SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

CONTRACTED STUDY AGREEMENT REG / POL / 1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 1

BACKGROUND METHODOLOGIES

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A.STRASZAK

ZTS/ZPZC/ZTSW 1-36/85

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Consisting of 3 Parts

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VIII. COOPERATIVE AGREEMENTS AND CREDIBILITY IN DYNAMIC SOCIO-ECONOMIC SYSTEMS

by J. Stefański

VIII.1 Introduction

In many socio-economic systems in which the existence of a multiplicity of decision makers plays an important role it appears that collaboration between parties is advantageous to them. Typically such a collaboration is based on an agreement reached in a bargaining process. An example of such a situation connected with the problem of planning tax policy in a region has been described in the previous chapter. Other examples are connected with cooperation and bargaining in enterprises (Chen, Leitman, 1980; Stefański, 1985) or in larger economic systems (Hamalainen et al., 1983; Straszak et al., 1986). In most of the existing models of bargaining it is assumed that once an agreement has been reached it is absolutely binding (Nash, 1950; Kalai, Smorodinsky, 1975; Roth, 1979; Yu, 1973), even if the dynamics of the negotiation process is taken into account (Rubinstein, 1982). In this paper we do not make that assumption, following Tolwiński (1982), and Haurie and Tolwiński (1984), because in most situations it seems to be unrealistic (see the previous chapter for an example). In such a case the players try to make an agreement lasting by incorporating retaliation threats into their strategies. Such threats are announced in advance and are to be carried out if the partner breaks the agreement. The way in which an equilibrium in a game of this kind can be determined has been described in Haurie and Tolwiński (1984).

A situation of the above mentioned kind, in which a center makes an agreement with economic agents, has been described in the previous chapter (a specific feature of that model is the nonsymmetry of the statuses of the parties).

In this chapter we concentrate on the credibility and other properties an effective retaliation threat (incorporated into an agreement as a clause which is to be applied in the case of breaking anagreement) should possess. The problem of credibility of the announced strategies has been discussed for the first time in the contex of Stackelberg games (Ho, Olsder, 1981; Luh , Chang, Chang, 1984; Luh, Zheng, Ho, 1984). We assume that decision makers apply memory strategies. In such a case there exist infinitely many Nash equilibria (Basar, 1984; Basar, Olsder, 1982), and the proposed approach makes it possible to choose in a rational way one of them. In the paper we introduce a measure of credibility, which allows us to determine a set of ε-credible threats. This set is employed when determining an effective retaliation threat (other proposals of the choice of threats were suggested in earlier papers (Luh, Chang, Chang, 1984; Haurie , Tolwiński, 1984; Ray, Blaquière, 1981)). We distinguish four properties a threat should have, they are linked with the twofold role it plays, i.e. with making an agreement lasting, and with the influence on the negotiation process and final agreement. The aspect of bluffing during negotiations is also discussed.

VIII.2 Cooperation in dynamic systems

Consider a dynamic system controlled by two decision makers who in each time period $t \in \{0,1,\dots T-1\}$ make decisions $u_i(t) \in U_i^t \subset R^{m_i}$, $i=1,2,$. The dynamics is described by the state equation:

$$x(t+1) = f^t(x(t), u_1(t), u_2(t)), \quad t \in \{0,1,\dots,T-1\}, \qquad \text{(VIII.1)}$$

where $x(t) \in X^t \subset R^n$. If the system is in a state $x(t)$ then the future trajectory $x(t+1), x(t+2),\dots,x(T)$ depends on $x(t)$ and the decision sequences:

$$\tilde{u}_i^t \triangleq (u_i(t), u_i(t+1),\dots,u_i(T-1)), \quad i=1,2. \qquad \text{(VIII.2)}$$

When choosing the above sequence each decision maker wants to maximize the following stage-additive objective function

$$G_i(t,x(t),\tilde{u}_1^t, \tilde{u}_2^t) =$$

$$= \sum_{s=t}^{T-1} g_i^s(x(s), u_1(s), u_2(s)) + g_i^T(x(T)). \qquad \text{(VIII.3)}$$

We assume that both players know initial state $x(0)$ and recall all past decisions, i.e. the information the i-th player at a stage t has is

$$z_i^t = (x(0);\ u_1(0),\ u_1(1),\dots,u_1(t-1);\ u_2(0),\ u_2(1)\dots$$
$$\dots,\ u_2(t-1)). \tag{VIII.4}$$

Then, the players' strategies are the sequences $(\gamma_i^t)_{t=0,1,\dots,T-1}$ of the following mappings

$$\gamma_i^t : X^0 \times \prod_{s=0}^{t-1} U_1^s \times \prod_{s=0}^{t-1} U_2^s \to U_i^t,\quad i=1,2. \tag{VIII.5}$$

