INTERNATIONAL JOURNAL OF RESEARCH IN COMMERCE, IT & MANAGEMENT

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AXIOMATIZATION OF THE PREFERENCE CORE IN MULTICRITERIA COOPERATIVE GAMES

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ABSTRACT
In a multicriteria game each player may have several criteria; where as the classical cooperative game has only one criterion. In this paper, we analyze the preference core and some of its properties are discussed. We axiomatized the preference core by means of reduced game properties.

JEL CLASSIFICATION
C71

KEYWORDS
Cooperative games; multicriteria games; preference core.

1. INTRODUCTION
Operations research models consist of optimization problems in which the members involved in decision making models must take into account of one or several objective functions and analyze how to act in an optimal way. Optimization theory analyzes situation in which a decision maker faces an optimization problem with one or several criteria. Instead of a single decision maker if several decision makers interact, then game theory is a suitable framework. In scalar valued cooperative games, problems have been analyzed from a single criterion perspective. Multi-criteria game theory arises when several members of decision making models, each one controlling several criteria which can not be isolated. This type of situation occurs in many economic, political and social contexts.

Multicriteria strategic form games were first introduced by Blackwell (1956). A methodological approach to vector valued cooperative games has been addressed in Jornsten et al. (1995) and Fernandez et al. (2002). Voorneveld and van den Nouweland (1998) introduced a general model of cooperative multi-criteria game with public and private criteria which includes the multi-commodity games as a particular case. Two different notions are considered in order to establish a solution in multi-criteria games. In literature, the core solutions are proposed in the papers of Fernandez and Puerto (1996), Fernandez et al. (1998), Puerto et al. (1999), Borm et al.(2003) and Fernandez et al. (2002). In this paper, we focus on axiomatization of the preference core in cooperative vector-valued games. In strategic form games, Peleg (1986), and Tadenuma (1992) provide several axiomatizations for finite strategic form games. In this paper one of these axiomatizations have immediate generalization.

The organization of the paper is as follows. In Section 2, we summarize the necessary definitions and basic results. In section 3, the preference core is defined, and the solution concept is axiomatized. Finally, section 4 gives the concluding remarks.

2. NOTATIONS AND BASIC RESULTS
We shall consider a multicriteria game with *n* players. Let *N* = {1, 2 ,…., *n*} denote the set of players. We assume that each player $i \in N$ values the same set of criteria {1, 2 ,…., m}.

Definition 2.1

A cooperative multicriteria vector valued transferable utility *(TU)* game is a pair *(N,v), where N is the set of players and a characteristic function v* : $2^N \to R^m$ *associating a vector* $v(S) \in R^m$ *, to every subset (coalition)* $S \in 2^N \setminus \{\phi\}$, and $v(\phi) = 0 = \{(0,0,\ldots,0)^t\} \in R^m$. For each coalition $S \subseteq N$, the vector $v(S) \in R^m$ is interpreted as the total gain or worth which the members of S can achieve by cooperation. We denote by G^v the class of all cooperative vector-valued transferable utility (TU) games.

If all players in *N* decide to cooperate, then the well-known game theoretic problem is how the vector $v(N) \in R^m$ should be allocated among the players in *N* by taking into account all possible coalitions under each criterion. An allocation in a vector-valued game can be represented by a *m*×*n* payoff matrix,

$$X = \begin{pmatrix} x_1^1 & x_1^2 & \ldots & x_1^n \\ x_2^1 & x_2^2 & \ldots & x_2^n \\ \ldots & \ldots & \ldots & \ldots \\ x_m^1 & x_m^2 & \ldots & x_m^n \end{pmatrix}$$

The i^{th} column of matrix $X,\ X^i = (x_1^i, x_2^i, \ldots, x_m^i)^t \in R^m$ represents the payoffs of player *i,* in each of the *m* criteria.

The j^{th} row of matrix $X,\ X^j = (x_j^1, x_j^2, \ldots, x_j^n) \in R^n$ represents the payoffs for each player in the j^{th} criterion.

