the  $i$ -th unit vector, for some  $i = 1, 2, 3$ . For  $n \in \mathbb{N}$ , let  $(p^n, a^n)$  be an SSPE of  $(u, \rho^n)$  and denote the corresponding delay probability by  $\delta_n$ . Then  $\lim_{n \rightarrow \infty} \delta_n = 1$ .*

Theorem 7.2 complements Theorem 7.1 and shows that extreme SSPE delay may occur for certain distributions of bargaining power. To explain the result of Theorem 7.2, it should be recalled that SSPE continuation payoffs are always less than or equal to  $u_{m_i}^i$ . Assume player  $i$  has  $\rho_i$  close to one. When he proposes his first-best, it should be turned down with probability close to 1, to avoid his continuation payoff reaching values above  $u_{m_i}^i$ . His continuation payoff will actually be equal to  $u_{m_i}^i$  in an SSPE, implying that player  $i$  proposes his best outcome with probability 1 and his middle outcome with probability 0. On the equilibrium path it therefore holds that player  $i$  is recognized as a proposer almost all the time, he proposes his best outcome with probability 1, which is subsequently turned down with probability close to 1. The probability of delay is therefore close to 1 in every bargaining round.

We also analyze whether cycles can occur. Cycles should occur according to the Condorcet logic. Other authors like Chwe (1994) have argued using tools from cooperative game theory that cycles should not occur when players are farsighted. We say that a particular play of the game has resulted in a *cycle* if all three alternatives have been proposed and rejected, before some alternative is accepted. An SSPE is said to have a *cycle* if there is a positive probability that the equilibrium path has resulted in a cycle. If an SSPE has a cycle, then clearly there is also a positive probability on an equilibrium path where *consecutively* alternatives 1, 2, 3, and 1 are proposed and rejected.

**THEOREM 7.3** *The set of games  $(u, \rho) \in \mathcal{G}$  admitting SSPEs with cycles has Lebesgue measure zero.*

Cycles occur with positive probability in the SSPEs of Theorem A.1 and A.4.3. It is easily verified that for Theorem A.1 there is always an SSPE where the equilibrium path results in a cycle with probability arbitrarily close to one. But the conditions of these theorems hold in degenerate cases only.

## 8 The Role of Risk Aversion

In this section we investigate the role of risk aversion. We concentrate on the impact of risk aversion on the SSPE outcome probability vector  $(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3)$ . Player 1 is at least as well off with the lottery  $(\bar{\pi}'_1, \bar{\pi}'_2, \bar{\pi}'_3)$  instead of  $(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3)$  when  $\bar{\pi}'_1 \geq \bar{\pi}_1$  and  $\bar{\pi}'_3 \leq \bar{\pi}_3$ , which corresponds to the criterion of first-order stochastic dominance.

The standard approach to risk aversion in bargaining is to take a concave transformation of one of the player's utility functions. Taking such a transformation for player  $i$  will reduce his risk coefficient, because the gap between  $u_{m_i}^i$  and  $u_{w_i}^i$  will become relatively larger than the gap between  $u_{b_i}^i$  and  $u_{m_i}^i$ . The SSPE probability vector  $(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3)$  can be rewritten in terms of risk coefficients only and for that reason we perform the comparative statics exercise with respect to changes in risk aversion as changes in the player's risk coefficients.

Table 9 reports the SSPE outcome probability vectors. For Theorem A.4.3, first line,  $\lambda \geq 1$  should be chosen to satisfy

$$\frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2} < \lambda\rho_1 \leq \frac{\alpha_2 + \rho_1}{1 + \alpha_2 + \alpha_1\alpha_2}$$

and

$$\lambda\rho_1 < \frac{1}{1 + \alpha_1 + \alpha_1\alpha_3}.$$

For the other two lines corresponding to Theorem A.4.3,  $\lambda \geq 1$  should satisfy the appropriate analogues of these inequalities. We evaluate the local effects of a change in a player's risk coefficient for the non-degenerate cases.

Consider the first line of Theorem A.3.1 and A.4.2<sup>3</sup> for which

$$(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3) = \left( \frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}, \frac{1}{1 + \alpha_2 + \alpha_1\alpha_2}, \frac{\alpha_1\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2} \right).$$

We have that

$$\begin{aligned} \frac{\partial \bar{\pi}_1}{\partial \alpha_1} &< 0, & \frac{\partial \bar{\pi}_2}{\partial \alpha_1} &< 0, & \frac{\partial \bar{\pi}_3}{\partial \alpha_1} &> 0, \\ \frac{\partial \bar{\pi}_1}{\partial \alpha_2} &> 0, & \frac{\partial \bar{\pi}_2}{\partial \alpha_2} &< 0, & \frac{\partial \bar{\pi}_3}{\partial \alpha_2} &> 0, \\ \frac{\partial \bar{\pi}_1}{\partial \alpha_3} &= 0, & \frac{\partial \bar{\pi}_2}{\partial \alpha_3} &= 0, & \frac{\partial \bar{\pi}_3}{\partial \alpha_3} &= 0, \end{aligned}$$

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<sup>3</sup>The second and third line corresponding to Theorem A.3.1 and A.4.2 are obtained by a permutation of the players and lead to analogous results.

Theorem	Utilities	$\bar{\pi}_1$	$\bar{\pi}_2$	$\bar{\pi}_3$	Occurrence
A.1	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{1}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{\alpha_1\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	Degenerate
A.3.1	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 < u_1^3$	$\frac{\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{1}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{\alpha_1\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	
	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{1}{1+\alpha_1+\alpha_1\alpha_3}$	$\frac{\alpha_1\alpha_3}{1+\alpha_1+\alpha_1\alpha_3}$	$\frac{\alpha_1}{1+\alpha_1+\alpha_1\alpha_3}$	
	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{\alpha_2\alpha_3}{1+\alpha_3+\alpha_2\alpha_3}$	$\frac{\alpha_3}{1+\alpha_3+\alpha_2\alpha_3}$	$\frac{1}{1+\alpha_3+\alpha_2\alpha_3}$	
A.3.2	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 < u_1^3$	$\frac{\alpha_2(\alpha_3+\rho_2)}{1+\alpha_3+\alpha_2\alpha_3}$	$\frac{\alpha_3+\rho_2}{1+\alpha_3+\alpha_2\alpha_3}$	$\frac{1-\rho_2(1+\alpha_2)}{1+\alpha_3+\alpha_2\alpha_3}$	
	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 < u_1^3$	$\frac{\alpha_2+\rho_1}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{1-\rho_1(1+\alpha_1)}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{\alpha_1(\alpha_2+\rho_1)}{1+\alpha_2+\alpha_1\alpha_2}$	
	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{1-\rho_3(1+\alpha_3)}{1+\alpha_1+\alpha_1\alpha_3}$	$\frac{\alpha_3(\alpha_1+\rho_3)}{1+\alpha_1+\alpha_1\alpha_3}$	$\frac{\alpha_1+\rho_3}{1+\alpha_1+\alpha_1\alpha_3}$	
A.4.1	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{1}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{\alpha_1\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	Degenerate
A.4.2	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 < u_1^3$	$\frac{\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{1}{1+\alpha_2+\alpha_1\alpha_2}$	$\frac{\alpha_1\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$	
	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{1}{1+\alpha_1+\alpha_1\alpha_3}$	$\frac{\alpha_1\alpha_3}{1+\alpha_1+\alpha_1\alpha_3}$	$\frac{\alpha_1}{1+\alpha_1+\alpha_1\alpha_3}$	
	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 = u_1^3$	$\frac{\alpha_2\alpha_3}{1+\alpha_3+\alpha_2\alpha_3}$	$\frac{\alpha_3}{1+\alpha_3+\alpha_2\alpha_3}$	$\frac{1}{1+\alpha_3+\alpha_2\alpha_3}$	
A.4.3	$\bar{z}^1 = u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 < u_1^3$	$\lambda\rho_1$	$1 - \lambda\rho_1(1 + \alpha_1)$	$\alpha_1\lambda\rho_1$	Degenerate
	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 = u_3^2 \quad \bar{z}^3 < u_1^3$	$\alpha_2\lambda\rho_2$	$\lambda\rho_2$	$1 - \lambda\rho_2(1 + \alpha_2)$	Degenerate
	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 = u_1^3$	$1 - \lambda\rho_3(1 + \alpha_3)$	$\alpha_3\lambda\rho_3$	$\lambda\rho_3$	Degenerate
A.4.4	$\bar{z}^1 < u_2^1 \quad \bar{z}^2 < u_3^2 \quad \bar{z}^3 < u_1^3$	$\rho_1$	$\rho_2$	$\rho_3$	

Table 9: SSPE outcome probabilities.

and  $\partial\bar{\pi}_1/\partial\alpha_i + \partial\bar{\pi}_2/\partial\alpha_i + \partial\bar{\pi}_3/\partial\alpha_i = 0$  for  $i = 1, 2, 3$ .

An increase in  $\alpha_1$  yields player 1 lower probabilities for obtaining his best and middle alternatives and an increased probability for obtaining his worst alternative. So, a *less* risk averse type of player 1 is unambiguously *worse off*. The next question is whether one or both other players benefit from such a change. This issue is straightforward for player 3, who would face an increased probability for obtaining his best alternative and lower probabilities for obtaining his middle and worst alternatives. Therefore, player 3 is unambiguously better off if player 1 becomes less risk averse. Player 2 faces lower probabilities for both his best and worst alternatives and an increased probability for his middle alternative. Notice however that player 2 obtains an SSPE utility of  $\bar{z}^2 = u_3^2$ , which is not affected by a change in the risk coefficient of player 1.

Next, an increase in  $\alpha_2$  yields player 2 a lower probability for obtaining his best alternative and increased probabilities for attaining his middle and worst alternatives. A *less* risk averse type of player 2 is unambiguously *worse off*, albeit that player 2 is affected in a different manner than player 1 is affected by changes in  $\alpha_1$ . Since player 3 faces increased probabilities for obtaining his best and middle alternatives and a lower probability for obtaining his worst alternative, player 3 is unambiguously better off if player 2 becomes less risk averse. Player 1's SSPE utility is not affected by player 3's risk coefficient.

Finally, changes in player 3's risk coefficient have no effect on the outcome probability vector, so both situations are unambiguously equivalent for all the players.

The crucial insight for changes in  $\alpha_1$  and  $\alpha_2$  is that when at an SSPE a player's continuation value is equal to the utility of his middle alternative, this property is preserved under small changes of the player's utility function. When the player's risk coefficient increases, the only way to keep his continuation utility equal to the utility of the middle alternative, is to improve the probability by which he obtains his best outcome and lower the probability by which he obtains his worst outcome. It follows that an increase in a player's risk aversion improves his bargaining position. The effect of a change in  $\alpha_3$  is more subtle. Since player 1 and 2 have a continuation value equal to the utility of their middle alternative, the ratio of the probability of receiving the best outcome and the probability of receiving the worst outcome should not be affected by a change in  $\alpha_3$ . Since freezing both ratios means that the outcome probability vector does not change, we find that a change in  $\alpha_3$  has no effects.

Our result here contrasts the finding of the bargaining literature with unanimous approval and side-payments that risk-aversion undermines a player's bargaining position, see e.g. Roth (1985), Safra, Zhou, and Zilcha (1990), and Kihlstrom, Roth, and Schmeidler (1991). Harrington (1990) shows that under majority voting with side-payments, such a result is no longer unambiguously true and higher degrees of risk aversion may be beneficial to a player under certain circumstances. The reason there is that it is less costly to make an offer to a more risk averse player, so a more risk averse player is more likely to be part of a winning coalition. The total effect for a risk averse player is therefore ambiguous since he receives lower offers, but at a higher frequency. We see here that in the context of bargaining over a finite number of alternatives, higher degrees of risk aversion are always beneficial.

