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Lower and Upper Bounds for ‘Useful’ Jensen Functional Convexity

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Abstract: In the present paper, we will study the class of convex functions and emphasized certain basic conclusions related to the Jensen functional and its behavior in the setting of the convex function due to the scarcity of literature on the subject. The Jensen functional has been studied under a variety of assumptions, including strong convexity, quasiconvexity, and convexity, quasiconvexity. We present some new improvements on lower and upper bounds for the ‘useful’ Jensen functional in this paper. To explain the idea of a strongly convex function, we utilize a combination of old and recent results.

Keywords: Convex function, Bounds, ‘Useful’ Jensen functional, Convexity.

1. Introduction

The goal of this study is to explore new Jensen functional findings in the context of strong convexity [13-25]. We will work with the category of convex functions throughout this work, which will ultimately encompass functions from other classes discussed in the literature, and the interested reader will be able to get more suitable predictions that use the same basic method. Before going into depth, we'll mention a few important findings for the reader's convenience. Lower and Upper boundsare presented by Dwivedi and Sharma [12] for the ‘useful’ Renyi information rate [26-45].One of the most well-known and widely applied inequalities in modern mathematics is Jensen's inequality for convex functions. The AM-GM-HM inequality, the generalized triangle inequality, the positivity of relative entropy in Information Theory, Levinson's inequality, Ky Fan's inequality, Shannon's inequality, and other conclusions are all based on it. See [7], [9], and [2] for further information on modern and classical expansions connected to the Jensen inequality [46-87].

Let $Z = (z_1, z_2, \dots, z_r)$is a continuous random variable with the probability dispersion $C = (c_1, c_2, \dots, c_r)$ such that $c_l \geq 0 \forall l = 1,2, \dots, r$ and $\sum_{l=1}^{r} c_l = 1$. The entropy, or Shannon's information measure, is therefore defined as (Shannon, 1948)

$$H(C) = z - \sum_{l=1}^{r} c_l \log c_l \qquad (1)$$

Let $U = (u_1, u_2, \dots, u_r)$ represent a collection of non-negative integers with $u_l > 0$ and u_l representing the usefulness of the appearance of the component z_l. The utility is independent of chance $c_{l.}$ The pattern of information provided by

$$\begin{bmatrix} z_1 & z_2 & \cdots & z_r \\ c_1 & c_2 & \cdots & c_r \\ u_1 & u_2 & \cdots & u_r \end{bmatrix}; \quad u_l > 0, c_l \geq 0 \,\&\, \sum_{l=1}^{r} c_l = 1 \qquad (2)$$

Utility information strategy is the term given to the scheme mentioned above. Belis and Guiasu (1968) provided the following information measure, which corresponded to the scheme (2):

$$H(C; U) = -\sum_{l=1}^{r} u_l c_l \log c_l \qquad (3)$$

The information measures defined in (3) are called 'useful' information [88-101]. This measurement may be used to determine the average amount of 'useful' information delivered by the information scheme (2), when utilities are ignored then (3) reduces to Shannon’s Information (1).

Definition 1 Suppose$g$ is a real-valued function, which is defined on the interval Z and has the property that$c_1, c_2, \dots, c_r \in (0,1)$ with $\sum_{l=1}^{r} c_l = 1$and $z_1, z_2, \dots z_r \in Z$, and $U = (u_1, u_2, \dots, u_r), u_l > 0$are the utilities attached to probabilities. Then the‘useful’ Jensen functional is defined by

$$\mathfrak{J}(g, \boldsymbol{c}, \boldsymbol{z}, U) \equiv \frac{\sum_{l=1}^{r} u_l c_l \, g(z_l)}{\sum_{l=1}^{r} u_l c_l} - g \frac{\left(\sum_{l=1}^{r} u_l c_l \, z_l\right)}{\sum_{l=1}^{r} u_l c_l}$$

(See [1]).

Definition 2A function g withabsolute value$m > 0$is strongly convex, and the function is defined on the interval Z, then

$$g\big((1-\alpha)z + \alpha t\big) \le (1-\alpha) g(z) + \alpha g(t) - m\alpha(1-\alpha)(t-z)^2 \,, \qquad (4)$$

for all $z, t \in Z$, and all $\alpha \in [0,1]$. g with absolute value$m$is strongly convex, if there is a $m > 0$, we call it strongly convex.