The overall payoff obtained by coalition $S \in 2^N \setminus \{\phi\}$, is the sum $X^S = \sum_{i \in S} X^i$.

We denote $X^*(N,v) = \{X \in R^{m \times n} : X^N \leqq v(N)\}$. The set $X^*(N,v)$ is the set of feasible allocations for the game (*N, v*).

A Solution on G^v is a function σ which associates with each game $(N,v) \in G^v$ a subset $\sigma(N,v)$ *of* $X^*(N,v)$.

We denote $X^0(N,v) = \{X \in R^{m\times n} : X^N = v(N)\}$. The set $X^0(N,v)$ is the set of Pareto optimal allocations or the set of preimputations for the game (*N, v*).

For any positive integer *m*, the following notation will be used with respect to given vectors $x = (x_1, x_2,..., x_m) \in R^m$, $y = (y_1, y_2,..., y_m) \in R^m$. We denote by

$x \leqq y \quad if \quad x_i \leqq y_i \quad for\ all \quad i = 1,2,..., m; \quad x \le y \ if \ x \leqq y \ but \ x \ne y.$

If *N* is a grand coalition, then we denote $\mathcal{P}(N) = \{S \subseteq N : |S| = 2\}.$

3. THE PREFERENCE CORE

For any positive integer m > 1, it is known that any two vectors in R not comparable always. Fernandez et al. (2002) have proposed that at least two different orderings are possible among the vectors. The core concept of the scalar valued cooperative TU games is extended to vector-valued cooperative TU games. In literature, several core concepts are defined based on the ordering of vectors in the payoff space. We consider allocations in which no coalition has any incentive to deviate irrespective of the criteria and define the concept of preference core.

DEFINITION: 3.1

The Preference Core $PC(N,v)$ of a vector-valued cooperative TU game $(N,v) \in \mathcal{G}^v$ defined by

$PC(N,v) = \{X \in X^0(N,v) / X^S \geqq v(S), \ for\ all \ S \subset N, \ S \ne \phi\}$

Fernandez et al. (2002) have given a necessary and sufficient condition for the non-emptiness of the preference core.

4. AXIOMATIZATION OF THE PREFERENCE CORE

In this section we describe the axioms which are used to axiomatize the preference core. First, we define a reduced game of a vector-valued game $(N,v) \in \mathcal{G}^v$.

Definition: 4.1

Let $(N,v) \in \mathcal{G}^v$, $S \in 2^N \setminus \{\phi\}$, and let $X \in X^*(N,v).$ The reduced game (S, v_X^S) *with respect to allocation X and coalition S* is the game defined by

$$v_X^S(T) = \begin{cases} 0 & if \ T = \phi; \\ v(N) - X^{N\setminus S} & if \ T = S; \\ V^{\max}_{Q\subseteq N\setminus S}(v(T\cup Q) - X^Q), & otherwise \end{cases}$$

We generalized the definition of Davis and Maschler (1965) for single criteria games. The reduced game (S, v_X^S) describes the following situation. Assume that all agents in *N* agree that agents of $N \setminus S$ will get $X^{N\setminus S}$. Then, the agents in *S* may receive $v(N) - X^{N\setminus S}$. Furthermore, assume that the agents in $N \setminus S$ continue to cooperate (not expecting the worth more than $X^{N\setminus S}$) with the agents of S. Then, for every $T \ne \phi$, $T \subset S$, can cooperate with some of the agents in $N \setminus S$ and increase their worth $v_X^S(T)$ is the maximum payoff that the coalition *T* is expected to get.

Let us consider the following axioms that are used in the rest of this section. Let σ be a solution on the class of all vector-valued cooperative games $\mathcal{G}^v$.

Non-emptiness (NE): For all $(N,v) \in \mathcal{G}^v$, $\sigma(N,v) \ne \phi$.

Pareto optimality (PO): For all $(N,v) \in \mathcal{G}^v$, $\sigma(N,v) \subseteq X^0(N,v)$.