We verify that also in the case of Theorem A.3.2 and A.4.4 higher degrees of risk aversion improve the bargaining position. Consider the first line corresponding to Theorem A.3.2 for which

$$(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3) = \left( \frac{\alpha_2(\alpha_3 + \rho_2)}{1 + \alpha_3 + \alpha_2\alpha_3}, \frac{\alpha_3 + \rho_2}{1 + \alpha_3 + \alpha_2\alpha_3}, \frac{1 - \rho_2(1 + \alpha_2)}{1 + \alpha_3 + \alpha_2\alpha_3} \right).$$

We have that

$$\begin{aligned} \frac{\partial \bar{\pi}_1}{\partial \alpha_1} &= 0, & \frac{\partial \bar{\pi}_2}{\partial \alpha_1} &= 0, & \frac{\partial \bar{\pi}_3}{\partial \alpha_1} &= 0, \\ \frac{\partial \bar{\pi}_1}{\partial \alpha_2} &> 0, & \frac{\partial \bar{\pi}_2}{\partial \alpha_2} &< 0, & \frac{\partial \bar{\pi}_3}{\partial \alpha_2} &< 0, \\ \frac{\partial \bar{\pi}_1}{\partial \alpha_3} &> 0, & \frac{\partial \bar{\pi}_2}{\partial \alpha_3} &> 0, & \frac{\partial \bar{\pi}_3}{\partial \alpha_3} &< 0, \end{aligned}$$

and  $\partial \bar{\pi}_i / \partial \alpha_i + \partial \bar{\pi}_2 / \partial \alpha_i + \partial \bar{\pi}_3 / \partial \alpha_i = 0$  for  $i = 1, 2, 3$ . For this derivation, observe that

$$\frac{\partial}{\partial \alpha_3} \frac{\alpha_2(\alpha_3 + \rho_2)}{1 + \alpha_3 + \alpha_2\alpha_3} = \frac{\alpha_2(1 - \rho_2(1 + \alpha_2))}{(1 + \alpha_3 + \alpha_2\alpha_3)^2} = \frac{\alpha_2}{1 + \alpha_3 + \alpha_2\alpha_3} \bar{\pi}_3 > 0.$$

First, changes in player 1's risk coefficient have no effect. Second, in case player 2 becomes *less* risk averse then this player is always *worse off* and player 1 is always better off. The marginal effect of a change in  $\alpha_2$  on the SSPE utility of player 3 is given by

$$\begin{aligned}\frac{\partial \pi_1}{\partial \alpha_2} u_1^3 + \frac{\partial \pi_2}{\partial \alpha_2} u_2^3 + \frac{\partial \pi_3}{\partial \alpha_2} u_3^3 &= \frac{(\alpha_3 + \rho_2)(1 + \alpha_3)}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} u_1^3 - \frac{(\alpha_3 + \rho_2)\alpha_3}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} u_2^3 - \frac{\alpha_3 + \rho_2}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} u_3^3 \\ &= \frac{\alpha_3 + \rho_2}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} \alpha_3 (u_1^3 - u_2^3) - \frac{\alpha_3 + \rho_2}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} (u_3^3 - u_1^3) = 0.\end{aligned}$$

Third, in case player 3 becomes *less* risk averse then this player is always *worse off* and player 1 is always better off. The marginal effect of a change in  $\alpha_3$  on the SSPE utility of player 2 is given by

$$\begin{aligned}\frac{\partial \pi_1}{\partial \alpha_3} u_1^2 + \frac{\partial \pi_2}{\partial \alpha_3} u_2^2 + \frac{\partial \pi_3}{\partial \alpha_3} u_3^2 &= \frac{\alpha_2(1 - \rho_2(1 + \alpha_2))}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} u_1^2 + \frac{(1 - \rho_2(1 + \alpha_2))}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} u_2^2 - \frac{(1 - \rho_2(1 + \alpha_2))(1 + \alpha_2)}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} u_3^2 \\ &= -\frac{1 - \rho_2(1 + \alpha_2)}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} \alpha_2 (u_3^2 - u_1^2) + \frac{1 - \rho_2(1 + \alpha_2)}{(1 + \alpha_3 + \alpha_2 \alpha_3)^2} (u_2^2 - u_3^2) = 0.\end{aligned}$$

The second and third line corresponding to Theorem A.3.2 are obtained by a permutation of the players and lead to analogous results.

Since  $\bar{z}^2 = u_3^2$ , an increase in  $\alpha_2$  is detrimental for player 2 by the same reasoning as before. To explain the effect of an increase in  $\alpha_3$  requires a new insight. Player 1 and 2 propose their best alternative for sure, followed by acceptance with probability 1, a feature that is preserved following changes in  $\alpha_3$ . Player 3 randomizes as a proposer between his best and his middle alternative, and his continuation utility *conditional* on being a proposer is equal to  $u_1^3$ , a property that is preserved under small changes in  $\alpha_3$ . An increase in  $\alpha_3$  therefore results in a worse probability mix on outcomes for player 3 conditional on being the proposer, and given unchanged behavior following the recognition of player 1 and 2 as a proposer, this result in a worse ex ante probability mix on outcomes for player 3. Since player 1 plays a pure strategy, a change in  $\alpha_1$  has no effect.

Consider Theorem A.4.4 for which  $(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3) = (\rho_1, \rho_2, \rho_3)$ . Then changes in any player's risk aversion have no effect on the outcome probability vector and for each player the situation before and after such a change is unambiguously equivalent. This result is caused by the fact that all players play a pure strategy.

In summary, we obtain for the three cases of Theorem A.3.1, A.3.2, and A.4.2 that less risk aversion leads to a worse outcome in the sense that the probability of attaining the best alternative decreases while the probability for obtaining the worst alternative increases. In the remaining main case, the one of Theorem A.4.4, changes in risk attitudes have no effect. So, combining these four cases, we find beneficial effects for risk aversion on the own bargaining position.

## 9 Concluding Remarks

We have modeled decision making by three players over a set consisting of three alternatives as a bargaining game in extensive form with exogenous recognition probabilities. The set-up corresponds to the well-known Condorcet paradox in the sense that the players' utility functions are such that naive majority voting over the alternatives results in a Condorcet cycle. We have derived the conditions under which rational players will defy the Condorcet logic and reach agreement in finite time with probability one whenever the geometric mean of their risk coefficients is less than or equal to one.

The message that risk-averse players are willing to accept second-best alternatives, thereby defying the Condorcet logic, is valid well beyond the simple case analyzed in this paper. In a general setting with many players and many alternatives, players may accept unfavorable alternatives, if they face the risk of ending up with an outcome that is even worse. It also holds with great generality that the situation where an agreement is never reached cannot be supported in an SSPE. Indeed, such a situation cannot occur whenever there is an outcome that a majority of players prefers over not reaching an agreement, and at least one such player has a positive recognition probability.

Many SSPEs feature delay before an agreement is reached. We show that for any specification of the players' risk coefficients, there are recognition probability vectors for which no delay occurs before an agreement is reached, but also that expected delay goes to infinity when in the limit a single player is the only proposer. To what extent such results hold in more general settings is an open issue, but our conjecture is that under quite general circumstances players with high bargaining power will be disciplined by the other players by means of frequent rejections of their proposals.

We have argued that increasing risk aversion unambiguously strengthens the bargaining position of a player. This insight is also valid in more general set-ups. If a player uses a pure strategy in equilibrium, then small changes in risk aversion will not affect his equilibrium behavior. Consider a player who randomizes when responding to a particular proposal. If an increase in risk aversion affects his utility of this proposal positively, then the player's continuation utility has to increase to keep him indifferent between accepting and rejecting. But then the player's equilibrium utility increases as well, so he benefits from an increase in risk aversion.

# Appendix A

## A.1 Three Players with $\bar{p}_{m_i}^i > 0$ .

In this subsection we are analyzing SSPEs where every player makes a proposal with probability one, proposes his middle alternative with positive probability, does not propose his worst alternative, and may propose his best alternative with positive probability less than one.

Consider a game  $(u, \rho) \in \mathcal{G}$  and let  $((\bar{p}_{b_i}^i, \bar{p}_{m_i}^i, \bar{a}_{m_i}^i, \bar{z}^i)_{i=1,2,3}, \bar{\pi})$  be a solution to (4.15)–(4.22) with  $\bar{p}_{m_i}^i > 0$ ,  $i = 1, 2, 3$ . From (4.15), for every  $i$ ,  $u_{m_i}^i \geq \bar{a}_{m_{i-1}}^{i-1} u_{b_i}^i + (1 - \bar{a}_{m_{i-1}}^{i-1}) \bar{z}^i$ , so  $\bar{z}^i \leq u_{m_i}^i$ . We argue next that for every  $i$ ,  $\bar{z}^i = u_{m_i}^i$ . Suppose, for some  $i$ ,  $\bar{z}^i < u_{m_i}^i$ . Then  $\bar{a}_{m_i}^i = 1$  by (4.17), so  $\bar{p}_{m_{i+1}}^{i+1} = 0$  by (4.15), a contradiction since we are considering the case  $\bar{p}_{m_{i+1}}^{i+1} > 0$ . It follows that for every  $i$ ,  $\bar{z}^i = u_{m_i}^i$ , and by (4.15),  $\bar{a}_{m_{i-1}}^{i-1} = 0$ , so the proposal  $x_{m_i}$  by a player  $i$  is accepted with probability 1 and the proposal  $x_{b_i}$  by a player  $i$  is rejected with probability 1. Note that since a proposal  $x_{b_i}$  by player  $i$  is rejected for sure, player  $i$  is indifferent between making such a proposal and giving up the right to propose, i.e. propose  $x_0$ .

Equations (4.19)–(4.20) now reduce to the system

$$\bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 = u_2^1, \quad (\text{A.1})$$

$$\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 = u_3^2, \quad (\text{A.2})$$

$$\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 = u_1^3, \quad (\text{A.3})$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1. \quad (\text{A.4})$$

Equations (4.21) and (4.22) can be simplified to

$$\bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 = \rho_3 \bar{p}_{m_3}^3 : \rho_1 \bar{p}_{m_1}^1 : \rho_2 \bar{p}_{m_2}^2. \quad (\text{A.5})$$

Whenever utilities are such that (A.1)–(A.4) has a solution  $\bar{\pi} \gg 0$ , an equilibrium of the type we are looking for in this subsection exists. We derive now under what assumptions on utilities such a solution  $\bar{\pi}$  exists. We will show that there is at most one solution, so a solution, if it exists, is unique.

From equalities (A.1) and (A.4), we obtain

$$(1 - \bar{\pi}_2)(u_2^1 - u_3^1) = \bar{\pi}_1(u_1^1 - u_3^1). \quad (\text{A.6})$$

Combining (A.2) and (A.4) leads to

$$\begin{aligned} \bar{\pi}_1(u_3^2 - u_1^2) &= \bar{\pi}_2(u_2^2 - u_3^2) \\ &= (u_2^2 - u_3^2) - \bar{\pi}_1(u_2^2 - u_3^2) \frac{u_1^1 - u_3^1}{u_2^1 - u_3^1}, \end{aligned} \quad (\text{A.7})$$

where the second equality follows using (A.6). Rewriting the last equality leads to

$$\bar{\pi}_1 = \frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}.$$

It is immediate that  $0 < \bar{\pi}_1 < 1$ .

