Bargaining and Cooperation in Strategic Form Games

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("Cooperative Games in Strategic Form")
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http://www.ma.huji.ac.il/hart/abs/st-val.html
PROGRAM:

GIVEN: game in strategic form
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AIM: bargaining and cooperation
PROGRAM:

- GIVEN: game in strategic form
- AIM: bargaining and cooperation

Nash (1953): 2-person ("variable-threat")
PROGRAM:

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Nash (1953): 2-person ("variable-threat")

Harsanyi (1959, 1963): $N$-person
PROGRAM:

- GIVEN: game in strategic form
- AIM: bargaining and cooperation

Nash (1953): 2-person ("variable-threat")

Harsanyi (1959, 1963): $N$-person

But: the players are **not** the original players (each coalition has a "player")
The standard approach:
The standard approach:

(1) Derive a COALITIONAL GAME from the strategic form
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1. Derive a **COALITIONAL GAME** from the strategic form

2. Apply a **COOPERATIVE SOLUTION** to the **COALITIONAL GAME**
The standard approach:

(1) Derive a **COALITIONAL GAME** from the strategic form

(2) Apply a **COOPERATIVE SOLUTION** to the **COALITIONAL GAME**

OR

(2’) Apply a **NONCOOPERATIVE BARGAINING PROCEDURE** to the **COALITIONAL GAME**
Bargaining and Cooperation
Bargaining and Cooperation

Strategic Form

Strategic
Form
Bargaining and Cooperation

- Strategic Form
- Cooperative Outcomes
Bargaining and Cooperation

STRATEGIC FORM

? \rightarrow

COOPERATIVE OUTCOMES
Bargaining and Cooperation

Strategic Form → ? → Cooperative Outcomes

Coalitional Form
Bargaining and Cooperation

- Strategic Form
- Cooperative Outcomes
- Coalitional Form

(1) (2) (2')
Bargaining and Cooperation

Strategic Form → Cooperative Outcomes

(1) → (2)

Coalitional Form

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The standard approach:

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   OR

2'. Apply a **NONCOOPERATIVE BARGAINING PROCEDURE** to the **COALITIONAL GAME**
Introduction

How to define the COALITIONAL GAME?
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(von Neumann and Morgenstern)
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  (Aumann: \(\alpha\)-, \(\beta\)-)
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- "C-GAMES" (Shapley and Shubik):
  - the coalitional form is "self-evident" and "uncontroversial"
  - example: market games
Introduction

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- **TU** (transferable utility) (von Neumann and Morgenstern)
- **NTU** (non-transferable utility) (Aumann: \(\alpha\)-, \(\beta\)-)
- "**C-GAMES**" (Shapley and Shubik):
  - the coalitional form is "self-evident" and "uncontroversial"
  - example: market games

**Question:** Is the "factorization" through the coalitional game appropriate?
Propose a specific ("simple" and "natural") bargaining procedure:
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- The **PC PROCEDURE** ("Proposer Commitment")
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- Study its outcomes and implications in various setups
Propose a specific ("simple" and "natural") bargaining procedure:

- The **PC PROCEDURE** ("Proposer Commitment")

Study its outcomes and implications in various setups

Get general conclusions on the "program"
$N$-person GAME IN STRATEGIC FORM $G$
\( N \)-person GAME IN STRATEGIC FORM \( G \)

\( N = \) (finite) set of players
The Model

$N$-person GAME IN STRATEGIC FORM $G$

- $N = \text{(finite) set of players}$
- For each $i \in N$:
  - $A^i = \text{(finite) set of actions}$
  - $u^i : A \rightarrow \mathbb{R} = \text{payoff function}$
The Model

$N$-person GAME IN STRATEGIC FORM $G$

- $N = \text{(finite) set of players}$
- For each $i \in N$:
  - $A^i = \text{(finite) set of actions}$
  - $u^i : A \rightarrow \mathbb{R} = \text{payoff function}$

Notations:

- $x^i \in \Delta(A^i)$: mixed action of player $i \in N$
- $z^S \in \Delta(A^S)$: correlated action of coalition $S \subset N$ (where $A^S = \prod_{i \in S} A^i$)
The **PC Procedure** ("**Proposer Commitment**")
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(the probability of "REPEAT").
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(cf. Hart and Mas-Colell, Econometrica 1996)

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  - The set of "ACTIVE" players is $S \subset N$
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- Let $0 \leq \rho < 1$ be a fixed parameter (the probability of "REPEAT").

