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# An econometric property of the g-index

by

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## ABSTRACT

Let $X = (x_1,...,x_N)$ and $Y = (y_1,...,y_N)$ be two decreasing vectors with positive coordinates such that $\sum_{j=1}^{N} x_j = \sum_{j=1}^{N} y_j$ (representing e.g. citation data of articles of two authors or journals with the same number of publications and the same number of citations (in total)). It is remarked that if the Lorenz curve $L(X)$ of X is above the Lorenz curve $L(Y)$ of Y, then the g-index $g(X)$ of X is larger than or equal to the g-index $g(Y)$ of Y. We indicate that this is a good property for so-called impact measures which is not shared by other impact measures such as the h-index. If $L(X) = L(Y)$ and $\sum_{j=1}^{N} x_j > \sum_{j=1}^{N} y_j$ we prove that $g(X) \geq g(Y)$. We can even show that $g(X) > g(Y)$ in case of integer values $x_i$ and $y_i$ and we also investigate this property for other impact measures.

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# I. Introduction

First we will re-introduce Lorenz concentration theory and then discuss some well-known impact measures.

I.1 Concentration theory: discrete Lorenz curve

Lorenz concentration theory was invented by Lorenz in 1905 (Lorenz (1905)) and is used to measure the concentration or inequality between a set of positive numbers (e.g. the salaries of employees). Lorenz concentration theory has also found its way into informetrics e.g. to measure the inequality in citations of papers of an author or to measure the inequality in productivity of authors (i.e. in the number of papers of these authors) – see basically Egghe (2005), Chapter IV and many references therein. The application of Lorenz concentration theory in informetrics is no surprise since – as in econometrics – many (if not all) source-item distributions are very skew: many sources have few items and few sources have many items – see Egghe (2005), Chapter I and IV where these inequalities are described via the laws of Lotka and Zipf (but we will not use these laws in this paper).

Let us, briefly, describe Lorenz concentration theory. Let $X = (x_1,...,x_N)$ be a decreasing vector with positive coordinates $x_i, i = 1,...,N$. The Lorenz curve $L(X)$ of X is the polygonal curve connecting $(0,0)$ with the points $\left(\frac{i}{N}, \sum_{j=1}^{i} a_j\right)$ $i = 1,...,N$ where

$$a_i = \frac{x_i}{\sum_{j=1}^{N} x_j} \tag{1}$$

Note that for $i = N$ we have $(1,1)$ as end point of $L(X)$. Let X and $Y = (y_1,...,y_N)$ be two such vectors. We say that X is more concentrated than Y if $L(X) > L(Y)$. We also say that the coordinates of X are more unequal than the ones of Y.

That Lorenz curves are the right tool to measure concentration or inequality is seen by the result of Muirhead (1903) stating[2] that $L(X) > L(Y)$ if and only if X is constructed, starting from Y, by a finite applications of elementary transfers. An elementary transfer (e.g. on $Y = (y_1,...,y_N)$) changes Y into the vector

$$\left(y_1,...,y_i + h,...,y_j - h,...,y_N\right) \tag{2}$$

where $1 \le i < j \le N$ and $h > 0$. Since Y is decreasing, this means, in econometric terms that "we take away $(h > 0)$ from the poor (j) and give it to the rich (i)" which indeed yields a more unequal (concentrated) situation, which is applied repeatedly to yield X out of Y.

For further use, we also note the following. If $L(X) = L(Y)$ we have that $X = aY$ for a certain value $a > 0$, namely (use (1))

$$a = \frac{\sum_{j=1}^{N} x_j}{\sum_{j=1}^{N} y_j} \tag{3}$$

Indeed, denote $a_i$ for X as in (1) and denote

$$b_i = \frac{y_i}{\sum_{j=1}^{N} y_j} \tag{4}$$

, $i = 1,...,N$ for Y. Since $L(X) = L(Y)$ we have $a_1 = b_1$, $a_1 + a_2 = b_1 + b_2,...,\ a_1 + ... + a_N = b_1 + ... + b_N (= 1)$ so that $a_i = b_i$ for all $i = 1,...,N$ from which $X = aY$ with a as in (3) follows.

