MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

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Mathematische Spieltheorie

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Leitung: W.F. Lucas, Cornell
J. Rosenmüller, Bielefeld
D. Schmeidler, Tel-Aviv

This was the 2nd meeting on Mathematical Game Theory to take place in Oberwolfach; participants from Europe, the United States, the Middle East, India, and Japan contributed to the discussions and presented lectures. The purpose of the meeting was to present recent results obtained by the participants and to discuss current research and mainstreams of developments in Game Theory. All talks presented were dealing with a particular topic, there were no survey lectures offered. In equilibrium, it turned out that there were about three lectures offered in the morning and two smaller talks presented in the afternoon. In addition, on Tuesday evening there was a meeting on "Open Problems", which, on an informal basis, gave the opportunity for the participants to describe problems and obstacles in their current research. Also, on Thursday evening several rounds of experiments took place where members of the conference played a 3-person side payment game given in characteristic function form; the prices being represented by books on Game Theory and other topics.

Topics to be dealt with in the discussions and talks were about evenly distributed over the areas of cooperative Game Theory, noncooperative Game Theory, and applications of Game Theory to various economical questions.

As to cooperative theory, NTU-values played a central rôle. New concepts for NTU-values (or classes of NTU-values) were defined; their existence and properties established and discussed. Also, the axiomatization of

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well known concepts for NTU-values was established. For the transferable case, several talks dealt with what is now called "weighted Shapley values". The development of this new concept and its properties played an important rôle on the conference. There were also new results in reasonable outcomes, the core, and stable sets, the rôle of the Shapley value in games connected with graphs (as a measure of centrality).

In the territory of noncooperative games, stochastic games with several variations of the possibility of control by the players were discussed. Also games with incomplete information on both sides (or "on 1 1/2 side") were of interest. Here the players are unaware of the state of nature (the game that is actually played) but may observe the outputs of certain signalling matrices according to which strategies are being played.

Correlated equilibria were discussed as fundamental concepts as well as in connection with games with incomplete information.

Various applications of Game Theory and game theoretical models were submitted: models for inspection and safeguarding systems, auctions, bargaining about the value of a patent, inventory models, electoral problems, and the like were being discussed. Finally there were also algorithms to be presented concerning the computation of solution concepts in the widest sense.

The meeting offered an excellent overview into the present state of research in Game Theory. The opportunity to exchange ideas and discuss the development of the theory was highly welcomed.

Vortragsauszüge

Correlated Equilibrium as an Expression of Bayesian Rationality

R.J. Aumann, Jerusalem

It may be asked why rational decision makers who treat ordinary 1-person decision problems by the use of the theory of subjetive probabilities à la Savage should use a completely different paradigm - that of the Nash Equilibrium Point - to treat games. Why shouldn't they simply estimate their subjetive probabilities of the actions of the other players, and then maximize against them?

In fact, it may be shown that if it is common knowledge that all players are rational decision makers, in the sense of having a subjective probability distribution and choosing their actions to yield a maximum utility given this distribution, then the result must be a correlated equilibrium point (c.e.p.).

Let us be given a game in strategic form, defined by n pure strategy sets $S^1,\dots,S^n$, and n payoff functions $h^i : S^1 \times\dots\times S^n \to \mathbb{R}$. A c.e.p. is defined to consist of

(i) A probability space (Γ, p)

(ii) Functions $f^i : \Gamma \to S^i$ $(i=1,\dots,n)$ such that

$$E\, h^i(f) \geq E\, h^i(f|g^i)$$

for any function $g^i : \Gamma \to S$ that is a function of f^i (A similar concept was defined in the paper "Subjectivity and Correlation in Randomized Strategies", JME Vol. 1 No. 1).

To make precise the principle stated above, denote by Ω the set of all states of the world; a state of the world prescribes all aspects of the world that are given to uncertainty by some player, including what strategies will be chosen by each player. Denote by P^i the information partition of player i. For simplicity, assume the Harsanyi Doctrine, which states that all players have the same priors on Ω (though their posteriors given their information may of course be different). The above principle can then be given the following precise formulation:

<u>Theorem</u> Suppose that at each point of ω of Ω, each player i plays a strategy α that maximizes his expected utility given his information. Then the total expected payoff is a correlated equilibrium payoff.

Without assuming the Harsanyi Doctrine, one can prove an appropriate generalization of this theorem.

