Measuring Inequality for the Rural Households of Eritrea Using Lorenz Curve and Gini Coefficient

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Abstract
This paper attempts to accurately measure inequality. The large sample of consumption expenditure data taken from Eritrean rural household survey of 2009 allows the use of parameterized continuous functions of Lorenz Curve to estimate Gini Coefficient. Among other assumed functions of the Lorenz Curve, the generalized Beta Lorenz Curve gives the best estimate of the Gini Coefficient which in turn results in a low degree of inequality. Thus, considering the current low standard of living of the households, the results appear to partially support poverty and inequality trade-off.
Keywords: Inequality, Lorenz Curve, Gini Coefficient, Consumption Expenditure

1. Introduction

There are various ways of measuring inequality but Lorenz Curve (Lorenz 1905) and Gini Coefficient (Gini 1912) which are mathematically related are the most common techniques in economic literatures. By the same token, they are adopted in this paper in an attempt of measuring inequality of Eritrean rural households based on the data taken from the household survey conducted in 2009 to study the contribution of farm and non-farm economy on the food security of the rural households in Eritrea (Tekleghiorghis *et al.* 2009).

Although the aforementioned techniques of measuring inequality were originally applied to the distribution of wealth or income and, for that reason, remained to be popular in economic literatures, their applications have now become wider covering many disciplines. However, the use of consumption expenditure variable instead of wealth or income in this study stems from the fact it is rather more difficult; especially, in developing countries to obtain accurate and reliable data about wealth or income (see Deaton & Zaidi 2002).

The issue of inequality is closely linked to welfare or poverty, and that is why it is often studied as part of these concepts. However, unlike welfare, inequality is independent of the mean of distribution. This implies that the measures of inequalities are insensitive to the absolute level of welfare of individuals/households, and they can provide meaningful information about the general welfare status of the individuals/households only if they are used in combination with other absolute measures of welfare such as poverty (Datt 1998). Yet, as Sen (1981) points out it is important to conceptually draw a line between poverty and inequality even though they are related. Indeed, the computation of poverty differs from that of inequality since the former is based on only part of the distribution.

In particular, the theoretical relationship between inequality and welfare can be established through the axioms of inequality. The Gini Coefficient measure of inequality unconditionally fulfills the criteria set by the anonymity principle (symmetry principle), the Pigue-Dalton transfer principle, scale-invariance principle and Dalton population principle. However, it meets the decomposability principle only if the subgroups of the population do not overlap in the distribution of the variable of interest (Litchfield 1999). In fact, there have been attempts to decompose Gini Coefficient with overlapping distributions of subsections of the populations (see Araar 2006; for instance, for the decomposition of absolute Gini Coefficient).

Nevertheless, despite the fact that other inequality measures such as Generalized Entropy (GE) class of inequality measures possess all the above desirable properties (see Litchfield 1999), Gini Coefficient derived from Lorenz Curve happens to be a popular measure of inequality in economic literatures. Even though Gini Coefficient is not an absolute measure for lack of a true zero value, Traves Hale (nd) describes it as sufficiently appropriate method of measuring inequality; especially, when one has access to individual data.

In addition to the aforementioned theoretical focus, some studies have also attempted to establish empirical relationships between inequality, on the one hand, and welfare or poverty, on the other. For instance, Kakwani (1980) shows a positive relationship between different poverty measures and income inequality for various household composition groups using the data from Australian Household Expenditure Survey. Again, Datt (1998) combines inequality measures with measures of poverty to simulate the level of poverty using data from Consumption Expenditure Survey for the rural India; and in the decomposition of the change in aggregate level of poverty, he finds some evidence of 'redistributive component' in the reduction of poverty for the period from 1983 to 1986-89; in fact, the greater component happens to be the 'growth component' arising purely from the growth of mean consumption.

Conversely, Landes *et al.* (2003), in the context of South African poverty and inequality find a negative relationship between the two measures. Supporting Kuznet's (1955) historical evidence, they conclude that inequality is exacerbated during the take-off stage of economic progress before trickle-down takes effect. However, drawing evidence from the experience of developing countries, Ravellion (2005) challenges the so-called Kuznet Hypothesis suggesting that the trade-off exists between poverty and absolute inequality (measured simply by the range) but not with relative inequality (measured, say, by Gini Coefficient).

