World Development Vol. 37, No. 1, pp. 11–25, 2009

0305-750X/$ - see front matter

ELSEVIER
www.elsevier.com/locate/worlddev

doi:10.1016/j.worlddev.2007.12.006

The Evolution of World Inequality in Well-being

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Summary. — In this paper, we use the tools offered by the recent literature on multidimensional inequality measurement to investigate the evolution of the inequality in well-being across different countries during 1975–2000. We focus on three important dimensions of life: standard of living, health, and education. Inequality in the three dimensions shows a different trend during 1975–2000. We propose a flexible measure of well-being to quantify the evolution of overall intercountry well-being inequality. The empirical results are sensitive to different normative choices on the trade-offs between the different dimensions. Especially the concave transformation of income turns out to be decisive for the evolution of world inequality in well-being.

Key words — multidimensional inequality measurement, index of well-being, inter-country inequality

1. INTRODUCTION

Measuring global inequality has received an increasing amount of attention both in theoretical and in policy oriented research. [1] The focus of this literature is largely on income inequality. There is by now nearly consensus that income inequality across *countries* has *in*creased during the last decades, if one considers each country as a unit of observation and does not weigh for population. There is a lively debate, however, about the relevancy of such unweighted income inequality measures (Milanovic, 2005).

Of course, while the development of income inequality *per se* is worth investigating, income is only one dimension of economic well-being. There is no a priori reason to expect that the evolution over time is the same along the income and the non-income dimensions of well-being (Bourguignon & Morrisson, 2002). In fact, many claim that the international inequality in *well-being* is *de*creasing over time, be it at a slowing pace:

> "For most of the past 40 years human capabilities have been gradually converging. From a low base, developing countries as a group have been catching up with rich countries in such areas as life expectancy, child mortality, and literacy. A worrying aspect of human development today is that overall state of converging is slowing—and for a large group of countries divergence is becoming the order of the day." (Human Development Report, 2005).

In this paper, we want to investigate this claim.

Different approaches to measure inequality in well-being have been proposed in the literature. At one extreme, one finds the authors who look at the inequality of the individual dimensions separately and refrain from constructing any composite index of well-being. Examples are Slottje, Scully, Hirschberg, and Hayes (1991), Easterlin (2000), Hobijn and Franses (2001), Neumayer (2003), or the World Development Report (2006). This approach makes it difficult to formulate an overall conclusion, if the evolution on the different individual dimensions is different. At the other extreme, one finds the approaches that first construct a composite index of well-being and then measure the inequality in that composite index (e.g., Becker, Philipson, & Soares, 2005; Fischer, 2003; McGillivray & Pillarisetti, 2004; or Noorbakhsh, 2006). The most popular composite index of well-being is the Human Development Index (HDI), summarizing the performance of the countries on the three dimensions of well-being: standard of living, health, and education. Fischer (2003) has argued that inequality in well-being measured by the HDI has decreased over time. Becker *et al.* (2005) also find a decrease in inequality with an alternative measure of well-being, summarizing income and life expectancy. The construction of a composite index of well-being implies that one basically reduces the multidimensional nature of the problem to one dimension.

In this paper, we will apply an approach which is in between these two extremes, and which to the best of our knowledge has not yet been applied to analyze the evolution of well-being inequality in the world: the use of recently developed measures of multidimensional inequality. While this approach refrains from reducing the multidimensional problem to a unidimensional one and reformulates the Pigou–Dalton transfer principle explicitly in a multidimensional setting, in the end it results in one overall index of inequality. We will compare this multidimensional approach to the other approaches. [2]

In our empirical application, we quantify the evolution of inequality in well-being since 1975. To make our results comparable with earlier work, we focus on the dimensions that are also taken up in the HDI. Unfortunately, individual data about the non-income dimensions of well-being are not available for all countries of the world. Indicators aggregated at the country level, however, can be obtained for a growing number

* A previous version of this paper has been presented at the 2006 Social Choice and Welfare conference in Istanbul, at the "Global Distributive Justice"-seminar, organized by the World Bank in May 2007, at the 2007 IIPF-conference in Warwick and at seminars in Barcelona and Leuven. We thank the participants of these conferences and four anonymous referees for valuable comments and suggestions. The usual disclaimer applies. Final revision accepted: December 12, 2007.

of countries. Therefore, we work with aggregated data and consider countries as units of observation. We then face the same question about population weighting that is well known from the literature on income inequality. We opt for looking at *un*weighted inequality across countries, so that all countries count the same, small or large. It is obviously debatable that huge countries like China get the same weight as very small countries (see, e.g., Sala-i-Martin, 2006). We will therefore also show some results for population weighted inequality. Yet, we attach more importance to the unweighted inequality measures, for at least three reasons. First and most importantly—since one of our purposes is to compare the evolution in well-being inequality with the evolution in income inequality—the least ambiguous results can be obtained by taking as a benchmark the evolution of unweighted income inequality. Indeed, as mentioned before, there is a general consensus that this concept has increased in recent decades. We will then investigate whether the same conclusion holds for well-being inequality. Second, "countries" can be seen as sets of policies implemented at the national level, and these sets can be usefully compared according to their effectiveness in generating well-being for their citizens. [3] Finally, weighted inequality figures tend to be very sensitive to the performance of a few populated countries like China or India. Small measurement errors are likely to have a large impact.