By (A.7) we have  $\bar{\pi}_2 = \bar{\pi}_1/\alpha_2$ , and we find that

$$\bar{\pi}_2 = \frac{1}{1 + \alpha_2 + \alpha_1\alpha_2}.$$

Since  $\bar{\pi}_3 = 1 - \bar{\pi}_1 - \bar{\pi}_2$ , we find that

$$\bar{\pi}_3 = \frac{\alpha_1\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}.$$

Obviously, it holds that  $0 < \bar{\pi}_2 < 1$  and  $0 < \bar{\pi}_3 < 1$ . At this point we have established that there is at most one solution to (A.1)–(A.4). For there to be some solution, (A.3) should hold. Using the already derived expressions for  $\bar{\pi}_1$ ,  $\bar{\pi}_2$ , and  $\bar{\pi}_3$ , we find that (A.3) holds if and only if  $\alpha_1\alpha_2\alpha_3 = 1$ . This equation holds in degenerate cases only. It requires that the product over the players of the utility difference between their best and middle alternative be exactly equal to the product of the utility difference between the middle and the worst alternative.

A game  $(u, \rho)$  with  $\alpha_1\alpha_2\alpha_3 = 1$  has many equilibria  $(\bar{p}, \bar{a})$  of the type described in this subsection. All such equilibria can be constructed as follows. Let  $\bar{\pi}$  be the uniquely determined probabilities by which the alternatives are implemented at equilibrium. Let  $\lambda > 0$  be such that, for  $i = 1, 2, 3$ ,  $\lambda\bar{\pi}_{m_i} \leq \rho_i$ . If player  $i$  is selected as proposer, he proposes  $x_{m_i}$  with probability  $\lambda\bar{\pi}_{m_i}/\rho_i$  and  $x_{b_i}$  with probability  $1 - \lambda\bar{\pi}_{m_i}/\rho_i$ . The former proposal is accepted, the latter rejected. This construction ensures that (A.5) holds. The higher  $\lambda$ , the less delay before an outcome is accepted. The highest possible choice of  $\lambda$  occurs when there is at least one player  $i$  for which  $\bar{p}_{m_i}^i = 1$ . In that case, the selection of player  $i$  as a proposer leads to a proposal that is accepted for sure.

Summarizing, we have the following. Let utilities be such that  $\alpha_1\alpha_2\alpha_3 = 1$ , so there is a unique solution  $\bar{\pi} \gg 0$  to (A.1)–(A.4). Then the set of SSPEs with all players making a proposal with probability one is given by

$$\bar{p} = \begin{bmatrix} 1 - \bar{p}_{m_1}^1 & 0 & \bar{p}_{m_3}^3 \\ \bar{p}_{m_1}^1 & 1 - \bar{p}_{m_2}^2 & 0 \\ 0 & \bar{p}_{m_2}^2 & 1 - \bar{p}_{m_3}^3 \end{bmatrix} \quad (\text{A.8})$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}, \quad \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}, \quad \text{and} \quad \bar{a}^3 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad (\text{A.9})$$

where  $\bar{p}$  satisfies (A.5). The other SSPEs are obtained by transferring part or all of the probability  $1 - \bar{p}_{m_i}^i$  by which  $x_{b_i}$  is proposed by player  $i$  to the option not to make a proposal,  $x_0$ .

In this SSPE, each player randomizes between his security utility  $u_{m_i}^i$ , knowing it will be accepted for sure by player  $i + 1$ , and some gamble among all three alternatives in case he either proposes his best alternative, knowing the latter will be rejected for sure, or does not make a proposal at all. In this gamble, at some future date either player  $i - 1$  proposes player  $i$ 's best alternative and player  $i$  accepts, or player  $i + 1$  may propose player  $i$ 's worst alternative but since this is player  $i - 1$ 's best alternative the latter player accepts, or player  $i$  proposes his middle alternative, which is accepted by player  $i + 1$ . Notice that all SSPEs are symmetric whenever the recognition probabilities  $(\rho_1, \rho_2, \rho_3)$  are identical to  $(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_1)$ , because the latter ensures that the probabilities of proposing the middle alternative are equal. In that case there is one SSPE without delay, i.e.  $\bar{p}_{m_i}^i = 1$  for all  $i$ . All other SSPEs involve delay.

All SSPEs  $(\bar{p}, \bar{a})$  lead to the same equilibrium payoffs  $\bar{z}$  given by  $\bar{z}^i = u_{m_i}^i$ . We have uniqueness in equilibrium utilities but multiplicity in the supporting equilibrium strategies. therefore, as mentioned before, the multiplicity of SSPEs is inessential. Since also  $\bar{v}_i^i = u_{m_i}^i = \bar{z}^i$ , there is no advantage in being the proposer. The recognition probabilities  $\rho$  do not influence the probability  $\bar{\pi}_j$  that the bargaining process ends with outcome  $x_j$ . These probabilities depend on the utilities only.

We can summarize our findings regarding SSPE existence in the following theorem.

**THEOREM A.1** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_{m_i}^i > 0$ ,  $i = 1, 2, 3$ , if and only if  $\alpha_1 \alpha_2 \alpha_3 = 1$ . In this case, there is a unique SSPE with minimal expected delay, given by the solution  $(\bar{p}, \bar{a})$  to (A.5), (A.8), and (A.9) with  $\bar{p}_{m_i}^i = 1$  for at least one player  $i$ , where  $(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3)$  is the unique solution to (A.1)–(A.4). Other SSPEs are obtained by proportionally lowering  $\bar{p}_{m_i}^i$  across players  $i$ , as well as by shifting probability weight from  $\bar{p}_{b_i}^i$  to  $\bar{p}_0^i$ . All SSPEs induce the same equilibrium utilities, given by  $\bar{z}^i = u_{m_i}^i$ ,  $i = 1, 2, 3$ .*

## A.2 Two Players with $\bar{p}_{m_i}^i > 0$ .

Next we consider SSPEs where one player, without loss of generality player 1, proposes his best outcome for sure, and the other two players put positive weight on their middle outcome. We argue that no such SSPEs exist.

Consider a game  $(u, \rho) \in \mathcal{G}$  and let  $((\bar{p}_{b_i}^i, \bar{p}_{m_i}^i, \bar{a}_{m_i}^i, \bar{z}^i)_{i=1,2,3}, \bar{\pi})$  be a solution to (4.15)–(4.22) with  $\bar{p}_1^1 = 1$ ,  $\bar{p}_3^2 > 0$ , and  $\bar{p}_1^3 > 0$ . By (4.15),  $\bar{a}_2^1 u_2^2 + (1 - \bar{a}_2^1) \bar{z}^2 \leq u_3^2$ , so  $\bar{z}^2 \leq u_3^2$ . Suppose  $\bar{z}^2 < u_3^2$ . Then  $\bar{a}_3^2 = 1$  by (4.17), so  $\bar{p}_1^3 = 0$  by (4.15), a contradiction to  $\bar{p}_1^3 > 0$ . It follows that  $\bar{z}^2 = u_3^2$ . Now (4.15) implies  $u_3^2 \geq \bar{a}_2^1 u_2^2 + (1 - \bar{a}_2^1) u_3^2$ , so  $\bar{a}_2^1 = 0$ . It follows that if

player 2 proposes his best alternative, it is rejected for sure. No other player ever proposes this alternative. The bargaining process never ends with outcome  $x_2$ , i.e.  $\bar{\pi}_2 = 0$ . This is a contradiction to  $\bar{\pi}_2 > 0$ . We conclude that there are no SSPEs with the properties as stated in this subsection.

**THEOREM A.2** *There is no SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with for some  $i = 1, 2, 3$ ,  $\bar{p}_{m_i}^i = 0$ ,  $\bar{p}_{m_{i-1}}^{i-1} > 0$ , and  $\bar{p}_{m_{i+1}}^{i+1} > 0$ .*

### A.3 One Player with $\bar{p}_{m_i}^i > 0$ .

Now we consider SSPEs with two players proposing their best outcome for sure, and where one player, without loss of generality player 3, puts positive weight on his middle outcome.

Consider a game  $(u, \rho) \in \mathcal{G}$  and let  $((\bar{p}_i^i, \bar{p}_{m_i}^i, \bar{a}_{m_i}^i, \bar{z}^i)_{i=1,2,3}, \bar{\pi})$  be a solution to (4.15)–(4.22) with  $\bar{p}_1^1 = 1$ ,  $\bar{p}_2^2 = 1$ , and  $\bar{p}_3^3 > 0$ . So, player 1 proposes  $x_1$ , player 2 proposes  $x_2$ , and player 3 mixes over  $x_3$  and  $x_1$ . To obtain  $\bar{\pi}_j > 0$ ,  $j = 1, 2, 3$ , we must have  $\bar{p}_3^3 > 0$ ,  $\bar{a}_2^1 > 0$ , and  $\bar{a}_3^2 > 0$ . By (4.15) and (4.16) we find

$$\begin{aligned} \bar{a}_1^3 u_1^1 + (1 - \bar{a}_1^3) \bar{z}^1 &\geq u_2^1, \\ \bar{a}_2^1 u_2^2 + (1 - \bar{a}_2^1) \bar{z}^2 &\geq u_3^2, \\ \bar{a}_3^2 u_3^3 + (1 - \bar{a}_3^2) \bar{z}^3 &= u_1^3. \end{aligned}$$

Since  $\bar{a}_3^2 > 0$  and  $u_3^3 > u_1^3$ , the equality implies  $\bar{a}_3^2 \in (0, 1)$  and  $\bar{z}^3 < u_1^3$ . It follows by (4.17) and (4.18) that  $\bar{z}^2 = u_3^2$ . Since  $\bar{z}^3 < u_1^3$ , we have  $\bar{a}_1^3 = 1$  by (4.17), so the proposal of player 1 is accepted for sure. By  $\bar{a}_2^1 > 0$  and (4.18), we also must have  $\bar{z}^1 \leq u_2^1$ . There are now two possible cases. Case 1 where  $\bar{z}^1 = u_2^1$  and Case 2 with  $\bar{z}^1 < u_2^1$ . In Case 2 we have  $\bar{a}_2^1 = 1$  by (4.17).

#### A.3.1 Case 1

It holds that  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE if and only if there is  $\bar{\pi}$  such that

$$\bar{p} = \begin{bmatrix} 1 & 0 & 1 - \bar{p}_3^3 \\ 0 & 1 & 0 \\ 0 & 0 & \bar{p}_3^3 \end{bmatrix} \tag{A.10}$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ \bar{a}_2^1 \\ 0 \end{bmatrix}, \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ \bar{a}_3^2 \end{bmatrix}, \text{ and } \bar{a}^3 = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, \tag{A.11}$$

$$\bar{a}_3^2 u_3^3 + (1 - \bar{a}_3^2)(\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3) = u_1^3, \tag{A.12}$$

$$\bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 = u_2^1, \quad (\text{A.13})$$

$$\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 = u_3^2, \quad (\text{A.14})$$

$$\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 < u_1^3, \quad (\text{A.15})$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1, \quad (\text{A.16})$$

$$\bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 = \rho_1 + \rho_3(1 - \bar{p}_3^3) : \rho_2 \bar{a}_2^1 : \rho_3 \bar{p}_3^3 \bar{a}_3^2, \quad (\text{A.17})$$

where  $0 < \bar{p}_3^3 < 1$ ,  $0 < \bar{a}_2^1 \leq 1$ , and  $0 < \bar{a}_3^2 < 1$ .