For the purpose of measuring inequality, clear definition of the term is necessary. Technically, inequality is defined as a dispersion of income/expenditure distributions (Litchfield 1999). The criteria upon which the measurement of inequality depends may come from "ethical principles, appealing mathematical constructs or simple intuition" (Cowell 1998, p. 1).

Therefore, the next section illustrates the mathematical relationship between the Lorenz Curve and the Gini Coefficient. The third section presents and discusses the empirical results. The final section then concludes the paper with remarks.

2. The Relationship between Lorenz Curve and Gini Coefficient

In many applied research, Lorenz Curve is used to show the inequality in the distribution of the characteristics of households/individuals, and Gini Coefficient is a summary measure of the degree of inequality among individuals/households in the characteristics. In this paper, for instance, we show the Lorenz Curve of consumption expenditure of the Eritrean rural households by plotting the cumulative share of each of the household's consumption expenditure against the cumulative proportion of each household in the total sample where the households are initially ranked in ascending order according to their levels of consumption expenditure (see figure 1).

Generally, in measuring the income/expenditure inequality from Lorenz Curve, there are two extreme values. The first is complete equality, where expenditure/income is equally distributed among all individuals/households. This perfect equality results in a Gini Coefficient of zero, which coincides with the line of equality inclined at 45 degree. This means that one percent of the individuals/households account for one percent of the total income/expenditure. The second is complete inequality, where only one individual/household has all the income/expenditure and the other individuals/households have none. In this case, the resulting Gini Coefficient is one and the Lorenz Curve coincides to the line of horizontal axis and the line on the right-hand side of vertical axis. As it can be seen from figure 1, the Lorenz curve drawn from the consumption expenditure data lies between the two extreme lines. In fact, it appears to be closer to the line of perfect equality. Thus, a visual preliminary investigation shows that the distribution of consumption expenditure among the sample of households inclines toward equality. To substantiate our visual examination, however, we calculate the value of Gini Coefficient from the lower triangle of the square-box by comparing the area bounded by the Lorenz Curve to the total area represented by the lower triangle within the range of [0,1].

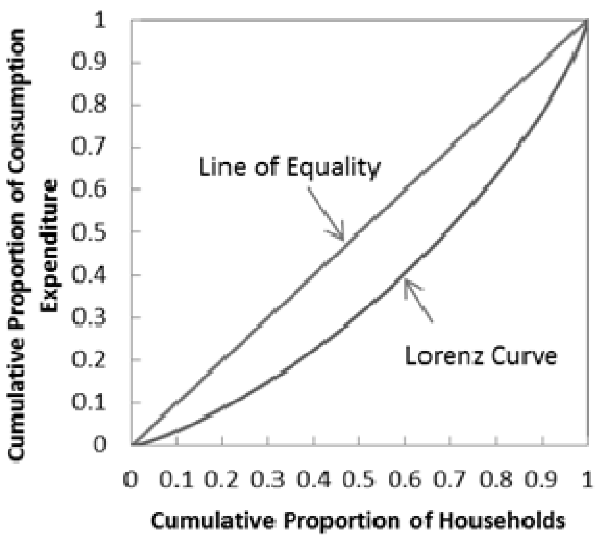

Figure 1: The Lorenz Curve of Consumption Expenditure of the Eritrean Rural Households

In other words, the value of Gini Coefficient is given by the ratio of the area between the Lorenz curve and the diagonal line of complete equality to the triangular area between the lines of complete equality and inequality. The calculation of the value proceeds as follows:

i) The consumption expenditures of the sample households are initially ordered from the lowest to the highest levels. That is,
Household Expenditure = $X_1, X_2, ..., X_N$
where X_1 is the expenditure of relatively poorest household
X_N is the expenditure of relatively richest household

ii) Then the cumulative share of the consumption expenditures of k households is obtained by summing up all expenditures less than or equal to the expenditure of k^{th} household divided by the total expenditures of the sample of N households. Mathematically,

$$L_k = \frac{1}{T}\sum_{i=1}^{k} X_i;\ k = 1,2,...,N \quad [1]$$

Where L_k is the share of cumulative expenditure of the bottom k households
T is the total of the expenditures of the sample of N households

