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COMPUTATIONAL TOOLS FOR POVERTY MEASUREMENT AND ANALYSIS

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ABSTRACT

This paper introduces some relatively simple computational tools for estimating poverty measures from the sort of data that are typically available from published sources. All that is required for using these tools is an elementary regression package. The methodology also easily lends itself to a number of poverty simulations that are discussed. The paper addresses the central question: How do we construct poverty measures from grouped data? Two broad approaches are examined: simple interpolation methods and methods based on parameterized Lorenz curves. The second method is examined in detail.

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1. INTRODUCTION

This paper introduces some relatively simple computational tools for estimating poverty measures from the sort of data that are typically available from published sources. In fact, all that is required for using these tools is an elementary regression package. The methodology also easily lends itself to a number of poverty simulations that are discussed later.

The typical form in which survey data on the size distribution of income or consumption are available is shown in Table 1. The first three columns of the table give the size distribution of consumption expenditure in rural India for 1983. This paper addresses the central question: How do we construct poverty measures from such grouped data? Two broad approaches can be identified: simple interpolation methods and methods based on parameterized Lorenz curves. For reasons noted later, the second approach often may be preferred to the first. However, the paper begins by briefly describing the first approach and some of the problems in its application.

Interpolation methods essentially involve fitting a distribution function to the grouped data. To estimate the head-count index, the distribution function is typically fitted over the class interval containing the poverty line. Linear and quadratic interpolation are good examples of this method. There are two basic limitations in using interpolation methods. First, they tend to provide relatively inaccurate predictions of the

Table 1—Size distribution of consumption expenditure in rural India, 1983

Monthly per capita expenditure in Rs	Percentage of persons	Mean monthly per capita expenditure in Rs	*p*	*L*
0 – 30	0.92	24.84	0.0092	0.00208
30 – 40	2.47	35.80	0.0339	0.01013
40 – 50	5.11	45.36	0.0850	0.03122
50 – 60	7.90	55.10	0.1640	0.07083
60 – 70	9.69	64.92	0.2609	0.12808
70 – 85	15.24	77.08	0.4133	0.23498
85 – 100	13.64	91.75	0.5497	0.34887
100 – 125	16.99	110.64	0.7196	0.51994
125 – 150	10.00	134.90	0.8196	0.64270
150 – 200	9.78	167.76	0.9174	0.79201
200 – 250	3.96	215.48	0.9570	0.86966
250 – 300	1.81	261.66	0.9751	0.91277
300 and above	2.49	384.97	1.0000	1.00000
All expenditure classes	100.00	109.90		

Source: *Sarvekshana* 1986.

Notes: *p* = cumulative proportion (or percentage) of population; *L* = cumulative proportion (or percentage) of consumption expenditure.

distribution function at selected points. This is particularly true of linear interpolation. Quadratic interpolation predicts more accurately, but can sometimes give rise to negative densities (when the slope of the distribution function becomes negative). Second, the calculation of distributionally sensitive poverty measures using interpolation methods can be cumbersome and inexact. There can be refinements of the interpolation methods, for instance, fitting different distribution functions to different class intervals (as in Kakwani and Subbarao 1993). But this introduces the further issue of which functions to fit over which class intervals.

An alternative methodology for estimating poverty measures is based on parameterized Lorenz curves. This methodology is preferred both for its relative accuracy and the ease with which it helps perform a number of poverty simulations. The implementation of this methodology is discussed below.

The following discussion assumes consumption expenditure to be the measure of individual welfare, and hence the variable in terms of which absolute poverty is measured. But this is only for expositional convenience; the methodology is perfectly general with respect to the choice of the individual welfare measures. It is also assumed throughout that a poverty line (defined in terms of the same variable chosen to measure poverty) has been previously determined.

2. POVERTY MEASURES DERIVED FROM PARAMETERIZED LORENZ CURVES

The basic building blocks of this methodology are the following two functions:

Lorenz curve: $L = L(p; \pi)$,

and

Poverty measure: $P = P(\mu/z, \pi)$,

where L is the share of the bottom p percent of the population in aggregate consumption, π is a vector of (estimable) parameters of the Lorenz curve, P is a poverty measure written as a function of the ratio of the mean consumption μ to the poverty line z and the parameters of the Lorenz curve.