The paper is organized as follows. In Section 2, we describe how the multidimensional measurement of inequality is to be compared with the other approaches to measure inequality in well-being. We propose to work with a flexible family of indices, one member of which is the multidimensional Atkinson index axiomatized by Tsui (1995). We will also discuss the relationship between our approach, the Human Development Index and the full income measure of Becker *et al.* (2005). Section 3, which is the core of the paper, presents our empirical results for unweighted inequality. After a brief overview of the data, we first analyze the dimensions of well-being separately. We then show the development of well-being inequality over time. Since we work with a flexible family of multidimensional indices, we can test the sensitivity of the trend in well-being inequality for different normative choices. It will turn out that the traditional claim of decreasing well-being inequality has to be qualified. In Section 4, we will show some results for population weighted inequality. Section 5 concludes.

2. HOW TO MEASURE INEQUALITY IN WELL-BEING?

Consider n countries and k dimensions of well-being. The state of the world at time t is then described by the $n \times k$ real valued positive distribution matrix X^t. Element x^t_{ij} represents the achievement of country i for indicator j in period t. For notational convenience we will usually drop the superscript t in the sequel. Define $x_{i.}$ as the row vector describing the achievement of country i with respect to the various indicators in the dataset and $x_{.j}$ as the column vector describing the achievements of all the countries for indicator j.

If one accepts that the different dimensions of well-being are incommensurable, one has to limit oneself to an analysis of the evolution of inequality for each of the dimensions separately, that is, to focus on the columns $x_{.j}$. However, as soon as the development of inequality on different dimensions diverges, not aggregating makes it impossible to draw any general conclusion about the evolution of overall inequality. On the other hand, all aggregation procedures necessitate the introduction of specific assumptions about the trade-offs between different dimensions in the construction of an overall index. A first approach consists in constructing a composite index of well-being. Since this basically makes the problem unidimensional, one can then in a second stage calculate traditional *unidimensional* inequality measures. A second approach is the direct measurement of *multidimensional* inequality. We will present these two approaches in this section, but first we will go deeper into the construction of a composite index of well-being.

(a) *A composite index of well-being*

The most natural approach to the aggregation problem may seem to construct a unidimensional composite index of well-being. We propose to work with a general and flexible class of indices, which can represent different normative choices. Often, the original values of the indicators in X are first transformed, for example, by taking logarithms or by standardizing to make the dimensions comparable. If we define f_j $(j = 1, \ldots, k)$ to be the dimension-specific transformation functions, we obtain the elements of the transformed distribution matrix Z:

$$z_{ij} = f_j(x_{ij}), \quad i = 1, \ldots, n; \;\; j = 1, \ldots, k. \tag{1}$$

To capture the trade-offs between the dimensions in a flexible way, the transformed data can then be aggregated by taking a generalized weighted mean of order β. [4] Since the latter parameter plays a crucial role, we use it to index the aggregation functions $S_\beta(z_{i.})$. The weights are denoted by w_j.

$$S_\beta(z_{i.}) = \left[\sum_{j=1}^{k} w_j z_{ij}^{\beta}\right]^{1/\beta}, \quad i = 1, \ldots, n. \tag{2}$$

The interpretation of β is obvious. For β equal to 1, the (transformed) dimensions of well-being are seen as perfect *substitutes*. A bad performance on one dimension can be compensated by a good performance on another dimension. For β going to $-\infty$, dimensions are treated as perfect complements and the aggregation function will favor an equal development along the dimensions. An intermediate case is obtained for β equal to 0 with the composite indicator of well-being of the Cobb–Douglas type. More generally, β equals $1 - 1/\sigma$, where σ is defined as the constant elasticity of substitution between the dimensions of well-being.

Introducing Eqn. (1) into (2) gives a general composite index of well-being:

$$\widetilde{S_\beta}(x_{i.}) = \left[\sum_{j=1}^{k} w_j [f_j(x_{ij})]^{\beta}\right]^{1/\beta}, \quad i = 1, \ldots, n. \tag{3}$$

Different choices for β, for the weights, and for the functions $f_j(\cdot)$ will lead to different composite indices. We illustrate this with two prominent examples: the Human Development Index and the full income concept suggested by Becker *et al.* (2005) (BPS in the sequel). The logic behind both the approaches is very different: the HDI embodies the a priori values of the analyst, while in the analysis of Becker *et al.* the parameter values are obtained by calibration based on market behavior. We will not go into these basic methodological differences, but rather focus on the differences concerning the trade-offs between the various dimensions.

(i) *Human development index*

The Human Development Index, published yearly by the UNDP since 1990, is a composite index of three basic dimensions of well-being: standard of living, health, and education, which are measured by four indicators (GDP *per capita*, life expectancy at birth, adult literacy rate, and the combined school enrollment rate). We will indicate the four indicators with the subscripts 1–4, respectively.

The four indicators are transformed by the following dimension-specific transformation function:

$$f_j^{HDI}(x_{ij}) = \frac{g_j(x_{ij}) - x_j^{\min}}{x_j^{\max} - x_j^{\min}}, \quad i = 1, \ldots, n; \; j = 1, \ldots, 4. \tag{4}$$

The values of the parameters are given in Table 1. For the calculation of the HDI, a logarithmic transformation is applied to the income dimension. [5] Anand and Sen (2000) defend this transformation by pointing out that the valued object is not income itself, but the things that people are able to do with the help of income. The strict concavity of the transformation function then reflects diminishing returns of the conversion of income into well-being. In addition, the HDI applies a standardization procedure, such that the standardized data reflect the achievements in terms of percentage from the minimal to the maximal value. Initially, these minimal and maximal values were obtained from the data at hand, but after the criticism by Anand and Sen (1993), fixed goalposts $x_j^{\min}$ and $x_j^{\max}$ have been used since 1994.