B. T. Polyak [10] was the first to introduce strongly convex functions. If $-g$ with absolute value$m$is strongly convex, it is nearly convex of order 2 [8] or called strongly concave with absolute value$m$.

Example 1 Each strongly convex function is, of course, convex. The convexity of affine functions is not very high. With absolute value$m$, the function $g(z) = cz^2 + bz + a$ is strongly convex, as well as the inequality (4) holds with an equivalence mark.

We have, according to HiriartUrruty and Lemarechal [3]:

Proposition 1 The function $f(z) = g(z) - mz^2$ is convex if and only if, the function g with absolute value$m$is strongly convex. The subsequent consequence is proven in [4]:

Proposition 2 The function g with module m are strongly convex, by considering $c_l \ge 0, l = 1, \dots, r$ with $\sum_{l=1}^{r} c_l = 1, \overline{z} = \frac{\sum_{l=1}^{r} u_l c_l z_l}{\sum_{l=1}^{r} u_l c_l}, u_l > 0$, then we have:

$$\mathfrak{J}(g, \boldsymbol{c}, \boldsymbol{z}, U) \ge m \frac{\sum_{l=1}^{r} u_l c_l (z_l - \overline{z})^2}{\sum_{l=1}^{r} u_l c_l} \qquad (5)$$

In a publication by T. Rajba and Sz. Wasowicz [11], this is demonstrated using a probabilistic technique. In addition, positive scalar multiplication.

In the next sections, we'll look at a more basic ‘useful’ Jensen functional and how it behaves in the presence of robust convexity.

2. New Improvements

Theorem 1 Suppose a strongly convex function$g$be with absolute value$m$described on $Z, z_1, z_2, \dots z_r \in Z$ and $c_1, c_2, \dots, c_r \in (0,1)$ with $\sum_{l=1}^{1} c_l = 1$and $U = (u_1, u_2, \dots, u_r), u_l > 0$are the utilities attached to probabilities [102-134].Then

$$\frac{\sum_{l=1}^{r} u_l c_l\, g\big((1-\alpha\beta)\overline{z}+\alpha\beta z_l\big)}{\sum_{l=1}^{r} u_l c_l} \le (1-\alpha)g(\overline{z}) + \alpha\left(\frac{\sum_{l=1}^{r} u_l c_l\, g\big((1-\beta)\overline{z}+\beta z_l\big)}{\sum_{l=1}^{r} u_l c_l}\right) - m\alpha(1-\alpha)\beta^2\left(\frac{\sum_{l=1}^{r} u_l c_l\,(z_l-\overline{z})^2}{\sum_{l=1}^{r} u_l c_l}\right)$$

for all$\alpha,\beta\in[0,1]$.

Proof: In (4) we replace t by $(1-\beta)\overline{z}+\beta z_l$ and z by $\overline{z}$. Hence,

$$g\big((1-\alpha\beta)\overline{z}+\alpha\beta z_l\big) \le (1-\alpha)g(\overline{z}) + \alpha g\big((1-\beta)\overline{z}+\beta z_l\big) - m\alpha(1-\alpha)\beta^2(z_l-\overline{z})^2$$

for all $l=1,\ldots,r$. We increase by $u_l c_l$ and afterward summarize from 1 to r, which drives us to the end. The specific case $\beta = 1$, $\alpha = \frac{1}{2}$ gives

$$\frac{\sum_{l=1}^{r} u_l c_l\, g\left(\frac{\overline{z}+z_l}{2}\right)}{\sum_{l=1}^{r} u_l c_l} \le \frac{1}{2}\left(g(\overline{z}) + \frac{\sum_{l=1}^{r} u_l c_l\, g(z_l)}{\sum_{l=1}^{r} u_l c_l}\right) - \frac{m}{4}\left(\frac{\sum_{l=1}^{r} u_l c_l\,(z_l-\overline{z})^2}{\sum_{l=1}^{r} u_l c_l}\right),$$

which is equivalent to

$$2\left(\frac{\sum_{l=1}^{r} u_l c_l g\left(\frac{\overline{z}+z_l}{2}\right)}{\sum_{l=1}^{r} u_l c_l} - g(\overline{z})\right) + \frac{m}{2}\left(\frac{\sum_{l=1}^{r} u_l c_l (z_l-\overline{z})^2}{\sum_{l=1}^{r} u_l c_l}\right) \le \mathfrak{J}(g,\boldsymbol{c},\boldsymbol{z},U)\,. \qquad (6)$$