And, since $T = \sum_{i=1}^{N} X_i$, then $L_N = 1$

iii) Again, the households are initially arranged from the relatively poorest to the richest (H_1, H_2, …, H_N)[1] before the cumulative proportion of households is computed as in the cumulative share of the expenditures of the households. That is,

$$p_k = \frac{1}{N}\sum_{j=1}^{k} H_j;\ k = 1,2,...,N \quad [2]$$

Where p_k is the cummulative proportion of k households
N is the total sample of households

But, since the value of H_j is constant at 1[2], then $\sum_{j=1}^{k} H_j = k$; thus, equation [2] reduces to $p_k = \frac{k}{N}$ and then it is simple to show that $p_N = 1$.

iv) Finally, the Gini Coefficient is estimated from the graph of Lorenz Curve showing the relationship between the cumulative share of expenditures of households (plotted on the vertical axis) and the cumulative proportion of households (plotted on the horizontal axis).

In this case, Gini Coefficient is derived from figure 1 by estimating the functions of the line of equality and the Lorenz Curve. As a matter of fact, it is mathematically straight forward to measure the area under the diagonal line of equality. That is,

$$L_k = p_k \qquad k = 1,2,...,N \quad [3]$$

More formally, the function of the line of equality is represented as

$$L(p_k) = p_k,\ k = 1,2,...,N \quad [4]$$

Assuming a continuous function, the integration of the function gives the area under the line such that

$$\int_0^1 L(p) = \int_0^1 pdp = \frac{1}{2} \quad [5]$$

Also, the area under the Lorenz Curve is obtained by integrating the function which fits the curve. However, the non-linear characteristic of the Lorenz Curve requires more complex mathematical functions and thus more rigorous integration. In the literature, various functions are suggested fitting the Lorenz Curve but with differing degrees of performance. In this paper, however, two functional forms along with four estimation methods are adopted.

2.1 Mathematical Functions of the Lorenz curve

The functions of the Lorenz Curve considered in this paper are sequentially the power function estimated using the least square and the average value methods, the restricted Beta Lorenz Curve and the generalized Beta Lorenz Curve.

The power function is given by

$$L(p) = p^{\alpha} \quad [6]$$

And the integration of this function is

[1] The subscript indicates the order of the households from the lowest to the highest based on their respective expenditures, which corresponds to the ranking made in the first step.

[2] The unit of analysis is the household, but no matter what, the value is always equals to one.

$$\int_0^1 L(p) = \int_0^1 p^{\alpha} dp = \frac{1}{\alpha+1} \quad [7]$$

Hence, equation [7] reveals that the value of α is necessary for evaluating the integration. One way of estimating the value of α is to use the least square method. However, linear transformation of the power function is a prerequisite for applying this method and it can be accomplished by taking the natural logarithm of the function. That is,

$$\ln L_k = \alpha \ln p_k \quad [8]$$

An alternative method is to solve for α

$$\alpha = \frac{\ln L_k}{\ln p_k} \quad [9]$$

Then a reasonable estimate of α is obtained by forming the ratio $\frac{\ln L_k}{\ln p_k}$ for each point (p_k, L_k) in the data set, and the average of these ratios is taken as an estimate of α.