The transformed dimensions of the HDI are aggregated by making use of a simple weighted average, with weights w_j. This implies that the parameter β in expression Eqn. (3) is set equal to 1, that is, that the dimensions are seen as perfect substitutes. It is worthwhile noting that this contradicts the proclaimed philosophy of the Human Development approach, as stated, for example, in a recent Human Development Report:

> "Losses in human welfare linked to life expectancy, for example, cannot be compensated for by gains in other areas such as income or education." (Human Development Report, 2005).

In Table 2, we quantify the implicit trade-offs between the dimensions of well-being by calculating the marginal rates of substitution (MRS), reflecting the rate at which countries can trade off a small change in one dimension for another. A country stays at the same level of human development if it trades off 1 year of life expectancy for 10% of its GDP *per capita*. For example, Sweden and Belgium have a roughly equal level of human development (0.94), with the GDP *per capita* of Belgium being 10% higher than that of Sweden, whereas Swedes live one year longer on average. Similarly: an increase by 1% of the literacy rate can be traded off for 4% of GDP *per capita*, or for about 0.41 years (about 5 months) of longevity. Similar results have been obtained by Lind (2004) and Ravallion (1997).

(ii) *The full income approach of Becker et al. (2005)*

Becker *et al.* (2005) developed a model to incorporate the gains in longevity into an overall assessment of well-being inequality. Contrary to the HDI, they do not take up educational indicators. [6] Their transformation functions of income and longevity are both concave. Income is transformed by the iso-elastic function proposed in the literature on inequality measurement by Atkinson (1970). In addition, they translate the transformed income dimension over ζ_1, in order to calibrate the value of being alive rather than dead:

$$f_1^{BPS}(x_{i1}) = \frac{(x_{i1})^{1-\eta}}{1-\eta} - \zeta_1, \quad i = 1, \ldots, n. \tag{5}$$

The parameter η measures the extent of diminishing returns in the process of transforming income into well-being. It is the elasticity of the marginal well-being with respect to income, or equivalently the inverse of the inter-temporal elasticity of substitution. For the transformation to be concave, η should be non negative. If $\eta = 0$, well-being is linear in income. As η approaches 1, the transformation becomes the logarithmic one. From the literature on the value of life, Becker *et al.* (2005) calibrate the parameter ζ_1 to a value of 16.2 and the parameter η to a value of 0.8. This calibration implies that an individual with an annual income equal to \$353 would be indifferent between being alive or dead. [7]

The longevity dimension is transformed by the standard expression for the annuity with interest rate r and length equal to the life expectancy:

$$f_2^{BPS}(x_{i2}) = \int_0^{x_{i2}} \exp(-rt)\mathrm{d}t = \frac{1}{r}(1 - \exp(-rx_{i2})), \quad i = 1, \ldots, n. \tag{6}$$

Due to the concavity of this expression, the increase in well-being obtained by a small prolongation of longevity is larger at lower levels of life expectancy. The higher r, the more concave the transformation of longevity. If r approaches 0, the transformation function becomes a constant function. In the BPS-approach, r is assumed to be equal to 0.03. Note that the HDI transformation functions g_j summarized in Table 1 are essentially limit cases of the above functions (5) and (6), with parameter values $\eta = 1$, $\zeta_1 = 0$ and $r = 0$, respectively.

The BPS-approach aggregates the transformed dimensions by a simple multiplication. This is equivalent to taking the square of the Cobb–Douglas aggregation function with equal weights. The Cobb–Douglas aggregation function can be obtained by setting $\beta = 0$ in expression Eqn. (2), which shows the close formal connection between both the approaches. Squaring the aggregation function does not alter the underlying preferences over the dimensions. Using a first-order Taylor expansion and imposing the condition that ζ_1 is close to 0, the marginal rate of substitution between income and longevity in the BPS-approach can be approximated by

$$MRS_i^{BPS} \approx \frac{1}{(1-\eta)} \frac{x_{i1}}{x_{i2}}, \quad i = 1, \ldots, n. \tag{7}$$

Note that for parameter η equal to 0.8, and a longevity of 50 years, an extra year of life expectancy can be traded off for about 10% of GDP/*capita*, similar to the assumed marginal rate of substitution in the Human Development Index. Especially, for the countries with a low life expectancy the BPS-approach allows less substitution than the Human Development Index.

(b) *Measuring unidimensional inequality in well-being*

Once one agrees about a composite index of well-being, one can easily calculate overall inequality by applying a traditional unidimensional inequality measure. Becker *et al.* (2005) analyze cross-country inequality in a money metric of their BPS-index using the relative mean deviation, the coefficient of variation, the standard deviation of logs, and the Gini coefficient. McGillivray and Pillarisetti (2004) calculate both

Table 1. *Transformation, goalposts, and weights in the human development index*

Indicator	$g(x_{.j})$	$x_j^{\min}$	$x_j^{\max}$	w_j
GDP *per capita*	$\log(x_{.j})$	log(100)	log(40,000)	0.333
Longevity	$x_{.j}$	25	85	0.333
Literacy rate	$x_{.j}$	0	100	0.222
Enrollment rate	$x_{.j}$	0	100	0.111

Table 2. *Marginal rates of substitution between the dimensions of well-being in the HDI*

	GDP *per capita*	Longevity	Literacy	Enrollment
GDP *per capita*	1			
Longevity	10% of GDP	1		
Literacy rate	4% of GDP	0.41	1	
Enrollment rate	2% of GDP	0.21	0.50	1

Theil's indices and the Wolfson index of the HDI and two other gender-related composite indicators of well-being: the Gender-related Development Index (GDI) and the Gender Empowerment Measure (GEM). Noorbakhsh (2006) investigates convergence in the HDI by calculating various convergence measures, among which the standard deviation of logs, the coefficient of variation, and the Gini coefficient.

