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쇼케이 적분 기준을 통한 구간치 필요측도에 관한 연구

A study on interval-valued necessity measures through the Choquet integral criterian

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Abstract

Y. Réballé[Fuzzy Sets and Systems, vol.157, pp.3025-2039, 2006] discussed the representation of necessity measure through the Choquet integral criterian. He also considered a decision maker who ranks necessity measures related with Choquet integral representation. Our motivation of this paper is that a decision maker have an "ambiguity" necessity measure to present preferences. In this paper, we discuss the representation of interval-valued necessity measures through the Choquet integral criterian.

Key Words : non-additive measures, necessity measures, Choquet integrals.

1. Introduction

Murofushi and Sugeno[10] have been studying Choquet integrals which allow to define necessity measures and risk measure. Y. Réballé[11] discussed the representation of necessity measure through the Choquet integral criterian. He also considered a decision maker who ranks necessity measures related with Choquet integral representation. Another researchers have been studying topics related with Choquet integrals, for examples, preference representation theorem(Y. Réballé [11]), integral representation(D. Schmeidler[12]), subjective probability and expected utility without additivity(D. Schmeidler[13]), interval-valued Choquet price functionals(L. Jang[8]), applications in pricing risks(L. Jang[9]), etc.

Motivation of this paper is that a decision maker have ambiguity necessity measures to present risky prospects in the sense of mathematical theory. We note that ambiguity measures can be represented by interval-valued necessity measure. We can see that this idea is similar to the concept of the Choquet integral of an interval-valued measurable function (see [1, 2, 5-9]).

In this paper, we discuss the representation of interval-valued necessity measures through the Choquet integral criterian.

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2. Definitions and Preliminaries

In this section we list the set-theoretical arithmetic operations on the set of subintervals of an unit interval $I=[0,1]$ in $\mathbb{R}$. We denote $[I]$ by

$$[I]=\{\bar{a}=[a^-,a^+]\mid a^-,a^+\in I \text{ and } a^-\le a^+\}.$$

For any $a\in I$, we define $a=[a,a]$. Obviously, $a\in[I]$.

Definition 2.1 ([7-9]) If $\bar{a},\bar{b}\in[I], k\in I$, then we define
(1) $\bar{a}+\bar{b}=[a^-+b^-, a^++b^+]$,
(2) $k\bar{a}=[ka^-, ka^+]$,
(3) $\bar{a}\wedge\bar{b}=[a^-\wedge b^-, a^+\wedge b^+]$,
(4) $\bar{a}\vee\bar{b}=[a^-\vee b^-, a^+\vee b^+]$,
(5) $\bar{a}\le\bar{b}$ if and only if $a^-\le b^-$ and $a^+\le b^+$,
(6) $\bar{a}<\bar{b}$ if and only if $\bar{a}\le\bar{b}$ and $\bar{a}\ne\bar{b}$,
(7) $\bar{a}\subset\bar{b}$ if and only if $b^-\le a^-$ and $a^+\le b^+$.

Theorem 2.2 ([7-9]) Let $\bar{a},\bar{b}\in[I]$. Then the followings hold.
(1) idempotent law: $\bar{a}\wedge\bar{a}=\bar{a}, \bar{a}\vee\bar{a}=\bar{a}$,
(2) commutative law: $\bar{a}\wedge\bar{b}=\bar{b}\wedge\bar{a}, \bar{a}\vee\bar{b}=\bar{b}\vee\bar{a}$,
(3) associative law: $(\bar{a}\wedge\bar{b})\wedge\bar{c}=\bar{a}\wedge(\bar{b}\wedge\bar{c})$,
$(\bar{a}\vee\bar{b})\vee\bar{c}=\bar{a}\vee(\bar{b}\vee\bar{c})$,
(4) absorption law: $\bar{a}\wedge(\bar{a}\vee\bar{b})=\bar{a}\vee(\bar{a}\wedge\bar{b})=\bar{a}$,
(5) distributive law: $\bar{a}\wedge(\bar{b}\vee\bar{c})=(\bar{a}\wedge\bar{b})\vee(\bar{a}\wedge\bar{c})$,
$\bar{a}\vee(\bar{b}\vee\bar{c})=(\bar{a}\vee\bar{b})\wedge(\bar{a}\vee\bar{c})$,

It is easily to see that $([I],d_H)$ is a metric where d_H is the Hausdorff metric defined by

$d_H(A,B)$
$=\max\{\vee_{a\in A}\wedge_{b\in B}|a-b|, \vee_{b\in B}\wedge_{a\in A}|a-b|\}$
for all $A,B\in[I]$. Clearly, we have the following theorem for multiplication and Hausdorff metric on $[I]$.