Verification of Material Balance Sequences Data

R. Avenhaus, Neubiberg

In earlier papers it was shown that the optimal test procedure for safeguarding the nuclear material in the nuclear industry for one material balance area and one inventory period is based on the MUF-D statistic where MUF is the usual material balance test statistic and D the algebraic sum of the differences of operator and inspector measurements.

In this contribution the problem of the verification of material balance data of a sequence of inventory periods is analyzed. A two person game between an inspector and a plant operator is formulated, where the set of admitted tests on one hand, and the set of possible material diversion strategies for given total diversion (including the case of no diversion) on the other are the strategy sets of both players.

The best test statistic is determined; it is shown that the MUF-D statistic is no longer optimal, but is replaced by a linear combination of the sums of the MUF- resp. D-statistics for the single material balance areas, weighted with appropriate variances.

Reliable control strategies safeguarding illegal activities

D. Bierlein, Regensburg

Our concept is an alternative to that of the inspector's non-constant sum game (M. Maschler 66/67, J.A. Filar, and others). A control strategy of a safeguard authority is said to be "reliable" if it arranges the inspectee's decision state in such a way that the only optimal reaction of the inspectee is to behave legally. What budget is required such that a reliable strategy exists in the set P_{k_0} of control strategies being at the disposal of the authority?

We assume that the inspectee is the operator of l plants and he can combine illegal actions at any (non-empty) subset A of these plants. The set Q of the operator's mixed strategies is the set of all $q = q'xq''$ where q' resp. q'' denote the distribution of the starting time t resp. of the range A of an illegal action.

As mixed control strategies, we consider direct products $p = p_1 x \ldots x p_l$ of probability measures where the time distances $s_\lambda^{(i)}$ between the inspections i and $i-1$ of plant λ are random variables i.i.d. according p_λ $(\lambda = 1,\ldots,l)$.

The payoff $a(p,q)$ is the expectation value of the operator's loss.

We state necessary and sufficient conditions for stationary and for reliable control strategies. Finally, we define a constant S determined by the political and technological data such that we get the result:

> If $k_0 > S$ and an additional assumption are valid, P_{k_0} contains reliable strategies. In particular a stationary reliable strategy of P_{k_0} can be given explicitly. On the other hand, if P_{k_0} contains stationary reliable control strategies, generally $k_0 > S$ holds.

Player Aggregation in the Travelling Inspector Model

J.A. Filar, Maryland

We consider a model of a dynamic inspection/surveillance process of a number of facilities in different geographical locations. The inspector in this process travels from one facility to another and performs an inspection at each facility he visits. His aim is to devise an inspection/travel schedule which minimizes the losses to society (or to his employer) resulting both from undetected violations of the regulations and from the costs of the policing operation. This model is formulated as a non-cooperative, single-controller, stochastic game. The existence of stationary Nash Equilibria is established as a consequence of aggregating all the inspectees into a single "aggregated inspectee". It is shown that such player aggregation causes no loss of generality under very mild assumptions. A notion of an "optimal Nash equilibrium" for the inspector is introduced and shown to be well-defined in this context. Some relevant properties of the class of single-controller stochastic games will be discussed in the process.

Auctions, Public Tenders, and Inheritance Problems - An Axiomatic Approach -

W. Güth, Köln

Auctions, public tenders, and inheritance problems are considered as special games with incomplete information. The speciality of these games is that choosing a strategy in such a game amounts to revealing the (not necessarily true) preferences. Whereas auctions and public tenders have to assume outside traders, namely the seller or the buyer, inheritance problems are closed in this respect.

Our main axiom of revealed envyfreeness states according to his revealed preferences no player should prefer another player's net trade to his own. This axiom and the well-known requirement of incentive compatibility imply the rules of auctions and public tenders which were originally discussed by

Vickrey. We consider our axiomatic characterization as a strong support for the Vickrey-rules. There is no obvious reason why the actually applied rules, for instance, the rules of public tenders in the Federal Republic of Germany, do not conform to the Vickrey-rules.

For inheritance problems the two axioms, revealed envyfreeness and incentive compatibility, are shown to be mutually inconsistent. It is argued that revealed envyfreeness, a special aspect of the basic norm of equality, is a more important than the efficiency requirement and ethical principle of incentive compatibility. By weakening the axiom fo incentive compatibility to underbidding proofness we determine rules for inheritance problems which are an obvious analogue of the Vickrey-rules for auctions and public tenders. It is interesting how the result of the game depends on the information about the true preferences of the others: If someone is exploited by others he must blame himself for not sufficiently hiding his true preferences. If information about the true preferences is sufficiently poor, all players will bid truthfully. Finally, it is discussed how our ideas can be extended to market-like allocation problems.