Using the same derivation as in Subsection A.1, it can be shown that there is a solution  $\bar{\pi} \gg 0$  to the system (A.13)–(A.16) if and only if

$$\alpha_1 \alpha_2 \alpha_3 < 1. \quad (\text{A.18})$$

Moreover, each specification of utilities satisfying (A.18) leads to a unique solution  $\bar{\pi} \gg 0$  to (A.13)–(A.16). Indeed, as before it holds that

$$\begin{aligned} \bar{\pi}_1 &= \frac{\alpha_2}{1 + \alpha_2 + \alpha_1 \alpha_2}, \\ \bar{\pi}_2 &= \frac{1}{1 + \alpha_2 + \alpha_1 \alpha_2}, \\ \bar{\pi}_3 &= \frac{\alpha_1 \alpha_2}{1 + \alpha_2 + \alpha_1 \alpha_2}. \end{aligned}$$

Inequality (A.18) specifies that the product over the players of the utility difference between their best and middle alternative should be less than the product of the utility difference between the middle and worst alternative.

Rewriting (A.12), we obtain

$$\bar{a}_3^2 = \frac{\bar{\pi}_2 - \alpha_3 \bar{\pi}_3}{\alpha_3 + \bar{\pi}_2 - \alpha_3 \bar{\pi}_3},$$

and substitution of the expressions for  $\bar{\pi}_2$  and  $\bar{\pi}_3$  results in

$$\bar{a}_3^2 = \frac{1 - \alpha_1 \alpha_2 \alpha_3}{1 + \alpha_3 + \alpha_2 \alpha_3}. \quad (\text{A.19})$$

Notice that  $0 < \bar{a}_3^2 < 1$ . By (A.17) we have

$$\alpha_1 = \frac{\rho_3 \bar{p}_3^3 \bar{a}_3^2}{\rho_1 + \rho_3(1 - \bar{p}_3^3)}.$$

Substitution of the expression for  $\bar{a}_3^2$  in the latter equation, and then solving for  $\bar{p}_3^3$  results in

$$\bar{p}_3^3 = \frac{\rho_1 + \rho_3}{\rho_3} \frac{\alpha_1 + \alpha_1 \alpha_3 + \alpha_1 \alpha_2 \alpha_3}{1 + \alpha_1 + \alpha_1 \alpha_3}. \quad (\text{A.20})$$

Obviously, it holds that  $\bar{p}_3^3 > 0$ . Moreover, we have that  $\bar{p}_3^3 < 1$  if and only if

$$\frac{\rho_1}{\rho_3} < \frac{1 - \alpha_1\alpha_2\alpha_3}{\alpha_1 + \alpha_1\alpha_3 + \alpha_1\alpha_2\alpha_3} (< \frac{1}{\alpha_1}). \quad (\text{A.21})$$

By (A.17) we have

$$\alpha_2 = \frac{\rho_1 + \rho_3(1 - \bar{p}_3^3)}{\rho_2\bar{a}_2^1}.$$

We substitute the expression found for  $\bar{p}_3^3$  and solve the resulting equation for  $\bar{a}_2^1$ , and obtain that

$$\bar{a}_2^1 = \frac{\rho_1 + \rho_3}{\rho_2} \frac{1 - \alpha_1\alpha_2\alpha_3}{\alpha_2 + \alpha_1\alpha_2 + \alpha_1\alpha_2\alpha_3}. \quad (\text{A.22})$$

This expression is clearly positive. It is less than or equal to one if and only if

$$\rho_2 \geq \frac{1 - \alpha_1\alpha_2\alpha_3}{1 + \alpha_2 + \alpha_1\alpha_2}. \quad (\text{A.23})$$

Since all players  $i$  propose their best outcome  $x_{b_i}$  with positive probability, and since  $\bar{a}_1^3 = 1$ ,  $\bar{a}_2^1 > 0$ , and  $\bar{a}_3^2 > 0$  implies that such a proposal is accepted with positive probability, no player wants to use the option not to make a proposal. Finally, the SSPE utilities satisfy  $\bar{z}^1 = u_2^1$ ,  $\bar{z}^2 = u_3^2$ , and  $\bar{z}^3 < u_1^3$ .

We summarize our findings in the following theorem.

**THEOREM A.3.1** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_2^1 = 0$ ,  $\bar{p}_3^2 = 0$ ,  $\bar{p}_1^3 > 0$ , and  $\bar{z}^1 \geq u_2^1$  if and only if  $\alpha_1\alpha_2\alpha_3 < 1$  and  $\rho$  is such that (A.21) and (A.23) are satisfied. In this case, such SSPE is unique. It is given by (A.10), (A.11), (A.19), (A.20), and (A.22). The equilibrium utilities satisfy  $\bar{z}^1 = u_2^1$ ,  $\bar{z}^2 = u_3^2$ , and  $\bar{z}^3 < u_1^3$ .*

For given utilities satisfying (A.18), (A.21) requires  $\rho_3$  to be sufficiently high compared to  $\rho_1$ , and (A.23) requires  $\rho_2$  to be sufficiently high.

To summarize, players 1 and 2 propose their best alternative whenever they are the recognized player. Player 1's best alternative is accepted for sure, whereas player 2's best alternative may be rejected with positive probability. By proposing his best alternative, this player chooses the risky option over his riskless security utility  $u_{m_2}^2$ . Player 3's proposal consists of randomizing between his best and middle alternative. Notice that, unlike the SSPEs of Theorem A.1, players never use the option to refrain from making a proposal, i.e.,  $p_0^i = 0$ ,  $i = 1, 2, 3$ . Since conditional equilibrium utilities satisfy  $\bar{v}_i^i > \bar{z}^i$ ,  $i = 1, 2, 3$ , each player enjoys an advantage whenever he is the recognized player. Moreover, conditional on being the recognized player, player 1 achieves his best alternative, player 2 is strictly

better off compared to his security level, and player 3 is kept at his security level. In many bargaining models, the advantage to propose vanishes in taking the limit to the no discounting case. Here the advantage is present under no discounting.

The SSPE leads to a positive expected delay. The reason is that player 3 is recognized with positive probability and proposes  $x_3$  with positive probability. This proposal is rejected by both players with positive probability. Player 1 always proposes  $x_1$ , which is accepted by player 3. Player 2 always proposes  $x_2$ , which is accepted by player 1 with positive probability  $\bar{a}_2^1$  and is rejected by both players otherwise.

Using a straightforward relabeling of the players, we find fully symmetric results for SSPEs with  $\bar{p}_2^2 = \bar{p}_3^3 = 1$  and player 1 mixing between  $x_1$  and  $x_2$ , and SSPEs with  $\bar{p}_1^1 = \bar{p}_3^3 = 1$  and player 2 mixing between  $x_2$  and  $x_3$ .

### A.3.2 Case 2

It holds that  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE if and only if there is  $\bar{\pi}$  such that

$$\bar{p} = \begin{bmatrix} 1 & 0 & 1 - \bar{p}_3^3 \\ 0 & 1 & 0 \\ 0 & 0 & \bar{p}_3^3 \end{bmatrix} \quad (\text{A.24})$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}, \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ \bar{a}_3^2 \end{bmatrix}, \text{ and } \bar{a}^3 = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, \quad (\text{A.25})$$

$$\bar{a}_3^2 u_3^3 + (1 - \bar{a}_3^2) (\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3) = u_1^3, \quad (\text{A.26})$$

$$\bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 < u_2^1, \quad (\text{A.27})$$

$$\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 = u_3^2, \quad (\text{A.28})$$

$$\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 < u_1^3, \quad (\text{A.29})$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1, \quad (\text{A.30})$$

$$\bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 = \rho_1 + \rho_3(1 - \bar{p}_3^3) : \rho_2 : \rho_3 \bar{p}_3^3 \bar{a}_3^2, \quad (\text{A.31})$$

where  $0 < \bar{p}_3^3 < 1$  and  $0 < \bar{a}_3^2 < 1$ .

We can rewrite (A.26)–(A.29) as

$$\alpha_3 - (1 - \bar{a}_3^2)(\bar{\pi}_1 + \bar{\pi}_2(1 + \alpha_3)) = 0, \quad (\text{A.32})$$

$$\bar{\pi}_1 \alpha_1 - \bar{\pi}_3 < 0, \quad (\text{A.33})$$

$$-\bar{\pi}_1 + \bar{\pi}_2 \alpha_2 = 0, \quad (\text{A.34})$$

$$-\bar{\pi}_2 + \bar{\pi}_3 \alpha_3 < 0. \quad (\text{A.35})$$

We have a system (A.30), (A.31), (A.32), (A.34) with five equations in the five unknowns  $\bar{\pi}_1$ ,  $\bar{\pi}_2$ ,  $\bar{\pi}_3$ ,  $\bar{p}_3^3$ , and  $\bar{a}_3^2$ . Solving this system results in outcome probabilities

$$\bar{\pi}_1 = \frac{\alpha_2(\alpha_3 + \rho_2)}{1 + \alpha_3 + \alpha_2\alpha_3}, \quad \bar{\pi}_2 = \frac{\alpha_3 + \rho_2}{1 + \alpha_3 + \alpha_2\alpha_3}, \quad \text{and} \quad \bar{\pi}_3 = \frac{1 - \rho_2(1 + \alpha_2)}{1 + \alpha_3 + \alpha_2\alpha_3},$$

and SSPE action probabilities

$$\bar{p}_3^3 = \frac{\rho_1 - \alpha_2\rho_2 + \rho_3}{\rho_3}, \tag{A.36}$$

$$\bar{a}_3^2 = \frac{\rho_2}{\alpha_3 + \rho_2}. \tag{A.37}$$

It is immediate that the solution satisfies  $0 < \bar{a}_3^2 < 1$ .

The inequality (A.33) is equivalent to

$$\rho_2 < \frac{1 - \alpha_1\alpha_2\alpha_3}{1 + \alpha_2 + \alpha_1\alpha_2} \left( < \frac{1}{1 + \alpha_2} \right). \tag{A.38}$$

The inequality (A.35) is always satisfied.

The requirement  $\bar{p}_3^3 > 0$  is equivalent to  $\rho_2 < 1/(1 + \alpha_2)$ , which implies  $\bar{\pi}_3 > 0$ . This requirement follows from (A.38). The requirement  $\bar{p}_3^3 < 1$  is equivalent to

$$\frac{\rho_1}{\rho_2} < \alpha_2. \tag{A.39}$$

Since all players  $i$  propose their best outcome  $x_{b_i}$  with positive probability, and since  $\bar{a}_1^3 = 1$ ,  $\bar{a}_2^1 = 1$ , and  $\bar{a}_3^2 > 0$  implies that such a proposal is accepted with positive probability, no player wants to use the option not to make a proposal. We summarize our findings in the following theorem.

**THEOREM A.3.2** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_2^1 = 0$ ,  $\bar{p}_3^2 = 0$ ,  $\bar{p}_1^3 > 0$ , and  $\bar{z}^1 < u_2^1$  if and only if  $\alpha_1\alpha_2\alpha_3 < 1$  and  $\rho$  is such that (A.38) and (A.39) are satisfied. In this case, an SSPE is unique. It is given by (A.24), (A.25), (A.36), and (A.37). Equilibrium utilities satisfy  $\bar{z}^1 < u_2^1$ ,  $\bar{z}^2 = u_3^2$ , and  $\bar{z}^3 < u_1^3$ .*

For given utilities satisfying (A.18), (A.38) requires  $\rho_2$  to be sufficiently low. It complements (A.23) which implies that SSPEs as in Case 1 cannot coexist with those as in Case 2. Inequality (A.39) requires  $\rho_1$  to be sufficiently low compared to  $\rho_2$ . Notice that, like the SSPE of Theorem A.3.1, the option not to make a proposal cannot be chosen with any positive probability.