Theorem 2.3 ([7-9]) (1)If we define
$\bar{a}\cdot\bar{b}=\{x\cdot y \mid x\in\bar{a}, y\in\bar{b}\}$
for $\bar{a},\bar{b}\in[I]$, then $\bar{a}\cdot\bar{b}=[a^-\cdot b^-, a^+\cdot b^+]$.
(2) If $d_H: [I]\times[I]\to[0,\infty)$ is the above Hausdorff metric, then $d_H(\bar{a},\bar{b})=\max\{|a^- - b^-|, |a^+ - b^+|\}$.

Let Ω be a non-empty set and $\mathfrak{I}(\Omega)$ a non-empty family of subsets of Ω. A function X: $\Omega\to I$ is said to be $\mathfrak{I}(\Omega)$-measurable if for every $\alpha\in(0,1)$, $\{w\in\Omega \mid X(w)\geq\alpha\}\in\mathfrak{I}(\Omega)$.

Let $B(\Omega,\mathfrak{I}(\Omega))$ be the set of $\mathfrak{I}(\Omega)$-measurable functions. We remark that $B(\Omega,\mathfrak{I}(\Omega))$ is not convex (see [11]). We also list non-additive measures, possibility measures, and necessity measures.

Definition 2.4 ([3, 7-9, 10-13]) A set function μ on $\mathfrak{I}(\Omega)$ is called a non-additive measure if $\mu(\varnothing)=0$ and $\mu(A)\leq\mu(B)$ whenever $A,B\in\mathfrak{I}(\Omega)$ and $A\subset B$.

Definition 2.5 ([11, 14]) (1) A set function μ on $\mathfrak{I}(\Omega)$ is called a possibility measure if $\mu(\varnothing)=0$ and $\mu(X)=1$ and $\mu(\bigcup_i A_i)\leq\max_i\mu(A_i)$ for all collections $\{A_i\}\subset\mathfrak{I}(\Omega)$.
(2) A set function ν on $\mathfrak{I}(\Omega)$ is called a necessity measure if $\nu(A)=1-\mu(A^c)$ for all $A\in\mathfrak{I}(\Omega)$ and $A^c=\{w\in\Omega \mid w\notin A\}$.

We note that every possibility measure and necessity measure is a non-additive measure. Let us discuss the following Choquet integral.

Definition 2.4 ([3, 7-9, 10-13]) Let μ be a non-additive measure on $\mathfrak{I}(\Omega)$ and $X\in B(\Omega,\mathfrak{I}(\Omega))$. The Choquet integral of X with respect to μ is defined by

$$(C)\int f d\mu=\int_0^1\mu_X(\alpha)\,d\alpha$$

where $\mu_X(\alpha)=\mu(\{w\in\Omega \mid X(w)>\alpha\})$ and the integral on the right hand side is Lebesgue integral.

For the case of characteristic function, one has $(C)\int I_A d\mu=\mu(A)$ where $A\in\mathfrak{I}(\Omega)$ and I_A is the characteristic function of A. We note that if Ω is a finite set and $X\in B(\Omega,\mathfrak{I}(\Omega))$, then there is a unique decomposition of X in the following manner $X=\sum_{i=1}^n\alpha_i I_{A_i}$, where $\alpha_1,\cdots,\alpha_n>0$ and $\sum_{i=1}^n\alpha_i\leq 1$ and $A_1\supset A_2\supset\cdots\supset A_n\neq\varnothing$ and $A_i\in\mathfrak{I}(\Omega)$ for all $i=1,2,\cdots,n$, possibly $A_1=\Omega$ if $\Omega\in\mathfrak{I}(\Omega)$. The computation of the Choquet integral of X with respect to μ gives

$$(C)\int X d\mu=\sum_{i=1}^n\alpha_i\mu(A_i).$$

Definition 2.5 ([3, 7-9, 10-13]) Let $X,Y\in B(\Omega,\mathfrak{I}(\Omega))$. We say that X and Y are comonotonic, in symbol $X\sim Y$ if

$$X(w)<X(w')\Rightarrow Y(w)\leq Y(w')$$

for all $w,w'\in\Omega$.