Non-Transferable Utility Games: Solutions, Axioms, and Examples

S. Hart, Tel-Aviv

Consider the class of n-person cooperative games with non-transferable utility (or non-sidepayments; NTU-games, for short). Solutions for such games have been proposed, among others, by Harsanyi and by Shapley. They were constructed so as to coincide with the Shapley value on the class of transferable utility games, and with the Nash bargaining solution on the class of two-person bargaining problems. Both these solutions were defined axiomatically, which was not the case for the NTU-solutions of Shapley and Harsanyi.

Recently, Aumann has provided an axiomatic characterization for the Shapley NTU-value.

We present here an axiomatization for the Harsanyi NTU-solution. A solution point of an NTU-game (N,V) is a payoff configuration

$x = (x_S)_{S \subset N}$, where $x_S \in \mathbb{R}^S$ is an S-payoff vector $x_S = (x_S^i)_{i \in S}$ for all coalitions $S \subset N$. The following axioms are imposed on a solution function, which associates to each NTU-game the set of its solution points: 1. Efficiency; 2. Scale Covariance; 3. Conditional Additivity; 4. Independence of Irrelevant Alternatives; 5. Unanimity Games; and 6. Zero-Inessential Games. The main result is that there exists a unique solution function satisfying these axioms; it is the Harsanyi solution function.

One outstanding remark is that these axioms (1-5) and those used by Aumann for the Shapley NTU-value are in form essentially identical; the difference lies only in the space to which the solution points belong.

Further relations between the two solutions are explored. In particular, an example shows that the Shapley NTU-value does not satisfy the axiom of zero-inessential games.

Next, two examples of Roth and Shafer are shown to possess quite reasonable Harsanyi solutions.

Finally, it is suggested that the Shapley NTU-value is adequate mainly for "large" games.

Strong Equilibria of a Repeated Game with Randomized Strategies

T. Ichiishi, Iowa City

A version of Aumann's (1976) model of a repeated game with randomized strategies is studied. The pure strategy set of each player is assumed to be a compact metric space. It is proved that the following three conditions are equivalent:

(i) u^* is in the β-core of the one-shot game with correlated strategies;

(ii) u^* is a lower strong equilibrium utility allocation of the repeated game with randomized strategies;

(iii) u* is a utility allocation of a certain equilibrium of the repeated game with randomized strategies - this equilibrium concept is stronger than the lower strong equilibrium and is weaker than the upper strong equilibrium.

An example of 2 x 2 bimatrix game is constructed for which the β-core of the associated one-shot game with correlated strategies is nonempty, but for which an upper strong equilibrium of the associated repeated game does not exist.

A Monotonic Solution to General Cooperative Games

E. Kalai (joint work with D. Samet), Evanston

A monotonic solution to general cooperative games (coalitional form games where utility is not assumed to be transferable) is introduced under the name of the egalitarian solution. It is shown that in the presence of other weak axioms the egalitarian solution is the only monotonic solution. The egalitarian solution generalizes the Shapley value defined on the subclass of cooperative games with transferable utility and Kalai's proportional solution defined on the subclass of bargaining games. It is demonstrated that the monotonicity condition is essential from considerations of individual utility maximization if individuals can control their level of cooperation.

Simple Games and Farkas' Theorem

W.F. Lucas, Ithaca

Simple games and the subclass of weighted voting games along with their power indices such as the Banzhaf-Coleman index arise in many theoretical contexts and applications which involve binary input data and binary outputs. This includes the subjects of the threshold logic, coherrent systems, clutters, blocking systems, and fault tree analysis, as well as simple games, and relates to edges in matroids. Many of the diverse results in these essentially equivalent subjects can be unified using the techniques of linear algebra and linear programming. Farkas' theorem provides a simple characterization of when simple games are weighted majority games or not, and when the (extend) swing counts for games are unique. The weighted games correspond to extreme points of an associated polyhedron. The resulting theorems of the alternative provide a bisis for an algorithm developed in the Ph.D. thesis by Michael Hilliard (Cornell University, August 1983) for determining whether a simple game is weighted or not, and for computing such a set of weights when they exist, or giving a set of multipliers to show that the game is not weighted.