The Lorenz curve captures all the information on the pattern of *relative inequalities* in the population. It is independent of any considerations of absolute living standards. The poverty measure captures our assessment of the absolute living standards of the poor. As written above, the poverty measure is homogenous of degree zero in mean consumption and the poverty line—that is, if mean consumption and the poverty line change by the same proportion, poverty will remain unchanged. Homogeneity of degree zero is a property that is satisfied by a large class of poverty measures and is unrestrictive. The function *L* subsumes alternative parameterizations of the Lorenz curve, while function *P* subsumes different poverty measures.

As for the poverty measures, we will be concerned with those in the Foster-Greer-Thorbecke (FGT) class. The FGT class of poverty measures have some desirable properties (such as additive decomposibility), and they include some widely used poverty measures (such as the head-count and the poverty gap measures). The FGT poverty measures are defined as

$$P_\alpha = \int_0^z \left[\frac{z - x}{z}\right]^\alpha f(x)dx \qquad \alpha \geq 0 \, ,$$

where x is the household consumption expenditure, $f(x)$ is its density (roughly the proportion of the population consuming x), z denotes the poverty line, and α is a nonnegative parameter. Higher values of the parameter α indicate greater sensitivity of the poverty measure to inequality among the poor. In what follows, we will be concerned with the estimation of poverty measures P_α for $\alpha = 0$, 1, and 2, which respectively define the head-count index, the poverty gap index, and the squared poverty gap index. Hereafter, these measures are denoted *H*, *PG*, and *SPG*.

The literature on the estimation of Lorenz curves provides a number of different functional forms. Two of the best performers among them are the general quadratic (GQ) Lorenz curve (Villasenor and Arnold 1984, 1989) and what may be called the Beta Lorenz curve (Kakwani 1980). The Lorenz functions for these two specifications are given in the top row of Table 2. Table 2 also gives the formulas for the poverty measures *H*, *PG*, and *SPG* for each of these two parameterizations of the Lorenz curves. The poverty measures are calculated using these formulas.

The question of which of the two parameterizations of the Lorenz curve should be chosen for estimating poverty measures is addressed in Section 5. For the present, let us note that both tend to be fairly accurate. There is some evidence for Indonesia that the Beta model yields somewhat more accurate predictions of the Lorenz ordinates at the lower end of the distribution, though the same study found that the GQ model is more accurate over the whole distribution (Ravallion and Huppi 1990). The GQ model, however, does have one comparative advantage over the Beta model, namely, that it is computationally simpler. While all the poverty measures for the GQ model are readily calculated using a simple regression program, the Beta model requires solving an implicit nonlinear equation in order to estimate *H* and evaluating incomplete beta functions to

Table 2—Poverty measures for alternative parameterizations of the Lorenz curve

	Beta Lorenz Curve	GQ Lorenz Curve
Equation of the Lorenz curve L(p)	$L(p) = p - \theta p^{\gamma}(1-p)^{\delta}$	$L(1-L) = a(P^2-L) + bL(p-1) + c(p-L)$ *or* $L(p) = -\frac{1}{2}\left[bp + e + (mp^2+np+e^2)^{1/2}\right]$
Headcount index (H)	$\theta H^{\gamma}(1-H)^{\delta}\left[\frac{\gamma}{H} - \frac{\delta}{(1-H)}\right] = 1 - \frac{z}{\mu}$	$H = -\frac{1}{2m}\left[n + r(b+2z/\mu)\{(b+2z/\mu)^2-m\}^{-1/2}\right]$
Poverty gap index (PG)	$PG = H - (\mu/z)\,L(H)$	$PG = H - (\mu/z)\,L(H)$
Distributionally sensitive poverty index (SPG)	$P_2 = (1-\mu/z)\left[2(PG) - (1-\mu/z)H\right] + \theta^2\left(\frac{\mu}{z}\right)^2\left[\gamma^2 B(H,2\gamma-1,2\delta+1) - 2\gamma\delta B(H,2\gamma,2\delta) + \delta^2 B(H,2\gamma+1,2\delta-1)\right]$	$P_2 = 2(PG) - H - \left(\frac{\mu}{z}\right)^2\left[aH + bL(H) - \left(\frac{r}{16}\right)\ln\left(\frac{1-H/s_1}{1-H/s_2}\right)\right]$