Definition 2.6 ([11]) We say that the Choquet integral has comonotonic affinity if $X,Y\in B(\Omega,\mathfrak{I}(\Omega))$ and $\alpha\in(0,1)$ and $\alpha X+(1-\alpha)Y\in B(\Omega,\mathfrak{I}(\Omega))$ and $X\sim Y$, then

$$(C)\int(\alpha X+(1-\alpha)Y)d\mu$$
$$=\alpha(C)\int X d\mu+(1-\alpha)(C)\int Y d\mu.$$

Now, we introduce the following basic properties of the comonotonicity and the Choquet integral.

Theorem 2.7 ([3, 10-13]) Let $X,Y,Z\in B(\Omega,\mathfrak{I}(\Omega))$. Then we have the following.
(1) $X\sim X$,
(2) $X\sim Y\Rightarrow Y\sim X$,
(3) $X\sim a$ for all $a\in I$,
(4) $X\sim Y$ and $X\sim Z\Rightarrow X\sim Y+Z$.

Theorem 2.8 ([3, 10-13]) Let $X,Y\in B(\Omega,\mathfrak{I}(\Omega))$. Then we have the following.
(1) If $X\leq Y$, then $(C)\int X d\mu\leq(C)\int Y d\mu$.
(2) If $A\subset B$ and $A,B\in\mathfrak{I}(\Omega)$, then

$$(C)\int_A X d\mu\leq(C)\int_B X d\mu.$$

(3) If $X\sim Y$ and $a,b\in I$, then

$$(C)\int(aX+bY)d\mu=a(C)\int X d\mu+b(C)\int Y d\mu.$$

(4) If $(X\vee Y)(w)=X(w)\vee Y(w)$ and $(X\wedge Y)(w)=X(w)\wedge Y(w)$ for all $w\in\Omega$, then

$$(C)\int X\vee Y d\mu\geq(C)\int X d\mu\vee(C)\int Y d\mu$$

and

$$(C)\int X\wedge Y d\mu\leq(C)\int X d\mu\wedge(C)\int Y d\mu.$$

3. Non-additive interval-valued measures

Definition 3.1 An interval-valued set function

$\overline{\mu}: \Im(\Omega) \to [I]$ is a non-additive interval-valued measure if $\overline{\mu}(\varnothing) = \overline{0}$ and $\overline{\mu}(A) \leq \overline{\mu}(B)$, whenever $A, B \in \Im(\Omega)$ and $A \subset B$.

It is easily to see that for each $\overline{\mu}$, there are uniquely two non-additive measures μ^- and μ^+ on $\Im(\Omega)$ such that $\overline{\mu} = [\mu^-, \mu^+]$.

Definition 3.2 The Choquet integral with respect to $\overline{\mu} = [\mu^-, \mu^+]$ of $X \in B(\Omega, \Im(\Omega))$ is defined by

$$(C)\int X d\overline{\mu} = [(C)\int X d\mu^-, (C)\int X d\mu^+].$$

Then we have the following characterization of the functional which is representable as the Choquet integral with respect to $\overline{\mu}$. We recall that a mapping $l: B(\Omega, \Im(\Omega)) \to I$ is said to be comonotonic affine functional if for all $X, Y \in B(\Omega, \Im(\Omega))$ and $\alpha \in (0,1)$,

$$l(\alpha X + (1-\alpha) Y) = \alpha l(X) + (1-\alpha) l(Y)$$

and it is said to be monotone if for all $X, Y \in B(\Omega, \Im(\Omega))$ and $X \leq Y$, $l(X) \leq l(Y)$.

Definition 3.3 A mapping $T: B(\Omega, \Im(\Omega)) \to [I]$ is said to be comonotonic affine interval-valued functional if for all $X, Y \in B(\Omega, \Im(\Omega))$ and $\alpha \in (0,1)$,

$$T(\alpha X + (1-\alpha) Y) = \alpha T(X) + (1-\alpha) T(Y)$$

and it is said to be monotone if for all $X, Y \in B(\Omega, \Im(\Omega))$ and $X \leq Y$, $T(X) \leq T(Y)$.

Note that a mapping $T = [l_1, l_2]: B(\Omega, \Im(\Omega)) \to [I]$ is a monotone comonotonic affine interval-valued functional if and only if $l_i: B(\Omega, \Im(\Omega)) \to I$ is a monotone comonotonic affine interval-valued functional for $i = 1,2$.