Moreover, from (5) for $z_l \to \frac{\overline{z}+z_l}{2}$,we end up with a twofold inequality that refines the inequality of Merentes Nikodem (5):

Corollary 1 Suppose that$g$with absolute value$m$is a strongly convex function and defined on an interval$Z, z_1, z_2, \ldots z_r \in Z$ and $c_1, c_2, \ldots, c_r \in (0,1)$ with $\sum_{l=1}^{1} c_l = 1$and $U = (u_1, u_2, \ldots, u_r), u_l > 0$are the utilities attached to probabilities [135-156].Then

$$m\left(\frac{\sum_{l=1}^{r} u_l c_l (z_l-\overline{z})^2}{\sum_{l=1}^{r} u_l c_l}\right) \le 2\left(\frac{\sum_{l=1}^{r} u_l c_l g\left(\frac{\overline{z}+z_l}{2}\right)}{\sum_{l=1}^{r} u_l c_l} - g(\overline{z})\right) + \frac{m}{2}\left(\frac{\sum_{l=1}^{r} u_l c_l (z_l-\overline{z})^2}{\sum_{l=1}^{r} u_l c_l}\right) \le \mathfrak{J}(g,\boldsymbol{c},\boldsymbol{z},U)\,.$$

We present a more generalized function in a natural approach.

Definition 3 Let a real-valued function g described on Z,the real numbers $c_{lj}, l = 1,\ldots,k$ and $j = 1,\ldots,r_l$ such that $c_{lj} > 0, \sum_{j=1}^{r_l} c_{lj} = 1$for all $l = 1,\ldots,k$, we denote $\boldsymbol{c_l} = (c_{l_1}, c_{l_2}, \ldots, c_{lr_l})$,$U = (u_1, u_2, \ldots, u_r), u_l > 0$are the utilities attached to probabilities [157-186]. $\boldsymbol{z_l} = \left(z_{l_1}, z_{l_2}, \ldots, z_{lr_l}\right) \in Z^{r_l}$for all $l = 1,\ldots,k$ and $\boldsymbol{v} = (v_1, v_2, \ldots, v_k)$, $v_l > 0$ such that $\sum_{l=1}^{k} v_l = 1$. Then we have the 'useful' generalized Jensen functional is defined as follows:

$$\mathfrak{J}_k(g, u_1\boldsymbol{c_1}, \ldots, u_k\boldsymbol{c_k}, \boldsymbol{v}, \boldsymbol{z_1}, \ldots, \boldsymbol{z_k}) = \frac{\sum_{j_1,\ldots,j_k=1}^{r_1,\ldots,r_k} u_{1j_1} c_{1j_1} \ldots u_{kj_k} c_{kj_k} g\left(\sum_{l=1}^{k} v_l z_{lj_l}\right)}{\sum_{j_1,\ldots,j_k=1}^{r_1\ldots,r_k} u_{kj_k} c_{kj_k}}$$

$$-g\left(\frac{\sum_{l=1}^{k} v_l \sum_{j=1}^{r_l} u_{lj}\, c_{lj}\, z_{lj}}{\sum_{j=1}^{r_l} u_{lj}\, c_{lj}}\right) \qquad (7)$$

We can see that when $k = 1$, this equation becomes Definition 1.

The reader is directed to the articles [5,6] for further information on Jensen's function.