Note: $B(k,r,s) = \int_0^k p^{r-1}(1-p)^{s-1}\,dp$

$e = -(a+b+c+1)$

$m = b^2 - 4a$

$n = 2be - 4c$

$r = (n^2 - 4me^2)^{1/2}$

$s_1 = (r-n)/(2m)$

$s_2 = -(r+n)/(2m)$

estimate *SPG*. For illustrative purposes, the GQ model of the Lorenz curve is used here. Implementing the Beta model is analogous.

The estimation of the poverty measures is based on the formulas in Table 2. Before moving on to the recipe for poverty estimation, it may be useful to understand how these formulas are derived.

1. ***The head-count index H***. This is derived using the following relationship between the Lorenz curve and the distribution function (notice that p as a function of x is, in fact, the distribution function):

$$L'(p;\pi) = x/\mu ,$$

where $L'(.)$ is the slope of the Lorenz curve. Evaluated at the poverty line z, this becomes

$$L'(H;\pi) = z/\mu .$$

Solving for H yields the formulas for the head-count index in Table 2.

2. ***The poverty gap index PG***. To derive *PG*, it is useful to rewrite the FGT class of poverty measures as

$$P_\alpha = \int_0^H \left[1-(\mu/z)L'(p;\pi)\right]^\alpha dp \qquad \alpha \geq 0 ,$$

which, upon evaluating the integral for $\alpha = 1$, yields

$$PG = H - (\mu/z)L(H;\, \pi).$$

Thus, once H has been calculated, it is straightforward to calculate PG using this formula.

3. ***The distributionally sensitive poverty measure SPG***. This is derived by evaluating the above integral for $\alpha = 2$. The explicit formula for SPG given in Table 2 is simply the value of this integral.

3. A RECIPE FOR CONSTRUCTING POVERTY MEASURES

For the general quadratic model of the Lorenz curve, the FGT class of poverty measures for $\alpha = 0,1,2$ are constructed as follows.

Step 1. Prepare data for the estimation of the Lorenz curve.

This involves constructing (p, L) data points from the survey data on the size distribution of consumption. The values of p and L are obtained, respectively, as the cumulative proportion of population and their (cumulative) share in aggregate consumption. For the illustrative Indian data, these are shown in columns 4 and 5 of Table 1.

Step 2. Regress $L(1 - L)$ on $(p^2 - L)$, $L(p - 1)$, and $(p - L)$ to estimate the GQ Lorenz curve parameters *a*, *b*, and *c*.

Make sure that there is no intercept in the regression. The parameters *a*, *b*, and *c* can be estimated by ordinary least squares, using all except the last observation for (p, L). The last observation, which by construction has the value (1, 1), is excluded since the functional form for the Lorenz curve already forces it to pass through the point (1, 1). Table 3 shows the regression output corresponding to the data in the last two columns of Table 1. Notice that R^2 is approximately unity. Such high values of R^2 are typical for both the GQ and Beta parameterizations of the Lorenz curve. However, a good fit for the Lorenz curve $L(p; \pi)$ need not imply an equally good fit for the distribution function. Some checks will be discussed below.

Step 3. Specify the mean consumption (μ) and the poverty line (*z*).

Care should be taken that the poverty line is specified in the same units as the mean expenditure. Also, the poverty line needs to be within an admissible range determined by the support for the density function associated with the parameterized Lorenz curve. The determination of this range is discussed further in Section 5. The values of μ and z for our illustrative Indian data are shown at the top of Table 4.

Table 3—Regression output: General quadratic Lorenz curve for rural India, 1983

DEP VARIABLE: $L(1–L)$

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	0.26314592	0.08771531	231115.290	0.0001
ERROR	9	0.00000341577	3.79531E-07		
U TOTAL	12	0.26314934			

ROOT MSE	0.0006160605	R-SQUARE	1.0000
DEP MEAN	0.1219933	ADJ R-SQ	1.0000
C.V.	0.5049954		

NOTE: NO INTERCEPT TERM IS USED.