We introduce the notation

$$\tilde{\gamma}_i^t \overset{\Delta}{=} (\gamma_i^s)_{s=t,t+1,\dots,T-1} \tag{VIII.6}$$

$$J_i(t,x(t),\tilde{\gamma}_1^t,\ \tilde{\gamma}_2^t) = G_i(t,x(t),\tilde{u}_1^t,\tilde{u}_2^t),$$
$$i = 1,2 \tag{VIII.7}$$

where

$$u_i(s) = \tilde{\gamma}_i^s(z_i^s),\qquad s\in\{t,t+1,\dots,T-1\} \tag{VIII.8}$$

We will say that a pair of strategies $(\tilde{\gamma}_1^{*t},\tilde{\gamma}_2^{*t})$ constitutes an <u>equilibrium</u> at $x(t)$ if for all stages $s=t,t+1,\dots,T-1$ the subsequences of strategies satisfy:

$$\tilde{\gamma}_i^{*s} = \arg\max_{\tilde{\gamma}_i^s\in\tilde{\Gamma}_i^s} J_i\ (s,x^*(s),\ (\tilde{\gamma}_i^s,\tilde{\gamma}_j^{*s})),\ i=1,2, \tag{VIII.9}$$

where $(\tilde{\gamma}_i^s,\tilde{\gamma}_j^{*s})$ denotes $(\tilde{\gamma}_1^s,\tilde{\gamma}_2^{*s})$ or $(\tilde{\gamma}_1^{*},\tilde{\gamma}_2^s)$ depending on whether i=1 or 2, and $\tilde{\Gamma}_i^s$ is the set of admissible strategies (VIII.5). The set of all equilibria $(\tilde{\gamma}_1^{*t},\tilde{\gamma}_2^{*t})$ will be denoted by $E(t,x(t))$. For the simplicity of considerations we assume that the solution of (VIII.9) exist and are unique.

Now we can determine the set of feasible outcomes of the game

$$S(x(0))=\{(y_1,y_2) : y_i = J_i(0,x(0),\tilde{\gamma}_1^0,\tilde{\gamma}_2^0),\quad \tilde{\gamma}_1^0\in\tilde{\Gamma}_1^0,\ \tilde{\gamma}_2^0\in\tilde{\Gamma}_2^0,\ i=1,2\}. \tag{VIII.10}$$

We assume that players can communicate and make agreements but we do not assume that there exists any external force which is in a position to make an agreement binding. In such a case players try to make the agreement lasting by incorporating into their strategies threats which are to be carried out if the partner breaks the agreement. We assume that a <u>retaliation threat</u> r_i has the form of a feedback strategy $r_i: (t,x(t))\to U_i^t$. The parties negotiate at the beginning of the game, at $x(0)$, and declare that if the other party breaks the agreement they will retaliate up to the end of the game. This results in the following strategies, for $t=0$:

$$\gamma_i^{A0}(z^0) = u_i^A(0), \tag{VIII.11}$$

and for $t=1,2,\dots,T-1$:

$$\gamma_i^{At}(z_i^t) = \begin{cases} u_i^A(t) \text{ if } u_j(s) = u_j^A(s) \text{ for } s=0,1,\dots,t-1 \\ r_i(t,x(t)) \text{ otherwise,} \end{cases} \tag{VIII.12}$$

$i,j=1,2,\quad i\neq j,$ where the control sequences $\tilde{u}_i^{A0} = (u_i^A(t))_{t=0,1,\dots,T-1}$ follow from the agreement.

Breaking an agreement at t player i can expect the following pay-off for the stages $t,t+1,\dots,T$:

$$M_i(t,x^A(t),u_j^A(t)) = \max_{u_i(t)} g_i^t(t,x^A(t),(u_i(t),u_j^A(t))) + \max_{u_i^{t+1}} G_i(t+1,f^t(x^A(t),(u_i(t),u_j^A(t)),(\tilde{u}_i^{t+1},\tilde{u}_j^{r,t+1})) \tag{VIII.13}$$

where $i\neq j$, and $\tilde{u}_j^{r,t+1}$ is the control sequence which results from retaliation, i.e. $u_j^r(s)=r_i(s,x(s))$. On the other hand, if player i respects the agreement he can expect $G_i(t,x^A(t), \tilde{u}_1^{At}, \tilde{u}_2^{At})$. Therefore the players have no incentive to break an agreement determined by $(\tilde{u}_1^{A0}, \tilde{u}_2^{A0})$ if for i=1,2:

$$G_i(t,x^A(t), \tilde{u}_1^{At}, \tilde{u}_2^{At}) \geqslant M_i(t,x^A(t),u_j^A(t)) \quad \text{(VIII.14)}$$

for t=0,1,...,T-2 and

$$G_i(T-1,x^A(T-1),u_i^A(T-1), u_2^A(T-1)) = \max_{u_i(T-1)} G_i(T-1, x^A(T-1), (u_i(T-1),u_j^A(T-1)). \quad \text{(VIII.15)}$$