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[2] Muirhead's theorem was published in 1903, two years before Lorenz introduced the Lorenz curve (Lorenz (1905)). Muirhead's theorem hence did not use the Lorenz terminology but a combinatorial variant of it. Here we present the Lorenz variant of Muirhead's theorem. Muirhead's theorem can also be found in Hardy, Littlewood and Pólya (1952) and in Egghe and Rousseau (1991).

## I.2 Impact measures

This theory will now be linked with a set of new impact measures, defined only since 2005 onwards. Impact measures are defined on the same type of vectors X and Y as described above. Usually we now interpret the coordinates as the number of citations to N papers of an author or a journal X or Y, but this is not really necessary. In the above interpretation, impact measures then measure the overall visibility, impact,… of a journal or of an author's career. Let us briefly re-introduce the impact measures that we will use in this paper.

It all started with the introduction of the Hirsch index (or h-index): Hirsch (2005). Let the vector $X = (x_1,...,x_N)$ be as above: a decreasing sequence of N positive numbers. Then X has h-index h if $r = h$ is the largest rank such that each paper on rank $1,...,h$ has h or more citations. As mentioned in many papers, h is a unique index that combines quantity (number of papers) with quality (or rather visibility) (number of citations to these papers) and it is a robust measure in the sense that it is not influenced by a set of lowly cited papers nor by the exact number of citations to the first h papers in the ranking in X (the so-called h-core) (see Braun, Glänzel and Schubert (2006), Egghe (2006)). However, the latter property is considered as a disadvantage of the h-index: once a paper is in the h-core, it does not matter how many citations (above h) it received or will receive: this does not influence the value of h. We agree with a measure that does not take into account some (or several) lowly cited papers as long as it takes into account the number of citations to the highly cited papers. Therefore, Egghe introduced in 2006, see Egghe (2006), an improvement of the h-index: the g-index.

Note that the papers in the h-core, together, have at least $h^2$ citations. Now the g-index is the largest rank $r = g$ such that all papers on rank $1,...,g$, together, have at least $g^2$ citations. Obviously $g \geq h$ but that is not an important issue here. It has been recognized that the g-index has more discriminatory power than the h-index (Schreiber (2008a,b), Tol (2008)).

The R-index, introduced in Jin, Liang, Rousseau and Egghe (2007), serves the same goal as the g-index on the improvement of the h-index although it uses the h-index in its definition:

$$R = \sqrt{\sum_{i=1}^{h} x_i} \qquad (5)$$

where $X = (x_1,...,x_N)$ is as above and h is the h-index of X. Note again, as in the case of the g-index, that the actual $x_i$-values (the highest ones) are effectively used.

Kosmulski's $h^{(2)}$-index is similar to the h-index but now one requires $r = h^{(2)}$ to be the largest rank such that each paper on rank $1,...,h^{(2)}$ has $\left(h^{(2)}\right)^2$ or more citations – see Kosmulski (2006). It was introduced to save time in calculating impact measures: $h^{(2)}$ is much smaller than h since one requires (at least) the square of the rank as the number of citations (see below for the impact measure values of this author).

Since $g \geq h$ it might be interesting to apply Kosmulski's idea also to the g-index. Note that the first $h^{(2)}$ papers, together, have, at least $\left(h^{(2)}\right)^3$ citations. We now define $g^{(2)}$ as the highest rank such that the first $g^{(2)}$ articles, together, have, at least $\left(g^{(2)}\right)^3$ citations. The $g^{(2)}$ impact measure is new and is introduced here for the first time.

Table 1 gives the citation data of this author, based on the Web of Science on July 24, 2008. We only present the first 23 papers since we do not need higher ranks. As needed for the calculation of the g-index, we also present the cumulative scores and the squares of the ranks.