For later reference, it is useful to describe in more detail the normative approach to the measurement of inequality, pioneered by Atkinson (1970). This approach starts from the explicit specification of an additively separable social welfare function, defined over the well-being levels.

$$W(Z) = \frac{1}{1-\varepsilon}\sum_{i=1}^{n}[S_\beta(z_{i.})]^{1-\varepsilon}. \tag{8}$$

The parameter ε reflects the social aversion to inequality in the composite indicator of well-being and can take values ranging from zero to infinity. When $\varepsilon > 0$, there is social aversion to inequality. This means that one accepts the Pigou–Dalton transfer principle in the space of well-being indices, that is, *a redistribution of well-being from a worse-off country to a better-off country is assumed to decrease overall world well-being.* As ε rises, society attaches more weight to income transfers at the lower end of the distribution and less weight to transfers at the top. The unidimensional Atkinson–Kolm–Sen inequality index is then defined as $I^U(Z)$, being the scalar that solves:

$$W[(1 - I^U(Z))\mu(S_\beta)] = W(Z). \tag{9}$$

The mean composite well-being index across the countries of the world is denoted by $\mu(S_\beta)$. The scalar $I^U(Z)$ is the fraction of the total well-being that could be destroyed, if well-being is equalized across the countries thereby keeping the obtained distribution socially indifferent to the original one. It measures the waste due to inequality in well-being. Starting from the specification of the social welfare function (8), the unidimensional Atkinson measure of inequality can then be written as

$$I^U_\beta(Z) = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\left[\left(\frac{S_\beta(z_{i.})}{\mu(S_\beta)}\right)^{1-\varepsilon}\right]\right]^{1/1-\varepsilon}. \tag{10}$$

Once one has chosen a specific functional form for $S_\beta(z_{i.})$, calculation of overall inequality with (10) is straightforward. As all (relative) inequality measures, the Atkinson-index is invariant for the proportional changes in the well-being levels, but will change with other transformations. Ordinal transformations of $S_\beta(z_{i.})$ will in general lead to changes in the inequality measure. To give a specific example: if there is no natural zero in the measurement of well-being, that is, if translations are acceptable, each of these translations will lead to a different value of the Atkinson-index. Therefore, within this framework, the choice of the transformation functions Eqn. (1) should be considered carefully.

Less explicit, but similar to the above approach is the two-step procedure proposed by Maasoumi (1986), in which a generalized entropy index is calculated for a vector of $S_\beta(z_{i.})$, where the specification of the latter is based on information theoretic considerations. This procedure shares all the advantages and disadvantages of the unidimensional approach.

(c) *Measuring multidimensional inequality in well-being*

Although the introduction of an overall index of well-being may seem a natural approach, it sweeps the multidimensional nature of well-being under the carpet. In recent years a growing number of authors have tried to generalize the unidimensional Pigou–Dalton transfer principle into a multidimensional setting. They directly impose conditions in the space of the distribution matrices Z (or X) themselves (see Marshall & Olkin, 1979, chap. 15). Two popular generalizations are considered here.

First, in his seminal article Kolm (1977) proposed the condition that premultiplication of a distribution matrix with a bistochastic matrix [8] should lead to a socially preferred state. This averaging procedure leads to a mean preserving decrease in the dispersion of the dimensions and is called *uniform majorization (UM)*. For the flexible class of well-being indices given by specification (8), the principle of uniform majorization is satisfied if $\varepsilon > 0$ and $\beta < 1$. Both conditions limit the normative space: the former condition makes sure that society shows aversion to well-being inequality and the latter imposes a preference for more equally developed countries across dimensions.

Second, Atkinson and Bourguignon (1982) build on the compelling idea that for two distribution matrices with the same distributions for the dimensions separately but a different degree of correlation between the dimensions, less correlation is socially preferred. *Ceteris paribus*, a world where the richest country is also the healthiest and the best educated and the second richest country the second healthiest and so on, is less preferable than a world with the same distributions for the dimensions but where the ranks are less correlated. Tsui (1999) formalized this intuition and baptized the criterion *correlation increasing majorization (CIM)*. Atkinson and Bourguignon show that the condition of correlation increasing majorization is fulfilled for any increasing indicator of well-being with negative cross-derivatives. [9] For specification (8) the principle of correlation increasing majorization translates in $\varepsilon + \beta > 1$.

