

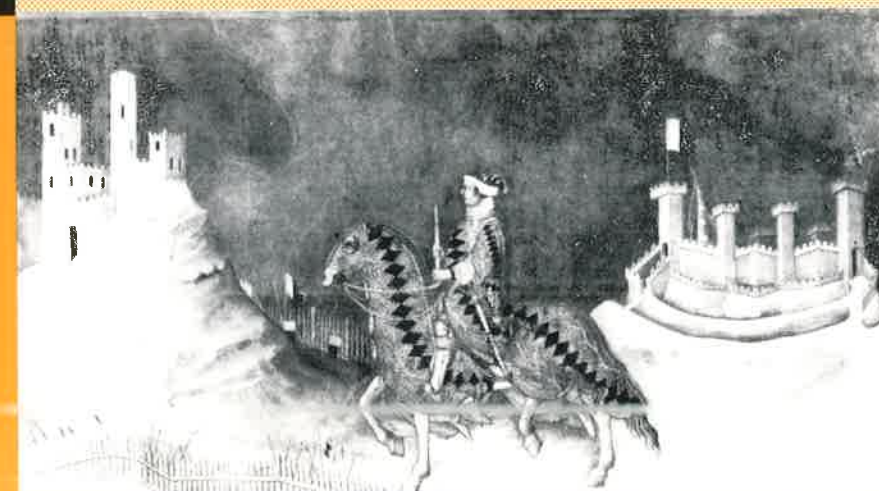
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QUADERNI DEL DIPARTIMENTO
DI ECONOMIA POLITICA

NICOLA DIMITRI

**RANDOMIZATION AND COOPERATION
WITH KNIGHTIAN UNCERTAINTY**



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Nicola Dimitri

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Siena, Novembre 1995

ABSTRACT

This paper shows that in a *stage game* Prisoner's Dilemma Knightian uncertainty, modelled by non-additive probabilities, can justify cooperation in a purely mixed equilibrium of the game. We first extend the standard notion of Mixed Strategy Nash Equilibrium in 2X2 normal form games by introducing two notions of equilibrium, and then show that pure randomization can be accommodated by one of these generalizations. With additivity either all strategies are stochastically independent in pairs or not. Non-additivity eliminates this rigidity and allows "partial independence" between pair of strategies, a contingency under which cooperation is shown to obtain.

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1. Introduction

The "puzzle" stemming from the celebrated stage game Prisoner's Dilemma is still quite debated¹. As it is well known, the problem lies in the fact that the outcome associated to the unique Nash Equilibrium of the game is Pareto inferior to another outcome of the game itself, typically referred to as the *cooperative* outcome. In a non-cooperative context however the latter is not self-sustaining and so can not be an equilibrium.

Moreover, since the defecting (from cooperation) strategy is strictly dominating, both the unique Mixed Strategy Nash Equilibrium (MSNE) and the Correlated Equilibrium assign probability one to defection. So, it just seems to be very difficult to characterize cooperation as an equilibrium phenomenon.

In this paper we discuss a possible way out to the problem, *via* the introduction of non-additive probabilities. It has recently been suggested (Schmeidler (1989), Gilboa-Schmeidler (1993)) that non-additive probabilities can be used to model individuals' decisions under genuine (Knightian) uncertainty. This kind of uncertainty arises when a decision maker is unable to produce reliable probabilistic evaluations concerning the relevant random mechanism.

Mathematically, non-additive probabilities are *capacities*, namely monotonic set functions; hence, standard (additive) probabilities are nothing but a special case of capacities, which further satisfy the property of being additive over disjoint sets. This

difference is very important because it renders the non-additive world more flexible and suitable for formalizing situations which otherwise could not be captured with additivity.

This is precisely what one observes when introducing a notion of stochastic independence; in particular, the binary "independence relation" between pair of events seems to be less "rich", namely it does not satisfy a number of properties which instead hold true with additivity².