Table 1. Paper-Citation data of L. Egghe (dd. July 24, 2008)
(r = rank of the paper, # = number of citations,
Σ# = cumulative number of citations)

| r | | # | $r^2$ | | Σ# |
|---|---|---|---|---|---|
| 1 | | 56 | 1 | | 56 |
| 2 | | 44 | 4 | | 100 |
| 3 | | 43 | 9 | | 143 |
| 4 | | 36 | 16 | | 179 |
| 5 | | 27 | 25 | | 206 |
| 6 | | 22 | 36 | | 228 |
| 7 | | 21 | 49 | | 249 |
| 8 | | 20 | 64 | | 269 |
| 9 | | 18 | 81 | | 287 |
| 10 | | 17 | 100 | | 304 |
| 11 | | 17 | 121 | | 321 |
| 12 | | 16 | 144 | | 336 |
| 13 | | 16 | 169 | | 353 |
| 14 | | 16 | 196 | | 369 |
| 15 | | 16 | 225 | | 385 |
| 16 | ≤ | 16 | 256 | | 401 |
| 17 | > | 15 | 289 | | 416 |
| 18 | | 15 | 324 | | 431 |
| 19 | | 14 | 361 | | 445 |
| 20 | | 14 | 400 | | 459 |
| 21 | | 14 | 441 | | 473 |
| 22 | | 13 | 484 | ≤ | 486 |
| 23 | | 13 | 529 | > | 499 |

It is clear from the inequality signs in the Table that $h = 16$ and $g = 22$. From this we have R = square root of the first 16 #-values = $\sqrt{401} = 20.025$. Since $27 > 5^2$ and $22 < 6^2$ we have $h^{(2)} = 5$. Similarly $228 > 6^3$ and $249 < 7^3$ so that $g^{(2)} = 6$.

It is not the purpose of this article to compare the advantages and disadvantages of all these impact measures. In this paper we will use these measures in the connection of Lorenz concentration theory. This is done in the next section.

# II. Lorenz curves and impact measures

## II.1 Properties of good impact measures: the concentration principle

It is not clear what properties impact measures must have to be “good” impact measures. In fact one can formulate many desirable properties but where one can show that no measure can satisfy them all. Also some “desirable” properties even contradict each other ! For more on these aspects, see Woeginger (2008a,b), Marchant (2008a,b).

Here we will focus on one – as we think – desirable property: the concentration aspect of citations. To give an intuitive feeling of what we mean by this, the following example. To our feeling it is better to have one article that receives 100 citations and 9 articles with no citations than having 10 articles each receiving 10 citations. Even more philosophical: it is better to write one highly cited paper than to write 10 averagely cited papers. We feel that this principle is non-controversial and worth studying: an impact measure should give a higher value to the former case than to the latter one. This vision is shared in Lehmann, Jackson and Lautrup (2008) (p. 370 and 375) and Leydesdorff (2008) (conclusions section).

Formulated more formally: Let $X = (x_1, \ldots, x_N)$ present the citation vector where there are N articles (e.g. of an author or a journal) and where $x_i$ is the number of citations to the $i^{th}$ article, where we have arranged the articles in decreasing order of the number of citations. Let $1 \le i < j \le N$ such that $x_i \ge x_j$. Let us change this citation situation into the following: take away one citation from the $j^{th}$ paper and “add” it to the $i^{th}$ paper. So we have now the vector Y

$$Y = (x_1, \ldots, x_i + 1, \ldots, x_j - 1, \ldots, x_N) \tag{6}$$

In view of the above, we want that an impact measure gives a higher value for situation Y than for situation X. By extension and using Muirhead’s theorem we can require that, if vectors X and Y are such that $\sum_{j=1}^{N} x_j = \sum_{j=1}^{N} y_j$ and $L(Y) > L(X)$, then we want that our impact measure gives a higher ($\ge$) value for situation Y than for situation X. Let us call this the <u>concentration principle</u>.