Both the extensions of the unidimensional Pigou–Dalton transfer principle can (*inter alia*) be implemented within the normative approach to multidimensional inequality measurement (see, e.g., Weymark, 2006). One starts from a multidimensional social welfare function *W(Z)*, representing the preference ordering of the social planner over the different distribution matrices. Then a relative multidimensional inequality measure $I^M(Z)$ can be derived from the following definition:

$$W[(1 - I^M(Z))Z_\mu] = W(Z). \tag{11}$$

Matrix Z_μ is a distribution matrix, where every observation is replaced by its column mean. The scalar $I^M(Z)$ is a multidimensional generalization of the standard unidimensional Atkinson–Kolm–Sen definition (9) of an inequality index. It is the fraction of the aggregate amount of each attribute that could be destroyed if every dimension is equalized thereby keeping the obtained distribution socially indifferent to the original one. Applying expression (8) to (11) yields the following multidimensional inequality index:

$$I_\beta^M(Z) = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\left[\left(\frac{S_\beta(z_{i.})}{S_\beta(\mu)}\right)^{1-\varepsilon}\right]\right]^{1/1-\varepsilon}. \qquad (12)$$

where μ is the vector of the column means of Z. When comparing this multidimensional index $I_\beta^M(Z)$ with its unidimensional counterpart $I_\beta^M(Z)$ in (10), two remarks can be made. First, the difference between the indices is in their denominator. Whereas the multidimensional index $I_\beta^M(Z)$ uses the composite indicator of a country with average performance on every indicator as a reference point, the indicator obtained by the two-step approach $I_\beta^U(Z)$ uses the average value of the composite indicator. Second, given that we work in both the cases with a similar specification (8) for the social welfare function, one should perhaps not expect large differences in the empirical application. Yet from the point of view of principles, both the approaches are really different. In general, the two-step approach does not necessarily satisfy uniform majorization nor correlation increasing majorization (Dardanoni, 1995). On the other hand, the multidimensional inequality measure (12) does not always satisfy the Pigou–Dalton principle in the space of the individual well-being indices. The main focus in our empirical application will be on the multidimensional inequality measures (12).

This class of multidimensional inequality indices encompasses the Tsui (1995) index [10], which is the special case with the indicator of well-being of a Cobb–Douglas type ($\beta = 0$) and the exponents $w_j\,(1-\varepsilon) = c_j$ such that $1-\varepsilon = \sum c_j$:

$$I_0^M(Z) = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\left[\prod_{j=1}^{k}\left(\frac{z_{ij}}{\mu_j}\right)^{c_j}\right]\right]^{1/\sum c_j} = I^{Tsui}(Z). \qquad (13)$$

3. RESULTS WITHOUT POPULATION WEIGHTING

We will now apply the different concepts laid down in the previous section to answer the questions raised in the introduction. How did world inequality in well-being develop over time? Does the introduction of multiple dimensions change the result of a steady increase in unweighted income inequality during recent decades? Choosing the relevant dimensions is not a merely technical choice, but relates to the implicit normative definition of what constitutes well-being. It could for instance be argued that educational achievement is not an independent component of well-being, but has only instrumental value. On the other hand, education may also be seen as an important dimension of human flourishing. Being able to use the senses, to imagine, think, and reason in a "truly human" way, a way informed and cultivated by an adequate education, is one of the capabilities in Nussbaum (2000)'s famous list. As we do not want to go deeply into this philosophical debate, we take a pragmatic approach: to make our results comparable to previous studies, we base our analysis on the four indicators of well-being that are also the components of the Human Development Index.

We describe the data used in more detail in the first subsection. In the second subsection, we set the stage for the later analysis by considering the evolution over time dimension by dimension. Finally, we come to the core of our empirical work: the development over time of multidimensional inequality as defined in (12). By varying the parameters ε and β, we test how sensitive the results are with respect to the choice of the specification of $W(Z)$. We will also compare our results to those obtained with the unidimensional approach defined in (10).

(a) *The data*

The data are from the World Development Indicators (2004) and cover the period during 1975–2000 with five-year intervals. Our first indicator is *GDP per capita*, measured in current US$ after correction for purchasing power parity. Dowrick and Akmal (2005) argue that purchasing power parities are not beyond controversy, yet they are easily available and can be considered to be the standard in the literature on global income inequality. The second indicator is *life expectancy at birth*, indicating the number of years a newborn infant would live if prevailing patterns of mortality were to stay the same throughout its life. Life expectancy at birth is used to measure health, admittedly in a rather rough way. Third, *adult literacy rate* measures the percentage of people of age 15 and above who can, with understanding, read and write. Finally, gross *secondary enrollment rate* [11] is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to secondary education. [12]

The original six distribution matrices have a total data coverage of only 61%. We therefore applied an interpolation procedure to construct a final dataset with a wider geographical scope. After these operations we have a sample with 97 countries, for which four indicators at six points of time are available (which is slightly less than half of the countries in the World Development Indicators database, representing up to 82% of total population in 2000). Detailed information on the countries covered and on the interpolation procedure is given in the appendix. Big absentees in our sample are many Sub-Saharan African countries [13] and virtually all Eastern European Countries, with Latvia and Hungary as exceptions. Omitting these countries was not a deliberate choice, but was imposed upon us by the limited availability of the data. Given what is known about the development of income and life expectancy in the omitted countries, we can hypothesize that this omission will lead to an underestimation of the true world inequality in well-being. In any case, our results should be interpreted cautiously.

(b) *Evolution of inequality dimension-by-dimension*

To get the feel of the data, we will first look at them dimension-by-dimension. For the obvious reasons of comparability with the multidimensional approach introduced before, we calculate inequality for every dimension with the standard unidimensional Atkinson (1970) index [14]:

$$I_j^U(x_{.j}) = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\left[\left(\frac{x_{ij}}{\mu(x_{.j})}\right)^{1-\varepsilon}\right]\right]^{1/1-\varepsilon}, \quad j = 1, \ldots, k. \qquad (14)$$

Table 3 summarizes the trends in inequality for the four indicators considered in our dataset. We set $\varepsilon = 2$, which reflects considerable inequality aversion. Inequality is normalized to be 100 in 1975.