Our work explores some implications of this fact within 2X2 normal form games, and more specifically within the stage game Prisoner's Dilemma³. Indeed, we first introduce two notions of mixed strategy equilibrium and then discuss whether and how cooperation can emerge according to these criteria. The basic underlying idea is truly simple, and certainly not completely new (Aumann, 1976; 1987).

In fact, we model two players who are uncertain about the opponent's choice, where the uncertainty is Knightian and represented through non-additive probabilities defined over the set of all strategies⁴. It is important to stress that, conceptually, the paper is based on the consideration that genuine uncertainty for a player can in principle affect both her unconditional and conditional (on her own strategy) beliefs of the opponent's choice. More explicitly, what we have in mind is that individuals may not know which strategies are chosen independently.

Dow-Werlang (1994) have already discussed the role of non-additive probabilities in finite normal form games, and proposed a notion of Nash Equilibrium which differs from ours. They too concentrate on the Prisoner's Dilemma but with a different goal, since their focus is on the link between genuine uncertainty and backward induction. Specifically, in a simple two period Prisoner's Dilemma game they show that with Knightian uncertainty

agents may not backward induct. When this is the case cooperation emerges as an equilibrium of that game.

Hence our paper, in a sense, integrates theirs. We work in a static, as opposed to dynamic, context and we concentrate on the role played by independence instead of checking the viability of backward induction.

The work is organized as follows. In section 2 the notions of mixed strategy equilibrium, and independence between pair of events with non-additive probabilities, are introduced and discussed. Section 3 focuses on the Prisoner's Dilemma while section 4 presents some concluding remarks.

2. Independence and Equilibrium

We start by setting the appropriate context.

Let S be a set and 2^S its power set; a non-additive probability is a (normalized) capacity, namely a set function $v(\cdot)$ satisfying the following properties:

- a) $v(\cdot): 2^S \rightarrow [0,1]$; $v(\emptyset)=0, v(S)=1$
- b) $A \subseteq B \Rightarrow v(A) \leq v(B) \quad \forall A, B \in 2^S.$

Gilboa-Schmeidler (1993) provide a notable characterization in terms, respectively, of *optimism* and *pessimism* of the following two remarkable rules for updating non-additive probabilities.

Gilboa-Schmeidler (GS)

$$v_{GS}(A|B) = v(A \cap B) / v(B) \quad \text{with} \quad v(B) > 0$$

and

Dempster-Shafer (DS)

$$v_{DS}(A|B) = [v(A \cup B^c) - v(B^c)] / [1 - v(B^c)] \quad \text{with} \quad v(B^c) < 1$$

To avoid a burdensome exposition what follows will mainly concentrate, even though not exclusively, on DS bearing in mind that a similar analysis could be undertaken for GS as well. Notice that *pessimism* and *optimism* are formalized, respectively, by a *convex* and a *concave* capacity (Schmeidler, 1989); in the sequel, however, DS will not always be associated to convex capacities⁵.

Before going into our privileged example, namely the one stage Prisoner's Dilemma game, it is necessary to introduce the underlying framework which would be valid for any 2X2 normal form game.

Consider two players, P_1 and P_2 , whose strategy sets are $S_1 = \{s_1, t_1\}$ and $S_2 = \{s_2, t_2\}$; since we are interested in modelling mixed strategies, S_1 and S_2 will be interpreted as state spaces of random experiments and pure strategies as states or elementary events. The power set $2^{S'}$ associated to the product space $S' = S_1 \times S_2$ then is

$$\{\{\emptyset\}, \{s_1\}, \{t_1\}, \{s_2\}, \{t_2\}, \{s_1 \cup s_2\}, \{s_1 \cup t_2\}, \{t_1 \cup s_2\}, \{t_1 \cup t_2\}, \{s_1 \cap s_2\}, \{s_1 \cap t_2\}, \{t_1 \cap s_2\}, \{t_1 \cap t_2\}, S'\}$$

where as usual $\{\cup\}$ and $\{\cap\}$ stand, respectively, for the union and the intersection of the relevant events.

