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A proposal of poverty measures based on the Bonferroni inequality index

1. INTRODUCTION

The construction of summary indices for quantifying the degree of poverty is still a topical subject. Many are the possible applications, such as the evaluation of the government financial manoeuvres or the comparison between the economic politics of different countries. To make it possible for these indices to catch and discriminate the various social realities, we periodically have to update them by pointing out the evolution of the phenomenon.

Even though the debate on poverty measurement, which began with Sen's (1976) pioneering paper, has given rise to conspicuous scientific production on the subject, nowadays there is not yet a single measure that could be considered perfect as recently stressed by Kakwani (1999, p. 627).

In accordance with Sen's (1976) approach, which is followed by a number of scholars [e.g. Thon (1979), Kakwani (1980), P.K. Sen (1986), Dagum *et al.* (1988, 1992)], a poverty measure must jointly take into account factors such as the diffusion, the intensity, the inequality among the poor, and other ones. For a clear and updated

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account of the developments on poverty measurement see, e.g., Foster and Sen (1997, pp. 164-194).

This paper fits into the aforesaid framework and aims at improving the poverty measurement by introducing the Bonferroni inequality index (B) within a poverty measure since B is particularly sensitive to low levels of income distribution (Giorgi and Mondani, 1995) and also has the same properties as the Gini concentration ratio (R). For what concerns some points of view on R sensitivity see Atkinson (1970), Dagum (1986) and Aaberge (2000), among the others. The fact that B is not very well-known may be attributed both to the prominence of R in literature, and to Gini's opposition to the other inequality indices (see Benedetti, 1980, p. 27; Giorgi, 1996, p. 12). For further information regarding B, also see Piesch (1975), Nygård and Sandström (1981), Giorgi and Mondani (1994).

Our paper is articulated as follows: in Section 2 some of the most well-known poverty summary measures are recalled and in Section 3 the Bonferroni index is reviewed. After having shown how the peculiarities of B could concern the study of poverty (Section 4), the Bonferroni inequality index is used to propose three new measures (Section 5). A remark on their peculiarities ends the article (Section 6).

2. Poverty measures

The evolution of contemporary society has determined an increase in the individual's availability of goods and services, some of which have changed people's life-style so much that they have become necessary to be completely integrated in the community. In this sense the concept of poverty must be linked not only to primary human needs but also to the standard of living and to the cultural models of each country. When a poverty measure has to be constructed, the first problems we face are the choice of a suitable variable and a threshold (z) below which a unit can be considered as poor.

The lack of statistical data concerning non-economic attributes often obliges scholars to consider only the most detectable variables, such as expenditure or income. As we want to focus on income inequality, we apply to income, whereas as far as the criteria for assessing the poverty lines and the equivalence scales are concerned see Dagum *et al.* (1988), Trivellato (1998), Cowell and Mercader (1999).

The approach given by the Nobel Prize winner for Economics Amartya Sen is also called "axiomatic" as in order to justify the summary poverty measure, the fulfilment of some basic axioms is demanded. To obtain the Sen index (S) the complete procedure is developed in his famous article published in 1976, but here we only show the steps we are interested in.

2.1. The Sen index of poverty

Let us consider an income distribution x, in a non-decreasing order, which concerns n units: $0 \leq x_1 \leq x_2 \leq \ldots \leq x_n$. Given the poverty line z, the number of poor is $q = \sum_{i=1}^{n} U\{x_i < z\}$, where U denotes the indicator function. Only with regard to the q poor units, the *poverty-gap* is the nonnegative difference $g_i = z - x_i$. Furthermore $m_p = \frac{1}{q}\sum_{i=1}^{q} x_i$ is the income mean among the poor and $m_i = \frac{1}{i}\sum_{j=1}^{i} x_j$ is the partial mean of the i lower incomes $(i = 1, \ldots, q-1)$.