Under the strong convexity condition, we present the performance of 'useful' generalized Jensen functional in concern to subsequent lemma [187-198]:

Lemma 1 Suppose that $g$with absolute value$m$is strongly convex and let$g, u_l, \boldsymbol{c_l}$, $\boldsymbol{z_l}$and$\boldsymbol{v}$be as in Definition3 and $U = (u_1, u_2, \dots, u_r), u_l > 0$are the utilities attached to probabilities.Then we have

$$\mathfrak{J}_k(g, u_1\boldsymbol{c_1}, \dots, u_k\boldsymbol{c_k}, \boldsymbol{v}, \boldsymbol{z_1}, \dots, \boldsymbol{z_k}) \geq m\frac{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}\left(\sum_{l=1}^{k} v_l\, z_{lj_l} - \bar{z}\right)^2}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{kj_k}c_{kj_k}},$$

where$\bar{z} = \frac{\sum_{l=1}^{k} v_l \sum_{j=1}^{r_l} u_{lj}\, c_{lj}\, z_{lj}}{\sum_{j=1}^{r_l} u_{lj}\, c_{lj}}$.

Proof: We have the following measure

$$\frac{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{kj_k}c_{kj_k}} = 1$$

and it holds obviously

$$\bar{z} = \frac{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}\sum_{l=1}^{k} v_l z_{lj_l}}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{kj_k}c_{kj_k}} = \frac{\sum_{l=1}^{k} v_l \sum_{j=1}^{r_l} u_{lj}\, c_{lj}\, z_{lj}}{\sum_{j=1}^{r_l} u_j\, c_j}.$$

The end follows from Proposition 2 and Definition 3.

We have the following bounds for strongly convex functions:

Theorem 2 Let the positive real numbersp_{lj} and $U = (u_1, u_2, \dots, u_r), u_l > 0$are the utilities attached to probabilities, $l = 1, \dots, k$and $j = 1, \dots r_l$such that $\sum_{j=1}^{r_l} p_{lj} = 1$, for all$l = 1, \dots., k$ and $g, u_l, \boldsymbol{c_l}, \boldsymbol{z_l}and\boldsymbol{v}$be as in Definition 3. Let$\boldsymbol{p_l} = \left(p_{l_1}, p_{l_2}, \dots, p_{lr_l}\right)$for all $l = 1, \dots, k$,

$$s = \min_{1 \leq j_1 \leq r_1, \dots, 1 \leq j_k \leq r_k}\left\{\frac{u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}}{p_{1j_1}\dots p_{kj_k}}\right\},$$

$$S = \max_{1 \leq j_1 \leq r_1, \dots, 1 \leq j_k \leq r_k}\left\{\frac{u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}}{p_{1j_1}\dots p_{kj_k}}\right\}.$$

Suppose that $g$is strongly convex with absolute value$m$, therefore:

$$\mathfrak{J}_k(g, u_1\boldsymbol{c_1}, \dots, u_k\boldsymbol{c_k}, \boldsymbol{v}, \boldsymbol{z_1}, \dots, \boldsymbol{z_k}) - s\mathfrak{J}_k(g, \boldsymbol{p_1}, \dots, \boldsymbol{p_k}, \boldsymbol{v}, \boldsymbol{z_1}, , \boldsymbol{z_k})$$

$$\geq m\frac{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k}\left(u_{1j_1}c_{1j_1},\dots u_{kj_k}c_{kj_k} - sp_{1j_1}\dots p_{kj_k}\right)\left(\sum_{l=1}^{k} v_l z_{lj_l} - \bar{z}\right)^2}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k} u_{kj_k}c_{kj_k}} + sm\left(\frac{\sum_{l=1}^{k} v_l \sum_{j=1}^{r_l}(p_{lj} - u_{lj}\, c_{lj})z_{lj}}{\sum_{j=1}^{r_l} u_{lj}\, c_{lj}}\right)^2 \quad (8)$$

and

$$S\mathfrak{J}_k(g, \boldsymbol{p_1}, \dots, \boldsymbol{p_k}, \boldsymbol{v}, \boldsymbol{z_1}, \dots, \boldsymbol{z_k}) - \mathfrak{J}_k(g, u_1\boldsymbol{c_1}, \dots, u_k\boldsymbol{c_k}, \boldsymbol{v}, \boldsymbol{z_1}, \dots, \boldsymbol{z_k})$$