With large samples, however, the function of the Beta Lorenz Curve which is known for its high performance is widely adopted. Thus, the functional form of the parameterized continuous Beta Lorenz Curve is given by (see Klein 2002)

$$L(p) = p - \theta p^{\alpha}(1-p)^{\beta} \text{ where } \theta>0,\ 0<\alpha \le 1 \text{ and } 0<\beta \le 1 \quad [10]$$

Nonetheless, calculating the integration of equation [10] is rather intractable. The solution is to impose restrictions on either α or β in order to make the calculation manageable. Therefore,

$$\begin{cases} \int_0^1 L(p)dp = \int_0^1 p - \theta p(1-p)^{\beta} dp \quad \text{where } \alpha=1 \\ \qquad = \frac{1}{2} - \frac{\theta}{(\beta+1)(\beta+2)} \\ \int_0^1 L(p)dp = \int_0^1 p - \theta p^{\alpha}(1-p) dp \quad \text{where } \beta=1 \\ \qquad = \frac{1}{2} - \frac{\theta}{(\alpha+1)(\alpha+2)} \end{cases} \quad [11]$$

The restricted Beta Lorenz Curve from equation [11] can then be estimated through the least square regression model by applying logarithmic transformation of the function. Taking the case where α = 1, only θ and β can be estimated with the transformed log-linear function. That is,

$$\ln\left[p - L(p)\right] - \ln p = \ln\theta + \beta \ln(1-p) \quad [12]$$

But, in the generalized Beta Lorenz Curve, there is the advantage of estimating all parameters of the function, viz, θ, α, and β. Therefore, with some modification to equation [11], the integration of the general function is given by:

$$\begin{aligned} \int_0^1 L(p)dp &= \int_0^1 p - \theta p^{\alpha}(1-p)^{\beta} dp \\ &= \frac{1}{2} - \frac{\theta}{(\beta+1)(\beta+2)} \bullet \frac{3!}{(\alpha+1)(\alpha+2)} \end{aligned} \quad [13]$$

Equation [13] reduces to the restricted Beta Lorenz Curve in equation [11] when either α or β is equal to 1. Accordingly, the generalized Beta Lorenz Curve is estimated using the least square method after logarithmic transformation of the function. Hence,

$$\ln\left[p - L(p)\right] = \ln\theta + \alpha \ln p + \beta \ln(1-p) \quad [14]$$

After integrating the Lorenz curve, the computation of the Gini Coefficient is relatively simple.

2.2 Mathematical Formulation of the Gini Coefficient

As noted above, for large sample, a good estimate of Gini Coefficient can be obtained from the line of Lorenz Curve. Consequently, Gini Coefficient is expressed in terms of the parameters of the functions of Lorenz Curve as follows (*ibid*):

$$Gini\ Coefficient = \frac{Area\ bounded\ by\ the\ Lorenz\ Curve\ and\ L_k = p_k}{Area\ of\ triangle\ for\ Perfect\ Equality} \quad [15]$$

Therefore, the Gini Coefficient generated from the Lorenz Curve is given by (*ibid*)

$$G = \frac{\frac{1}{2} - \int_0^1 L(p)dp}{\frac{1}{2}} = 1 - 2\int_0^1 L(p)dp \quad [16]$$

As it can be inferred from the equation [16], the value of Gini Coefficient depends on the integration of Lorenz curve. This relationship is also reflected in table 1, which shows that Gini Coefficient can be computed from the parameters of Lorenz Curve estimated using linear regression model and average value methods.

Table 1: Formulae for Estimating the Power Functions and Beta Lorenz Curves, and the Corresponding Gini Coefficients

Type	Power Function		Beta Lorenz Curve	
	Least Square	*Ratio (Average Value)*	*Restricted* $(\alpha = 1,\ 0 < \beta \leq 1,\ \theta > 0)$	*Generalized* $(0 < \alpha \leq 1, 0 < \beta \leq 1,\ \theta > 0)$
Lorenz Curve	$\ln L(p_j) = \ln E_i = \alpha \ln p_j$	$\alpha = \frac{\ln E_i}{\ln p_j}$	$\ln[p - L(p)] - \ln p = \ln\theta + \beta\ln(1-p)$	$\ln[p - L(p)] = \ln\theta + \alpha\ln p + \beta\ln(1-p)$
Gini Coefficient	$\frac{\alpha - 1}{\alpha + 1}$	$\frac{\alpha - 1}{\alpha + 1}$	$\frac{2\theta}{(\beta+1)(\beta+2)}$	$\frac{12\theta}{(\beta+1)(\beta+2)(\alpha+1)(\alpha+2)}$

3. Results and Discussions

This paper uses the consumption expenditure data collected from 1172 Eritrean rural households in 2009 in order to empirically estimate several comparable Lorenz Curves and Gini Coefficients. And, table 2 presents the coefficients of the power function of Lorenz Curve and the associated Gini Coefficients. However, the two estimation methods, the least square and the average value, do not give consistent results.

