On Risk and Time in Poverty Measurement

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Abstract: Poverty indices are usually calculated on the basis of cross section income data. As an indicator of well-being the results of such analyses have two shortcomings. First, income insecurity and the risk of becoming poor may affect a person's well-being even if ex post her income is above the poverty line. Second, poverty measurement should take into account time. The longer a period of deficient income lasts the worse is the situation of the individual or household in poverty. The paper generalises some common poverty measures to account for risk and time.

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1 Introduction

Well-being is located in three dimensions. First, well-being is individuals' well-being. Second, well-being comes to people at different times. Third, well-being is a matter of circumstances. Thus we are concerned with its distribution across individuals, across time and across possible states of world.[1] The literature on poverty measurement has almost entirely focused on distributions across individuals.[2] Time and risk have not received sufficient attention.[3]

Poverty measurement focuses on the group of people who cannot achieve or do certain things and cannot meet a certain standard of opportunities or well-being as defined by the poverty line. In a market society income and wealth are relevant, although far from perfect, indicators of what a person can achieve. For ease of presentation I shall focus on income. Note, however, that the main ideas of the paper are independent of the choice of indicator.

Most studies in poverty measurement use household income data to calculate one or more of various poverty measures, such as the head count ratio, the income gap ratio or Sen's poverty index, to name a few. The measurement implicitly assumes a fixed income. This reflects an *ex post* perspective. However an assessment of the current state of poverty must take an *ex ante* perspective to account for the uncertainty of income. According to the standard definition of poverty a person is poor if her income is less than the minimum income defined by the poverty line. However, even if both, her expected and her ex post income are above the poverty line there may still exist a threat of falling below the poverty line which affects a person's well-being. Neither the actual income earned in a given period nor the expected income do provide a sufficient basis

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[1] John Broome (1990) develops this framework to characterise the structure of good.

[2] Cf. e.g. the extensive surveys by Seidl (1988) and Zheng (1997).

[3] Bigman (1993) is a notable exception.

for judgements on the extent of poverty. The standard measures employed in poverty measurement must be refined to take into account the uncertainty of future earnings. Also future needs may be uncertain.

The distribution of income across time has an important impact on how poverty affects a person's well-being. A long period of poverty may be worse than several shorter periods. Poverty measurement is usually based on cross section data. This neglects the time dimension. Information about the length of time a person remains in poverty is important for a judgement of how badly this person is doing. The *anonymity axiom* seems to rule out the consideration of time and duration of poverty in a formal analysis. Anonymity requires that it does not matter who is poor. However, poverty is worse for a person if *this* person has also been poor in the preceding period. A similar argument applies to the *focus axiom*. The focus axiom states that a change in income of a non-poor person should not affect the poverty measure. But the status of poverty of a person can be affected by her income in the preceding period even if at that time she has not been poor. The anonymity axiom and the focus axiom need careful interpretation when applied to poverty measurement in a multiperiod context.

The plan of the paper is as follows. The next section introduces the basic notation and definitions. Section 3 suggests a refinement of poverty measurement which takes uncertainty of future incomes into account. Aspects of time in poverty measurement are discussed in section 4. Section 5 concludes.

2 Notation and definitions

One important indicator to judge success or failure of a society's political and economic system is how well it protects individuals from poverty. A prerequisite of such judgement is a definition and a measure of poverty. A definition of poverty is necessary to identify the poor. It must – in principle – be possible to state whether or not individual i is poor. This is the so-called identification problem. We can identify the poor by checking each individual's income and compare it to some standard or minimum income that ought to be met. Formally, the identification problem is solved by defining a minimum income, the poverty line z, such that all individuals i who earn income $y_i < z$ are said to be poor.

If we can identify the poor, it is possible to calculate the ratio of the poor in a society. However, the resulting figure does not tell very much about the severity of poverty. Therefore, according to Sen (1976), an aggregate measure of poverty must rely on additional information like, for example, the income inequality among the poor or the income gap which is the amount of money needed to raise an average poor person's income up to the poverty line. Suppose there are n members of society. A poverty measure is a normalised index $P \in [0, 1]$ attached to each vector of incomes and a poverty line, $(y_1, y_2, ..., y_n; z)$. Without loss of generality, we assume $y_1 \leq y_2 \leq ... \leq y_q < z \leq y_{q+1} \leq ... \leq y_n$. Thus q is the number of the poor.