$$\geq m\frac{\sum_{j_1,\dots,j_k=1}^{r_1\dots r_k}\left(Sp_{1j_1}\dots p_{kj_k}-u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}\right)\left(\sum_{l=1}^{k}v_l z_{lj_l}-\overline{z}\right)^2}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k}u_{kj_k}c_{kj_k}}+m\left(\frac{\sum_{l=1}^{k}v_l\sum_{j=1}^{r_l}(p_{lj}-u_{lj}c_{lj})z_{lj}}{\sum_{j=1}^{r_l}u_{lj}c_{lj}}\right)^2 \quad (9)$$

where$\overline{z}=\frac{\sum_{l=1}^{k}v_l\sum_{j=1}^{r_l}u_{lj}c_{lj}z_{lj}}{\sum_{j=1}^{r_l}u_{lj}c_{lj}}$.

Proof: Only the first inequality is proven. Clearly

$$\begin{aligned}&\mathfrak{J}_k(g,u_1\boldsymbol{c_1},\dots,u_k\boldsymbol{c_k},\boldsymbol{v},\boldsymbol{z_1},\dots,\boldsymbol{z_k})-s\mathfrak{J}_k(g,\boldsymbol{p_1},\dots,\boldsymbol{p_k},\boldsymbol{v},\boldsymbol{z_1},\dots,\boldsymbol{z_k})\\&=\frac{\sum_{j_1,\dots,j_k=1}^{r_1,\dots,r_k}\left(u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}-sp_{1j_1}\dots p_{kj_k}\right)g\left(\sum_{l=1}^{k}v_l z_{lj_l}\right)}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k}u_{kj_k}c_{kj_k}}\\&\quad+sg\left(\sum_{l=1}^{k}v_l\sum_{j=1}^{r_l}p_{lj}\ z_{lj}\right)-g\left(\frac{\sum_{l=1}^{k}v_l\sum_{j=1}^{r_l}u_{lj}c_{lj}\ z_{lj}}{\sum_{j=1}^{r_l}u_{lj}c_{lj}}\right)\end{aligned}$$

Since

$$\begin{aligned}&\frac{\sum_{l=1}^{k}v_l\sum_{=1}^{r_l}u_{lj}c_{lj}\ z_{lj}}{\sum_{j=1}^{r_l}u_{lj}c_{lj}}\\&=\frac{\sum_{j_1,\dots,j_k=1}^{r_1,\dots,r_k}\left(u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}-sp_{1j_1}\dots p_{kj_k}\right)\sum_{l=1}^{k}v_l z_{lj_l}}{\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k}u_{kj_k}c_{kj_k}}+s\sum_{j=1}^{k}v_l\sum_{j=1}^{r_l}p_{lj}\ z_{lj}\end{aligned}$$

Lemma 1 is used to reach the desired outcome.

A demonstration of the other inequality proceeds, in the same way, because

$$\begin{aligned}&\sum_{l=1}^{k}v_l\sum_{j=1}^{r_j}p_{lj}\ z_{lj}\\&=\frac{\sum_{j_1,\dots,j_k=1}^{r_1,\dots,r_k}Sp_{1j_1}\dots p_{kj_k}-u_{1j_1}c_{1j_1}\dots u_{kj_k}c_{kj_k}\sum_{l=1}^{k}v_l z_{lj_l}}{S\left(\sum_{j_1,\dots,j_k=1}^{r_1\dots,r_k}u_{kj_k}c_{kj_k}\right)}\\&\quad+\frac{1}{S}\left(\frac{\sum_{l=1}^{k}v_l\sum_{j=1}^{r_l}u_{lj}c_{lj}z_{lj}}{\sum_{j=1}^{r_l}u_{lj}c_{lj}}\right).\end{aligned}$$

The specifics are omitted.

In some circumstances, the theorem is simplified. Let's look at the outcome for $\boldsymbol{c_1}=\dots=\boldsymbol{c_k}=\boldsymbol{c},u_1=\dots=u_k=U$ and $\boldsymbol{z_1}=\dots=\boldsymbol{z_k}=\boldsymbol{z}$.