Rationality of the Information Exchange in Games

M. Mares, Prag

The exchange of at least partial information about the chosen strategies can be regarded as a specific form of cooperation in the considered game. The contribution should be subjected to the rationality of such cooperation, especially to the utility of the offered or obtained information, and, consequently, to its acceptable price.

Non Symmetric Values

M. Maschler, Jerusalem (joint work with D.Samet,Evanston)

Side payment games

Values for side payment games are considered, which satisfy the following axioms: (1) Pareto optimality, (2) The dummy property, (3) Additivity, (4) Homogeneity.

We prove that every value that satisfies these axioms can be constructed with the aid of a vector $(\lambda_S)_{S\subseteq N}$ satisfying $\lambda_S = (\lambda_S^i)_{i\in S}$, $\sum_{i\in S} \lambda_S^i = 1$, as follows:

Start with a game v and choose a coalition S whose worth is not zero. Devide its worth among its members in the ratio of the λ_S^i and then move to a game w such that $w(T) = v(T) - v(S)$ whenever $T \supseteq S$, $w(T) = v(T)$ otherwise. Continue in the same fashion until you reach the inessential game. The value of v is the accumulated payoff to the players. It can be described by

$$\varphi_\lambda^i [v] = \sum_{S\ni i} \gamma_S(v)\, \lambda_S^i \text{ , where } \gamma_S(v) = \sum_{T\subseteq S} (-1)^{s-t}\, v(T) .$$

Another formula is

$$\varphi^i [v] = \sum_{S\not\ni i} c_S^i\, [v(S \cup \{i\}) - v(S)] \text{ , where}$$

$c_S^i = \sum_{R\supset S\cup\{i\}} (-1)^{\gamma-S-1} \lambda_R^i$. There is another representation of the form

$\varphi_\lambda^i [v] = \sum_{\pi:N\to N} d(\pi)\, [v(\pi^i \cup \{i\}) - v(\pi^i)]$, where π is a permutation of N and π^i is the set of players preceeding i in π. The relation of the $d(\pi)$'S to the λ_S^i is not 1 - 1 and too difficult to reproduce here. The c_S^i and the $d(\pi)$ need not be non-negative so the solutions need not be individually rational for 0-monotonic games.

Interpretation: $(N;v)$ is a cooperative whose subsets are considered as subsidiary companies. $v(S)$ = worth of assets of all subsets of S in the market. The problem is to allocate $v(N)$ among its members, taking into account that members of S also own the shares of S in the proportion λ_S .

Non Side payment games

We consider games (N; v) where v(S) is a subset of $\mathbb{R}_+^S = \{x \in \mathbb{R}^N = x_i = 0 \ \forall i \notin S\}$, non empty, closed, and S-comprehensive.

A carrier is a coalition S satisfying $v(T) = v(T \cap S) - \mathbb{R}_+^T$, all T . For $a \in \mathbb{R}^N$ we define $\hat{a}_S$ to be a game on N satisfying $\hat{a}_S(T) = a^S - \mathbb{R}_+^T$ if $T \supseteq S$, $\hat{a}_S(T) = 0 - \mathbb{R}_+^T$, otherwise. We consider solutions satisfying the following axioms: (1) Weak Pareto optimal, (2) Homogeneity, (3) Additivity endowments; i.e., if $\varphi(\hat{a}_S) = a_S$ then $\varphi(V + \hat{a}_S) = \varphi(V) + a_S$ all v . (4) IIA;, i.e., if U and V are games with a carrier S, V(T) = U (T) all $T \neq S$, $U(S) \subseteq V(S)$ and $\varphi(V) \in U(N)$ then $\varphi(U) = \varphi(V)$. (5) Subgame substitution: If V and U are games on N and V(T) = U (T) all $T \not\supseteq S$ and if $\varphi(U_{|S}) = \varphi(V_{|S})$, where $U_{|S}$ and $V_{|S}$ are the restrictions of U and V to S then $\varphi(U) = \varphi(V)$.

We prove that a procedure similar to the side payment games, with $\lambda_S^i > 0$ all i , all S , generates such a solution. (The procedure is similar to Harsanyi procedure of allocation of dividends, except that the proportions may be different for different coalitions and the order of pickung up the coalitions need not be specified.) Conversely, every solution that satisfies the axioms is a φ_λ solution with positive λ_S^i .