To demonstrate the impact of risk and time in poverty measurement I consider four poverty measures defined below: the headcount ratio H, the income gap ratio I, Sen's (1976) poverty measure S, and the measure suggested by Foster, Greer and Thorbecke (1984) F. However, the approach developed in the following sections is more general and can be applied to other measures as well.

The simplest and most widely used poverty measure is the head count ratio

$$H = \frac{q}{n}. \tag{2.1}$$

Let $\bar{y} = \frac{1}{q}\sum_{i=1}^{q} y_i$ be the average income of the poor. Then the income gap ratio is defined as

$$I = \frac{z - \bar{y}}{z}. \tag{2.2}$$

Sen's (1976) poverty measure is

$$S \;= H[I + (1 - I)G], \tag{2.3}$$

where G is the Gini coefficient of the income distribution of the poor:

$$G = \frac{1}{2\bar{y}q^2}\sum_{i=1}^{q}\sum_{j=1}^{q}\left|y_i - y_j\right|. \tag{2.4}$$

The measure suggested by Foster, Greer and Thorbecke (1984) is

$$F = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{z - y_i}{z}\right)^{\alpha}, \tag{2.5}$$

where $\alpha \geq 0$ is a constant. Note that $F=H$ for $\alpha=0$ and $F=HI$ for $\alpha=1$. F is known to satisfy various desirable properties for $\alpha>2$.[4]

[4] See Foster, Greer and Thorbecke (1984) and Zheng (1997, 150 f.) for a full account its properties.

3 The risk dimension in poverty measurement

An individual i who has earned a sufficient income $y_i \geq z$ in a given period does not count as poor. Uncertainty may change the picture. There are two cases. First, future needs are uncertain. Since the poverty line defines the minimum income necessary to reach a certain standard of needs satisfaction, uncertainty of needs can be captured by introducing uncertainty of the poverty line z into a model of measurement. This case has been dealt with elsewhere and I do not want to repeat the analysis.[5] The second case is the uncertainty of income. If y_i is close enough to z and of uncertain magnitude *ex ante*, i faces a risk of being poor. This risk may affect i's well-being and, therefore, it seems worth considering its impact. Poverty measures using information about the incomes in past periods may understate the impact of poverty when future incomes are uncertain. An individual may be threatened by poverty without actually being poor. Hence the purpose of this section is to construct poverty measures which take income uncertainty into account. The next section will deal with time.

An *ex ante* poverty measure can be constructed on the basis of the probability distribution of i's income expressed by a density function $f_i(y_i)$. We can write the probability that i's income will fall below the poverty line, i.e. the probability that i is poor as

$$\pi_i = \int_0^z f_i(y_i)\, dy_i \ . \tag{3.1}$$

Given individuals' probability distributions of income, we can calculate the expected poverty rate as

$$\hat{H} = \frac{1}{n} \sum_{i=1}^{n} \pi_i \ . \tag{3.2}$$

$\hat{H}$ is a generalisation of measure H. If probabilities π_i are restricted to be either 0 or 1, then $\hat{H}$ collapses to H (see equation 2.1).

Furthermore, $\frac{1}{\pi_i} \int_0^z y_i f_i(y_i)\, dy_i$ is the expected income of person i, if i turns out to be poor. Note that in this case $\pi_i > 0$. Define

[5] Uncertainty of needs has been discussed in the context of nutritional needs. See Anand and Harris (1992), Kakwani (1992) and Gabbert and Weikard (1999).

$$\hat{y}_i = \begin{cases} \dfrac{1}{\pi_i}\displaystyle\int_0^z y_i f_i(y_i)dy_i & \text{if } \pi_i > 0 \\ z & \text{if } \pi_i = 0 \end{cases} . \tag{3.3}$$