The SSPE leads to a positive expected delay. The reason is that player 3 is recognized with positive probability, proposes  $x_3$  with positive probability, which is rejected by both players with positive probability. The proposals of players 1 and 2 are accepted for sure.

Similar to the previous case, all three players have an advantage to propose. Conditional on being the recognized player, player 3 cannot do better than getting the utility of his middle alternative. Conditional on being the proposer, both player 1 and player 2 achieve the utility of the best alternative.

By a relabeling of the players, we find fully symmetric results for SSPEs with  $\bar{p}_2^2 = \bar{p}_3^3 = 1$  and player 1 mixing between  $x_1$  and  $x_2$ , and SSPEs with  $\bar{p}_1^1 = \bar{p}_3^3 = 1$  and player 2 mixing between  $x_2$  and  $x_3$ .

#### A.4 No Player with $\bar{p}_{m_i}^i > 0$ .

We finally consider SSPEs where all players propose their best outcome for sure. Let  $(\bar{p}_i^i, \bar{p}_{m_i}^i, \bar{a}_{m_i}^i, \bar{z}^i)$  be a solution to (4.15)–(4.22) with  $\bar{p}_1^1 = \bar{p}_2^2 = \bar{p}_3^3 = 1$ . To obtain  $\bar{\pi}_j > 0$ ,  $j = 1, 2, 3$ , we must have  $\bar{a}_1^3 > 0$ ,  $\bar{a}_2^1 > 0$ , and  $\bar{a}_3^2 > 0$ . It follows from (4.18) that  $\bar{z}^1 \leq u_2^1$ ,  $\bar{z}^2 \leq u_3^2$ , and  $\bar{z}^3 \leq u_1^3$ . Since all players propose their best outcome with positive probability, and since such a proposal is accepted with positive probability, no player wants to use the option not to make a proposal. We distinguish four possible cases of interest. In Case 1, there are three players with  $\bar{z}^i = u_{m_i}^i$ , in Case 2 there are two such players, without loss of generality, players 1 and 2, in Case 3 there is one such player, without loss of generality player 1, and in Case 4 all players have  $\bar{z}^i < u_{m_i}^i$ .

##### A.4.1 Case 1

It holds that  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE if and only if there is  $\bar{\pi}$  such that

$$\bar{p} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{A.40}$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ \bar{a}_2^1 \\ 0 \end{bmatrix}, \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ \bar{a}_3^2 \end{bmatrix}, \text{ and } \bar{a}^3 = \begin{bmatrix} \bar{a}_1^3 \\ 0 \\ 1 \end{bmatrix}, \tag{A.41}$$

$$\bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 = u_2^1,$$

$$\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 = u_3^2,$$

$$\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 = u_1^3,$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1,$$

$$\bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 = \rho_1 \bar{a}_1^3 : \rho_2 \bar{a}_2^1 : \rho_3 \bar{a}_3^2. \tag{A.42}$$

As in Section A.1 we obtain that

$$\alpha_1\alpha_2\alpha_3 = 1, \tag{A.43}$$

$$\bar{\pi}_1 = \frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}, \tag{A.44}$$

$$\bar{\pi}_2 = \frac{1}{1 + \alpha_2 + \alpha_1\alpha_2}, \tag{A.45}$$

$$\bar{\pi}_3 = \frac{\alpha_1\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}. \tag{A.46}$$

The SSPE is not unique. Let  $\lambda > 0$  be such that, for  $i = 1, 2, 3$ ,  $\lambda\bar{\pi}_{m_i} \leq \rho_{m_i}$ . If player  $i$  has to respond to the proposal  $x_{m_i}$ , he accepts with probability  $\bar{a}_{m_i}^i = \lambda\bar{\pi}_{m_i}/\rho_{m_i} > 0$  and rejects with probability  $1 - \lambda\bar{\pi}_{m_i}/\rho_{m_i} < 1$ . This construction ensures that (A.42) holds. The higher  $\lambda$ , the less delay before an outcome is accepted. The highest possible choice of  $\lambda$  occurs when there is at least one player  $i$  for which  $\bar{a}_{m_i}^i = 1$ . In that case, selection of player  $i + 1$  as proposer leads to a proposal that is accepted for sure. Note that  $\lambda = 0$  would violate  $\bar{\pi}_{m_i} > 0$ . The set of SSPEs is not closed. The no discounting case differs in this respect from the discounting case where the set of SSPEs is compact.

By definition of this case, the equilibrium utilities satisfy  $\bar{z}^i = u_{m_i}^i$ ,  $i = 1, 2, 3$ . Since also  $\bar{a}_{m_i}^i > 0$  and  $\bar{z}^i = u_{m_i}^i$ , the conditional equilibrium utilities satisfy  $\bar{v}_i^i \in (u_{m_i}^i, u_{b_i}^i)$ ,  $i = 1, 2, 3$ . We conclude that there is an advantage in becoming the recognized player and that a recognized player does strictly better than his security level  $u_{m_i}^i$ .

**THEOREM A.4.1** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ , and  $\bar{z}^i \geq u_{m_i}^i$ ,  $i = 1, 2, 3$ , if and only if  $\alpha_1\alpha_2\alpha_3 = 1$ . In this case, there is a unique SSPE with minimal delay. It is given by the solution  $(\bar{p}, \bar{a})$  to (A.40), (A.41), and (A.42) with  $\bar{a}_{m_i}^i = 1$  for at least one player  $i$ , where  $(\bar{\pi}_1, \bar{\pi}_2, \bar{\pi}_3)$  is defined in (A.44)–(A.46). Other SSPEs are obtained by proportionally lowering  $\bar{a}_{m_i}^i$  across players  $i$ . All SSPEs induce the same equilibrium utilities, given by  $\bar{z}^i = u_{m_i}^i$ ,  $i = 1, 2, 3$ .*

#### A.4.2 Case 2

It holds that  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE if and only if there is  $\bar{\pi}$  such that

$$\bar{p} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{A.47}$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ \bar{a}_2^1 \\ 0 \end{bmatrix}, \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ \bar{a}_3^2 \end{bmatrix}, \text{ and } \bar{a}^3 = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, \tag{A.48}$$

$$\bar{a}_3^2 u_3^3 + (1 - \bar{a}_3^2)(\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3) \geq u_1^3, \quad (\text{A.49})$$

$$\begin{aligned} \bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 &= u_2^1, \\ \bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 &= u_3^2, \\ \bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 &< u_1^3, \\ \bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 &= 1, \\ \bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 &= \rho_1 : \rho_2 \bar{a}_2^{-1} : \rho_3 \bar{a}_3^{-2}. \end{aligned} \quad (\text{A.50})$$

As in Subsection 9 we obtain that

$$\alpha_1 \alpha_2 \alpha_3 < 1, \quad (\text{A.51})$$

$$\bar{\pi}_1 = \frac{\alpha_2}{1 + \alpha_2 + \alpha_1 \alpha_2}, \quad \bar{\pi}_2 = \frac{1}{1 + \alpha_2 + \alpha_1 \alpha_2}, \quad \text{and} \quad \bar{\pi}_3 = \frac{\alpha_1 \alpha_2}{1 + \alpha_2 + \alpha_1 \alpha_2}.$$

From (A.50) it then follows that

$$\bar{a}_2^{-1} = \frac{\rho_1}{\alpha_2 \rho_2}, \quad (\text{A.52})$$

$$\bar{a}_3^{-2} = \frac{\alpha_1 \rho_1}{\rho_3}. \quad (\text{A.53})$$

To satisfy (A.49) we need that

$$\frac{\rho_1}{\rho_3} \geq \frac{1 - \alpha_1 \alpha_2 \alpha_3}{\alpha_1 + \alpha_1 \alpha_3 + \alpha_1 \alpha_2 \alpha_3} \left( \leq \frac{1}{\alpha_1} \right). \quad (\text{A.54})$$

The requirements  $\bar{a}_2^{-1} \leq 1$  and  $\bar{a}_3^{-2} \leq 1$  lead to

$$\frac{\rho_1}{\rho_2} \leq \alpha_2, \quad (\text{A.55})$$

$$\frac{\rho_3}{\rho_1} \geq \alpha_1. \quad (\text{A.56})$$

By definition of the case, the equilibrium utilities satisfy  $\bar{z}^1 = u_{m_1}^1$ ,  $\bar{z}^2 = u_{m_2}^2$ , and  $\bar{z}^3 < u_{m_3}^3$ . For  $i = 1, 2$ ,  $\bar{a}_i^{i-1} > 0$  and  $\bar{z}^i = u_{m_i}^i$  imply that the conditional equilibrium utilities satisfy  $\bar{v}_i^i > u_{m_i}^i$ . Since  $\bar{z}^3 < u_{m_3}^3$ , it follows that player 3 has an advantage to propose.

We can summarize our findings in the following theorem.

**THEOREM A.4.2** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 \geq u_2^1$ ,  $\bar{z}^2 \geq u_3^2$ , and  $\bar{z}^3 < u_1^3$  if and only if  $\alpha_1 \alpha_2 \alpha_3 < 1$  and  $\rho$  is such that (A.54), (A.55), and (A.56) are satisfied. In this case, there is a unique SSPE. It is given by (A.47), (A.48), (A.52), and (A.53). The equilibrium utilities satisfy  $\bar{z}^1 = u_2^1$ ,  $\bar{z}^2 = u_3^2$ , and  $\bar{z}^3 < u_1^3$ .*

For given utilities satisfying (A.51), (A.54) requires  $\rho_1$  to be sufficiently high compared to  $\rho_3$ , and (A.56) requires  $\rho_1$  to be sufficiently low. Moreover,  $\rho_1$  should be sufficiently low compared to  $\rho_2$  by (A.55). Notice that, unlike the SSPE of Theorem A.1, the option not to make a proposal cannot be chosen with any positive probability.

By (A.50), the SSPE does not involve delay if and only if  $\rho_i$  is equal to  $\bar{\pi}_i$  for ALL  $i = 1, 2, 3$ .

By a relabeling of the players, we obtain fully symmetric results for SSPEs with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 \geq u_2^1$ ,  $\bar{z}^2 < u_3^2$ , and  $\bar{z}^3 \geq u_1^3$ , and for SSPEs with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 < u_2^1$ ,  $\bar{z}^2 \geq u_3^2$ , and  $\bar{z}^3 \geq u_1^3$ .

### A.4.3 Case 3

It holds that  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE if and only if there is  $\bar{\pi}$  such that

$$\bar{p} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.57})$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ \bar{a}_2^1 \\ 0 \end{bmatrix}, \quad \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}, \quad \text{and} \quad \bar{a}^3 = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, \quad (\text{A.58})$$

$$\bar{a}_2^1 u_2^2 + (1 - \bar{a}_2^1)(\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2) \geq u_3^2, \quad (\text{A.59})$$

$$\bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 = u_2^1, \quad (\text{A.60})$$

$$\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 < u_3^2, \quad (\text{A.61})$$

$$\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 < u_1^3, \quad (\text{A.62})$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1,$$

$$\bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 = \rho_1 : \rho_2 \bar{a}_2^1 : \rho_3. \quad (\text{A.63})$$

Rewriting (A.60) and using (A.63), we find that

$$\rho_3 = \alpha_1 \rho_1. \quad (\text{A.64})$$

It follows that Case 3 admits SSPEs in degenerate cases only, more precisely, when (A.64) holds. In these degenerate cases, there is a continuum of SSPEs, inducing a continuum of SSPE utilities for players 2 and 3. We parametrize the SSPEs by means of the positive real number  $\lambda$  and using (A.63) we write

$$\bar{\pi}_1 = \lambda \rho_1 \quad \text{and} \quad \bar{\pi}_3 = \alpha_1 \lambda \rho_1.$$

Suppose by means of contradiction that  $\lambda < 1$ . Using (A.63), we find that

$$\bar{\pi}_1 = \lambda\rho_1 < \rho_1, \quad \bar{\pi}_2 = \frac{\bar{\pi}_1\rho_2\bar{a}_2^1}{\rho_1} = \lambda\rho_2\bar{a}_2^1 < \rho_2, \quad \text{and} \quad \bar{\pi}_3 = \frac{\bar{\pi}_1\rho_3}{\rho_1} = \lambda\rho_3 < \rho_3.$$

We obtain the contradiction  $1 = \bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 < \rho_1 + \rho_2 + \rho_3 = 1$ . Consequently, we have shown that  $\lambda \geq 1$ .