Sen (1976), after having introduced an axiomatic frame, proposes the construction of the summary index S as an increasing function of the following arguments (1), (2) and (3) satisfying the axioms of monotonicity (A), transfer (B), and the poor proportion (C), respectively:

$$I = \frac{\sum_{i=1}^{q}(z - x_i)}{qz} = \frac{\bar{g}}{z}, \quad I \in [0, 1] \quad \text{(poverty-gap ratio)} \tag{1}$$

$$R_p = 1 - \frac{2\sum_{i=1}^{q-1} i m_i}{q(q-1)m_p}, \quad R_p \in [0, 1] \quad \text{(Gini index among the poor)} \tag{2}$$

$$H = \frac{q}{n}, \quad H \in [0, 1] \quad \text{(head-count ratio)}. \tag{3}$$

The summary measure S is defined as a normalized weighted sum of the poverty-gaps g_i:

$$S = A(z, x)\sum_{i=1}^{q} g_i v_i(z, x), \tag{4}$$

where $v_i(z, x)$ are nonnegative weights and $A(z, x)$ is the normalizing term. To assess S uniquely, two more axioms are required (Sen, 1976, pp. 221-223):

Axiom D (ordinal rank weights). *The weight $v_i(z, x)$ related to g_i is the rank of x_i in the non-increasing income order of the poor. Expressed by formula:*

$$v_i(z, x) = q + 1 - i, \ i = 1, \dots, q . \tag{5}$$

Axiom E (normalized poverty value). *If all the poor receive the same income, the index S will be equal to the product of the head-count ratio H and the poverty-gap ratio I.*

On the basis of the above-mentioned axioms (A,B,C,D,E), the Sen index of poverty (Sen, 1976, Theorem 1) results as being:

$$S = H\left\{1 - (1 - I)\left[1 - R_p\left(\frac{q}{q+1}\right)\right]\right\}, \quad S \in [0, 1] . \tag{6}$$

S is a normalized index and the extreme values of its range are obtained when there are no poor and when all the n units have zero income, respectively. The great limit of the Sen index is that it is not sensitive to what happens above the poverty line z. It is clear, in fact, that S does not take into consideration either the income inequality changes for the non-poor or the economic distance between the two subgroups discriminated by z.

2.2. *Some other indices of poverty*

With the aim of improving the analytical approach to poverty quantification, Dagum, Lemmi and Cannari (1988) have proposed a new measure (P_1) capable of evaluating the effect of relative deprivation that arises in an individual when he compares his income to all the others.

In addition to components (1), (2) and (3) also included in S, it has been taken into account the Gini concentration ratio among the non-poor (R_{np}) and the relative economic distance (D) between the two subgroups (Dagum, 1980). The index P_1 is

$$P_1 = HI[1 + (1 - I)R^*] \tag{7}$$

where

$$R^{\star} = w_1(H)R_p + w_2(H)R_{np} + w_3(H)D\,;$$
$$\sum_{i=1}^{3} w_i(H) = 1; \quad w_i(H) > 0, \quad i = 1, 2, 3\,.$$

For further information about P_1, see Dagum, Lemmi and Cannari (1988, pp. 87-91).

Afterwards, using the same factors constituting P_1, Dagum, Gambassi and Lemmi (1992) have introduced another poverty measure:

$$P_2 = H(I + D + R_p + \alpha \mid R_p - \beta R_{np} \mid)/3; \; 0 < (\alpha, \beta) < 1\,. \qquad (8)$$

The basic idea for P_2 is to evaluate, by a suitable comparison between the income inequality among the poor and among the non-poor, if the observed community stands chances of social mobility. This subject plays an important role since the poverty perception can change according to whether a society offers the same opportunities to everyone or not. In a country with an acceptable degree of social mobility, for instance, we expect that $R_{np} > R_p$ at least because the non-poor incomes vary in the range $[z, \infty)$, certainly wider than the range $(0, z)$ of the poor incomes. If $R_p = \beta R_{np}$, the difference between the two subgroups' income inequality does not affect the value of P_2. It means that β explains what level of the ratio of R_p to R_{np} we could agree with. In all the other cases the absolute value makes the total inequality increase compared to R_p. The constant α gives a suitable weight to the factor of adjustment. In a private correspondence Dagum suggested to us, on the basis of his empirical studies on the topic, that it is reasonable to put $\alpha = 0.6$ and $\beta = 0.4$.

3. The Bonferroni inequality index

Referring to the income distribution x we have introduced in Section 2.1, and denoting with m the income mean and with m_i the partial mean of the i lower incomes ($i = 1, \ldots, n-1$), the *Bonferroni index* is

$$B_n = \frac{1}{n-1}\sum_{i=1}^{n-1}\frac{m - m_i}{m} = 1 - \frac{1}{n-1}\sum_{i=1}^{n-1}\frac{m_i}{m}, \; B_n \in [0, 1]\,. \qquad (9)$$

It fulfils the following properties:

I. $B_n = 0$ if and only if the n units have the same income.

II. $B_n = 1$ if and only if the total income belongs to one unit.

III. B_n satisfies the Pigou-Dalton transfer principle.

IV. B_n is invariant for changes in the income scale.

V. If there is an increment of h in all the n units' income, with $h > 0$, the Bonferroni index decreases and tends to 0 for large h. This replacement, in fact, does not change the difference $m - m_i$ between the mean and the partial means, but makes the denominator increase. This operation changes (9) in

$$B_n = \frac{1}{n-1} \sum_{i=1}^{n-1} \frac{m - m_i}{m + h}$$

hence

$$\lim_{h \to \infty} \frac{1}{n-1} \sum_{i=1}^{n-1} \frac{m - m_i}{m + h} = 0 \,.$$

VI. Given $a_i = (m - m_i)/m$, with $i = 1, \dots, n-1$, the Bonferroni index (9) is the mean of the relative differences a_i, that is

$$B_n = \frac{1}{n-1} \sum_{i=1}^{n-1} a_i \,.$$

Instead, the Gini concentration ratio can be formulated as a weighted mean of a_i with weights equal to the ranks i:

$$R_n = \frac{\sum_{i=1}^{n-1} i(m - m_i)}{m \sum_{i=1}^{n-1} i} = \frac{\sum_{i=1}^{n-1} i a_i}{\sum_{i=1}^{n-1} i} \,.$$

If $r_i = i / \sum_{i=1}^{n-1} i$, $b_i = 1/(n-1)$, we can write: $R_n = \sum_{i=1}^{n-1} a_i r_i$ and $B_n = \sum_{i=1}^{n-1} a_i b_i$.

When i increases, the relative difference a_i decreases, so the low values of a_i are more weighted in R_n rather than in B_n (the opposite happens for the high values of a_i). It means that $B_n \geq R_n$ where the sign of equality is obtained only in the extreme cases $B_n = R_n = 1$ ($a_i = 1, \forall i$) and $B_n = R_n = 0$ ($a_i = 0, \forall i = 1, \ldots, n$).

From property VI, it can be easily deduced that the Bonferroni index is more sensitive than the Gini index to low levels of income distribution. Both these inequality indices are consistent with the Pigou-Dalton principle which means that they increase if there is a transfer of income from a poorer to a richer individual.

In the following Section we show that B_n, contrary to R_n, satisfies the *diminishing transfer principle* (see Mehran, 1976; Nygård and Sandström, 1981, Section 7.4; Aaberge, 2000, p. 649) also known in literature as the *principle of positional transfer sensitivity* (see Zoli, 1999). To clear up this point, ΔR_n only depends on the distance between the ranks of the donor and of the recipient, whereas ΔB_n is also sensitive to their exact positions in the income ordering. In our opinion, this peculiarity makes the Bonferroni index particularly suitable for being used within a summary poverty measure.

4. A COMPARISON BETWEEN THE SENSITIVITY TO TRANSFERS OF B AND R

Now let us formalize what we have just introduced in the few lines above. The Pigou-Dalton principle demands that, given two observations $x_i \leq x_j$, if there is a positive transfer δ from x_i to x_j, such that x_i and x_j are replaced in the income distribution by $x_i - \delta$ and $x_j + \delta$ (with $0 < \delta < x_i$), the inequality index has to increase. In this Section we focus on the comparison between the sensitivity to income transfers of the Gini concentration ratio and the Bonferroni index. For doing that we have to distinguish two cases according to whether the transfer changes the income ordering or not.

i) Rank-preserving transfer

This circumstance arises when $0 < \delta < \min\{(x_i - x_{i-1}); (x_{j+1} - x_j)\}$. The starting income order of the n units

$$x_1 \leq \ldots \leq x_{i-1} \leq x_i \leq x_{i+1} \leq \ldots \leq x_{j-1} \leq x_j \leq x_{j+1} \leq \ldots \leq x_n \,,$$

becomes

$$x_1 \leq \ldots \leq x_{i-1} \leq x_i - \delta \leq x_{i+1} \leq \ldots \leq x_{j-1} \leq x_j + \delta \leq x_{j+1} \leq \ldots \leq x_n \,.$$

The increase of R_n can be computed (Nygård and Sandström, 1981, p. 275) by

$$\Delta R_n = \frac{2\delta(j-i)}{n(n-1)m}. \qquad (10)$$

Therefore the Gini concentration ratio is sensitive to transfers in the same way whether they take place at the top of the distribution or they concern the low incomes only if the difference between the ranks of the donor and of the recipient is the same.