The expected income gap ratio of individual *i* (conditional on *i* being poor) is given by

$$\hat{I}_i = \frac{z-\hat{y}_i}{z} . \tag{3.4}$$

Again, for y_i known with certainty, $\hat{I}_i$ collapses to $\dfrac{z-y_i}{z}$. To derive the expected income gap ratio for society we must consider the average expected income of the poor which is given by

$$\bar{\hat{y}} = \frac{1}{n\hat{H}}\sum_{i=1}^{n}\pi_i\hat{y}_i . \tag{3.5}$$

Note that $n\hat{H}$ corresponds to the number of poor individuals in society. Given (3.4) the expected income gap ratio can be written in the usual form:

$$\hat{I} = \frac{z-\bar{\hat{y}}}{z} . \tag{3.6}$$

In order to derive the analogue to Sen's poverty measure for the case of uncertain income the Gini-coefficient of the distribution of the poor must be adapted in a similar manner. Let $\tilde{y}_i$ be *i*'s minimum income. Suppose, without loss of generality, $\tilde{y}_i \le \tilde{y}_j \Leftrightarrow i \le j$. Let $\tilde{m}$ be the number of individuals for whose minimum income is below the poverty line, $\tilde{y}_{\tilde{m}} < z \le \tilde{y}_{\tilde{m}+1}$. Thus, π_i>0 for all $i \le \tilde{m}$. Then the expected Gini-coefficient of the income distribution of the poor can be written as follows:

$$\hat{G} = \frac{1}{2\bar{\hat{y}}(n\hat{H})^2}\sum_{i=1}^{\tilde{m}}\sum_{j=1}^{\tilde{m}}\frac{1}{\pi_i\pi_j}\int_0^z\int_0^z \left|y_i - y_j\right| f_i(y_i)f_j(y_j)dy_i dy_j . \tag{3.7}$$

Given (3.2), (3.6) and (3.7) the uncertainty formulation of Sen's poverty index is

$$\hat{S} = \hat{H}[\hat{I} + (1-\hat{I})\hat{G}] . \tag{3.8}$$

Given (3.4) the Foster-Greer-Thorbecke measure of poverty can refined in a similar way:

$$\hat{F} = \frac{1}{n}\sum_{i=1}^{n}\pi_i\hat{I}_i^{\alpha} . \tag{3.9}$$

Table 1 gives a summary of the basic concepts dealing with the case of uncertain income in poverty measurement.

Table 1: Basic concepts for poverty measurement with uncertain income

	certainty	uncertainty
probability of being poor	either 0 or 1	$\pi_i = \int_0^z f(y_i)\,dy_i$
expected income if poor	y_i	$\hat{y}_i = \frac{1}{\pi_i}\int_0^z y_i f_i(y_i)\,dy_i$
number of the poor	q	$\sum_{i=1}^{n} \pi_i$
head count ratio	$H = \frac{q}{n}$	$\hat{H} = \frac{1}{n}\sum_{i=1}^{n} \pi_i$
average income of the poor	$\bar{y} = \frac{1}{q}\sum_{i=1}^{q} y_i$	$\bar{\hat{y}} = \frac{1}{n\hat{H}}\sum_{i=1}^{n} \pi_i \hat{y}_i$
income gap ratio	$I = \frac{z-\bar{y}}{z}$	$\hat{I} = \frac{z-\bar{\hat{y}}}{z}$

The remainder of this section illustrates the differences between the *ex post* and the *ex ante* approach by means of an example. Compare two situations, A and B. In situation A each person receives her expected income with certainty, while in situation B individual *i* receives an uncertain income, all else the same. To keep matters simple, I assume that *i*'s income is low y_i^l with probability λ_i, or high y_i^h with probability $1-\lambda_i$. Denote *i*'s (unconditional) expected income $\hat{\hat{y}}_i = \lambda_i y_i^l + (1-\lambda_i) y_i^h$.[6]

There are four cases:

(i) $y_i^l > z$. In this case *i* faces no risk of being poor. *i*'s uncertainty of income plays no role for poverty measurement.