In other words: if we have two authors with the same number of papers and with the same number of citations in total, we say that this author has a greater impact if its Lorenz curve is the highest.

The most important index, the h-index does <u>not</u> satisfy this property. Indeed take $X = (5,5,5,5,5)$ and $Y = (6,5,5,5,4)$. So Y is of the form (6) via one elementary transfer of 1 citation from the fifth paper to the first one. It is clear that $h(Y) = 4 < h(X) = 5$ so that the h-index violates this concentration principle. The same example gives for R: $R(X) = \sqrt{25} = 5 > R(Y) = \sqrt{21}$, hence R does not satisfy this principle either. The same for Kosmulski's measure $h^{(2)}$: take $X = (4,4)$ and $Y = (5,3)$. Then $h^{(2)}(X) = 2 > h^{(2)}(Y) = 1$.

That the g-index satisfies the concentration principle is a simple consequence of Muirhead's theorem.

<u>**Theorem**</u>: The g-index satisfies the concentration principle.

<u>**Proof**</u>: Using Muirhead's theorem it satisfies to prove this for one elementary transfer (6). By construction of the g-index we have that, up to the $(i-1)^{th}$ paper, there is no change (we have the same cumulative number of citations) and that from the $i^{th}$ paper up to the $(j-1)^{th}$ paper, we have one more citation. Finally, from the $j^{th}$ paper up to the $N^{th}$ we have the same number of citations. Hence in no way, the g-index can decrease, hence $g(Y) \geq g(X)$. □

<u>**Note**</u>: In Woeginger (2008c), a private communication of Egghe is acknowledged mentioning the above theorem. In Woeginger (2008c), even an axiomatic characterization of the g-index is given, where $g(Y) \geq g(X)$ in case (6) is one of the axioms.

The same argument shows that also $g^{(2)}$ satisfies the concentration principle and the same is true if other exponents are used.

<u>II.2 Properties of good impact measures: the quantity principle</u>

It is clear that, in general, if $L(X)$ and $L(Y)$ intersect in an abscissa different from 0 and 1 that no conclusions on the values $g(X)$ and $g(Y)$ (and similar for $g^{(2)}$) can be drawn. But what if $L(X) = L(Y)$ ?

We feel that it is logical, if $L(X) = L(Y)$ (i.e. if the concentration of citations over papers is the same) that, if $\sum_{j=1}^{N} x_j > \sum_{j=1}^{N} y_j$, the impact measure of X should be larger ($\geq$) than the value on Y. Let us call this the <u>quantity principle</u>. This principle is easily satisfied by our impact measures under study. Indeed, by the above, $a_i = b_i$ for all $i = 1,\ldots,N$. If $\sum_{j=1}^{N} x_j > \sum_{j=1}^{N} y_j$ we hence have

$$a_i\left(\sum_{j=1}^{N} x_j\right) > b_i\left(\sum_{j=1}^{N} y_i\right)$$

for all $i = 1,\ldots,N$. By (1) and (6) we have that $x_i > y_i$, for all $i = 1,\ldots,N$. It is now clear that all our impact measures give a higher ($\geq$) value on X than on Y.

**<u>Proposition</u>**: If $L(X) = L(Y)$ and if $\sum_{j=1}^{N} x_j > \sum_{j=1}^{N} y_j$, then $h(X) \geq h(Y)$, $g(X) \geq g(Y)$, $R(X) \geq R(Y)$, $h^{(2)}(X) \geq h^{(2)}(Y)$ and $g^{(2)}(X) \geq g^{(2)}(Y)$.

It is clear that equality still is possible if we allow for non-entire values of $y_j$. Example: $X = (12,12,12,12,12,12,12,9,3,3)$ and $Y = 0.99X$ then (e.g. for g) $g(X) = g(Y) = 9$. For R we can improve the Proposition: we always have $R(X) > R(Y)$ under the conditions of the Proposition. This follows from the proven fact that $x_i > y_i$ for all $i = 1,\ldots,N$ and $h(X) \geq h(Y)$.