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Let $\omega = (S, b^{N\setminus S})$ (the "STATE").

- Start in state $(N, \cdot)$ (everyone is "active").
In each state $\omega = (S, b^{N\setminus S})$
The PC Procedure

In each state \( \omega = (S, b^{N\setminus S}) \)

1. A "PROPOSER" \( k \) in \( S \) is selected at random
The PC Procedure

In each state $\omega = (S, b^{N\setminus S})$

1. A "PROPOSER" $k$ in $S$ is selected at random
2. The proposer $k$ chooses
   
   $z^S \in \Delta(A^S)$ (a "PROPOSED AGREEMENT")
The PC Procedure

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2. The proposer $k$ chooses
   - $z^S \in \Delta(A^S)$ (a "PROPOSED AGREEMENT")
   - $x^k \in \Delta(A^k)$ (a "THREAT")

3. If all players in $S$ AGREE to $z^S$ then
   - $a^S \in A^S$ is selected according to the distribution $z^S$, and
   - the procedure ENDS: the $N$-tuple of actions $(a^S, b^{N\setminus S}) \in A$ is played in $G$
In each state $\omega = (S, b^{N\setminus S})$
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4. If at least one player in $S$ REJECTS $x^S$ then
The PC Procedure

In each state $\omega = (S, b^{N\setminus S})$

4. If at least one player in $S$ REJECTS $z^S$ then
   - with probability $\rho$, REPEAT (the state remains $\omega = (S, b^{N\setminus S})$);
   - with probability $1 - \rho$, the proposer $k$ becomes INACTIVE:
The PC Procedure

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4. If at least one player in $S$ REJECTS $z^S$ then
   - with probability $\rho$, REPEAT (the state remains $\omega = (S, b^{N\setminus S})$);
   - with probability $1 - \rho$, the proposer $k$ becomes INACTIVE:
     - $b^k \in A^k$ is selected according to the distribution $x^k$ (the threat is realized)
     - the new state is $\omega' = (S\setminus\{k\}, (b^{N\setminus S}, b^k))$
The PC Procedure

In each state $\omega = (S, b^{N\setminus S})$

4. If at least one player in $S$ REJECTS $z^S$ then
   - with probability $\rho$, REPEAT (the state remains $\omega = (S, b^{N\setminus S})$);
   - with probability $1 - \rho$, the proposer $k$ becomes INACTIVE:
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5. Start a new round (i.e., go back to step 1).
The procedure ends with probability 1 (since $\rho < 1$)
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The procedure ends with an $N$-tuple of actions $a \in A$ being played in the original strategic game $G$
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**SP equilibrium**: a (subgame-) Perfect equilibrium in Stationary strategies
Given an SP EQUILIBRIUM \( \sigma = (\sigma^i)_{i \in N} \) and a state \( \omega = (S, b^{N \setminus S}) \):
Outcomes and Equilibria

Given an \( \text{SP EQUILIBRIUM} \ \sigma = (\sigma^i)_{i \in N} \) and a state \( \omega = (S, b^{N\setminus S}) \):

\( \zeta^S_\omega \in \Delta(A^S) \) is the expected outcome starting at \( \omega \).
Given an **SP EQUILIBRIUM** \( \sigma = (\sigma^i)_{i \in N} \) and a state \( \omega = (S, b^{N\setminus S}) \):