Stable sets for simple games, and their applications to social choice theory

S. Muto, Sendai

In this talk, conditions for the existence of stable sets for simple games are investigated, in case each player possesses a weak order preference relation on a finite set of alternatives.

In the consequence, it is shown that a condition for the existence of a unique stable set for any combination of players' preferences, is exactly same as the condition for the existence of the core. Moreover, a necessary and sufficient condition that there exist at least one stable set is clarified, in case the game is proper.

Applying the results obtained above to social choice theory, we could provide a necessary and sufficient condition that there exist a class of social choice functions with stable set property, and make clear under what conditions such a social choice function be oligarchic.

Indices of power as measures of centrality in social networks

G. Owen, Iowa City

Centrality is an important concept in the theory of social networks. Essentially, a node has greater or lesser centrality in a network depending on whether paths between pairs of points in the network tend to pass through that node. The concept has not however, been given a precise mathematical definition.

It is shown that, if we represent a network as a game - where the payoff lies in the number of messages that can be delivered through the network - the game-theoretic indices of power (Shapley value, Banzhaf-Coleman index) can be used as reasonable measures of centrality. Moreover, these indices are in many cases relatively easy to compute, and in the special case that the network is a tree, the computation is especially simple. Several examples are worked out in detail.

On the numerical Computation of the Pareto Path by the Ellipsoid Method

D. Pallaschke, Karlsruhe

The ellipsoid method is used to determine inner points of convex sets in $\mathbb{R}^n$, whose boundary is described by quadratic functions. The procedure is similar as in the linear case. By cutting successively sections from the starting convex sets, pareto points are determined. Thus, if $h_i : \mathbb{R}^n \to \mathbb{R}$ is convex and continuous, $\varphi_1, \varphi_2 : \mathbb{R}^n \to \mathbb{R}$ are quadratic functions, then:

$$\min\ (\varphi_1, \varphi_2)$$

under $$x \in P := \{y \in \mathbb{R}^n \mid h_i(g) \leq h_i,\ i \in \{1,\dots,m\}\}\ .$$

is solved as follows: Determine an inner point $\tilde{x} \in P$ by ellipsoid method. Then reduce the region P to

$$P_1 := \{x \in P \mid \varphi_1(x) \leq \varphi_1(\tilde{x})\}\ .$$

Next determine $\tilde{\tilde{x}} \in P_1$ by the same technique and reduce P_1 to
$P_2 := \{x \in P_1 \mid \varphi_2(x) \leq \varphi_2(\tilde{\tilde{x}})\}$.
Continuing in such a way, we get a Pareto-Point.

On Simple Games

T. Parthasarathy, New Delhi

In this talk two points will be brought out. (i) We show that conceptually simple games and coherent systems in reliability engineering are equivalent. Known results about factorization of coherent systems are translated into corresponding results for simple games.

(ii) We show that the assumption of general homogeneity made by Straffin is closely related to the concept of exchangeability of probability theory and study its implications.

Core Stability and Duality of Effectivity Functions

B. Peleg, Jerusalem

This work is devoted to a systematic study of properties of effectivity functions. First we describe how effectivity functions are derived from α and β-effectiveness notions. Then we formulate eight basis properties of effectivity functions, and proceed to explore their relationship to duality and stability. In particular, the following results may be of interest: (i) A precise formulation of a duality principle for effectivity functions. (ii) A characterization of neutral and convex effectivity functions. (iii) A new class of stable effectivity functions. (iv) A new duality theorem.

A Simple Game with no Symmetric Solution

M. Rabie, Sana'a

The following basic question was raised by L.S. Shapley at the Fourth International Workshop on Game Theory in 1978. Does every simple game have a solution that leaves the symmetry of the game?

This paper answerd this question in the negative way by exhibiting simple games that have no symmetric solutions. These are either non-proper or non-strong. It remains open whether every simple strong and proper game has a symmetric solution.