Individual rationality (IR): For all $(N,v) \in \mathcal{G}^v$, and $X \in \sigma(N,v)$, then $X^i \geqq v(\{i\})$ for all $i \in N$.

Superadditivity (SUPA): $\sigma(N,v_1) + \sigma(N,v_2) \subseteq \sigma(N, v_1 + v_2)$ whenever $(N,v_1), (N,v_2)$ and $(N, v_1 + v_2)$ are in $\mathcal{G}^v$.

Reduced Game Property (RGP): For all $(N,v) \in \mathcal{G}^v$, $S \subseteq N, \ S \ne \phi \ and \ X \in \sigma(N,v)$, then $(S, v_X^S) \in \mathcal{G}^v$ and $X^S \in \sigma(S, v_X^S)$.

Weak Reduced Game Property (WRGP): For all $(N,v) \in \mathcal{G}^v$, $S \subseteq N, 1 \le |S| \le 2, \ and \ X \in \sigma(N,V)$, then $(S, v_X^S) \in$ G^v and $X^S \in \sigma(S, v_X^S)$.

Converse Reduced Game Property (CRGP): For all $(N,v) \in \mathcal{G}^v$, $|N| \ge 2, \ and \ X^* \in \sigma(N,V),$ $(S, v_X^S) \in \mathcal{G}^v$ and $X^S \in \sigma(S, v_X^S)$ for every $S \in \mathcal{P}(N), \ then \ X \in \sigma(N,v).$

It is straightforward that the preference core satisfies IR, and SUPA.

We denote $\mathcal{G}^v_{PC} = \{(N,v) \in \mathcal{G}^v : PC(N,V) \ne \phi\}$ where $\mathcal{G}^v$ is the class of all vector-valued cooperative TU games.

Lemma 4.1 *The preference core satisfies* RGP *on* $\mathcal{G}^v_{PC}$.

Proof: Let $(N,v) \in \mathcal{G}^v_{PC}$, $X \in PC(N,v)$, and let $\phi \ne S \subseteq N. \ Let \ T \in 2^S \setminus \{\phi\}$.

If $T = S$, then $v_X^S(T) = v(N) - X^{N\setminus S} = X^N - X^{N\setminus S} = X^S$, since $v(N) = X^N$.

If $T \ne S$, then $v_X^S(T) - X(T) = v^{\max}_{Q\subseteq N\setminus S}(v(T\cup Q) - X^Q) - X^T$

$= v^{\max}_{Q\subseteq N\setminus S}(v(T\cup Q) - X^{T\cup Q}) \leqq 0.$

Thus $X^S \in PC(S, v_X^S)$. This completes the proof.

Note that the property WRGP is weaker version of RGP, RGP implies WRGP.

Lemma 4.2 *The preference core satisfies* CRGP *on* $\mathcal{G}^{\nu}$.

Proof: Let $(N,v) \in \mathcal{G}^{\nu}$, $X \in X^0(N,v)$, and let for every $S \in \mathcal{P}(N)$, $(S, v_X^S) \in \mathcal{G}^{\nu}$, *and* $X^S \in PC(S, v_X^S)$.

As $v_X^S(S) = X^S$ and $v_X^S(S) = v(N) - X^{N \setminus S}$ implies that $X^N = v(N)$.

Now let $T \in 2^N \setminus \{\phi, N\}$. Choose $i \in T$, $j \in N \setminus T$ and let $S = \{i, j\}$.

Since $X^S \in PC(S, v_X^S)$, $0 \geqq v_X^S(\{i\}) - X^i \geqq v(T) - X^T$, by definition of RGP. Thus, $X^T \geqq v(N)$ *for all* $T \in 2^N \setminus \{\phi, N\}$.

Hence $X \in PC(N, v)$.

Lemma 4.3 *Let* σ *be a solution on a set* $\mathcal{G}^{\nu}$ *of games. If* σ *satisfies* IR *and* WRGP*, then it also satisfies* PO.