(ii) $\hat{\hat{y}}_i \geq z$ and $y_i^l < z$. In this case, although her expected income is above the poverty line, *i* faces a risk of being poor. Thus the head count measure $\hat{H}$ is increased by λ_i compared to situation A where *i* receives $\hat{\hat{y}}_i$ with certainty.

To study the effect of uncertainty on the expected poverty gap ratio $\hat{I}$, note that $\hat{y}_i = y_i^l$.

We must distinguish two cases. If the average income of the poor $\bar{\hat{y}}$ is lower than $\hat{y}_i$, then the income gap ratio $\hat{I}$ is lower in situation B than in A. The expected average

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[6] This is to be distinguished from *i*'s expected income if *i* is poor; see equation (3.3).

income shortfall decreases and, thus, the income gap ratio decreases when an individual who is not as poor as the others joins the group of the poor. If, on the other hand, $\bar{\hat{y}} > \hat{y}_i$, then the income gap ratio $\hat{I}$ is higher in situation B than in A. The poverty gap ratio increases when an individual who is poorer than the others joins the group of the poor.

The effect of income uncertainty on Sen's poverty measure and on the Foster-Greer-Thorbecke measure is unambiguous since both measures satisfy a strong monotonicity condition.[7] Both measures show an increase of poverty when we move from situation A to B.

(iii) $\hat{\hat{y}}_i < z$ and $y_i^h \geq z$. The analysis of this case is similar to case (ii). Comparing A and B, we find $\hat{H} < H$, because there is a positive probability that i is above the poverty line. We find a higher (lower) expected poverty gap ratio $\hat{I}$ if $\hat{y}_i$ is above (below) $\bar{\hat{y}}$. The chance to receive an income above the poverty line decreases Sen's poverty measure as well as the Foster-Greer-Thorbecke measure.

(iv) $y_i^h < z$. Finally, we consider an uncertain income of a poor individual i, where i remains among the poor even if she receives the high income y_i^h. Here we find no effect of adding uncertainty with regard to the measures $\hat{H}$, $\hat{I}$ and, therefore, $\hat{F}$ by inspection of equation (3.9). However, Sen's poverty measure $\hat{S}$ may show an increase in poverty. Since $\hat{H}$ and $\hat{I}$ are unaffected, this effect is due to a possible change in the Gini coefficient. This can be seen as follows: In situation A $\hat{G}$ is based on differences y_i–y_j. With uncertainty of y_i we must instead consider a weighted sum $\lambda_i \left| y_i^l - y_j \right| + (1-\lambda_i) \left| y_i^h - y_j \right|$. Since, for an arbitrary y_j it holds that

$$\lambda_i \left| y_i^l - y_j \right| + (1-\lambda_i) \left| y_i^h - y_j \right| \geq \left| \hat{\hat{y}}_i - y_j \right|,$$

it follows that $\hat{G}$(A)$\leq\hat{G}$(B). Hence, $\hat{S}$ may increase when the income uncertainty of the poor increases.

4 The time dimension in poverty measurement

Consider a person living for T_i^* periods with a certain income path $y_i = (y_{i1},...,y_{iT_i^*})$. With perfect capital markets the time dimension will cause no difficulty for poverty measurement. Capital markets allow a shift of income from one period to another. Thus, in order to assess a person's poverty status, it is sufficient to check the total life-time income and compare it to an appropriately defined poverty line. A person should be considered as poor if and only if

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[7] See Zheng (1997).

$$\sum_{t=0}^{T_i^*} y_{it}(1+r)^{-t} < \sum_{t=0}^{T_i^*} z_t(1+r)^{-t}, \tag{4.1}$$

where r is the interest rate and z_t is the poverty line at time t. Equation (4.1) states that the net present value of earnings is to be compared to the net present value of the income needs. Note that this definition is appropriate only under conditions of certainty and perfect capital markets. The definition still works under uncertainty if the relevant insurance markets exist. Under such conditions poverty measurement over time simply uses the method of discounting. Income paths and needs paths can be compared by looking at their net present values.