Since  $\rho_1 + \rho_2 + \rho_3 = 1$  and  $\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1$ , we have

$$\rho_2 = 1 - (1 + \alpha_1)\rho_1, \quad \text{and} \quad \bar{\pi}_2 = 1 - (1 + \alpha_1)\lambda\rho_1.$$

Using (A.63), we have

$$\bar{a}_2^1 = \frac{1 - (1 + \alpha_1)\lambda\rho_1}{\lambda - (1 + \alpha_1)\lambda\rho_1}. \quad (\text{A.65})$$

The denominator of (A.65) is positive if and only if  $\rho_1 < 1/(1 + \alpha_1)$ . The inequalities in (A.61) and (A.59) are satisfied if and only if

$$\frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2} < \lambda\rho_1 \leq \frac{\alpha_2 + \rho_1}{1 + \alpha_2 + \alpha_1\alpha_2} \left( < \frac{1}{1 + \alpha_1} \right). \quad (\text{A.66})$$

The inequality in (A.66) in parentheses implies that  $\bar{a}_2^1$  and  $\bar{\pi}_2$  are positive.

The inequality (A.62) is satisfied if and only if

$$\lambda\rho_1 < \frac{1}{1 + \alpha_1 + \alpha_1\alpha_3}. \quad (\text{A.67})$$

The first inequality of (A.66) together with (A.67) imply that  $\alpha_1\alpha_2\alpha_3 < 1$ . There is some  $\lambda \geq 1$  such that (A.66) and (A.67) are satisfied if and only if  $\alpha_1\alpha_2\alpha_3 < 1$  and

$$\rho_1 < \frac{1}{1 + \alpha_1 + \alpha_1\alpha_3}. \quad (\text{A.68})$$

The lowest possible value of  $\lambda \geq 1$  such that (A.66) and (A.67) are satisfied is given by

$$\max\left\{1, \frac{1}{\rho_1} \frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}\right\}. \quad (\text{A.69})$$

We can summarize our findings in the following theorem.

**THEOREM A.4.3** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 \geq u_2^1$ ,  $\bar{z}^2 < u_3^2$ , and  $\bar{z}^3 < u_1^3$  if and only if  $\alpha_1\alpha_2\alpha_3 < 1$ ,  $\rho_3 = \alpha_1\rho_1$ , and  $\rho_1$  satisfies (A.68). In this case there is a continuum of SSPEs. Any  $\lambda \geq 1$  satisfying (A.66) and (A.67) induces an SSPE given by (A.57), (A.58), and (A.65). Equilibrium utilities depend on  $\lambda$  and satisfy  $\bar{z}^1 = u_2^1$ ,  $\bar{z}^2 < u_3^2$ , and  $\bar{z}^3 < u_1^3$ .*

Notice that, unlike the SSPE of Theorem A.1, the option not to make a proposal cannot be chosen with any positive probability. The SSPE does not involve delay if and only if  $\lambda = 1$ . Whenever  $\rho_1 < \frac{\alpha_2}{1+\alpha_2+\alpha_1\alpha_2}$ , the lowest possible choice for  $\lambda$  strictly exceeds 1, and delay cannot be avoided.

Fully symmetric results hold for SSPEs with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 < u_2^1$ ,  $\bar{z}^2 \geq u_3^2$ , and  $\bar{z}^3 < u_1^3$ , and for SSPEs with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 < u_2^1$ ,  $\bar{z}^2 < u_3^2$ , and  $\bar{z}^3 \geq u_1^3$ .

#### A.4.4 Case 4

It holds that  $(\bar{p}, \bar{a}) \in P \times A$  is an SSPE if and only if there is  $\bar{\pi}$  such that

$$\bar{p} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.70})$$

$$\bar{a}^1 = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}, \bar{a}^2 = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}, \text{ and } \bar{a}^3 = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, \quad (\text{A.71})$$

$$\bar{\pi}_1 u_1^1 + \bar{\pi}_2 u_2^1 + \bar{\pi}_3 u_3^1 < u_2^1, \quad (\text{A.72})$$

$$\bar{\pi}_1 u_1^2 + \bar{\pi}_2 u_2^2 + \bar{\pi}_3 u_3^2 < u_3^2, \quad (\text{A.73})$$

$$\bar{\pi}_1 u_1^3 + \bar{\pi}_2 u_2^3 + \bar{\pi}_3 u_3^3 < u_1^3, \quad (\text{A.74})$$

$$\bar{\pi}_1 + \bar{\pi}_2 + \bar{\pi}_3 = 1,$$

$$\bar{\pi}_1 : \bar{\pi}_2 : \bar{\pi}_3 = \rho_1 : \rho_2 : \rho_3. \quad (\text{A.75})$$

The equalities in (A.75) immediately lead to the conclusion that  $\bar{\pi}_1 = \rho_1$ ,  $\bar{\pi}_2 = \rho_2$ , and  $\bar{\pi}_3 = \rho_3$ . The inequalities in (A.72)–(A.74) are equivalent to the following conditions:

$$\frac{\rho_3}{\rho_1} > \alpha_1, \quad (\text{A.76})$$

$$\frac{\rho_1}{\rho_2} > \alpha_2, \quad (\text{A.77})$$

$$\frac{\rho_2}{\rho_3} > \alpha_3. \quad (\text{A.78})$$

It is immediate to verify that (A.76)–(A.78) imply that  $\alpha_1 \alpha_2 \alpha_3 < 1$ .

By definition of the case, the equilibrium utilities satisfy  $\bar{z}^1 < u_{m_1}^1$ ,  $\bar{z}^2 < u_{m_2}^2$  and  $\bar{z}^3 < u_{m_3}^3$ . Since each player accepts his middle alternative for sure, the conditional equilibrium utilities satisfy  $\bar{v}_1^1 = u_1^1$ ,  $\bar{v}_2^2 = u_2^2$  and  $\bar{v}_3^3 = u_3^3$ . Therefore, each player has an advantage to propose and, as the recognized player, each player can realize his best alternative for sure.

We can summarize our findings in the following theorem.

**THEOREM A.4.4** *There is an SSPE  $(\bar{p}, \bar{a}) \in P \times A$  with  $\bar{p}_{m_i}^i = 0$ ,  $i = 1, 2, 3$ ,  $\bar{z}^1 < u_2^1$ ,  $\bar{z}^2 < u_3^2$ , and  $\bar{z}^3 < u_1^3$  if and only if  $\alpha_1\alpha_2\alpha_3 < 1$  and  $\rho$  is such that (A.76)–(A.78) are satisfied. In this case there is a unique SSPE. It is given by (A.70) and (A.71). The equilibrium utilities satisfy  $\bar{z}^1 < u_2^1$ ,  $\bar{z}^2 < u_3^2$ , and  $\bar{z}^3 < u_1^3$ .*

Notice that, unlike the SSPE of Theorem A.1, the option not to make a proposal cannot be chosen with any positive probability. The SSPE is in pure strategies in which each player always proposes his best alternative and always accepts his best and middle alternative. These strategies imply immediate agreement and the probability distribution over the three alternatives coincides with the recognition probabilities, i.e.  $\bar{\pi}_i = \rho_i$ . The SSPE utilities are below the utility of the middle alternative, which makes accepting the middle alternative the unique best response. The recognized player takes full advantage of this response by proposing his best alternative knowing it will be accepted for sure.

## Appendix B

**PROOF OF THEOREM 4.2:**

$\Rightarrow$  After observing that  $\sum_{j=0}^3 p_j^h r_{jh}^{h-1} r_{jh}^{h+1} < 1$  for some player  $h$ , i.e. player  $h$  makes with positive probability a proposal that is accepted with positive probability is equivalent to  $\pi_0 = 0$ , this direction follows from the derivations in this section.

$\Leftarrow$  We first argue that a solution  $(p, r, v, z)$  to (4.1)–(4.7) corresponds to a strategy profile  $(p, r)$  inducing utilities  $(v, z)$  and satisfying the one-shot deviation property. To show that  $(v, z)$  are the utilities induced by  $(p, r)$  we have to show that given the strategy profile  $(p, r)$  the system (4.1)–(4.2) has a unique solution. We substitute the expression for  $v_h^i$  given in (4.1) in (4.2) and obtain a system of three equations and three unknowns of the form

$$z^i = c^i + dz^i, \quad i = 1, 2, 3.$$

The constant  $d$  is given by

$$d = \sum_{h=1}^3 \rho_h \sum_{j=0}^3 p_j^h r_{jh}^{h-1} r_{jh}^{h+1} < 1,$$

where the inequality follows from the fact that  $\rho_h$  is positive for all  $h$ . Since  $d < 1$ , the uniqueness of  $z$  follows immediately, leading to the uniqueness of  $v$ . Now it follows from (4.1)–(4.7) that  $(p, r)$  has the one-shot deviation property.

We argue next that the absence of a profitable one-shot deviation implies the absence of a profitable deviation, proving that  $(p, r)$  is an SSPE. The usual proofs do not apply because future payoffs are not discounted. Nevertheless, the property that for some  $h$  it

holds that  $\sum_{j=0}^3 p_j^h r_{jh}^{h-1} r_{jh}^{h+1} < 1$  coupled with the observation that  $\rho_h > 0$  implies that every round there is a positive probability that negotiations terminate. Suppose there is some player, say  $i$ , who has a profitable deviation from  $(p, r)$  at some decision node. The feature that every round there is a positive probability that negotiations terminate implies that player  $i$  also has a profitable deviation from  $(p, r)$  that coincides with the strategy prescribed by  $(p^i, r^i)$  except for a finite number of decision nodes, exactly as in the case with discounting. Finally, the usual backwards induction argument shows that player  $i$  must then also have a profitable one-shot deviation. *Q.E.D.*

**PROOF OF THEOREM 4.3:** We show first that each player  $i$  has  $z^i$  strictly exceeding the utility  $u_{w_i}^i$  of his worst outcome. Suppose, on the contrary, that player  $i$  has  $z^i = u_{w_i}^i$ . The probability is therefore 1 that the outcome  $x_{w_i}$  is accepted at some point in time, since otherwise the utility of  $i$  strictly exceeds  $u_{w_i}^i$ . Therefore, it follows that  $z^{i-1} = u_{b_{i-1}}^{i-1}$  and  $z^{i+1} = u_{m_{i+1}}^{i+1}$ . Since  $u_{m_i}^{i-1} = u_{w_{i-1}}^{i-1} < u_{b_{i-1}}^{i-1} = z^{i-1}$ , (4.7) yields that player  $i-1$  rejects proposal  $x_{m_i}$  by player  $i$  with probability 1, so  $r_{m_i i}^{i-1} = 1$ . Since  $r_{m_i i}^{i-1} = 1$  and  $z^{i+1} = u_{m_{i+1}}^{i+1} < u_{b_{i+1}}^{i+1} = u_{m_i}^{i+1}$ , (4.4) yields that player  $i+1$  rejects proposal  $x_{m_i}$  by player  $i$  with probability 0. Proposal  $x_{m_i}$  by player  $i$  is therefore accepted with probability 1, so  $v_i^i \geq u_{m_i}^i > u_{w_i}^i$ . Since  $v_{i-1}^i \geq u_{w_i}^i$  and  $v_{i+1}^i \geq u_{w_i}^i$ , we find that  $u_{w_i}^i = z^i = \rho_1 v_1^i + \rho_2 v_2^i + \rho_3 v_3^i > u_{w_i}^i$ , a contradiction. We conclude that each player has  $z^i$  strictly exceeding  $u_{w_i}^i$ , i.e.