Let $v_i(\cdot)$, with $i=1,2$, be a capacity defined on $2^{S'}$; such capacities formalize players' uncertainty concerning the events in $2^{S'}$. The interpretation of $v_i(\cdot)$ however requires careful specification, as non-additive probabilities represent *subjective* uncertainty.

When the argument of the capacity is an opponent's pure strategy the interpretation is standard, namely it formalizes the (unconditional) personal belief on the other player's action. If the argument is a pure strategy of the player herself the capacity should be interpreted in terms of *physical randomization*. Namely, an agent's subjective uncertainty about her own choice coincides with the *objective* probabilities effectively governing the randomizing device that she decided to use. Finally, whenever both players' strategies appear in the argument, the capacity can be thought of as quantifying a "perceived degree of correlation" between them.

More explicitly, we shall interpret $v_i(s_i) = p$, with $0 \leq p \leq 1$, as player i choosing pure strategy s_i with probability p ⁶. Evidently, while this interpretation in principle does not *conceptually* impose additivity on the probabilities concerning the opponent's pure strategies it does, still *conceptually* speaking, impose it on the probabilities concerning the player's own pure strategies.

Finally, let $CE(\pi_i | s_i)$ and $CE(\pi_i | t_i)$, with $i=1,2$, the Choquet Expected Payoff of agent i conditional on her having chosen, respectively, strategies s_i and t_i . The Choquet Integral (Summation) has been introduced in Decision Theory mainly, though not exclusively, to provide a representation for the Ellsberg' Paradox findings (Ellsberg, 1961) in which individuals are thought to exhibit a form of uncertainty aversion (Schmeidler, 1989)⁷. For this reason, the updating rule we shall be using to calculate its conditional version is DS

Obviously, the rule itself could always be introduced with no reference to uncertainty attitude; this is indeed what we shall also be doing in the sequel.

We are now ready to formulate our definitions of randomized equilibrium.

Definition 1 In a 2×2 normal form game we define a Weak Mixed Strategy Subjective Nash Equilibrium (WMSSNE) to be a pair $\{v_1(\cdot), v_2(\cdot)\}$ of capacities on 2^S such that:

$$a) v_1(s_i) = v_2(s_i); v_1(t_i) = v_2(t_i)$$

$$b) v_i(s_i) + v_i(t_i) = 1$$

$$c) v_i(s_i) \text{ maximizes}$$

$$\Pi_i[v_i(s_i)] = v_i(s_i)CE(\pi_i | s_i) + v_i(t_i)CE(\pi_i | t_i) \quad \text{given } v_{-i}(s_{-i}) \quad \text{with } i=1,2$$

where $v_{-i}(s_{-i})$ is player i opponent's capacity evaluated at the opponent's strategy s , indicated by s_{-i} .

Moreover, we define a Mixed Strategy Subjective Nash Equilibrium (MSSNE) to be a pair of convex capacities $\{v_1(\cdot), v_2(\cdot)\}$ satisfying (a)-(c).

Some comments are in order. Obviously any MSSNE is also a WMSSNE; furthermore, it is important to specify that a WMSSNE is modelling players who are not necessarily pessimistic, but behave *as if* they were. This is the sense in which we intend this notion of equilibrium to be *weak*, since it gains relevance only in those situations where an agent's characterization in terms of her uncertainty attitude is not fully consistent.

Point a) says that both players' subjective uncertainty on the opponent's strategies must coincide with the actual probabilities governing the opponent's randomizing device; namely, in *equilibrium* we require probabilistic conjectures to be correct⁸. Point b) formalizes the idea that players are not "Knightian" uncertain about their own randomizing device. Finally, c) defines the goal and the objective function of an agent. The former is the standard

maximization criterion while the latter is consistent with (b) in stipulating that "genuine" uncertainty for an individual arises *after* having chosen her own strategy. It is worth observing that both $CE(\pi_i | s_i)$ and $CE(\pi_i | t_i)$ are functionals which, in equilibrium, depend upon $v_i(s_i)$ and, moreover, that $\Pi_i[1]$ and $\Pi_i[0]$ are well defined since they are equal, respectively, to $CE(\pi_i | s_i)$ and $CE(\pi_i | t_i)$ which indeed are well defined at $v_i(s_i)=1$ and $v_i(s_i)=0$.