- \( \zeta^S_\omega \in \Delta(A^S) \) is the expected outcome starting at \( \omega \)
- \( \zeta^S_{\omega,k} \in \Delta(A^S) \) is the expected outcome starting at \( \omega \) with proposer \( k \)
Outcomes and Equilibria

Given an \textbf{SP EQUILIBRIUM} $\sigma = (\sigma^i)_{i \in N}$ and a state $\omega = (S, b^{N \setminus S})$:

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- $\zeta^S_{\omega,k} \in \Delta(A^S)$ is the expected outcome starting at $\omega$ with proposer $k$.

- $\zeta^S_\omega = \frac{1}{|S|} \sum_{k \in S} \zeta^S_{\omega,k}$
Given an \textbf{SP equilibrium} $\sigma = (\sigma^i)_{i \in N}$ and a state $\omega = (S, b_{N \setminus S})$:

- $\zeta^S_\omega \in \Delta(A^S)$ is the expected outcome starting at $\omega$
- $\zeta^S_{\omega,k} \in \Delta(A^S)$ is the expected outcome starting at $\omega$ with proposer $k$
- $\zeta^S_\omega = \frac{1}{|S|} \sum_{k \in S} \zeta^S_{\omega,k}$
- $\ldots$
Given an **SP EQUILIBRIUM** $\sigma = (\sigma^i)_{i \in N}$ and a state $\omega = (S, b^{N \setminus S})$:
Outcomes and Equilibria

Given an **SP EQUILIBRIUM** \( \sigma = (\sigma^i)_{i \in N} \) and a state \( \omega = (S, b^{N \setminus S}) \):

- \( \ldots \)

- \( Z^*_{\omega,k}(\zeta) \) is the set of "acceptable" (given \( \zeta \)) proposals of \( k \) that maximize \( k \)'s payoff
Outcomes and Equilibria

Given an \textbf{SP EQUILIBRIUM} $\sigma = (\sigma^i)_{i \in N}$ and a state $\omega = (S, b^{N\setminus S})$:

\begin{itemize}
  \item $\ldots$
  \item $Z^*_{\omega,k}(\zeta)$ is the set of "acceptable" (given $\zeta$) proposals of $k$ that maximize $k$’s payoff
\end{itemize}

\textbf{Proposition.} \textit{The SP EQUILIBRIA are characterized by:}
Outcomes and Equilibria

Given an SP EQUILIBRIUM \( \sigma = (\sigma^i)_{i \in N} \) and a state \( \omega = (S, b^{N \setminus S}) \):

- \( \dots \)
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Proposition. The SP EQUILIBRIA are characterized by:

\[
\zeta^S_{\omega,k} \in Z^*_{\omega,k}(\zeta)
\]

for all \( \omega \) and \( k \).
Proposition. *An SP EQUILIBRIUM always exists.*
Proposition. *An SP EQUILIBRIUM always exists.*

Proposition. *The SP EQUILIBRIUM outcomes become Pareto efficient as $\rho \to 1.*
Two-Person Games

\[ N = \{1, 2\} \]

\[ D := \text{co} \{ (u^1(a), u^2(a)) : a \in A \} \]

\[ q^i := \min_{a^j \in A^j} \max_{a^i \in A^i} u^i(a^i, a^j) \]
Two-Person Games

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**Proposition.** Let \( G \) be a two-person strategic game such that \((D, q)\) is a pure bargaining problem. As \( \rho \rightarrow 1 \) the SP equilibrium outcomes converge to the **Nash bargaining solution** of \((D, q)\).
Transferable Utility

Definition. $G$ is a **STRATEGIC TU GAME** if for every state $(S, b^N\setminus S)$ there exists a real number $v(S, b^N\setminus S)$ such that any $c = u^S(z^S, b^N\setminus S)$ (for some $z^S \in \Delta(A^S)$) that is Pareto efficient for $S$ and individually rational satisfies
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$$\sum_{i \in S} c^i = v(S, b^{N\setminus S})$$
Transferable Utility