In practice, the coordinates of X and Y are entire numbers. In this case we have the following improvement of the Proposition above.

**Proposition**: If $x_i, y_i \neq 0$ for every $i = 1,\dots,N$, $x_i, y_i \in \mathbb{N}$ for every $i = 1,\dots,N$, $y_N = 1$, then $L(X) = L(Y)$, $\sum_{j=1}^{N} x_j > \sum_{j=1}^{N} y_j$ imply $g(X) > g(Y)$ if $g(X) \neq 1$.

**Proof**: Since X and Y have entire coordinates and since $y_N = 1$ we have that there exists a number $a \in \mathbb{N}$, $a \geq 2$ such that $X = aY$. By definition of $g(X)$ we have

$$\sum_{j=1}^{g(X)} x_j \geq g(X)^2 \tag{7}$$

$$\sum_{j=1}^{g(X)+1} x_j < (g(X)+1)^2 \tag{8}$$

We have proved that $g(X) > g(Y)$ if we can show that

$$\sum_{j=1}^{g(X)} y_j < g(X)^2 \tag{9}$$

But

$$\sum_{j=1}^{g(X)} y_j = \sum_{j=1}^{g(X)} \frac{1}{a} x_j$$

$$\leq \frac{1}{2} \sum_{j=1}^{g(X)} x_j$$

$$= \frac{1}{2} \sum_{j=1}^{g(X)+1} x_j - \frac{x_{g(X)+1}}{2}$$

$$< \frac{1}{2}(g(X)+1)^2 - \frac{x_{g(X)+1}}{2}$$

$$= \frac{g(X)^2}{2} + g(X) + \frac{1}{2} - \frac{x_{g(X)+1}}{2}$$

Since $x_{g(X)+1} \neq 0$ and since it is a natural number we have that $x_{g(X)+1} \geq 1$. Hence

$$\sum_{j=1}^{g(X)} y_j < \frac{g(X)^2}{2} + g(X) \leq g(X)^2$$

if and only if $g(X) \geq 2$. Since $g(X) \neq 1$ and $g(X) \in \mathbb{N}$, this is true. Hence (9) is proved and hence $g(Y) < g(X)$. □

Note that we need the assumptions on the coordinates of X and Y. If the coordinates can be zero, then the conclusion of the above Proposition is false: take $X = (2,0,0)$ and $Y = \frac{1}{2}X$. Then $L(X) = L(Y)$, $\sum_{j=1}^{3} x_j > \sum_{j=1}^{3} y_j$ but $g(X) = g(Y) = 1$. We also need $g(X) \neq 1$ in the above Proposition: for $X = (2)$ (hence $N = 1$), take $Y = (1) = \frac{1}{2}X$. Now $L(X) = L(Y)$, $\sum x_j = x_1 = 2 > \sum y_j = y_1 = 1$ but $g(X) = g(Y) = 1$.

**<u>Note</u>**: Under the conditions of the above Proposition we have

$$g(X) \neq 1 \Leftrightarrow \dim X \neq 1$$

($\dim X =$ dimension of $X = N$)

**<u>Proof</u>**:

(i) Let $\dim X \neq 1$. Since $X = aY$ for a certain $a \in \mathbb{N}$, $a \geq 2$ and since $y_2 = 1$ we have that $x_2 \geq 2$ and hence $x_1 \geq x_2 \geq 2$, hence $g(X) \geq 2$, hence $g(X) \neq 1$.

(ii) Conversely it is trivial that $g(X) \neq 1$ implies $\dim X \neq 1$. □

For $g^{(2)}$ we have the following result.