In a world with imperfect insurance and capital markets the poor often cannot obtain credit, even if their later earnings are sufficient to pay back debt and interest. Time creates an asymmetry. Early earnings can be transfered to later periods, but later earnings cannot be transfered to earlier periods. It is easy to save when you are rich, but hard to borrough when you are poor. A person can be poor in one period, although her total income would be sufficient to avoid poverty in any period. The net present value of life-time income is no longer an adequate indicator of poverty. Instead it is necessary to check in every period whether or not a person is below or above the poverty line.

Who can save in one period can insure herself against poverty in later periods. With the basic understanding that poverty is the lack of access to sufficient means to obtain a certain living standard, income *plus* initial wealth is the relevant indicator. Savings can be seen as a transfer from a former to a later self. In this sense earlier savings are income for the later self. Thus, for what follows, i's income in period t is includes transfers from earlier periods to period t. Since this paper's focus is on poverty measurement, I do not discuss individual savings decisions nor social policies like obligatory savings and insurance. In this section the focus is entirely on the measurement of poverty across time; I do not consider uncertainty.

A time adjusted poverty measure seeks to assess the current status of poverty on the basis of individual histories. There are two problems. First, we must assess each person's poverty status on the basis of her own history. Second, we must define an aggregate poverty measure for society. Consider a society of n persons with a constant population. Person i's current age is T_i and she has received income y_{it} in period $t = (0, ..., T)$. A first step is to define an individual poverty rate

$$H_i^{'} = \frac{\sum_{t=0}^{T_i} a_{it}}{T_i}, \tag{4.2}$$

where

$$a_{it} = \begin{cases} 1 & \text{if } y_{it} < z_t \\ 0 & \text{otherwise} \end{cases} .$$

$H_i^{'}$ is the ratio of life time i has suffered from poverty.

Aggregate poverty can be assessed by the standard poverty measures. The headcount rate is given by

$$H^{'} = \frac{\sum_{i=1}^{n} \sum_{t=0}^{T_i} a_{it}}{\sum_{i=1}^{n} T_i} . \tag{4.3}$$

Measure (4.3) essentially aggregates the standard head count ratio over time based on a separability assumption. It takes into account each living person's history but it neglects the connections between periods. Consider, however, two individuals i and j living in periods t and t+1. Suppose i is poor and j is not poor in t. Then the measure should distinguish two situations, where either i or j is poor in period t+1. In one situation i is poor for two periods in sequence while j is not poor at all; in the other situation each is poor for only one period. If long term poverty deserves special attention, we must drop the separabiliy assumption on which (4.3) is based. This is done in what follows. The weight attached to person i's income if i is poor in period t depends on how well i is doing in other periods. Dropping separability across time means that the anonymity axiom cannot be required for an assessment of the state of poverty in a single period. Anonymity requires that the poverty measure is independent of any permutation of incomes. The use of the recorded income data must be independent of other characteristics of the individuals. Anonymity is adopted to ensure an impartial measurement. However, our example above shows that poverty in period t+1 is *not* independent of whether i or j receives an income below the poverty line. Anonymity requires too much if applied to the situation of a given period, but it can be retained with regard to income paths.

To deal with time appropriately we must consider income paths $(y_{i1},...,y_{iT})$. Each possible income path must be assessed with regard to its poverty status. Formally, we assign an individual poverty measure $P_{iT} \in [0, 1]$ to every possible income path of arbitrary length T. Poverty measurement based on income paths allows incomes above the poverty line to play a role. Earnings well above the poverty line will improve the person's capacity to cope with poverty in the future. It follows that in the context of time the focus axiom does not apply. The focus axiom states that a poverty measure should only be based on the income of the poor. A multiperiod measure of poverty P_T can be built around the idea that a person's capacity to cope with poverty is diminished in each period the income falls below z. Thus the measure must attach more weight to an income shortfall in period t the poorer the person has been in previous periods.

For what follows I adopt two simplifications, a zero interest rate and a poverty line z which is constant over time.