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\[
\sum_{i \in S} c^i = v(S, b^N \setminus S)
\]

Proposition. *Let \( G \) be a strategic TU game. Then the SP equilibrium outcomes are given by an "expected marginal contribution in a random order" formula . . . . * [read the paper]
Equilibria with Fixed Threats
Equilibria with Fixed Threats

**Definition.** An SP equilibrium $\sigma$ has **FIXED THREATS** $(f^k)_{k \in N} \in A$ if, for each player $k$, the threat of $k$ (whenever $k$ is the proposer) is $f^k$ in all states $(S, f^{N\setminus S})$ (i.e., along the "backward induction equilibrium path").
Equilibria with Fixed Threats

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In this case, define an NTU **coalitional game** $(N, V_{G,\sigma})$ by

$$V_{G,\sigma}(S) = \{ c \in \mathbb{R}^S : c \leq u^S(z^S, f^{N \setminus S}) \}$$

for some $z^S \in \Delta(A^S)$

for every coalition $S \subset N$. 
Equilibria with Fixed Threats

Proposition.

Let \((N, V_{G,\sigma})\) be derived from the strategic game \(G\)

Let \(\sigma\) be a **fixed-threat** equilibrium

Suppose that \((N, V_{G,\sigma})\) is a TU game
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Suppose that \((N, V_{G,\sigma})\) is a TU game.

Then the payoffs induced by \(\sigma\) equal the Shapley values of \((N, V_{G,\sigma})\) and its subgames.
Proposition.

- Let \((N, V_{G,\sigma})\) be derived from the strategic game \(G\).
- Let \(\sigma\) be a fixed-threat equilibrium.
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Then the payoffs induced by \(\sigma\) equal the SHAPLEY VALUES of \((N, V_{G,\sigma})\) and its subgames.

**NTU: MASCHLER–OWEN VALUES**
When can one get the \textit{fixed-threat} property?
When can one get the \textit{fixed-threat} property?

\textbf{Definition.} $d^k \in A^k$ is a \textbf{DAMAGING ACTION} of player $k$ if

$$u^i(d^k, a^{N\setminus k}) \leq u^i(a)$$

for every $a \in A$ and every player $i \neq k$. 
Games with Damaging Actions

- When can one get the *fixed-threat* property?

- **Definition.** $d^k \in A^k$ is a **DAMAGING ACTION** of player $k$ if

  $$u^i (d^k, a^{N \setminus k}) \leq u^i (a)$$

  for every $a \in A$ and every player $i \neq k$.

- **Definition.** A strategic game $G$ is a **D-GAME** if every player $k \in N$ has a damaging action.
Games with Damaging Actions
Proposition. Let $G$ be a strategic TU game which is a d-game.
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Then there exists a fixed-threat SP equilibrium of the PC procedure where each player $k$ uses a damaging $d^k$ action as threat.
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Then there exists a fixed-threat SP equilibrium of the PC procedure where each player $k$ uses a damaging $d^k$ action as threat.

What about NTU?
A "C-GAME" is a game where the coalitional function is "self-evident" and "uncontroversial" (Shapley and Shubik)
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For example: economic models of exchange without externalities (MARKET GAMES)
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Is a market game a D-GAME?
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Is a market game a D-GAME?

Yes: "Keep your endowment" is a damaging action
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Is a market game a D-GAME?

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Is this an optimal threat in equilibrium?
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For example: economic models of exchange without externalities (**MARKET GAMES**)

Is a market game a **D-GAME**?

**Yes**: "Keep your endowment" is a **damaging action**

Is this an **optimal threat** in equilibrium?

In the **TU** case: **YES**

(previous Proposition)
A "**C-GAME**" is a game where the coalitional function is "self-evident" and "uncontroversial" (Shapley and Shubik).