So, as in the standard MSNE, players here choose strategies *given* their own unconditional (marginal) probabilistic beliefs over the opponent's choice; there are however two main differences. Indeed, besides the introduction of non-additivity our definition does not say anything about independence. This is so in order to provide the analysis with the highest degree of generality within which to enclose any further assumption of interest. In particular, unlike what happens with additivity, we shall see that it is possible to accommodate an hypothesis of "partial independence" between pair of strategies. This would capture the idea that an individual may think that the opponent will react differently depending upon her own choice.

Observe, at this stage, that should players' randomizations be effectively performed independently, the "objective" joint (additive) probability would be the product of the two "objective" marginals. Nevertheless, since the model is based on the idea of subjective uncertainty, as formalized by non-additive probabilities, our interest rests in *perceptions* rather than in *truth*. Players might have correct perceptions, but this is not of central concern in the paper.

Indeed, for example, the following result can be easily verified.

Fact 1 Let $\{v_1(\cdot); v_2(\cdot)\}$ be both additive, and suppose there exists a pair of strategies $\{x_i, x_j\}$ (with $x_i \in \{s_i, t_i\}$, $x_j \in \{s_j, t_j\}$, $i \neq j$ and $i, j = 1, 2$) such that $v_i(x_i \cap x_j) = v_i(x_i)v_i(x_j)$; then $\{v_1(\cdot); v_2(\cdot)\}$ is a MSSNE iff it is a MSNE⁹.

The above coincidence of MSSNE and MSNE implies also that $v_1(\cdot) = v_2(\cdot)$, so that full correctness of personal probability conjectures is derived rather than assumed.

We focus now on the role played by the assumption of stochastic independence. It is well known that with additivity independence of, say, events A and B ¹⁰ entails the independence of A^c and B , A and B^c , A^c and B^c . This is why in 2X2 normal form games it suffices to introduce, only on the part of one player, the *perceived* independence of two strategies to obtain in equilibrium a standard MSNE where both players think that all pair of strategies are independent.

In contrast, with non-additivity the modeller is not "forced" to accept all the above relations. Below we investigate this issue and to do so it is convenient to introduce the following set functions.

Definition 2 We call $B_e(A) = v(A)$ and $P_l(A) = 1 - v(A^c)$, respectively, the Belief and the Plausibility functions concerning event A , $\forall A \in 2^S$.

Both $B_e(A)$ and $P_l(A)$ represent personal "probabilistic" evaluations for event A ; more specifically $1 - v(A^c)$ quantifies the *degree of disbelief* in A (Shafer, 1976). They can further be interpretable as the upper and lower probabilities that, in case of *Knightian* uncertainty, identify a numeric interval within which the "true" probability is thought to fall. Finally,

they can also be seen as formalizing an individual's *ambiguity* concerning the probability of the relevant random mechanism.

Since non-unique probability evaluations are intrinsic to non-additivity, the provision of two notions of independence, rather than one, seems justifiable¹¹. In particular, the following two generalize a principle used with additivity, which is of course operational only when the relevant denominators are not null.

Definition 3 We say that event A is B_e -independent of B if $v(A|B) = v(A)$ and P_l -independent of B if $1 - v(A^c|B) = 1 - v(A^c)$, i.e. iff A^c is B_e -independent of B ¹².