In this sense, the weighting system of the Bonferroni index gives rise to a behaviour pattern that conceptually has to be preferred. In fact if a unit, that in the non-decreasing income order occupies the position i, transfers the quantity δ to the one with rank j ($j > i$), the change in B_n (Nygård and Sandström, 1981, p. 276) is

$$\Delta B_n = \frac{\delta}{(n-1)m} \sum_{t=i}^{j-1} \frac{1}{t}, \qquad (11)$$

that strictly depends on the ranks related to (x_i, x_j) and not only on their difference.

In other words, for a fixed distance $(j-i)$ between the ranks of the two units involved in the transfer, R_n has a constant variation while the Bonferroni index increases as much as poorer the donor is.

ii) Non rank-preserving transfer

When the transferred quantity δ assumes a value

$$\max\{(x_i - x_{i-1}); (x_{j+1} - x_j)\} < \delta < x_i,$$

there is a change in the income ordering of the n units. Let us suppose that the quantity $x_i - \delta$ is in the position $i - k_1$, whereas $x_j + \delta$ takes the rank $j + k_2$. In this more general case it can be demonstrated that the Gini and the Bonferroni inequality indices have an increase which is equal to

$$\Delta R_n = \frac{2\{(j-i)\delta + \sum_{t=i-k_1}^{i-1} [x_t - (x_i - \delta)] + \sum_{t=j+1}^{j+k_2} [(x_j + \delta) - x_t]\}}{n(n-1)m}; \qquad (12)$$

$$\Delta B_n = \frac{\delta \sum_{t=i}^{j-1} \frac{1}{t} + \sum_{t=i-k_1}^{i-1} \frac{[x_t - (x_i - \delta)]}{t} + \sum_{t=j+1}^{j+k_2} \frac{[(x_j + \delta) - x_t]}{t-1}}{(n-1)m}. \qquad (13)$$

Also in this circumstance comes out that the Bonferroni index, if compared to R_n, results as giving "more weights to transfers among the poor" (Nygård and Sandström, 1981, p. 276).

5. A PROPOSAL OF NEW POVERTY MEASURES

In this Section the poverty measures (6), (7) and (8) are improved by replacing the Gini index with the Bonferroni one. We have said that S is the only index which satisfies the axioms A-B-C-D-E but since we want to use the index B rather than R, it will be necessary to revise the axiomatic approach given in Section 2.1.

In particular we change axiom D taking into account that if the individual's position in the income ordering is lower, his perception of poverty becomes greater. To stress this relation we consider new $v_i(z, x)$, related to the poverty-gaps g_i, that give more weight to the non-increasing income order of the poor.

Axiom F (ordinal rank weights revised). *The weights being associated with the q poverty-gaps are*

$$v_i(z, x) = \xi_i = \sum_{j=i}^{q} \frac{1}{j}, \qquad i = 1, \dots, q. \tag{14}$$

THEOREM 1. *The only index satisfying axioms* A-B-C-E-F *is:*

$$S_B = H \left\{ 1 - (1 - I) \left[1 - B_p \left(\frac{q-1}{q} \right) \right] \right\}, \tag{15}$$

where B_p is the Bonferroni inequality index (9) *computed among the poor.*

Proof: Bearing in mind (4) and (14),

$$\begin{aligned} A(z, x) \sum_{i=1}^{q} g_i v_i(z, x) &= A(z, x) \sum_{i=1}^{q} (z - x_i) \xi_i \\ &= A(z, x) \left[zq - \sum_{i=1}^{q} (x_i \xi_i) \right], \end{aligned} \tag{16}$$

since $q = \sum_{i=1}^{q} \xi_i$. Adjusting the B_p expression, we have:

$$B_p = \frac{q}{q-1}\left[1 - \frac{1}{qm_p}\sum_{i=1}^{q}(x_i \xi_i)\right]$$

from which

$$\sum_{i=1}^{q}(x_i \xi_i) = qm_p - m_p(q-1)B_p\,, \tag{17}$$

denoting with m_p the income mean among the poor.

Substituting (17) in (16), we obtain

$$\begin{aligned} &A(z,x)[zq - qm_p + m_p(q-1)B_p] \\ &= A(z,x)zq\left\{1 - \frac{m_p}{z}\left[1 - B_p\left(\frac{q-1}{q}\right)\right]\right\}. \end{aligned}$$

But considering that

$$\frac{m_p}{z} = 1 - I\,,$$

for fulfilling axiom E, it must be

$$A(z,x) = \frac{1}{zn}\,.$$

So we have demonstrated that S_B given in (15) is the only poverty measure which is consistent with axioms A-B-C-E-F.