Corollary 2 Let us consider $\boldsymbol{z}=(z_1,z_2,\dots,z_r)\in Z^r,\boldsymbol{c}=(c_1,c_2,\dots,c_r)$such that$c_l>0,\sum_{l=1}^{r}c_l=1,U=(u_1,u_2,\dots,u_r),u_l>0$are the utilities attached to probabilities.$\boldsymbol{v}=(v_1,v_2,\dots,v_k)$such that$v_l>0,\sum_{l=1}^{k}v_l=1(1\leq k\leq r)$and $\boldsymbol{p}=(p_1,p_2\dots,p_r)$such that$p_l>0,\sum_{l=1}^{r}p_l=1$. Wedenote

$s=\min_{1\leq l_1,\dots,l_k\leq r}\left\{\frac{u_{l_1}c_{l_1}\dots u_{l_k}c_{l_k}}{p_{l_1}\dots p_{l_k}}\right\}$, and $S=\max_{1\leq l_1,\dots,l_k\leq r}\left\{\frac{u_{l_1}c_{l_1}\dots u_{l_k}c_{l_k}}{p_{l_1}\dots p_{l_k}}\right\}$

We define

$$\mathfrak{J}_k(g,\boldsymbol{c},\boldsymbol{v},\boldsymbol{z},U) := \frac{\sum_{l_1\ldots,l_k=1}^{r} u_{l_1}c_{l_1}\ldots u_{l_k}c_{l_k}\, g\left(\sum_{j=1}^{k} v_{j}{}_{\chi_{l_j}}\right)}{\sum_{l_1\ldots,l_k=1}^{r} u_{l_k}c_{l_k}} - g\left(\frac{\sum_{j=1}^{r} u_l c_l z_l}{\sum_{j=1}^{r} u_l c_l}\right)$$

We have the following inequalities for strongly convex function g with absolute value$m$:

$$\mathfrak{J}_k(g,\boldsymbol{c},\boldsymbol{v},\boldsymbol{z},U) - s\mathfrak{J}_k(g,\boldsymbol{p},\boldsymbol{v},\boldsymbol{z})$$

$$\geq m\frac{\sum_{j_1,\ldots,j_k=1}^{r}\left(u_{j_1}c_{j_1}\ldots u_{j_k}c_{j_k} - sp_{j_1}\ldots p_{j_k}\right)\left(\sum_{l=1}^{k} v_l z_{j_l} - \bar{z}\right)^2}{\sum_{j_1,\ldots,j_k=1}^{r} u_{j_k}c_{j_k}} + sm\left(\frac{\sum_{j=1}^{r}(p_j - u_j c_j)z_j}{\sum_{j=1}^{r} u_j c_j}\right)^2$$

And

$$S\mathfrak{J}_k(g,\boldsymbol{p},\boldsymbol{v},\boldsymbol{z}) - \mathfrak{J}_k(g,\boldsymbol{c},\boldsymbol{v},\boldsymbol{z},U)$$

$$\geq m\frac{\sum_{j_1,\ldots,j_k=1}^{r}\left(Sp_{j_1}\ldots p_{j_k} - u_{j_1}c_{j_1}\ldots u_{j_k}c_{j_k}\right)\left(\sum_{l=1}^{k} v_l z_{j_l} - \bar{z}\right)^2}{\sum_{j_1,\ldots,j_k=1}^{r} u_{j_k}c_{j_k}} + m\left(\frac{\sum_{j=1}^{r}(p_j - u_j c_j)z_j}{\sum_{j=1}^{r} u_j c_j}\right)^2,$$

where $\bar{z} = \frac{\sum_{j=1}^{r} u_j c_j z_j}{\sum_{j=1}^{r} u_j c_j}$

In case $k = 1$, we obtain:

Corollary 3 We consider $z_l \in Z, u_l > 0, c_l > 0$with $\sum_{l=1}^{r} c_l = 1$, for $l = 1,\ldots,r$ and $p_l > 0$ with $\sum_{l=1}^{r} p_l = 1$. Let

$$s = \min_{l=1,\ldots,r}\left\{\frac{u_l c_l}{p_l}\right\}, \quad S = \max_{l=1,\ldots,r}\left\{\frac{u_l c_l}{p_l}\right\}$$