We will say, following Haurie and Tolwiński (1984), that if conditions (VIII.14), (VIII.15) are satisfied then there is <u>no temptation</u> (to break an agreement) associated with $(\tilde{u}_1^{A0}, \tilde{u}_2^{A0})$ under the threats (r_1,r_2).

If the pair $(\tilde{u}_1^{A0}, \tilde{u}_2^{A0})$ is without temptation, then the corresponding strategy pair $(\tilde{\gamma}_1^{A0}, \tilde{\gamma}_2^{A0})$ defined by (VIII.11), (VIII.12) is an equilibrium, i.e. $(\gamma_1^{A0}, \gamma_2^{A0}) \in E(0,x(0))$ (Haurie, Tolwiński, 1984). In such a case $(\gamma_1^{A0}, \gamma_2^{A0})$ determines a <u>lasting agreement.</u> The set of all lasting agreements under (r_1, r_2) will be denoted by $\Gamma^A(x(0), r_1,r_2)$. Thus, the set of <u>acceptable outcomes</u> is given by

$$S^A(x(0), r_1,r_2)=\{(y_1,y_2) : y_i= J_i(0,x(0),\tilde{\gamma}_1^{A0},\tilde{\gamma}_2^{A0}), (\tilde{\gamma}_1^{A0},\tilde{\gamma}_2^{A0})\in\Gamma^A(x(0),r_1,r_2), i=1,2\}. \quad \text{(VIII.16)}$$

Then, if players want to reach a lasting agreement they ought to choose one of the outcomes from $S^A(x(0), r_1,r_2)$. We assume, as it is usually done (Roth, 1979), that the status quo in negotiations $y^d= (y_1^d, y_2^d) \in S$ is determined by the disagreement strategies $(d_1,d_2) \in \Gamma_1^0 \times \Gamma_2^0$ announced in advance, i.e. $y_i^d = J_i(0,x(0),d_1,d_2)$, i=1,2. Thus, we obtain a <u>bargaining problem</u> defined by $(S^A(x(0), r_1,r_2), y^d)$.

Typically the methods of solving bargaining problems require the set of feasible outcomes to be convex (Nash, 1950; Yu, 1973) or its Pareto-frontier to be connected (Kalai, Smorodinsky, 1975; Stefański 1985). In our game however, the set $S^A(\cdot)$ cannot be assumed to be convex (or even connected).

Therefore Haurie and Tolwiński (1984) have suggested a new method of solving $(S^A(\cdot), y^d)$ assuming that $S^A(\cdot)$ is compact only. Let us denote that solution by $\Phi(S^A(\cdot), y^d)$ (the reader is referred to the cited paper). Thus, the outcome $y^A = \Phi(S^A(x(0), r_1, r_2), y^d)$ together with the corresponding pair of strategies $(\tilde{\gamma}_1^{A0}, \tilde{\gamma}_2^{A0})$ constitute the solution of our game.

The sequel of this paper is devoted to the roles and properties of retaliation threats (r_1, r_2) in the dynamic game under consideration.

VIII.3 Credibility of retaliation threats

The concept of a solution of the game presented in the preceding section is correct provided that the retaliation threats (r_1, r_2) announced in (VIII.12) are credible, i.e. that each player believes that the partner's threat will be carried out if he breaks the agreement. Stability of an agreement heavily depends on the credibility defined in that way.

In a situation in which the partner breaks an agreement at a stage $(t-1) \in \{0, 1, \ldots, T-2\}$ player i has two extreme possibilities (at t). The first is to retaliate with r_i, the second is to resign from realizing r_i and decide on the optimal reaction to the partner's deviation (who applies $\tilde{\gamma}_j^t$):

$$\tilde{\gamma}_i^{Rt} = \arg\max_{\tilde{\gamma}_i^t} J_i'(t, x(t), (\tilde{\gamma}_i^t, \tilde{\gamma}_j^t)). \qquad \text{(VIII.17)}$$