When the number of poor increases, (15) can be approximated by

$$S_B = H[I + (1-I)B_p]\,. \tag{18}$$

From the simplified expression (18) it is clearer that S_B is an increasing function of the three components I, B_p and H, fulfilling the axioms of monotonicity, transfer and the poor proportion, respectively. We note that in a very particular and rare case, the axioms B and C may contradict each other. This happens if an income transfer from a poor to another one, but which is richer than the donor, make the recipient exceed the line z. In this case the axiom B requires an increase in the poverty measure, but H causes the opposite effect. Therefore S_B is subjected to opposite sign variations and the overall effect cannot be analytically derived. This anomaly also concerns the Sen index, since it is an increasing function of H and of the Gini concentration ratio, which is consistent with the Pigou-Dalton principle. As S, finally, S_B ranges in the real interval [0, 1].

Then by using the Bonferroni inequality index in (7), we propose the new poverty measure

$$P_1^B = HI[1 + (1 - I)B^\star] \tag{19}$$

where

$$B^\star = w_1(H)B_p + w_2(H)B_{np} + w_3(H)D\,;$$
$$\sum_{i=1}^{3} w_i(H) = 1; \quad w_i(H) > 0, \quad i = 1, 2, 3\,.$$

For what we have said in Section 4, the summary index P_1^B is particularly sensitive to low levels of income distribution and, according to the properties of B, it also satisfies the diminishing transfer principle. It is worth mentioning that the component $B^\star$ summarizes the overall effect of deprivation due to the income inequality in the two subgroups and to their economic distance. $B^\star$ is introduced with the aim of quantifying the elements producing economic differences between individuals, as a whole. Since $B^\star \geq R^\star$ (see property VI, Section 3), it is clear how P_1^B is more affected by the deprivation component rather than P_1. This can be considered an high quality for P_1^B, seeing that the poverty perception is upgraded by welfare inequality, specially in developed countries. By means of expression (19) we deduce how $B^\star$ factor's contribution is higher just when the poverty-gap assumes lower values (Dagum *et al.*, 1988, p. 88).

For the same reasons just mentioned, on the basis of (8) we introduce the poverty measure:

$$P_2^B = H(I + D + B_p + \alpha \mid B_p - \beta B_{np} \mid)/3; \quad 0 < (\alpha, \beta) < 1\,. \tag{20}$$

When a summary poverty index is taken into account, it is important to focus on its variations as a result of changes in the income distribution (e.g. due to income transfers between units, etc.). In this sense we note that P_2^B, like P_2 (see Dagum *et al.*, 1992), has an appreciable bent for varying in the expected direction.

6. A FINAL REMARK

Some statisticians and economists prefer to use the summary poverty indices only as ordinal measures and in this respect we cannot forget the title of Sen's famous article in 1976. This position finds a reasonable explanation in the inevitable arbitrariness of some hypotheses assumed for defining any poverty measure. However this must not prevent us to construct an index capable of quantifying and describing the phenomenon in the best way. In this sense, the new measures based on the Bonferroni index give more weight to the inequality component and are particularly sensitive to low levels of income distribution.

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A proposal of poverty measures based on the Bonferroni inequality index

SUMMARY

Within the most widely used poverty measures, the income inequality component is often described by the famous Gini concentration ratio (R). We prove that the Bonferroni inequality index (B), in addition to the properties of R, is particularly sensitive to lower levels of income distribution and gives more weight to transfers among the poor. Hence, to improve poverty measurement, we propose three new summary indices based on B.

Una proposta di misure di povertà basate sull'indice di disuguaglianza di Bonferroni

RIASSUNTO

All'interno delle misure di povertà più diffuse ed utilizzate, la componente di disuguaglianza è spesso descritta mediante il noto rapporto di concentrazione di Gini (R). In questo articolo mostriamo come l'indice di disuguaglianza di Bonferroni (B), oltre ad avere le medesime proprietà di R, sia particolarmente sensibile ai valori bassi delle distribuzioni di reddito e dia un peso maggiore ai trasferimenti tra i poveri. Quindi, per migliorare la misura della povertà, proponiamo tre nuove misure sintetiche basate su B.

KEY WORDS

Bonferroni inequality index; Gini concentration ratio; Sen and Dagum poverty measures; Pigou-Dalton transfer principle.

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