$$z^i > u_{w_i}^i, \quad i = 1, 2, 3. \quad (4.12)$$

We show next that each player  $i$  has  $z^i$  strictly lower than the utility of his best outcome,  $u_{b_i}^i$ . If some player  $i$  has  $z^i = u_{b_i}^i$ , then outcome  $x_{b_i}$  is accepted with probability 1, so  $z^{i+1} = u_{b_i}^{i+1} = u_{w_{i+1}}^{i+1}$ , a contradiction to (4.12). We have found that

$$z^i < u_{b_i}^i, \quad i = 1, 2, 3. \quad (4.13)$$

Next, we argue that any voter rejects his worst alternative for sure. To see this, when player  $h$  proposes outcome  $x_{w_i}$ ,  $i \neq h$ , then player  $i$  is the last one to vote. It holds by (4.12) that  $z^i > u_{w_i}^i$ , so by (4.7),  $r_{w_i h}^i = 1$ . We have shown that

$$r_{w_i h}^i = 1, \quad i = 1, 2, 3, \quad h \neq i. \quad (4.9)$$

We continue by establishing that, independent of who proposes, the recognized player can always conclude the bargaining for sure by proposing either his worst or his middle alternative. Consider a proposal  $x_{m_i}$  by player  $i$ , so player  $i$  proposes his middle outcome and player  $i+1$ , for whom this is the best alternative, votes before player  $i-1$ . We argue that this proposal will be accepted with probability 1 by player  $i+1$ , i.e.  $r_{m_i i}^{i+1} = 0$ . By

(4.9), since  $m_i = w_{i-1}$ ,  $r_{m_i}^{i-1} = 1$ . Using that  $m_i = b_{i+1}$ , we know by (4.13),  $u_{m_i}^{i+1} > z^{i+1}$ . Since  $r_{m_i}^{i-1} = 1$ , we use (4.4) to conclude that  $r_{m_i}^{i+1} = 0$ . We have derived that

$$r_{21}^2 = r_{32}^3 = r_{13}^1 = 0. \quad (4.10)$$

Consider now a proposal  $x_{w_i}$  by player  $i$  meaning player  $i$  proposes his worst outcome. We argue that this proposal will be accepted with probability one, i.e.  $r_{w_i}^{i-1} r_{w_i}^{i+1} = 0$ . Since  $w_i = b_{i-1}$ , it follows from (4.13) that  $u_{w_i}^{i-1} > z^{i-1}$ , so by (4.4),  $r_{w_i}^{i-1} = 0$  or  $r_{w_i}^{i+1} = 0$ . We have derived that

$$r_{31}^2 r_{31}^3 = r_{12}^1 r_{12}^3 = r_{23}^1 r_{23}^2 = 0. \quad (4.11)$$

As a corollary, a recognized player will never propose his worst alternative, because he can do strictly better by proposing his middle alternative, i.e.

$$p_{w_i}^i = 0, \quad i = 1, 2, 3. \quad (4.8)$$

We have already argued that each  $z^i$  is a weighted average of  $u_j^i$ ,  $j = 1, 2, 3$ , with weights  $\pi_j$  independent of  $i$ . We argue next that all these weights are positive. If only one weight would be positive, we would get a contradiction to (4.12) for some  $i$ . Suppose that exactly two weights are positive, without loss of generality the weights  $\pi_1$  on outcome  $x_1$  and  $\pi_2$  on  $x_2$  sum up to one and  $\pi_3 = 0$ , so  $z^i = \pi_1 u_1^i + \pi_2 u_2^i$ . For the equality  $\pi_3 = 0$  to hold, the proposal  $x_3$  by player 3 should be rejected with probability 1. The proposal  $x_1$  by player 3 is accepted with probability 1 according to (4.10). We can now use (4.3) to conclude that  $p_0^3 = p_3^3 = 0$ , and since  $p_2^3 = 0$  by (4.8), we know that  $p_1^3 = 1$ . From (4.4) and (4.9), the proposal  $x_1$  by player 1 is accepted with probability 1 by player 3. The proposal  $x_2$  by player 1 is accepted with probability 1 according to (4.10). We can now use (4.3) to conclude that  $p_0^1 = p_2^1 = 0$ , and since  $p_3^1 = 0$  by (4.8), we know that  $p_1^1 = 1$ . A proposal  $x_2$  by player 2 would be rejected with probability 1 by player 1 using (4.5) and the fact that  $r_{22}^3 = 0$  by (4.9). It now follows that  $\pi_1 = 1$ , a contradiction to (4.12). We conclude that all weights are positive,

$$\pi_1, \pi_2, \pi_3 > 0. \quad (4.14)$$

*Q.E.D.*

**PROOF OF THEOREM 4.4:** Assume that  $(p, r) \in P \times R$  satisfies (4.1)–(4.7). We show that  $(p, \bar{r})$  satisfies (4.1)–(4.7), where  $\bar{r}$  is as defined in Theorem 4.4. We verify first that  $\bar{r}$  is proposer independent. Indeed, for  $i = 1, 2, 3$ , we have the following. It holds by definition that  $\bar{r}_{0h}^i = 1$ ,  $h \neq i$ . We have by definition that  $\bar{r}_{b_{i+1}}^i = 0$  and  $\bar{r}_{b_{i-1}}^i = r_{b_{i-1}}^i = 0$ , where the last equality holds by (4.10). Also it holds by definition that  $\bar{r}_{m_{i+1}}^i = r_{m_{i+1}}^i$

and  $\bar{r}_{m_i i-1}^i = r_{m_i i+1}^i$ , so  $\bar{r}_{m_i i+1}^i = \bar{r}_{m_i i-1}^i$ . Finally, we have  $r_{w_i h}^i = 1$ ,  $h \neq i$ , by (4.9), and  $\bar{r}_{w_i h}^i = r_{w_i h}^i$ ,  $h \neq i$ , by definition.

We show next that

$$r_{jh}^{h-1} r_{jh}^{h+1} = \bar{r}_{jh}^{h-1} \bar{r}_{jh}^{h+1}, \quad h = 1, 2, 3, \quad j = 0, 1, 2, 3. \quad (\text{B.1})$$

For  $j = 0$ , this follows immediately from the definition of  $R$ . Three possible cases remain:

(i)  $j = b_h$ , (ii)  $j = m_h$ , and (iii)  $j = w_h$ .

Case (i),  $j = b_h$ . Since  $b_h = m_{h-1} = w_{h+1}$ , we have

$$\bar{r}_{b_h h}^{h-1} \bar{r}_{b_h h}^{h+1} = \bar{r}_{m_{h-1} h}^{h-1} \bar{r}_{w_{h+1} h}^{h+1} = r_{m_{h-1} h}^{h-1} r_{w_{h+1} h}^{h+1} = r_{b_h h}^{h-1} r_{b_h h}^{h+1},$$

where the second equality follows by definition of  $\bar{r}$ .

Case (ii),  $j = m_h$ . Since  $m_h = w_{h-1} = b_{h+1}$ , we obtain

$$\bar{r}_{m_h h}^{h-1} \bar{r}_{m_h h}^{h+1} = \bar{r}_{w_{h-1} h}^{h-1} \bar{r}_{b_{h+1} h}^{h+1} = r_{w_{h-1} h}^{h-1} r_{b_{h+1} h}^{h+1} = r_{m_h h}^{h-1} r_{m_h h}^{h+1},$$

where the second equality follows by definition of  $\bar{r}$ .

Case (iii),  $j = w_h$ . By (4.11), it holds that  $r_{w_h h}^{h-1} r_{w_h h}^{h+1} = 0$ . Since  $w_h = b_{h-1}$ , we have that  $\bar{r}_{w_h h}^{h-1} = \bar{r}_{b_{h-1} h}^{h-1} = 0$ , where the last equality follows by definition of  $\bar{r}$ . It follows that  $\bar{r}_{w_h h}^{h-1} \bar{r}_{w_h h}^{h+1} = 0$ .

Using (B.1) we have that  $(p, \bar{r}, v, z)$  satisfies (4.1), (4.2), and (4.3). We verify next that  $(p, \bar{r}, v, z)$  satisfies (4.4)–(4.7). Consider some  $\bar{r}_{jh}^i$ . If  $j = b_i$ , then  $\bar{r}_{jh}^i = 0$  and  $i = f_{jh}$ , so (4.4), (4.6), and (4.7) hold trivially. Implication (4.5) holds as well, since  $z^i < u_{b_i}^i$  by (4.13). If  $j = w_i$ , then  $\bar{r}_{jh}^i = r_{jh}^i = 1$  by (4.9), so (4.5) and (4.7) hold trivially. Since by (4.12)  $z^i > u_{w_i}^i$ , we find that (4.4) and (4.6) also hold. If  $j = m_i$  and  $h = i + 1$ , then  $i = f_{jh}$ , so (4.6) and (4.7) hold trivially. We have that  $\bar{r}_{jh}^i = r_{jh}^i$  and  $\bar{r}_{jh}^{i'} = \bar{r}_{w_{i-1} i+1}^{i-1} = r_{w_{i-1} i+1}^{i-1} = r_{jh}^{i'}$ , so (4.4) and (4.5) hold. Finally, we consider the case where  $j = m_i$  and  $h = i - 1$ , so  $i = s_{jh}$  and (4.4) and (4.5) hold trivially. Assume  $\bar{r}_{jh}^i > 0$ . Since by definition  $\bar{r}_{jh}^i = \bar{r}_{m_i i-1}^i = r_{m_i i+1}^i$ , we have  $r_{m_i i+1}^i > 0$ , so by (4.4)  $z^i \geq u_{m_i}^i$  or  $r_{m_i i+1}^{i-1} = 0$ . Since  $m_i = w_{i-1}$ , (4.9) implies  $r_{m_i i+1}^{i-1} = 1$ , so  $z^i \geq u_{m_i}^i$ . It follows that (4.6) holds. Assume  $\bar{r}_{jh}^i < 1$ . Since by definition  $\bar{r}_{jh}^i = \bar{r}_{m_i i-1}^i = r_{m_i i+1}^i$ , we have  $r_{m_i i+1}^i < 1$ , so by (4.5)  $z^i \leq u_{m_i}^i$  or  $r_{m_i i+1}^{i-1} = 0$ . Since  $m_i = w_{i-1}$ , (4.9) implies  $r_{m_i i+1}^{i-1} = 1$ , so  $z^i \geq u_{m_i}^i$ . It follows that (4.7) holds. *Q.E.D.*

#### PROOF OF THEOREM 4.5:

( $\Rightarrow$ ) This direction follows immediately from the results derived in this section.