Let σ_b and σ_p the binary "independence relations" induced by the above two notions of independence: in particular if, say, A is B_e -independent of B we write $A \sigma_b B$. Then, the following result can be immediately verified

Fact 2 $v(A|B) = v_{DS}(A|B) \Rightarrow A \sigma_b B \Leftrightarrow B^c \sigma_b A^c$ and $A \sigma_p B \Leftrightarrow B \sigma_p A$. $v(A|B) = v_{GS}(A|B) \Rightarrow A \sigma_b B \Leftrightarrow B \sigma_b A$ and $A \sigma_p B \Leftrightarrow B^c \sigma_p A^c$.

The main implication emerging from the above proposition is that, typically, σ_b and σ_p do not satisfy all the properties that the "analogous" binary relation obtained with additivity does. For this reason non-additivity appears to provide a more flexible framework, indeed capable of formalizing phenomena that additivity would generally not allow.

This consideration opens the avenue for discussing our privileged example, namely the Prisoner's Dilemma.

3. The Leading Example

In this section we concentrate our attention on the standard Prisoner's Dilemma normal form stage game, with payoff matrix

	s_1	t_1
s_2	a a	b c
t_2	c b	d d

where a, b, c, d are real numbers such that $c > a > d > b$. The left entry in each cell refers to P_2 and the right one to P_1 . The cooperative outcome then is the pair (a, a) while the outcome associated to the unique (defecting strategy) Nash Equilibrium is (d, d) .

By allowing non-additivity there is room for new phenomena to be captured. However, prior to discussing them it is useful to spell out the expression of the Conditional Choquet Expected Payoffs and present some preliminary characterizations. Consider P_i , with $i=1,2$; then

$$CE(\pi_i/s_i) = a [v_i(s_j \cup t_i) - v_i(t_i)] / [1 - v_i(t_i)] + b [1 - v_i(s_j \cup t_i)] / [1 - v_i(t_i)] \quad (1)$$

$$CE(\pi_i/t_i) = c [v_i(s_j \cup s_i) - v_i(s_i)] / [1 - v_i(s_i)] + d [1 - v_i(s_j \cup s_i)] / [1 - v_i(s_i)] \quad (2)$$

where $i \neq j$, and $i, j=1,2$.

The ensuing fact formalizes a result inherited from the MSSNE.

Fact 3 No WMSSNE accomodates pure cooperation while there exists a unique MSSNE accomodating pure defection.

Proof

Consider P_1 ; $v_1(s_2)=1$ entails $v_1(s_2 \cup t_1)=1=v_1(s_2 \cup s_1)$ which in turn imply

$$\Pi_1[v_1(s_1)] = av_1(s_1) + c[1-v_1(s_1)]$$

maximized for $v_1(s_1)=0$, and the first part is proved.

Assume $v_1(t_2)=1$; then by convexity it follows that $v_1(s_2 \cup t_1)=v_1(t_1)$ and $v_1(s_2 \cup s_1)=v_1(s_1)$.

Hence, the objective function of P_1 reduces to

$$\Pi_1[v_1(s_1)] = bv_1(s_1) + d[1-v_1(s_1)]$$

maximized by $v_1(s_1)=0$.

Supposing now that $v_2(t_1)=1$, and replicating the same type of reasoning from the point of view of P_2 , the second part of the proposition follows immediately noticing that uniqueness is entailed by the definition of equilibrium. Q.E.D.

For our purposes the importance of the above result is that, even in this more general environment, pure cooperation can not be justified as an equilibrium. This however does not say anything about the possibility that cooperation could emerge as a result of a randomizing choice. Additivity and (full) independence preclude this contingency, but we are going to show that non-additivity and (partial) independence can allow it. Indeed, Fact 2 tells us that one is not forced to work with full independence, namely independence between all possible pair of strategies, unless we choose to impose it as an external condition.

Before proving that it is possible to have a pure randomization equilibrium, it is useful to present a further "impossibility of cooperation" result suggesting that *not every* partial independence relation can entail cooperation.

Fact 4 Suppose P_1 thinks $s_2 \circ b s_1$; then no WMSSNE accomodates cooperation.