**Proposition**: Under the same conditions as in the previous Proposition we have that

$$g^{(2)}(X) > g^{(2)}(Y) \ \text{ if } \ g^{(2)}(X) \geq 4.$$

**Proof**: As in the proof of the above Proposition we have that there exists a number $a \in \mathbb{N}$, $a \geq 2$ such that $X = aY$. By definition of $g^{(2)}(X)$ we have

$$\sum_{j=1}^{g^{(2)}(X)} x_j \geq g^{(2)}(X)^3 \tag{10}$$

$$\sum_{j=1}^{g^{(2)}(X)+1} x_j < \left(g^{(2)}(X)+1\right)^3 \tag{11}$$

In order to show that $g^{(2)}(Y) < g^{(2)}(X)$ we have to prove that

$$\sum_{j=1}^{g^{(2)}(X)} y_j < g^{(2)}(X)^3 \tag{12}$$

But

$$\sum_{j=1}^{g^{(2)}(X)} y_j = \sum_{j=1}^{g^{(2)}(X)} \frac{1}{a} x_j$$

$$\leq \frac{1}{2} \sum_{j=1}^{g^{(2)}(X)} x_j$$

$$= \frac{1}{2} \sum_{j=1}^{g^{(2)}(X)+1} x_j - \frac{x_{g^{(2)}(X)+1}}{2}$$

$$< \frac{1}{2}\left(g^{(2)}(X)+1\right)^3 - \frac{x_{g^{(2)}(X)+1}}{2}$$

$$= \frac{1}{2}g^{(2)}(X)^3 + \frac{3}{2}g^{(2)}(X)^2 + \frac{3}{2}g^{(2)}(X) + \frac{1}{2} - \frac{x_{g^{(2)}(X)+1}}{2}$$

But $x_{g^{(2)}(X)+1} \geq 1$ since it is not zero and since it is a natural number. Hence

$$\sum_{j=1}^{g^{(2)}(X)} y_j < \frac{1}{2}g^{(2)}(X)^3 + \frac{3}{2}g^{(2)}(X)^2 + \frac{3}{2}g^{(2)}(X)$$

$$\leq g^{(2)}(X)^3 \tag{13}$$

if and only if

$$g^{(2)}(X)^2 \geq 3g^{(2)}(X) + 3$$

But the quadratic equation

$$x^2 - 3x - 3 = 0$$

has a root $x = \frac{3+\sqrt{21}}{2} = 3.79\ldots$. Hence, for $x \geq 4$ we have that (13) is valid and hence (12) is valid. □

The next examples show that the condition $g^{(2)}(X) \geq 4$ is necessary.

(i) <u>Case of $g^{(2)}(X) = 1$</u>

Take $N = 1$, $X = (2)$, $Y = (1)$. Hence $L(X) = L(Y)$, $\sum x_j = x_1 = 2 > \sum y_j = y_1 = 1$ but $g^{(2)}(X) = g^{(2)}(Y) = 1$.

(ii) <u>Case of $g^{(2)}(X) = 2$</u>

Take $N = 3$, $X = (8,8,2)$, $Y = (4,4,1)$. Hence $L(X) = L(Y)$, $\sum x_j = 18 > \sum y_j = 9$ but $g^{(2)}(X) = g^{(2)}(Y) = 2$.

(iii) <u>Case of $g^{(2)}(X) = 3$</u>

Take $N = 4$, $X = (20,20,16,2)$, $Y = (10,10,8,1)$. Hence $L(X) = L(Y)$, $\sum x_j = 58 > \sum y_j = 29$ but $g^{(2)}(X) = g^{(2)}(Y) = 3$ as is readily seen.

# <u>III. Conclusions</u>

In this paper we have highlighted that compatibility with the Lorenz concentration order is a desirable feature to have for an impact measure. We have shown that, essentially, only the g-type indices (such as g and $g^{(2)}$) satisfy this property.

We have also investigated the property $L(X) = L(Y)$ and $\sum_{j=1}^{N} x_j > \sum_{j=1}^{N} y_j$. All investigated measures give a larger $(\geq)$ value on X than on Y. For R we even have a strict inequality and for the g-type indices we also have a strict inequality under certain weak conditions.

We feel that this "econometric" property of g-type indices is remarkable and its use should be further investigated.

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