( $\Leftarrow$ ) This direction follows from Theorem 4.2 by defining, for  $h = 1, 2, 3$ ,  $i = 1, 2, 3$ , and  $j = 0, 1, 2, 3$ ,

$$\begin{aligned} \bar{v}_h^i &= \bar{p}_{m_h}^h u_{m_h}^i + \bar{p}_{b_h}^h \bar{a}_{b_h}^{h-1} u_{b_h}^i + \bar{p}_{b_h}^h (1 - \bar{a}_{b_h}^{h-1}) \bar{z}^i, \\ \bar{r}_{jh}^i &= 1 - \bar{a}_j^i, \end{aligned}$$

and verifying that a solution  $(\bar{p}, \bar{a}, \bar{\pi}, \bar{z})$  to (4.15)–(4.22) inducing expected utilities  $\bar{v}$  and rejection probabilities  $\bar{r}$  leads to a solution  $(\bar{p}, \bar{r}, \bar{v}, \bar{z})$  to (4.1)–(4.7) with  $\bar{\pi} = 0$ . *Q.E.D.*

**PROOF OF THEOREM 6.1:** Necessity follows by Table 7. We now turn to sufficiency of the condition. By Theorem A.1 an SSPE exists if  $\alpha_1\alpha_2\alpha_3 = 1$ . It remains to be shown that an SSPE exists if  $\alpha_1\alpha_2\alpha_3 < 1$ .

By Theorem A.4.4 an SSPE exists if  $\rho_1/\rho_2 > \alpha_2$ ,  $\rho_2/\rho_3 > \alpha_3$ , and  $\rho_3/\rho_1 > \alpha_1$ . Consider now the cases where the conditions of Theorem A.4.4 are not satisfied. We claim that then

$$\left(\frac{\rho_3}{\rho_1} \geq \alpha_1 \text{ and } \frac{\rho_1}{\rho_2} \leq \alpha_2\right) \text{ or } \left(\frac{\rho_1}{\rho_2} \geq \alpha_2 \text{ and } \frac{\rho_2}{\rho_3} \leq \alpha_3\right) \text{ or } \left(\frac{\rho_2}{\rho_3} \geq \alpha_3 \text{ and } \frac{\rho_3}{\rho_1} \leq \alpha_1\right). \quad (\text{B.2})$$

Indeed, assume, without loss of generality,  $\rho_1/\rho_2 \leq \alpha_2$ . Either it holds that  $\rho_3/\rho_1 \geq \alpha_1$  or  $\rho_3/\rho_1 < \alpha_1$ . In the former case the first formula in (B.2) is true, in the latter case it should hold that  $\rho_2/\rho_3 \geq \alpha_3$ , since otherwise

$$1 = \frac{\rho_1}{\rho_2} \frac{\rho_2}{\rho_3} \frac{\rho_3}{\rho_1} < \alpha_2\alpha_3\alpha_1 < 1,$$

and the third formula in (B.2) is true.

We show next that an SSPE exists whenever  $\rho_3/\rho_1 \geq \alpha_1$  and  $\rho_1/\rho_2 \leq \alpha_2$ . The other two cases in (B.2) follow by symmetry. If  $\rho_3/\rho_1 = \alpha_1$  and  $\rho_1/\rho_2 \leq \alpha_2$ , then line 1 in Theorem A.4.3 implies the existence of an SSPE since  $\rho_1/\rho_2 \leq \alpha_2$  implies  $\rho_1 < 1/(1 + \alpha_1 + \alpha_1\alpha_3)$ . Suppose, by contradiction, that  $\rho_1 \geq 1/(1 + \alpha_1 + \alpha_1\alpha_3)$ . Then

$$\begin{aligned} 1 &= \rho_1 + \rho_2 + \rho_3 \geq \frac{1}{1 + \alpha_1 + \alpha_1\alpha_3} + \frac{1}{\alpha_2 + \alpha_1\alpha_2 + \alpha_1\alpha_2\alpha_3} + \frac{\alpha_1}{1 + \alpha_1 + \alpha_1\alpha_3} \\ &= \frac{1 + \alpha_2 + \alpha_1\alpha_2}{\alpha_2 + \alpha_1\alpha_2 + \alpha_1\alpha_2\alpha_3} > 1, \end{aligned}$$

a contradiction. If  $\rho_1/\rho_2 = \alpha_2$  and  $\rho_3/\rho_1 > \alpha_1$ , then line 2 in Theorem A.4.3 implies the existence of an SSPE since  $\rho_3/\rho_1 \geq \alpha_1$  implies  $\rho_2 < 1/(1 + \alpha_2 + \alpha_1\alpha_2)$ . Suppose, by contradiction, that  $\rho_2 \geq 1/(1 + \alpha_2 + \alpha_1\alpha_2)$ . Then

$$1 = \rho_1 + \rho_2 + \rho_3 > \frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2} + \frac{1}{1 + \alpha_2 + \alpha_1\alpha_2} + \frac{\alpha_1\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2} = 1,$$

a contradiction.

It remains to be shown that an SSPE exists if  $\rho_3/\rho_1 > \alpha_1$  and  $\rho_1/\rho_2 < \alpha_2$ . By line 1 in Theorem A.4.2, an SSPE exists if  $\rho_3/\rho_1 \geq \alpha_1$ ,  $\rho_1/\rho_2 \leq \alpha_2$ , and  $\rho_1/\rho_3 \geq \beta_1$ , and by line 1 in Theorem A.3.1 an SSPE exists if  $\rho_1/\rho_3 < \beta_1$  and  $\rho_2 \geq \alpha_3\beta_3$ .

It remains to be shown that an SSPE exists if  $\rho_3/\rho_1 > \alpha_1$ ,  $\rho_1/\rho_2 < \alpha_2$ ,  $\rho_1/\rho_3 < \beta_1$ , and  $\rho_2 < \alpha_3\beta_3$ . This follows from line 1 in Theorem A.3.2. *Q.E.D.*

PROOF OF THEOREM 6.2: Existence follows from Theorem 6.1. Leave out the games satisfying the conditions of Theorem A.1, Theorem A.4.1, and Theorem A.4.3. This corresponds to a set of games whose closure has Lebesgue measure zero. Comparing the conditions in any two distinct rows (that do not correspond to Theorem A.3.1) of Table 7 leads to the conclusion that the corresponding two sets of parameters have an empty intersection. This conclusion follows directly in most cases. In some cases one has to make use of the property that  $\alpha_i\beta_i < 1$ , which implies that we cannot have simultaneously  $\rho_j/\rho_k < \alpha_i$  and  $\rho_k/\rho_j < \beta_i$ . Finally, each of the Theorem A.3.1, A.3.2, A.4.1, and A.4.4 identify a unique SSPE. *Q.E.D.*

PROOF OF THEOREM 7.1: First we consider the case where  $\alpha_1\alpha_2\alpha_3 = 1$ . From Table 8 and Theorem A.1 it follows that we can choose

$$\rho_1 = \frac{1}{1 + \alpha_2 + \alpha_1\alpha_2}, \quad \rho_2 = \frac{\alpha_1\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2}, \quad \text{and} \quad \rho_3 = \frac{\alpha_2}{1 + \alpha_2 + \alpha_1\alpha_2},$$

which leads to a delay probability of  $1-1=0$ .

Next we consider the case where  $\alpha_1\alpha_2\alpha_3 < 1$ . We show that  $\rho$  can be chosen such that the conditions of Theorem A.4.4 as listed in Table 7 are satisfied, which demonstrates the absence of delay. We define  $\gamma = 1/\sqrt[3]{\alpha_1\alpha_2\alpha_3} > 1$  and

$$\rho_1 = \frac{\gamma^2\alpha_2\alpha_3}{1 + \gamma\alpha_3 + \gamma^2\alpha_2\alpha_3}, \quad \rho_2 = \frac{\gamma\alpha_3}{1 + \gamma\alpha_3 + \gamma^2\alpha_2\alpha_3}, \quad \text{and} \quad \rho_3 = \frac{1}{1 + \gamma\alpha_3 + \gamma^2\alpha_2\alpha_3}.$$

It therefore holds that

$$\frac{\rho_1}{\rho_2} = \gamma\alpha_2 > \alpha_2, \quad \frac{\rho_2}{\rho_3} = \gamma\alpha_3 > \alpha_3, \quad \text{and} \quad \frac{\rho_3}{\rho_1} = \frac{1}{\gamma^2\alpha_2\alpha_3} = \gamma\alpha_1 > \alpha_1.$$

*Q.E.D.*

PROOF OF THEOREM 7.2: Without loss of generality, we may assume that for all  $n \in \mathbb{N}$ ,  $(u, \rho^n)$  satisfies the conditions of exactly one of the theorems, i.e. one of the 15 subcases displayed in Table 8.

According to Table 8, the lower bound on the delay probability following from an SSPE of Theorem A.1 is given by

$$1 - (1 + \alpha_2 + \alpha_1\alpha_2) \min\left\{\rho_1^n, \frac{\rho_2^n}{\alpha_1\alpha_2}, \frac{\rho_3^n}{\alpha_2}\right\}.$$

Clearly, this lower bound converges to 1 when  $n \rightarrow \infty$ .

According to Table 7, the first line of conditions in Theorem A.3.1 states that  $\rho_2^n \geq \alpha_3\beta_3$ , so  $\lim_{n \rightarrow \infty} \rho_2^n = 1$ . Then Table 8, first line corresponding to A.3.1, yields that  $\lim_{n \rightarrow \infty} \delta_n = 1$ . The other cases corresponding to Theorem A.3.1 follow by symmetry.

According to Table 7, the first line of conditions in Theorem A.3.2 states that  $\rho_2^n < \alpha_3\beta_3$ , so it is impossible that  $\lim_{n \rightarrow \infty} \rho_2^n = 1$ , so  $\lim_{n \rightarrow \infty} \rho_2^n = 0$ . Then Table 8, first line corresponding to A.3.2, yields that  $\lim_{n \rightarrow \infty} \delta_n = 1$ . The other cases corresponding to Theorem A.3.2 follow by symmetry.

It is evident from Table 8 that the delay probability following from Theorem A.4.1 goes to 1 when  $n$  goes to infinity.

According to Table 7, the first line of conditions in Theorem A.4.2 states that  $\rho_1^n \leq \alpha_2\rho_2^n$ , so  $\lim_{n \rightarrow \infty} \rho_1^n = 0$ . Then Table 8, first line corresponding to A.4.2, yields that  $\lim_{n \rightarrow \infty} \delta_n = 1$ . The other cases corresponding to Theorem A.4.2 follow by symmetry.

According to Table 7, the first line of conditions in Theorem A.4.3 states that  $\rho_1^n < 1/(1 + \alpha_1 + \alpha_1\alpha_3)$ , so  $\lim_{n \rightarrow \infty} \rho_1^n = 0$ . Then Table 8, first line corresponding to A.4.3, yields that the lower bound on the delay probability following from an SSPE converges to 1. The other cases corresponding to Theorem A.4.3 follow by symmetry.

Table 7 demonstrates that  $(u, \rho^n)_{n \in \mathbb{N}}$  cannot satisfy the conditions of Theorem A.4.4. Suppose without loss of generality that  $\lim_{n \rightarrow \infty} \rho_1^n = 0$ . Since  $\rho_2^n < \rho_1^n/\alpha_2$ , we have  $\lim_{n \rightarrow \infty} \rho_2^n = 0$ . Since  $\rho_3^n < \rho_2^n/\alpha_3$ , we have  $\lim_{n \rightarrow \infty} \rho_3^n = 0$ . It follows that  $\rho$  converges to the zero vector, a contradiction. *Q.E.D.*

**PROOF OF THEOREM 7.3:** It is easily verified that, with the exception of Theorem A.1 and A.4.3, there is always an alternative that, in an SSPE, is never rejected when being proposed. The Conditions in Theorem A.1 and A.4.3 are only satisfied for sets of games having a closure with Lebesgue measure zero. *Q.E.D.*

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