The first row of Table 3 confirms the general finding in the literature that unweighted income inequality has increased over time (Milanovic, 2005). [15] For the later interpretation of the HDI, it is useful to consider also the logarithmic transformation of GDP *per capita* instead of GDP *per capita* itself. As can be seen from the second row of Table 3, this strictly concave transformation alters the trend of income inequality: now

Table 3. *Evolution of the (unweighted) inequality in different dimensions of well-being, measured by the Atkinson index (ε = 2) (1975 = 100)*

Indicator	1975	1980	1985	1990	1995	2000
GDP/*capita*	100.0	100.8	102.3	105.9	108.8	113.0
log(GDP/*capita*)	100.0	89.6	85.5	86.3	88.1	91.4
Longevity	100.0	88.2	80.0	84.9	97.8	131.4
Literacy ratio	100.0	84.0	69.4	56.9	45.9	39.0
Enrollment ratio	100.0	83.1	73.0	65.7	62.9	58.9

inequality decreases in the first decade and increases only mildly in the last decade.[16]

Concerning longevity, many authors (e.g., Ram, 1998; Sen, 1998) expressed an optimistic view, which is shared by the Human Development Report (2005):

> In a little more than a decade average life expectancy in developing countries has increased by two years. On this indicator human development is converging: poor countries are catching up with rich ones. (Human Development Report, 2005).

Recent findings in the literature on global health inequality (McMichael, McKee, Shkolnikov, & Valkoren, 2004; Moser, Shkolnikov, & Leon, 2005) suggest a less rosy picture, because of the ongoing AIDS epidemic and the rising infection rates in Asia (see also Becker *et al.*, 2005). As can be seen in Table 3, our results are in line with this less optimistic view. After an initial decrease in inequality in life expectancy during the first decade, inequality skyrockets from the late 1980's onwards.[17]

Finally, inequality in educational indicators decreased over the entire period. Authors as Neumayer (2003) and McGillivray and Pillarisetti (2004) claim that this may be a statistical artifact due to the fact that the literacy rate and the enrollment rate are upward bounded and that many OECD countries have reached this limit. However, the indicator "average years of schooling" from the dataset of Barro and Lee (1996) is less likely to have a binding upper limit and shows a similar pattern of steep decrease in inequality.

We can conclude that unweighted income inequality increases over time, that inequality in the logarithm of income and in life expectancy shows a U-pattern and that the educational indicators show a steep decrease in inequality. If one wants to derive general conclusions, an aggregation procedure is badly needed.

(c) *Evolution of multidimensional inequality*

As a starting point and benchmark, Figures 1 and 2 show the development over time of the *unidimensional* inequality measure $I^U_\beta(Z)$ (see Eqn. (10)) for the HDI and the BPS-approach and for different values of ε. With the HDI, we recover the finding that world inequality in well-being declines over the relevant period. As noted, this is in stark contrast to the development of unweighted income inequality. Our results for the BPS-index are not directly comparable to those of Becker *et al.* (2005), because they compute population-weighted inequality measures. With the implied value of $\beta = 0$ and without the educational dimension, the decrease in well-being inequality as measured by the BPS-approach is less pronounced than for the HDI.

Let us now look at the evolution of *multidimensional* inequality, as measured by $I^M_\beta(Z)$ in expression (12). To evaluate the robustness of the results, we calculate $I^M_\beta(Z)$ for a broad range of sensible parameter values.

Figure 3 summarizes the trend in well-being inequality measured by the multidimensional Atkinson index, as defined in expression (12), for different values of the degree of inequality aversion ε. The other values are close to those of the HDI. We use the transformation functions as summarized in Table 1 and assume perfect substitutability between the dimensions, that is, $\beta = 1$. For all strictly positive ε-values, CIM is satisfied. Comparing Figures 1 and 3, it turns out that the shift from $I^U_\beta(Z)$ to the multidimensional measure $I^M_\beta(Z)$ does not have a strong effect on the results. The most striking finding is that the basic result of a decrease in well-being inequality over time is robust for changes in ε.

However, as argued before, the choices for β and η, implied by the definition of the HDI, are not self-evident. Let us there-

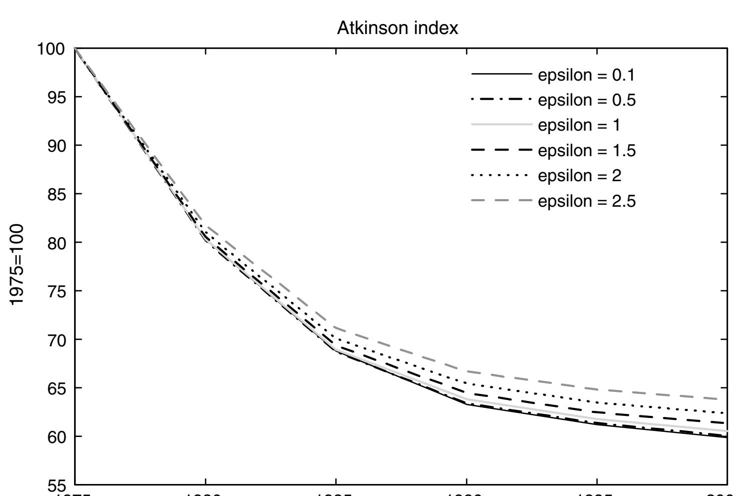


Figure 1. *Evolution of the unidimensional (unweighted) inequality of the Human Development Index, measured by the Atkinson index, for different ε-values.*