Proof

From Fact 3 we know that pure cooperation can never be enclosed in a WMSSNE. Then, to prove the result we need to show that no pure mixing either can be accomodated in equilibrium. Indeed, P_1 thinking that $s_2 \circ b s_1$ implies

$$\Pi_1[v_1(s_1)] < \Pi_1[0] \quad \text{for } 0 < v_1(s_1) < 1$$

which entails that $0 < v_1(s_1) < 1$ can not be a best reply to $0 < v_1(s_2) < 1$. Q.E.D.

We now prove the *possibility* of cooperation through pure mixing.

Fact 5 Suppose P_1 thinks $s_2 \circ b t_1$ and P_2 thinks $s_1 \circ b t_2$. Moreover, assume that $v_1(s_2) = (a-d)/(c-d) = v_2(s_1)$ and $v_1(s_2 \cup t_1) = 1 = v_2(s_1 \cup t_2)$. Then there exists a WMSSNE compatible with these assumptions.

Proof

Consider P_1 and observe that under the above assumptions $\Pi_1[v_1(s_1)] = a$ so that any $0 \leq v_1(s_1) \leq 1$ is an optimal choice. Since analogous considerations hold for P_2 , in equilibrium both players will purely randomize according to the probabilities specified in the hypotheses. Finally, it is simple to check that a capacity satisfying the alleged requirements does indeed exist, and the result is proved. Q.E.D.

We conclude observing that should agents' randomizations be effectively performed independently, cooperation would obtain with *objective* probability $[(a-d)/(c-d)]^2$.

4. Conclusions

The paper introduces non-additive probabilities in 2X2 noncooperative normal form games, and formalizes two notions of randomized equilibrium. With these notions one can model agents facing genuine, Knightian, uncertainty (captured by non-additivity) not only on the unconditional opponent's choice but also on the conditional one. The definitions retain some of the fundamental features of the standard criterion of Mixed Strategy Nash Equilibrium (MSNE) but not all.

The main findings of the paper exploit a wider range of modelling possibilities characteristic of non-additivity. More specifically, it is shown that one can incorporate situations of "partial independence", between pair of strategies, which entail a higher degree of flexibility. In fact, with additivity all pair of strategies are either independent or not; non-additivity instead eliminates this rigidity because from the independence of a pair does not necessarily follow that all other pairs.

We concentrated our attention on the stage game Prisoner's Dilemma and showed, on the one hand, that pure cooperation can never be accomodated as an equilibrium of the game. On the other hand however we were capable of proving that our weaker version of equilibrium can accomodate pure mixing.

The work does not aim at exposing a full theory on the matter. However, in spite of the analysis being confined to some specific circumstances, we believe that these results are shedding interesting light on the link between genuine uncertainty and cooperation in the *stage game Prisoner's Dilemma*.

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NOTES

1 For a thorough discussion on this see Binmore (1994).

2 This point is developed in Dimitri (1995). For completeness, the results which will be used in this paper are reported in Section 2.

3 The same analysis could be generalized to $n \times m$ normal form games. However, since we confine our discussion to independence between *pairs* of events, in this paper we won't pursue the above extension.

4 It has to be pointed out that in the work we do not address a most fundamental question, namely why should players be genuinely uncertain about their opponents' choices, and why strategies should be perceived as being correlated to begin with (Nozick, 1993). Plausibly, an evolutionary game theoretic context would seem to be a suitable environment to embed our model into (Weibull, 1995). This also explains why no discussion about sufficient epistemic conditions for an equilibrium (defined according to our notions) to obtain will be pursued (Aumann-Brandenburger, 1995).

5 A capacity is *Convex* if $v(A \cup B) + v(A \cap B) \geq v(A) + v(B)$, and *Concave* if the weak inequality holds in the opposite direction, for any pair of events A and B in the relevant sigma algebra. Convexity and concavity are also interpreted, respectively, as formalizing uncertainty aversion (pessimism) and uncertainty seeking (optimism).