Weighted Shapley Values

D. Samet (joint work with E. Kalai), Evanston

For a given vector of weights $\lambda > 0$ the λ-Shapley value φ_λ allocates one unit among the non-zero players in a unanimity game, proportionally to their weights. It is then extended linearly to any game. We first generalize this solution by using weight systems which allow for zero weight. The family of all weighted Shapley solutions is characterized by the following axioms: (1) Efficiency, (2) Additivity, (3) Positivity (i.e. the value of a monotonic game is nonnegative), (4) Dummy players, (5) Partnership. For the last axiom we define a coalition S to be a coalition of partners in the game v if for each $T \subsetneq S$ and $R \subseteq N \setminus S$, $v(R \cup T) = v(R)$. The partnership axiom requires that the values of players in S are proportional to their values in the unanimity game u_S. We define a value φ_λ^* by $\varphi_\lambda^*(v) = \varphi_\lambda(v^*)$ and axiomatize it analogously.

A Competitive Inventory Model

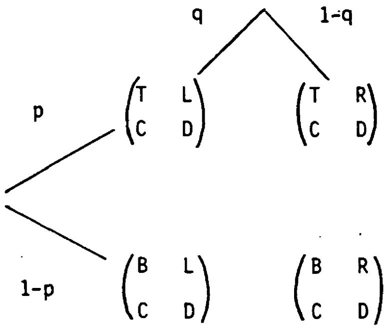
P. Shenoy, Kansas

The management of inventories in a competitive system - where the demand for a product at a vendor is a function of the level of the inventory of the product at that vendor relative to the inventories of the product held by competing vendors - using the mathematical theory of n-person games. The existence and computation of the Nash equilibrium is investigated under two different replenishment policies - continous and periodic. The cooperative solution is also studied.

On Repeated Games with State Dependent Signalling Matrices

S. Sorin, Paris

We study a two person zero-sum repeated game with incomplete information on both sides and the following structure of signalling matrices:



The main result is the existence of the maxmin and minmax of the infinitely repeated game.

The proofs use tools and results introduced in previous papers (Big Match with incomplete information, I and II) concerned with stochastic games with lack of information on one side and standard signalling.

It thus appears that games with incomplete information and stochastic games are more and more a single topic.

The Private Value of a Patent, a game theoretic analysis

Y. Tauman, Tel-Aviv

The paper examines the effect of a new innovation on the structure of the industry. We consider the game played by a patent holder and various firms in the industry. We answer the following questions (using the subgame perfect equilibrium of the game): What is the effect of a patent on the number of firms after the innovation? What is the profit of the innovator? Who benefits from the innovation? How the innovation changes the market price?

We compare different methods of payments for the right to use the patent: Fee, royalty, a combination of the two and profit sharing. Finally we study the effect of a contracting (or training) cost.

Stochastic Games with Stationary Optimal Strategies

S.H. Tijs, Nijmegen

Blackwell and Ferguson's big match shows that for average reward infinite horizon stochastic games there are not necessarily ε-optimal stationary strategies. This fact motivates the search for subclasses of stochastic games with stationary optimals. In the past decade four such subclasses have been introduced:

(i) One player control games.
(ii) Switching player control games.
(iii) AR-AT games (additive rewards and additive transitions).
(iv) SER-SIT games (separable rewards and state independent transitions).

The games in each of the four subclasses have the ordered field property and for all these games there exist finite algorithms to find optimal stationary strategies.

Reasonable Outcomes in Side-Payment Cooperative Games

S. Zamir, Jerusalem (joint work with L.A.Gerard-Varet, University of Toulouse)

We define axiomatically a correspondence R which assigns to each game v (a coalitional function of a game with side payment) a hypercube $R(v) = \underset{i \in N}{X} R_i(v)$ where $N = \{1,\dots,m\}$ is the set of players and $R_i(v)$ is an interval $[a_i(v), b_i(v)]$ to be thought of as the interval of conceivable payoffs for player i . The axioms we impose are:

Symmetry - i.e. independence of the names of the players

Covariance - with respect to changes of origins and units of the players' utilities.

Monotonicity of the reasonable outcomes with respect to the vector of marginal contributions in the superadditive cover of the game $\hat{v}$.

We then prove:

Theorem: The maximal correspondence R satisfying the above three axioms is $R_i(v) = [v(i), M_i(\hat{v})]$, [where v(i) is the individual rationality level and $M_i(\hat{v})$ is Milnor's upper-bound: The largest marginal contribution of player i in the superadditive cover game $\hat{v}$].

After defining and characterizing the set of reasonable outcomes we check the reasonability of various known solution concepts, i.e. we verify whether they lie in the reasonable set. In general we find that the core, the Shapley value, and the Nucleolus are quite reasonable while the Bargaining Set is not.

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