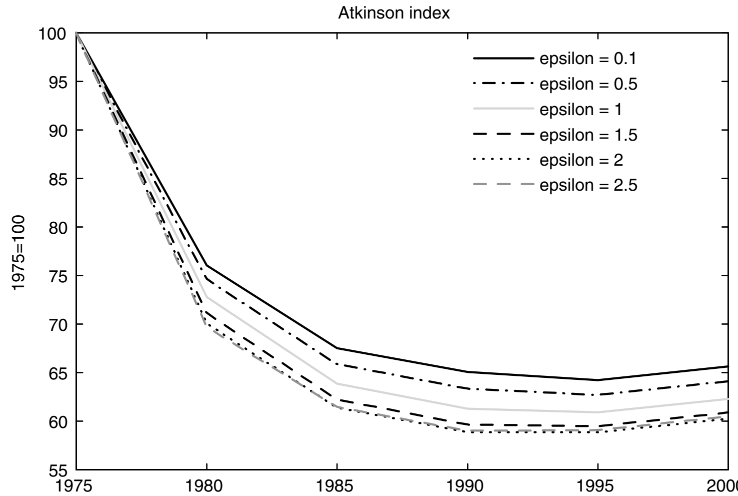


Figure 2. *Evolution of the unidimensional (unweighted) inequality of the BPS-approach, measured by the Atkinson index, for different ε-values.*

fore now check how robust the results in Figure 3 are for changes in these crucial parameters. Table 4 summarizes the main findings of this sensitivity analysis.[18] The columns in the table correspond to different values of β in the range $[-5, 1]$, the blocks correspond to different values of η, that is, the degree of concavity in the transformation function for income (see Eqn. (5)), the rows in each block correspond to different values of ε, the degree of inequality aversion. In each block, the area corresponding to parameter combinations that satisfy CIM, that is, $\varepsilon + \beta > 1$, is located in the bottom righthand corner. In the table, four different trends are distinguished: strictly increasing, strictly decreasing, and two U-shaped trends. In the first the inequality is larger in 2000 than in 1975; we denote this as "increasingly U-shaped." The opposite case, showing a larger inequality in 1975 is denoted "decreasingly U-shaped."

We first focus on the role of β: the smaller β, the lower the substitutability between the dimensions or the more an equal development across the dimensions is preferred. Remember that the BPS-index has $\beta = 0$, while the HDI has $\beta = 1$. In general, relaxing the linear aggregation procedure of the HDI does not change the trend in well-being inequality dramatically.

Varying the parameter η (i.e., the concavity of the transformation function of income) has more important consequences. This is illustrated well by Figure 4 which shows the trend in multidimensional inequality for $\varepsilon = 2$ and $\beta = 1$ (the HDI-case), but with different values for η. The case $\eta = 1$ is the HDI-case with the logarithmic transformation. The BPS-specification implies $\eta = 0.8$. The concave transformation has a clear effect on the inequality trends: for $\eta = 0$ inequality in well-being is no longer decreasing over the whole time period, but shows a distinct U-shape. Moreover, in the absence of a concave transformation of income, smaller values for β and ε further strengthen the trend of increasing well-being inequality (see Figure 5 and the first block of Table 4). The combination of no transformation of income ($\eta = 0$), a low degree of substitutability of the dimensions (β small), and a mild inequality aversion (ε small) lead to a relative *increase* in well-being inequality in the considered period.

The sensitivity of the results with respect to the concave transformations is not really surprising, since by definition they dampen the effect of increasing values at the higher end of the distribution. The result is more than a technical artifact, however. It raises the deeper question of what is well-being and how it should be measured. The concave transformation