6 Namely, we imagine that player i uses a *physical* randomizing device which, with probability p , gives s_i and with probability $1-p$ gives t_i . Osborne- Rubinstein (1994) discuss at length alternative interpretations of mixed strategies.

7 For the definition of Choquet integral (summation) see, among others, Gilboa-Schmeidler (1993). In the appendix we report its general formula.

8 A stronger notion of equilibrium might require $v_1(\cdot) = v_2(\cdot)$, for all events in 2^S , namely full symmetry. This however would be unnecessarily demanding for our purposes.

9 In this context additivity means that players are uncertainty *neutral*, and not that uncertainty is absent and players are only dealing with risk. Observe also that in this case DS and GS coincide with Bayes' rule.

10 Defined as $P(A \cap B) = P(A)P(B)$.

11 In what follows $v(A|B)$ stands for a generic updating rule calculated from a non-additive prior distribution.

12 Notice that with additivity these two notions of independence collapse to the same, and standard, one.

APPENDIX

We collect here few definitions and results that may be of help for the reader. The main references will be Schmeidler (1989) and Gilboa-Schmeidler (1993).

Let X be a set (of consequences), S the state space and Σ a sigma algebra made of subsets of S . Furthermore, let $v(\cdot)$ be a monotonic set function defined as $v(\cdot) : \Sigma \rightarrow [0, 1]$ and F be a real function defined on S . The Choquet Integral of F with respect to the non-additive measure v is given by.

$$I(F) = \int_S F(t) dv(t) = \int_0^\infty v(\{x \in S | F(x) \geq t\}) dt + \int_{-\infty}^0 [v(\{x | F(x) \geq t\}) - 1] dt$$

Should F be a step function taking a finite number of values $F(x_1) > F(x_2) > \dots > F(x_n)$ over the sets A_i , with $i=1, 2, \dots, n$, forming a partition of S , the above integral would reduce to

$$\sum_{i=1}^n (F(x_i) - F(x_{i+1})) v(\bigcup_{j=1}^i A_j)$$

Suppose f and g are two acts defined on S , namely functions such that $f, g : S \rightarrow X$. Then (Gilboa-Schmeidler), if $A \in \Sigma$, G is the set of all finite acts and $\oplus$ a weak order on G representing an individual's preferences over G , the *f*-Bayesian Updating rule for $\oplus$ given A is $\oplus(f, A)$ given by

$$g \oplus(f, A) h \Leftrightarrow (g, A ; f, A^c) \oplus (h, A ; f, A^c)$$

This is a notion of updated preferences, given event A , that allows a characterization of *pessimism* and *optimism* when f is, respectively, the constant act equal to the *best* and *worst* possible consequence.

this is equivalent to state that if $f \oplus g$ then $\alpha f + (1-\alpha)g \oplus g$, where $\alpha \in (0,1)$. The author proves that the following are equivalent:

1) $\oplus$ exhibits uncertainty aversion

2) $I(\alpha f + (1-\alpha)g) \geq \alpha I(f) + (1-\alpha)I(g)$

3) v is convex

4) $I(f) = \min \{ \int f d p \mid p \in \text{core}(v) \}$

where $\text{core}(v) = \{ p : \Sigma \rightarrow \mathbb{R} \mid p \text{ is additive, and } p(A) \geq v(A), \forall A \in \Sigma \}$

(1) - (4) say mainly that (a) convexity of v is equivalent to concavity of I and to uncertainty aversion (as defined above) (b) preferences representable by a Choquet integration with respect to a convex capacity, are also representable by the minimum Riemann integral taken with respect to the additive measures in the core of v . This provides a further characterization of uncertainty aversion, since the goal of an individual whose preferences are representable by the set of multiple priors in the core of a convex capacity is to maximize a minimum integral (*maxmin* criterion).

Finally, Gilboa-Schmeidler show that if $\oplus$ can be represented by both multiple priors and a convex capacity, then DS is the unique *f-Bayesian Updating* convex measure representing $\oplus(f,A)$.

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