Then, the relative cost of retaliation with r_i (at $x(t)$ and when the other party applies γ_j^t) can be defined in the following way:

$$c_i(t, x(t), (r_i, \tilde{\gamma}_j^t)) = [J_i(t, x(t), (\tilde{\gamma}_i^{Rt}, \tilde{\gamma}_j^t)) - J_i(t, x(t), r_i, \tilde{\gamma}_j^t))]/(\overline{y}_i - \underline{y}_i), \qquad \text{(VIII.18)}$$

where

$$\bar{y}_i = \max_{(\tilde{\gamma}^0_1, \tilde{\gamma}^0_2)} J_i(0, x(0), \tilde{\gamma}^0_1, \tilde{\gamma}^0_2),$$

$$\underline{y}_i = \min_{(\tilde{\gamma}^0_1, \tilde{\gamma}^0_2)} J_i(0, x(0), \tilde{\gamma}^0_1, \tilde{\gamma}^0_2). \tag{VIII.19}$$

Let us denote by $\alpha_i \in [0,1]$ the maximal relative cost of retaliation that player i is ready to pay. Then, α_i defines the player´s determination to carry out threats. It is a characteristic feature of the player.

Now we are in a position to define a measure of credibility of a given threat r_i (at a stage t, at the state $x(t)$, and as a function a determination α_i and the partner´s strategy $\tilde{\gamma}^t_j$):

$$\rho_i(t, x(t), (r_i, \tilde{\gamma}^t_j), \alpha_i) = \begin{cases} [\alpha_i - c_i(t, x(t), (r_i, \tilde{\gamma}^t_j))]/a & \text{if } a > 0 \\ 0 & \text{if } a > 0 \end{cases} \tag{VIII.20}$$

where

$$a = \max\{\alpha_i, c_i(t, x(t), (r_i, \tilde{\gamma}^t_j))\}. \tag{VIII.21}$$

If $\rho_i(\cdot) \geqslant 0$ then the threat is credible, if $\rho_i(\cdot) < 0$ it is not, whereas the value $\rho_i(\cdot) \in [-1,1]$ illustrates the credibility rate. Note, that in the case when determination $\alpha_i = 1$ credibility $\rho_i(\cdot) \geqslant 0$ and it is a linear function of the cost of retaliation.

We will say that a retaliation threat r_i is absolutely credible if

$$\rho_i(t, x(t), (r_i, \tilde{\gamma}^t_j), \alpha_i) = 1 \quad \forall x(t) \in X^t, \forall \tilde{\gamma}^t_j \in \tilde{\Gamma}^t_j, \tag{VIII.22}$$

$$\forall t \in \{0, 1, \dots, T-1\}, \alpha_i > 0.$$

Notice that absolutely credible is only the passive adaptation (VIII.17) to the other player´s deviation. Actually in such a case the passive player becomes a follower and the partner a leader of the game.

The set of <u>ε-credible retaliation threats</u> carried out at a stage t and the state $x(t)$ can be defined in the following way:

$$H_i^{\varepsilon}(t,x(t),\alpha_i)=\{r_i : \min_{\tilde{\gamma}_j^t} \rho_i(t,x(t),(r_i,\tilde{\gamma}_j^t),\alpha_i) \geqslant \varepsilon_i\}, \qquad \text{(VIII.23)}$$

where $\varepsilon_i \in [-1,1]$. Note, that in the above definition we assume that the partner does not want to minimize our objective $J_i(\cdot)$ but chooses his strategy in such a way that his deviation would be possibility harmful for us if we retaliated, and possibility advantageous if we did not.

VIII.4 The roles of threats in a dynamic game

The basic role of the threats (r_1,r_2) is to make the cooperative agreement lasting. It is worth emphasizing that that role is different from the roles threats play in static bargaining games where they determine the possibly advantageous point of departure for negotiations (Nash, 1953; Roth, 1979) (this is done in our game by the disagreement strategies (d_1,d_2)).

Then, the idea of a retaliation threat consists in the deterrence from breaking an agreement. We will say that a threat r_i is <u>deterrent</u> if it is credible and damaging. A threat is <u>credible</u> if it is chosen from the set $H_i^{\varepsilon}(0,x(0),\alpha_i)$ determined by (VIII.23) for a specific parameter $\varepsilon \geqslant 0$. On the other hand to what extent a threat r_i is <u>damaging</u> to the partner is reflected by the value of $\max_{\tilde{\gamma}_j^0} J_j(0,x(0),$ $(r_i, \tilde{\gamma}_j^0))$. If the announced threats (r_i,r_2) were "totally" deterrent then all agreements would be lasting and all feasible outcomes would be acceptable, i.e. $S^A(x(0),r_1,r_2)=S(x(0))$. However, a "total" deterrence is not possible, which results in the dependence of the final agreement (y_1^A, y_2^A) on (r_1,r_2), i.e.