PARAMETER ESTIMATES

PARAMETER	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H_0: PARAMETER=0	PROB > |T|
A	1	0.88743647	0.006672745	132.994	0.0001
B	1	–1.45133992	0.01902065	–76.303	0.0001
C	1	0.20249476	0.01281303	15.804	0.0001

Source: Author's calculations.

Table 4—Poverty measures, elasticities, and related statistics for rural India, 1983

Mean consumption (μ) = Rs 109.90, Poverty line (z) = Rs 89.00

Poverty measure/statistic	Estimated value	Elasticity with respect to Mean consumption	Elasticity with respect to Gini index
Head-count index (*H*)	45.06	–1.8677	0.4386
Poverty gap index (*PG*)	12.47	–2.6123	1.8483
Foster-Greer-Thorbecke (*SPG*)	4.752	–3.2503	3.2329
Gini index	0.289		
Admissible range for the poverty line	(39,308)		
Sum of squared error up to the head-count index			
–GQ Lorenz curve	5.663×10^{-6}		
–Beta Lorenz curve	14.678×10^{-6}		

Source: Author's calculations.

Step 4. Construct estimates of *H*, *PG*, and *SPG* using formulas in Table 2.

The estimated poverty measures for rural India (for 1983) are shown in Table 4. All poverty measures have been expressed as percentages.

4. CHECKING FOR A VALID LORENZ CURVE

A theoretically valid Lorenz curve satisfies the following four conditions:

1. $L(0;\pi) = 0$ 2. $L(1;\pi) = 1$ 3. $L'(0^+;\pi) \geq 0$ 4. $L''(p;\pi) \geq 0$ for $p \in (0,1)$.

The first two conditions, which may be called boundary conditions, imply that 0 and 100 percent of the population account for 0 and 100 percent of the total income or expenditure, respectively. However, small violations of the second condition, for example, $L(1;\pi) = 0.99$, need not be worrying from the point of view of poverty measurement, because the latter depends on the accurate tracking of the Lorenz curve up to the head-count index only. The third and fourth conditions ensure that the Lorenz curve is monotonically increasing and convex. There is no guarantee that the estimated parameters of the Lorenz curve will satisfy these conditions. The following chart shows how these conditions can be checked for either parameterization of the Lorenz curve.

Condition	**GQ Lorenz curve**	**Beta Lorenz curve**
$L(0;\pi) = 0$	$e < 0$	automatically satisfied by the functional form
$L(1;\pi) = 1$	$a + c \geq 1$	automatically satisfied by the functional form
$L'(0^+;\pi) \geq 0$	$c \geq 0$	$L'(0.001;\theta,\gamma,\delta) \geq 0$
$L''(p;\pi) \geq 0$ *for p within (0,1)*	(i) $m < 0$ or (ii) $0 < m < (n^2/(4e^2))$, $n \geq 0$ or (iii) $0 < m < -(n/2)$, $m < (n^2/(4e^2))$	$L''(p;\theta,\gamma,\delta) \geq 0$ *for* $p \in \{0.01, 0.02 \ldots 0.99\}$

Note: See Table 2 for the definitions of notation used above.

The formulas for the first and second derivatives of the Lorenz curves are given in Table 5. It is readily verified that the GQ specification is a valid Lorenz curve for the Indian data (see parameter estimates in Table 3). If, however, any of the four conditions were not satisfied, it would be worthwhile to try the alternative parameterization of the Lorenz curve, and if that, too, fails, one could revert to interpolation methods.

5. CHOICE OF THE LORENZ CURVE PARAMETERIZATION AND THE RANGE OF ADMISSIBLE POVERTY LINES

If both parameterizations of the Lorenz curve provide theoretically valid Lorenz curves, one may choose between them using a goodness-of-fit criterion. Since we are primarily interested in poverty measurement, the goodness-of-fit measure of the Lorenz curve may be constructed only up to the estimated head-count index. The preferred parameterization of the Lorenz curve is the one that yields a lower sum of squared errors up to the estimated head-count index. In particular, we construct the following:

-statistic:

$$= \sum_{i=1}^{k} (\hat{L}_i - L_i)^2 \quad \text{where } k = \left[k \mid \sum_{i=1}^{k-1} p_i \leq \hat{H} \leq \sum_{i=1}^{k} p_i \right].$$

For the rural India data, it turns out that the GQ specification has a lower -statistic (see bottom of Table 4).