For example: economic models of exchange without externalities (**MARKET GAMES**)

- Is a market game a **D-GAME**?
  - **Yes**: "Keep your endowment" is a **damaging action**

- Is this an **optimal threat** in equilibrium?
  - In the **TU** case: **YES**
    - (previous Proposition)
  - In the **NTU** case: **NOT NECESSARY**!
Market Games Are Not c-Games
Example.
Market Games Are Not c-Games

Example.

- A *pure exchange* economy (market)
Market Games Are Not c-Games

Example.

- A *pure exchange* economy (market)
- 4 *commodities*: \(b, c, f, g\)
- 3 *traders*: 1, 2, 3
Example.

- A *pure exchange* economy (market)
- 4 *commodities*: b, c, f, g
- 3 *traders*: 1, 2, 3
- *Initial endowments*:

\[
\begin{align*}
  e^1 &= (0, 0, 1, 1) \\
  e^2 &= (0, 1, 0, 0) \\
  e^3 &= (1, 0, 0, 0)
\end{align*}
\]
Market Games Are Not c-Games
Market Games Are Not c-Games

Utility functions:
Utility functions:

\[ u^1(b, c, f, g) = b \]
\[ u^2(b, c, f, g) = b + c - 1 \]
\[ u^3(b, c, f, g) = \frac{1}{2} c + \]
\[ + \max_{b^\prime + b^\prime\prime = b, b^\prime, b^\prime\prime \geq 0} \left\{ \frac{1}{2} \min\{b^\prime, f\} + \min\{b^\prime\prime, g\} \right\} \]
Market Games Are Not c-Games
The *strategic game* $G$ (Scarf 1971):
Market Games Are Not c-Games

The *strategic game* $G$ (Scarf 1971):

- Each player $i$ distributes his endowment $e_i$ among the 3 players:
Market Games Are Not c-Games

The *strategic game* $G$ (Scarf 1971):

- Each player $i$ distributes his endowment $e^i$ among the 3 players:
  - $d^{i,j} \in \mathbb{R}^4_+$ is the bundle that $i$ transfers to $j$
  - $e^i = \sum_{j=1}^{3} d^{i,j}$
  - $j$’s final payoff is $u^j \left( \sum_{i=1}^{3} d^{i,j} \right)$
Market Games Are Not "c-Games"
Proposition. In every SP equilibrium:
Proposition. In every SP equilibrium:

- The threat of player 1 in coalition \( \{1, 2, 3\} \) is to transfer 1 unit of good \( f \) to player 3

- The threat of player 1 in coalition \( \{1, 3\} \) is to keep his endowment
Proposition. In every SP equilibrium:

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\( \Rightarrow \) The fixed-threat property does not hold
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\[ \Rightarrow \] The fixed-threat property does not hold
\[ \Rightarrow \] The coalitional form is not well-defined
Market games are not really "c-games":
Conclusions

Market games are not really "c-games":
Defining the coalitional function as what a coalition can do with the total endowment of its members may not be adequate.
Conclusions

Market games are not really "c-games":

- Defining the coalitional function as what a coalition can do with the total endowment of its members may not be adequate.
- The problem arises only in the **NTU** case and not in the TU case.
Conclusions

In general strategic games:
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- The way to obtain the *coalitional form* from the *strategic form* depends on the bargaining procedure ("the institutional setup") that is used.
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- Going from the *strategic form* to *cooperative outcomes* should be done directly, not via the coalitional form.
Conclusions

- In general strategic games:
  - The way to obtain the *coalitional form* from the *strategic form* depends on the bargaining procedure ("the institutional setup") that is used.
  - There is *no universal way* to define a coalitional function from the strategic form.
  - Going from the *strategic form* to *cooperative outcomes* should be done directly, not via the coalitional form – in the general *NTU* case.
Bargaining and Cooperation
Bargaining and Cooperation

- Strategic Form
- Cooperative Outcomes
- Coalitional Form