Theorem 3.4 If $T = [l_1, l_2]: B(\Omega, \Im(\Omega)) \to [I]$ is a monotone and comonotonic affine interval-valued functional, then there exists a monotone non-additive interval-valued measure $\overline{\mu} = [\mu^-, \mu^+]$ uniquely defined by

$$\forall A \in \Im(\Omega), \overline{\mu}(A) = [\mu^-(A), \mu^+(A)]$$

such that

$$T(X) = (C)\int X d\overline{\mu}, \ \forall X \in B(\Omega, \Im(\Omega)).$$

Conversely, if $\overline{\mu} = [\mu^-, \mu^+]$ is a non-additive interval-valued measure on $\Im(\Omega)$, then $(C)\int (\cdot) d\overline{\mu}$ is a monotone and comonotonic affine interval-valued functional.

Proof. $(\Rightarrow)$ From the above note, we obtain $l_i: B(\Omega, \Im(\Omega)) \to I$ is a monotone comonotonic affine interval-valued functional for $i = 1,2$. By Theorem 2.1[11], there exist two non-additive measures μ_1, μ_2 such that

$$l_i(X) = (C)\int X d\mu, \ \forall X \in B(\Omega, \Im(\Omega)), \text{ for } i = 1,2.$$

Thus for all $X \in B(\Omega, \Im(\Omega))$,

$$\begin{aligned} T(X) &= [l_1(X), l_2(X)] \\ &= [(C)\int X d\mu_1, (C)\int X d\mu_2] \\ &= (C)\int X d\overline{\mu}. \end{aligned}$$

$(\Leftarrow)$ Let $\overline{\mu} = [\mu^-, \mu^+]$ be a non-additive interval-valued measure. If $X, Y \in B(\Omega, \Im(\Omega))$ and $X \leq Y$, by Theorem 2.4 (1),

$$\begin{aligned} (C)\int X d\overline{\mu} &= [(C)\int X d\mu^-, (C)\int X d\mu^+] \\ &\leq [(C)\int Y d\mu^-, (C)\int Y d\mu^+] \\ &= (C)\int X d\overline{\mu}. \end{aligned}$$

Thus $(C)\int (\cdot) d\overline{\mu}$ is monotone. If $X, Y \in B(\Omega, \Im(\Omega))$, $X \sim Y$ and $\alpha \in (0,1)$, then

$$\begin{aligned} &(C)\int [\alpha X + (1-\alpha) Y] d\overline{\mu} \\ &= [(C)\int [\alpha X + (1-\alpha) Y] d\mu^-, \\ &\qquad (C)\int [\alpha X + (1-\alpha) Y] d\mu^+] \\ &= [\alpha (C)\int X d\mu^- + (1-\alpha)\int Y d\mu^-, \\ &\qquad \alpha (C)\int X d\mu^+ + (1-\alpha)(C)\int Y d\mu^+] \\ &= \alpha [(C)\int X d\overline{\mu}, (C)\int X d\mu^+] \\ &\qquad + (1-\alpha)[(C)\int Y d\mu^-, (C)\int Y d\mu^+] \\ &= \alpha \int X d\overline{\mu} + (1-\alpha)\int Y d\overline{\mu}. \end{aligned}$$

Thus $(C)\int (\cdot) d\overline{\mu}$ is comonotonic affine.

4. Interval-valued necessity measures

In this section, we our concern is to rank interval-valued necessity measures. Let $\wp(\Omega)$ be the power set of Ω.

Definition 4.1 (1) An interval-valued set function $\overline{\nu}: \wp(\Omega) \to [I]$ is called an interval-valued possibility measure if

$$\overline{\nu}(\varnothing) = \overline{0}, \overline{\nu}(\Omega) = 1 \text{ and } \overline{\nu}(\bigcup_i A_i) = \max_i \overline{\nu}(A_i)$$

for all collections $\{A_i\} \subset \Im(\Omega)$.

(2) An interval-valued set function $\overline{\nu}$ on $\wp(\Omega)$ is called an interval-valued necessity measure if $\overline{\nu}(A) = 1 - \overline{\mu}(A^c)$ for all $A \in \wp(\Omega)$ and $A^c = \{w \in \Omega | w \not\in A\}$.

Let Ω be a finite non-empty set and $\wp(\Omega)$ a non-empty family of subsets of Ω. $A^u = \{B \mid A \subset B \subset \Omega\}$ stands for the upset generated by A. Then these sets of subsets of Ω are known as filters(see [11]), we denote the set of filters by $F(\Omega)$. We recall that a family F of subsets of Ω is said to be a filter if

(i) $\varnothing \notin F,\ \Omega \in F$,

(ii) $A,B \in F \Rightarrow A \cap B \in F$,

(iii) $A \in F, A \subset B \Rightarrow B \in F$.