Table 5—Formulas for the first and second derivatives of the Lorenz curve and the Gini index

	Beta Lorenz Curve	GQ Lorenz Curve
$L^{/}(p)$	$1 - \theta p^{\gamma}(1-p)^{\delta}\left[\frac{\gamma}{p} - \frac{\delta}{(1-p)}\right]$	$-\frac{b}{2} - \frac{(2mp+n)(mp^{2}+np+e^{2})^{-1/2}}{4}$
$L^{//}(p)$	$\theta p^{\gamma}(1-p)^{\delta}\left[\frac{\gamma(1-\gamma)}{p^{2}} + \frac{2\gamma\delta}{p(1-p)} + \frac{\delta(1-\delta)}{(1-p)^{2}}\right]$	$\frac{r^{2}(mp^{2}+np+e^{2})^{-3/2}}{8}$
Gini	$2\theta B(1+\gamma,1+\delta)$	$\frac{e}{2} - \frac{n(b+2)}{4m} + \frac{r^{2}}{8m\sqrt{-m}}\left[\sin^{-1}\frac{(2m+n)}{r} - \sin^{-1}\frac{n}{r}\right]$ $\quad if\ m<0$ $\frac{e}{2} - \frac{n(b+2)}{4m} - \frac{r^{2}}{8m\sqrt{m}}\ln\left[abs\left(\frac{2m+n+2\sqrt{m}(a+c-1)}{n-2e\sqrt{m}}\right)\right]$ $\quad if\ m>0$

Note: See Table 2 for the definition of parameters. $B(1+\gamma,1+\delta)$ is the beta function $\int_{0}^{1} p^{\gamma}(1-p)^{\delta}\,dp$.

For the GQ Lorenz curve, the Gini formulas are valid under the condition $a + c \geq 1$.

The range of admissible poverty lines for a Lorenz curve is given by the support of the density function associated with that Lorenz curve. This support is given by the interval $[\mu L'(0^{+};\pi), \mu L'(1^{-};\pi)]$. For a theoretically valid Lorenz curve, the range of admissible poverty lines is thus evaluated as $[\mu L'(0.001;\pi), \mu L'(0.999;\pi)]$. For the Indian data, this range is indicated in Table 4.

6. ESTIMATING INEQUALITY AND ELASTICITIES OF POVERTY MEASURES

A widely used measure of inequality, namely the Gini index, is easily calculated, using the estimated parameters of the Lorenz curve. The relevant formulas are given in Table 5.

One can also use this methodology to construct point estimates of the elasticities of poverty measures with respect to mean consumption and the Gini index. The formulas for these elasticities, derived from Kakwani (1990), are presented in Table 6. The formulas for the elasticities with respect to the Gini index assume the Lorenz curve shifts proportionally over the whole range. The calculation of these point elasticities is straightforward as we have already generated all the necessary information.

The estimates of the Gini index and the point elasticities of poverty measures for rural India are noted in Table 4.

Table 6—Elasticities of poverty measures with respect to the mean and the Gini index

Elasticity of	Mean (μ)	with respect to	Gini index
H	$-z/(\mu H L''(H))$		$(1-z/\mu)/(HL''(H))$
PG	$1 - H/PG$		$1 + (\mu/z - 1)H/PG$
SPG	$2(1 - PG/P_2)$		$2[1 + (\mu/z - 1)PG/P_2]$

Source: These formulas are derived from Kakwani (1990). *H* stands for head-count index, *PG* for poverty gap index, and *SPG* for the Foster-Greer-Thorbecke measure.

7. POVERTY SIMULATIONS

An important advantage of the Lorenz-curve-based method of estimating poverty is that it doubles up as a versatile poverty simulation device. A number of different simulations can be performed. A few of these are considered below.