The Gini Coefficient obtained from the least square method registers quite lower level of inequality. Indeed, the Lorenz Curve which is simulated using the least square method accurately predicts inequality only for the poorest 20% of the households but it steadily understates the inequality for the rest of the households (see figure 2). The paradox in this result is that the estimated regression equation produces a very significant coefficient with great explanatory power (reflected in the high level of R^2). Nor does the average value show accuracy in its prediction: it over- (under-)states inequality for the lower 60% (upper 40%) of the households (see also figure 2). Based on this result, it may be reasoned out that the Gini Coefficient computed from the average value method, on average, approximates the overall inequality observed among the households. This assertion, however, as reasonable as it may seem, is hardly generalizable and less likely to hold when inequality is very high.

Table 2: The Estimated Coefficients of the Power Functions and the Gini Coefficient

Coefficients	Least Square	Average Value
Lorenz Curve	1.488 (0.003)*	1.823
Gini Coefficient	0.196	0.292
R^2	0.995	-
Observations	1172	1172

* The standard error of the coefficient in bracket

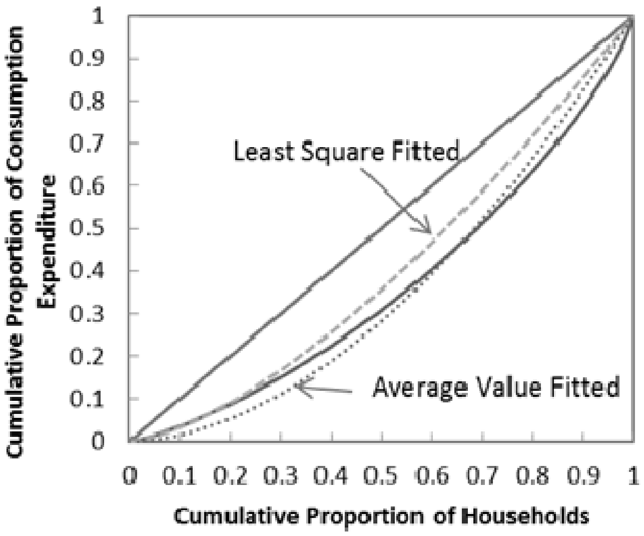

Figure 2: The Lorenz Curve Fitted with Power Functions

Nonetheless, an accurate prediction of the Lorenz Curve can be obtained over the entire range of the distribution using the Beta Lorenz Curve which is known for its high performance with large number of observations (Datt 1998, Kakwani 1980). Here, the two versions of the Beta Lorenz Curve (the restricted and the generalised) are therefore employed in order to make meaningful comparisons among alternative measures of Gini Coefficient. Applying these functions of Beta Lorenz Curve to the data however gives very close results although the generalized Beta Lorenz Curve has greater explanatory power with R^2 near unity. The results of both functions of Beta Lorenz Curve are reported in table 3.

Nevertheless, as observed above in relation to the power function and also indicated by Datt (1998), a good fit for the distribution function need not equally imply a good fit for the Lorenz Curve. Thus, the simulated Lorenz Curves have to be graphically fitted to the actual Lorenz Curve for visual evaluation of the degree of accuracy of the estimations.

Table 3: The Estimated Coefficients of the Beta Lorenz Curves and the Gini Coefficient

Coefficients	Restricted	Generalized
θ	0.664 (0.003)[a]	0.583 (0.002)[b]
α	1.000 (0.000)[c]	0.922 (0.001)
β	0.719 (0.002)	0.668 (0.001)
Gini Coefficient	0.284	0.280
R^2	0.992	0.998
Observations	1171[d]	1171[e]

[a,b] standard errors are in brackets and associated with lnθ.
[c] Since the function is constrained at $\alpha = 1$, its standard error, by construction, is zero.
[d,e] The sample was originally 1172 but in each case of the regression the last observation was lost in the logarithmic transformation of $(1 - p_i)$ where $p_N = 1$.