$$(y_1^A, y_2^A) = \Phi\,(S^A(x(0),r_1,r_2), y^d). \qquad \text{(VIII.24)}$$

This is connected with the second role of retaliation threats, namely with the their influence on the agreement itself, not only on its stability. Then, the threats ought to be rational in the sense that they should allow arriving at an advantageous agreement. This means that both parties must have incentive to cooperate. In other words a threat r_i should be inducing an advantageous agreement y_i^A, as well as it should be not anti-motivational to the partner, i.e. there must be

$$y_j^A > \mu\, y_j^d \;, \quad \mu > 1 \;, \tag{VIII.25}$$

where μ is a specified parameter, and y_j^d concerns the status quo. We will say that a threat is rational if it is inducing and not anti-motivational.

VIII.5 Bargaining and the choice of threats

To be deterrent and rational a threat should possess the four properties mentioned in the preceding section. However, one must seek a compromise when choosing a threat because, for instance, maximization of credibility need not be consistent with maximization of y_i^A, i.e. with inducing an advantageous agreement. It seems reasonable to choose the retaliation threat in such a way that it induces the possibly best agreement, under the condition that the other three properties manifest themselves to a certain (prespecified) extent, i.e. to choose r_i^* such that

$$r_i^* = \arg \max_{r_i \in H^{\varepsilon}(0,x(0),\alpha_i)} y_i^A \tag{VIII.26}$$

with additional constraints:

$$\max_{\tilde{\gamma}_j^0} J_j(0,x(0),(r_i,\tilde{\gamma}_j^0)) \leqslant \nu \;, \tag{VIII.27}$$

$$y_j^A \geqslant \mu\, y_j^d \;, \tag{VIII.28}$$

where (y_1^A, y_2^A) is the agreement (VIII.24), y_j^d concerns the status quo, and ε, ν, μ, are prespecified parameters.

We suggest the following sequence of actions during the bargaining process leading to an agreement:

1. The players determine status quo $y^d \in S$ choosing disagreement strategies $(d_1, d_2) \in \tilde{\Gamma}_1^0 \times \tilde{\Gamma}_2^0$.
2. Each player i, i=1,2, undertakes certain (unspecified) actions that enable the other party to assess his determination α_i. In other words he indirectly informs the partner about α_i. In fact there is no use to announce α_i openly because in theory each player is completely determined to realize his threats.
3. The players announce retaliation threats r_i, i=1,2, choosen in the way suggested by (VIII.26)-(VIII.28)
4. Determination of the set of acceptable outcomes $S^A(x(0), r_1, r_2)$ and the final negotiated outcome $(y_1^A, y_2^A) = \Phi(S^A(x(0), r_1, r_2), y^d)$.

Note that in the step 2 of the above algorithm we distinguish the assessment $\hat{\alpha}_i$ from the real determination α_i. As a rule player i wants to make an impression that α_i is high, i.e. $\hat{\alpha}_i > \alpha_i$, because it enhances the credibility of his threat. In such a case player i bluffs, and the <u>bluff rate</u> can be characterized by $\beta_i \in [0,1]$, where

$$\beta_i = \hat{\alpha}_i - \alpha_i, \quad i=1,2. \qquad \text{(VIII.29)}$$

In general the higher $\hat{\alpha}_i$, the better the situation of player i. However, he cannot exaggerate when bluffing because his partner might not believe in it, which, in turn, might destroy the stability of an agreement. If player i is convinced that the partner has belived in $\hat{\alpha}_i$, then he can use $\hat{\alpha}_i$ in (VIII.26) instead of the true α_i. This allows him to enlarge the set $H_i^{\varepsilon}(\cdot)$, which, in turn, makes it possible to choose a threat which induces a more advantageous agreement.

VIII.6 <u>Concluding remarks</u>

We have discussed a dynamic game in which the players negotiate a cooperative agreement and in order to make it lasting they incorporate retaliation threats into their strategies.

We have focussed our attention on the credibility and the roles which retaliation threats play in such a game. A measure of credibility has been proposed, which makes it possible to determine a set of ε-credible strategies. Four properties an effective threat should possess have been distinguished and discussed. They were used when determining an "optimal", i.e. at the same time deterrent and rational, threat. In the course of the negotiation process which we have suggested, the aspect of bluffing is taken into account.

There are still many interesting aspects of the application of threats which are worth considering but have not been discussed. Examples include the credibility and bluffing in a case of repeated bargaining or in the situation when the statuses of the players are not symmetric.

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STUDY REPORT

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