1. ***Simulating poverty measures for different poverty lines***. This can be done at negligible marginal computational cost by simply specifying alternative poverty lines in *Step 3* of the estimation of poverty measures (Section 3). The sensitivity of the poverty measures with respect to the poverty line thus can be easily examined for any chosen range of poverty lines. A special case is the estimation of ultra poverty, which is readily obtained by specifying an ultra poverty line, say at 75 or 80 percent of the regular poverty line.

2. ***Simulating poverty under distributionally neutral growth***. Distributionally neutral growth implies a change in the mean consumption (or whichever variable is used to measure the standard of living) without a change in relative inequalities as embodied in the Lorenz curve. The effect on poverty of distributionally neutral growth is easily simulated by using the projected value of the mean in *Step 3* of the estimation of poverty measures (Section 3). The World Bank's *World Development Report 1990* used such simulations to project poverty for the year 2000.

3. ***Decomposition of changes in poverty into growth and redistribution components***. This decomposition is discussed in detail in Datt and Ravallion (1992), but the basic idea is as follows. For any two dates 0 and 1, the *growth component* of a change in the poverty measure is defined as the change in poverty due to a change in the mean from μ_0 to μ_1 while holding the Lorenz curve constant at $L_0 = L(p;\pi_0)$. The *redistribution component* is defined as the change in poverty due to a change in the Lorenz curve from $L_0 = L(p;\pi_0)$ to $L_1 = L(p;\pi_1)$ while holding the mean constant at μ_0. Hence, the following decomposition:

$$P(\mu_1/z,\pi_1) - P(\mu_0/z,\pi_0) = [P(\mu_1/z,\pi_0) - P(\mu_0/z,\pi_0)] + [P(\mu_0/z,\pi_1) - P(\mu_0/z,\pi_0)] + \textit{Residual};$$

$$\text{Change in poverty} = \text{Growth component} + \text{Redistribution component} + \text{Residual.}$$

Thus, apart from the poverty measures at the two dates, we need two simulated poverty measures, namely $P(\mu_1,\pi_0)$ and $P(\mu_0,\pi_1)$, to compute the decomposition. The simulated poverty measures themselves are easily obtained by estimating poverty with the Lorenz parameters for one date and the mean for the other. Since the poverty line is kept fixed over the two dates, it should be ensured that the means have been adjusted for changes in the cost of living over the two dates. The results of the decomposition of change in poverty in rural India between 1983 and 1986–87 are shown in Table 7.

4. ***Simulating the contribution of regional or sectoral disparities in mean consumption to aggregate poverty***. This involves the following experiment. Suppose, there are n sectors or regions in the economy, each with its mean consumption, μ_i, and Lorenz curve, $L_i = L(p;\pi_i)$ for $i = 1,...,n$. Aggregate poverty in the economy is then derived as the population-weighted sum of poverty in each sector i as given by $P(\mu_i/z,\pi_i)$. We now ask the question: what would be the level of aggregate poverty if there were no disparities in sectoral mean consumptions while intrasectoral inequalities as embodied in the sector-specific Lorenz curves L_i remained unchanged? The answer is obtained by setting each μ_i (mean consumption in sector i) equal to μ (mean consumption for the economy), and evaluating the population-weighted sum of $P(\mu/z,\pi_i)$. The value of $P(\mu/z,\pi_i)$ can be calculated using the formulas in Table 2. The difference between the population-weighted sum of $P(\mu/z,\pi_i)$ and $P(\mu_i/z,\pi_i)$ measures the contribution of sectoral disparities in mean

Table 7—Decomposition of change in poverty in rural India between 1983 and 1986–87

Poverty measure	Total change in poverty	Growth component	Redistribution component	Residual
		(percentage points)		
Head-count index (*H*)	–7.833	–7.635	–0.317	0.119
Poverty gap index (*PG*)	–3.003	–2.817	–0.192	0.006
Foster-Greer-Thorbecke (*SPG*)	–1.438	–1.297	–0.149	0.008

Source: Author's calculations.

consumption to aggregate poverty. Such a simulation can be useful in explaining the poverty profile for a country insofar as it helps us assess how much of aggregate poverty is attributable to differences in mean consumption across regions, sectors, or socioeconomic groups. An application for India is given in Datt and Ravallion (1993).

These are only a few illustrative examples. But the tools presented here can be easily adapted to policy simulations of poverty in other contexts.

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