We recursively define i's income needs at time t, ν_{it} as

$$\begin{aligned} \nu_{i1} &= z \\ \nu_{i\,t+1} &= \begin{cases} z+\delta(\nu_{it}-y_{it}) & \text{if } \nu_{it} > y_{it} \\ z & \text{otherwise} \end{cases} \end{aligned} \tag{4.4}$$

where $\delta \geq 0$ is a weight attached to the income gap $(\nu_{it}-y_{it})$ of the previous period. If i's income needs in period t were not met, i would require an amount $\delta(\nu_{it}-y_{it})$ in addition to what would be necessary to meet the poverty line in period t+1. The multiperiod analogue to the individual income gap simply is

$$g_{it} = \begin{cases} \nu_{it}-y_{it} & \text{if } \nu_{it} > y_{it} \\ 0 & \text{otherwise} \end{cases} \quad . \tag{4.5}$$

The relevant information from the income path up to time t is captured by the income needs measure ν_{it}.

The next step in the construction of a multiperiod poverty measure is aggregation across persons. Given (4.5), without loss of generality we can sort inviduals such that $g_{1t} \geq g_{2t} \geq \ldots \geq g_{mt} > 0 = g_{mt+1} = \ldots = g_{nt}$. Thus m is the number of the poor. The head count ratio is then defined in the usual way

$$H_t = \frac{m_t}{n}\,. \tag{4.6}$$

Based on individual income gaps defined by (4.5) the income gap ratio of the society is

$$I_t = \frac{1}{m_t} \sum_{i=1}^{m_t} \frac{g_{it}}{\sum_{\tau=0}^{T_i} z\delta^\tau}\,, \tag{4.7}$$

where T_i is i's age at time t. If i would never receive any income, her income gap at age T_i would be $\sum_{\tau=0}^{T_i} z\delta^\tau$. This is used to normalise the measure.

To construct the analogue to Sen's measure S for the multiperiod case we rewrite S as

$$S = HI(1+G^*)\,, \tag{4.8}$$

where G^* denotes the Gini coefficient of the distribution of the individual income gaps:[8]

[8] See Clark/Hemming/Ulph (1981, 519).

$$G^* = \frac{1}{2\bar{g}q^2}\sum_{i=1}^{q}\sum_{j=1}^{q}\left|g_i - g_j\right|, \tag{4.9}$$

where $\bar{g}$ is the average income gap of the poor. Sen's measure can then be easily adjusted to account for accumulation effects of poverty by sustitutiong (4.5), (4.6) and (4.7) into (4.8) and (4.9), respectively.

$$S_t = H_t I_t (1 + G_t^*) \, . \tag{4.10}$$

Similarly the Foster-Greer-Thorbecke measure becomes

$$F_t = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{g_{it}}{\sum_{\tau=0}^{T_i} z\delta^{\tau}}\right)^{\alpha} \quad . \tag{4.11}$$

5 Concluding remarks

Risk and time are important dimensions when we try to assess the impact of poverty. This paper spells out how risk and time can be accounted for by a refinement of existing poverty measures. The existing literature on poverty measurement has not taken up this issue with exception of a paper by Bigman (1993). Bigman discusses the measurement of food security. However, in his analysis he does not clearly distinguish risk and time. While risk and time are connected because the future is uncertain, the concepts are clearly distinct and so is their impact on poverty measurement as shown in this paper.

While this paper looks at refinements of existing measures, future research can follow two different lines. Firstly, both, risk and time, seem to have a significant impact on poverty measures. If the distribution function of income across persons is asymmetric around *z*, the standard approach to poverty measurement generates an estimation error, if income is uncertain. For example, if there are more individuals just above than just below the poverty line (*z* is on the increasing part of the income distribution function), then we find underestimation of poverty for the standard (*ex post*) analysis. Note, that this applies to most countries. Empirical analysis can reveal the impact and significance of dealing with risk and time in poverty measurement. Secondly, one can specify suitable conditions (axioms) applicable to the situation of uncertain income and income deficiencies over time. Such axiomatic approach would yield further insight into the matter and it would most probably shed new light on the existing poverty measures.

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