From Definition 4.1(2) and Proposition 2.1([11]), we obtain the following theorem.

Theorem 4.2 An interval-valued set function $\bar{\nu} = [\nu^-, \nu^+] : \wp(\Omega) \to [I]$ is an interval-valued necessity measure if and only if ν^-, ν^+ are necessity measures on $\wp(\Omega)$.

Definition 4,.3 Interval-valued necessity measures $\bar{\nu}, \bar{\eta}$ are said to be agree if ν^-, η^- (ν^+, η^+, resp.) are agree, that is, there is no subsets $A,B \in \wp(\Omega)$ such that

$$\nu^-(A) > \nu^-(B) \text{ and } \eta^-(A) < \eta^-(B)$$
$$(\nu^+(A) > \nu^+(B) \text{ and } \eta^+(A) < \eta^+(B), \text{ resp.}).$$

From Definition 4.1 and Definition 4.3, clearly we have the following theorem.

Theorem 4.4 Let $\bar{\nu}, \bar{\eta}$ be interval-valued necessity measures and $\alpha \in (0,1)$. Then, one has

(1) $\alpha\bar{\nu} + (1-\alpha)\bar{\eta}$ is an interval-valued necessity measure.

(2) $\bar{\nu}, \bar{\eta}$ are agree if and only if $\alpha\bar{\nu} + (1-\alpha)\bar{\eta}$ is agree.

We recall that if $\bar{\nu} = [\nu^-, \nu^+] : \wp(\Omega) \to [I]$ is an interval-valued measure, then there is a unique decomposition of $\bar{\nu}$ over unanimity games known as Mobius transforms of ν^- and ν^+(see [11]):

$$\bar{\nu} = [\sum_{j=1}^{n} \alpha_j u^-_{A_j}, \sum_{k=1}^{m} \beta_k u^+_{B_k}]$$

where $\alpha_1, \cdots, \alpha_n > 0, \beta_1, \cdots, \beta_m > 0, \sum_{j=1}^{n} \alpha_j = 1, \sum_{k=1}^{m} \beta_k = 1$, $\Omega \supset A_1 \supset \cdots \supset A_n \neq \varnothing$, $\Omega \supset B_1 \supset \cdots \supset B_m \neq \varnothing$, u^-_A (u^+_A, resp.) denote a unanimity game associated with ν^- (ν^+, resp.), that is, elementary belief function with support A defined by,

$$\forall A \subset \Omega,\ u_A(B) = \begin{cases} 1 & \text{if } A \subset B \\ 0 & otherwise \end{cases}$$

or otherwise put, $\bar{\nu}$ can be expressed as follows,

$$\bar{\nu} = [\sum_{j=1}^{n} \alpha_j I_{A_j^u}, \sum_{k=1}^{m} \beta_k I_{B_k^u}]$$

where $\alpha_1, \cdots, \alpha_n > 0, \beta_1, \cdots, \beta_m > 0, \sum_{j=1}^{n} \alpha_j = 1, \sum_{k=1}^{m} \beta_k = 1$, $\varnothing \neq A_1^u \subset \cdots \subset A_n^u$ and $\varnothing \neq B_1^u \subset \cdots \subset B_m^u$.

As a consequence of Proposition 2.1([11]) and Proposition 2.2([11]) with ν^-, ν^+, given non-additive measures μ^-, μ^+ defined on $\wp(\Omega)$, we can obtain the Choquet integral of an interval-valued neccessity measure $\bar{\nu}$ with respect to an interval-valued nonadditive measure $\bar{\mu}$ as following:

$$(C)\int \bar{\nu}\, d\bar{\mu} = [\sum_{j=1}^{n} \alpha_j \mu^-(A_j^u),\ \sum_{k=1}^{m} \beta_k \mu^+(B_k^u)].$$

By using the above Choquet integral of an interval-valued necessity measure with respect to an interval-valued non-additive measure, we can discuss that this object is the criterion which is used to rank interval-valued necessity measures in order to obtain a weak integral representation, that is for all interval-valued necessity measures $\bar{\nu}, \bar{\eta}$:

$$\bar{\nu} \geq \bar{\eta} \Leftrightarrow (C)\int \bar{\nu}\, d\bar{\mu} \geq (C)\int \bar{\eta}\, d\bar{\mu}.$$

In the future, by using the above weak integral representation, we can study the integral representation of interval-valued preferences which are like ambiguity preferences.

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