Proof: Suppose, on the contrary, that σ does not satisfy PO. Then for some $(N,v) \in \mathcal{G}^{\nu}$, and some $X \in \sigma(N,v)$ such that $X^N \neq v(N)$.

Let *i*∈*N*. By WRGP, $(\{i\}, v_X^{\{i\}}) \in \mathcal{G}^{\nu}$, and $X^i \in \sigma(\{i\}, v_X^{\{i\}})$.

By Definition 4.1, $v_X^{\{i\}}(\{i\}) = v(N) - X^{N \setminus \{i\}} = v(N) - X^N + X^i \neq X^i$

Since $v(N) - X^N \neq 0$.

This contradicts the fact that $X^i \geqq v_X^{\{i\}}(\{i\})$.

This contradiction leads to the completion of the proof.

Lemma 4.4 *Let* σ *be a solution on a set* $\mathcal{G}^{\nu}$ *of games. If* σ *satisfies* IR *and* WRGP*, then* $\sigma(N,v) \subseteq PC(N,v)$ *for every* $(N,v) \in \mathcal{G}^{\nu}$.

Proof: Let $(N,v) \in \mathcal{G}^{\nu}$ be an *n*- person game.

If *n* = 1, then $\sigma(N,v) \subseteq PC(N,v)$ by IR.

By Lemma 4.3. σ Satisfies PO. Hence, if *n* = 2, then

$\sigma(N,v) = \{X \in X^0(N,v) : X^i \geqq v(\{i\}) \ \ for \ all \ \ i \in N\} = PC(N,v)$.

If *n* ≥ 3 and $X \in \sigma(N,v)$, then WRGP implies that $X^S \in \sigma(S, v_X^S)$ for all *S* ∈ P(*N*), so $X^S \in PC(S, v_X^S)$ for every *S* ∈ P(*N*).

By Lemma 4.2, $X \in PC(N,v)$.

Theorem 4.1 *A solution* σ *on* $\mathcal{G}_{PC}^{\nu}$ *satisfies* NE, IR, SUPA *and* WRGP*, if and only if* σ *is the preference core.*

Proof: On $\mathcal{G}_{PC}^{\nu}$, it is clear that the preference core satisfies NE, IR, and SUPA. By Lemma 4.1, the preference core satisfies WRGP. Let σ be a solution on $\mathcal{G}_{PC}^{\nu}$ that satisfies NE, IR, SUPA and WRGP and let $(N,v) \in \mathcal{G}_{PC}^{\nu}$ be an *n*-person game. We have to show that $\sigma(N,v) = PC(N,v)$.

By Lemma 4.4, $\sigma(N,v) \subseteq PC(N,v)$.

Thus we only have to show that $PC(N,v) \subseteq \sigma(N,v)$.

Let $X \in PC(N,v)$. The following two cases may occur.

Case 1: Let $(N,v) \in \mathcal{G}_{PC}^{\nu}$ with $n \geq 3$.

Define: $(N,v) \in \mathcal{G}_{PC}^{\nu}$ as $w(\{i\}) = v(\{i\})$ *for all* $i \in N$ *and* $w(S) = X^S$ *for all* $S \subseteq N$ *with* $|S| \geq 2$.

First, we show that $PC(N,w) = \{X\}$.

Let $Y \in PC(N,w)$ be given. For all $i \in N$, $Y^{N \setminus \{i\}} \geqq w(N \setminus \{i\}) = X^{N \setminus \{i\}}$.

Also $Y^N = w(N) = X^N$ implies that $Y^N = X^N$.

Thus $Y^N - Y^{N \setminus \{i\}} \leqq X^N - X^{N \setminus \{i\}}$.

That is, $Y^i \leqq X^i$ *for all* $i \in N$.

From these statements, we conclude that $Y^i = X^i$ *for all* $i \in N$.

Hence $PC(N,w) = \{X\}$. Since σ satisfies NE and $\sigma(N,v) \subseteq PC(N,v)$, then $\sigma(N,w) = \{X\}$.