We have the following inequalities for strongly convex function $g$with absolute value$m$:

$$\mathfrak{J}(g,\boldsymbol{c},\boldsymbol{z},U) - s\mathfrak{J}(g,\boldsymbol{p},\boldsymbol{z}) \geq m\frac{\sum_{j=1}^{r}(u_j c_j - sp_j)(z_j - \bar{z})^2}{\sum_{j=1}^{r} u_j c_j} + sm\left(\frac{\sum_{j=1}^{r}(p_j - u_j c_j)z_j}{\sum_{j=1}^{r} u_j c_j}\right)^2$$

And

$$S\mathfrak{J}_k(g,\boldsymbol{p},\boldsymbol{z}) - \mathfrak{J}_k(g,\boldsymbol{c},\boldsymbol{z},U) \geq m\frac{\sum_{j=1}^{r}(Sp_j - u_j c_j)(z_j - \bar{z})^2}{\sum_{j=1}^{r} u_j c_j} + m\left(\frac{\sum_{j=1}^{r}(p_j - u_j c_j)z_j}{\sum_{j=1}^{r} u_j c_j}\right)^2$$

where $\bar{z} = \frac{\sum_{j=1}^{r} u_j c_j z_j}{\sum_{j=1}^{r} u_j c_j}$

2.1 The Gamma Function Applications

A convergent improper integral is used to define the function Gamma as:

$$\Gamma(x) = \int_0^{\infty} z^{x-1}e^{-z}\mathrm{d}z, \quad x > 0$$

Weierstrass is responsible for the operational infinite product formulation for the Gamma function.

$$\Gamma(x) = \frac{e^{-\gamma x}}{x}\prod_{r=1}^{\infty}\left(1 + \frac{x}{r}\right)^{-1} e^{\frac{x}{r}}$$

This gives the following measure where the Euler-Mascheroni constant is $\gamma = 0.577216$ ....

$$\log \Gamma(x) = -\gamma x - \log x + \sum_{r=1}^{\infty}\left[\frac{x}{r} - \log\left(1 + \frac{x}{r}\right)\right] \qquad (10)$$

Proposition 3 The given result $g(x) = \log\Gamma(x^2+1) + \gamma x^2 + x \arctan x$in the function $g\colon [0,\infty) \to \mathbb{R}$,with absolute value 1 on $[0,\infty)$is strongly convex.

Proof From (10) we get

$$\log\Gamma(x^2+1) = -\gamma(x^2+1) - \log(x^2+1) + \sum_{r=1}^{\infty}\left[\frac{x^2+1}{r} - \log\left(1+\frac{x^2+1}{r}\right)\right] \tag{11}$$

We consider the function

$$f(x) = \log\Gamma(x^2+1) + \gamma x^2 + x \arctan x - x^2$$

defined on $[0,\infty)$. One has

$$f'(x) = -\frac{x}{x^2+1} + 2x\sum_{r=1}^{\infty}\left(\frac{1}{r} - \frac{1}{x^2+r+1}\right) + \arctan x - 2x$$

and

$$f''(x) = \frac{2x^2}{(x^2+1)^2} + 4x^2\sum_{r=1}^{\infty}\frac{1}{(x^2+r+1)^2} + 2\sum_{r=1}^{\infty}\left(\frac{1}{r} - \frac{1}{x^2+r+1}\right) - 2$$

The inequality

$$2\sum_{r=1}^{\infty}\left(\frac{1}{r} - \frac{1}{x^2+r+1}\right) - 2 \geq 2\sum_{r=1}^{\infty}\left(\frac{1}{r} - \frac{1}{r+1}\right) - 2 = 0$$

yields $f''(x) \geq 0$, therefore f is convex, so g with absolute value 1 on $[0,\infty)$is strongly convex. It is simple to understand:

Corollary 4 The given result $g(x) = \log\Gamma(x^2+1) + x \arctan x$ with absolute value$1-\gamma$is strongly convex on $[0,\infty)$ in the function $g\colon [0,\infty) \to \mathbb{R}$.

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