Figure 3 shows the simulated Beta Lorenz Curve for both functional forms, restricted and generalized, which provide almost perfect fit for the actual data as the curves of the former are overlaid one over the other on the actual Lorenz Curve.

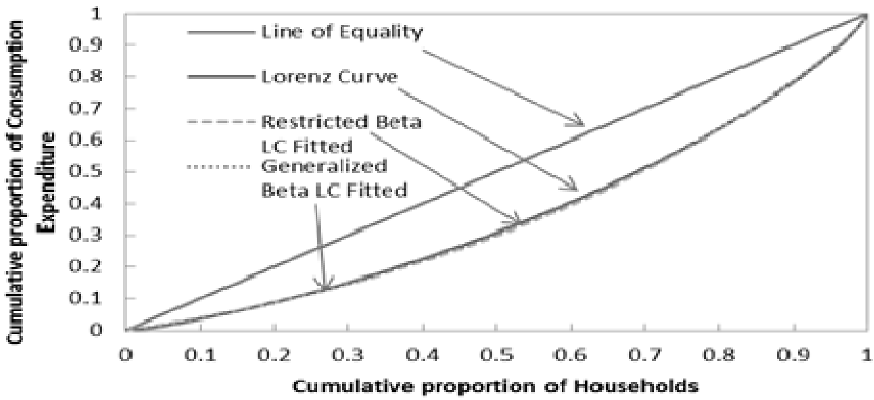

Figure 3: The Lorenz Curve Fitted with Beta Functions

In a situation such as this, the generalized Beta Lorenz Curve is a better choice for it has a higher goodness of fit. In fact, the general form of the Beta Lorenz Curve is usually employed in measuring relative poverty through the combination of Gini Coefficient and other poverty indices such as headcount and poverty gap (see Datt 1998, Kakwani 1980). Thus, the preceding analysis reinforces the robustness of using such functional form in measuring inequality. Most of all, it ensures the validity and reliability of the result. So much so, a Gini Coefficient of 0.28 reflects a low degree of inequality among the Eritrean rural households, and the value is in fact comparable to the Gini Coefficient of 0.289 for the rural India in 1983 (Datt 1998) which slightly declined to 0.263 in 2000 (Pal & Ghosh 2007).

In addition, Combining 28% Gini Coefficient with 86% head-count poverty index drawn from the same study (Tekleghiorghis *et al*. 2009) provides supporting evidence to the much acknowledged trade-off between poverty and inequality in developing countries where high level of poverty coexists with low level of inequality. Whether the trade-off will persist in the future with economic growth (or equivalently with poverty reduction) is determined by periodical measurements of the two indices. Indeed, there is growing evidence against the prevailing paradigm which states that inequality is exacerbated at initial level of development (Ravallion 2005, Uphoff c.2000). That is to say, the association of lower inequality with falling poverty in many instances is inducing a paradigm shift that low inequality (in contrast to high inequality) reinforces poverty reduction efforts (Uphoff *op cit*). The gist of measuring inequality, or Gini Coefficient for the matter, can therefore be seen from this perspective of making an input to developmental policies.

4. Concluding Remarks

Lorenz Curve and Gini Coefficient are interrelated mathematical tools used to measure inequality of a given population distribution. To generate a set of Gini Coefficients, the 'power' and 'beta' functions of Lorenz Curve are employed. The fitted Lorenz Curves almost perfectly coincide with the actual Lorenz Curve when the Beta Lorenz Curves are used. The conclusion is thus the Gini Coefficient derived from the Beta Lorenz Curve (especially, the generalized Beta Lorenz Curve) gives the best summary of inequality among Eritrean rural households. In fact, the Gini Coefficient obtained in this way indicates a low degree of inequality. Again, in combination with high level of head-count poverty index, this result partially reveals the existence of poverty and inequality trade-off. However, for a general result, Gini Coefficient along with other poverty measures has to be periodically computed for the whole country in order to fully inform public policies.

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