Let *u* = *v* –*w* such that $(N,u) \in \mathcal{G}_{PC}^{\nu}$.

Note that $u(\{i\}) = v(\{i\}) - w(\{i\}) = 0$ *for all* $i \in N$ *and* $u(N) = v(N) - w(N) = 0$.

Also, $u(S) = v(S) - w(S) = v(S) - X^S \leq 0$ *for all* $S \subseteq N$ *with* $|S| \geq 2$, *and* $S \neq N$.

Hence $PC(N,v) \subseteq \sigma(N,v)$.

Case 2: Let $n \leq 2$.

If *n* = 1, then $X \in \sigma(N,v)$ by NE and IR. So we assume that *n* = 2. Let $N = \{i, j\}$.

Let $k \notin N$ and let $M = \{i, j, k\}$. Define $(M,u) \in \mathcal{G}_{PC}^{\nu}$ as follows.

$$u(S) = \begin{cases} \sum_{l \in S \cap N} v(\{l\}) & if \quad S \neq M; \\ v(N) & if \quad S = M. \end{cases}$$

Let $X = (X^i, X^j) \in PC(N, v)$. Let $Y = (X^i, X^j, X^k)$, where $X^k = \{(0,0,....,0)^t\}$. Since $Y^N = X^N = v(N) = u(M)$ and $Y^S = \sum_{l \in S \cap N} X^i \leqq \sum_{l \in S \cap N} v(\{l\}) = u(S)$ for all $S \subset M$.

Thus, $Y \in PC(M, u)$.

As $|M| = 3, PC(M, u) \subseteq \sigma(M, u)$. Thus, $Y \subseteq \sigma(M, u)$.

Finally, we show that $(N, u_Y^N) = (N, v)$. Let $S \subset N$, $S \neq \phi$ be given.

$u_Y^N(S) = V^{\max}_{Q \subseteq M \setminus N}(u(S \cup Q) - Y^Q) = u(S \cup \{k\}) - Y^k = u(S \cup \{k\}) = v(S)$.

Further, $u_Y^N(N) = u(M) - Y^k = u(M) = v(N)$.

Hence by WRGP, $X \in \sigma(N, u_Y^N) = \sigma(N, v)$, and thus $PC(N, v) \subseteq \sigma(N, v)$. This completes the proof of the theorem.

Now we give the examples to show that the axioms that characterize the preference core are mutually independent.

Example 4.1 For all $(N, v) \in$, $\mathcal{G}^v$, . Then, σ satisfies IR, SUPA and WRGP but violates NE.

Example 4.2 For all $(N, v) \in \mathcal{G}^v_{PC}$, let $\sigma(N, v) = PC(N, v)$ if $|N| \geq 2$,

and let $\sigma(\{i\}, v) = X^i$ where $X \in R^{m \times n}$ such that $X^i \leqq v(\{i\})$ for all $i \in N$.

Then σ satisfies NE, SUPA and WRGP but violates IR.

Example 4.3 For all $(N, v) \in \mathcal{G}^v_{PC}$, let $\sigma(N, v) = \{X \in X^*(N, v) : X^i \geqq v(\{i\})$ for all $i \in N\}$. Then σ satisfies NE, IR and SUPA. By Lemma 4, it fails to satisfy WRGP.

Example 4.4 For all $(N, v) \in \mathcal{G}^v_{PC}$, $\sigma(N, v) = \mathcal{GN}$, where $\mathcal{GN}$ is the generalized nucleolus defined on $\mathcal{G}^v_{PC}$. This cost allocation rule satisfies NE, IR and WRGP but violates SUPA.

5. CONCLUDING REMARKS

In recent times, the multicriteria game techniques are analyzed more rapidly. This advancement allows us to address axiomatization of preference core. For multicriteria games, many types of core solution concepts are available in literature. In this paper, we consider only the preference core. We proved that the preference core satisfies non-emptiness, individual rationality, Pareto optimality, superaddivity reduced game property, weak reduced game property and converse reduced game property. We axiomatized the preference core based on some of the above mentioned properties.

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