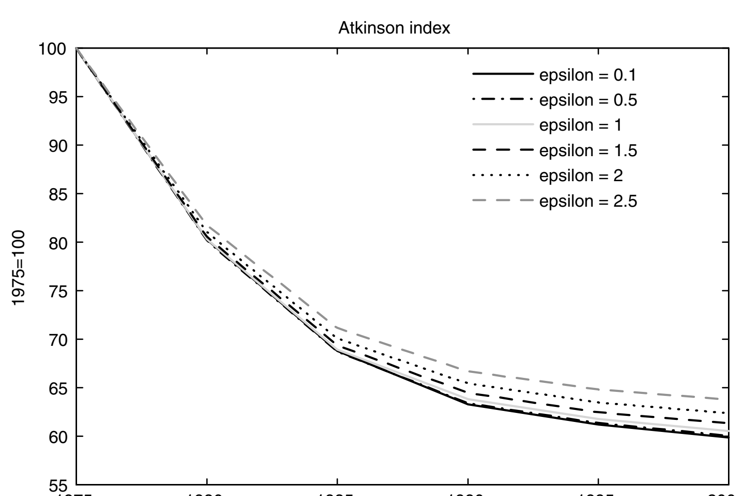
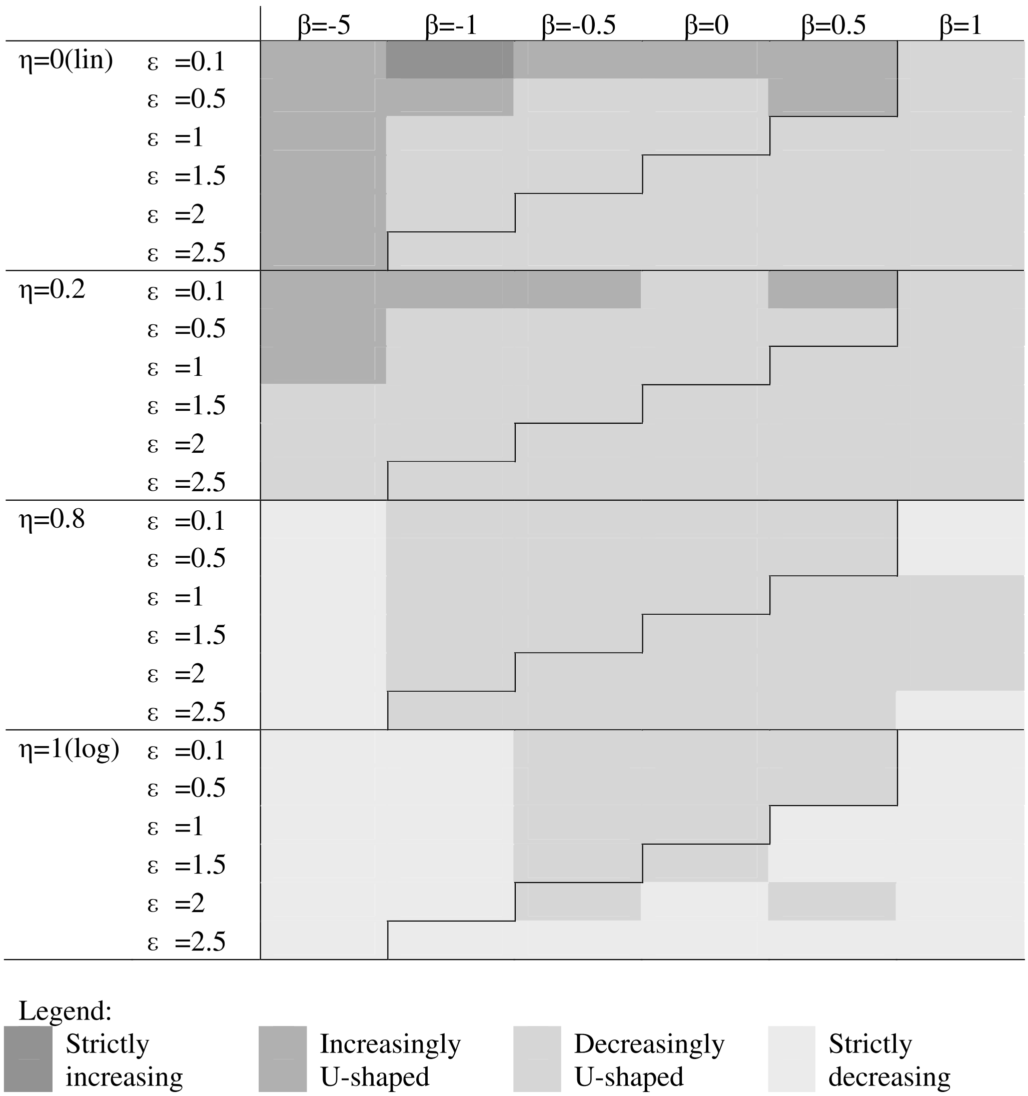


Figure 3. *Evolution of the (unweighted) well-being inequality, measured by the multidimensional Atkinson index, for different ε-values.*

Table 4. *Sensitivity analysis with respect to parameters ε, η, and β (summary table)*



of income implements the assumption that an income increase is worth less to a rich than to a poor country. It therefore also implies that a proportional increase in all incomes will *lower* inequality in well-being measured by a scale-invariant inequality measure. As we have mentioned before, the use of these concave transformations was a deliberate choice, both in the case of the HDI and in the case of the BPS-index. It reflects a certain conception of how to define what is ethically relevant inequality. There is room for discussion here. If we are interested in inequality in material well-being would it then not be more natural *not* to transform incomes? Of course, our results cannot answer these basically ethical questions. They show, however, that the discussion is important, since it turns out that it is basically the choice of a concave transformation that drives the result (obtained both with the HDI and with the BPS-index) that well-being inequality shows a decreasing trend in recent decades.

We tested the robustness of our findings further by implementing still other specifications of the transformation functions.[19] A first component is the weighting scheme, applied to the different dimensions. Both the HDI and the BPS-index weigh the considered dimensions equally. An alternative procedure, used by some authors, is to derive the weights directly from the data. In this respect, especially the use of principal components analysis has been popular (Noorbakhsh, 1998; Ram, 1982). It turns out that changes in the trend of well-being inequality due to the use of this alternative weighting scheme are minor. Of course, the use of more extreme weighting schemes allows obtaining virtually any trend in well-being inequality, since the dimensions separately show such a diverse pattern. This brings the weighting problem to the center of the discussion. Choices on weights are essentially normative choices, which should reflect universally acceptable social preferences over the different dimensions. The principal components approach, however, does not have any welfare-theoretic justification. Weighting schemes are very likely to be controversial and should therefore be stated explicitly, for example, as marginal rates of substitution.

Returning to the weighting scheme of the HDI, a second component of the transformation functions is the standard-

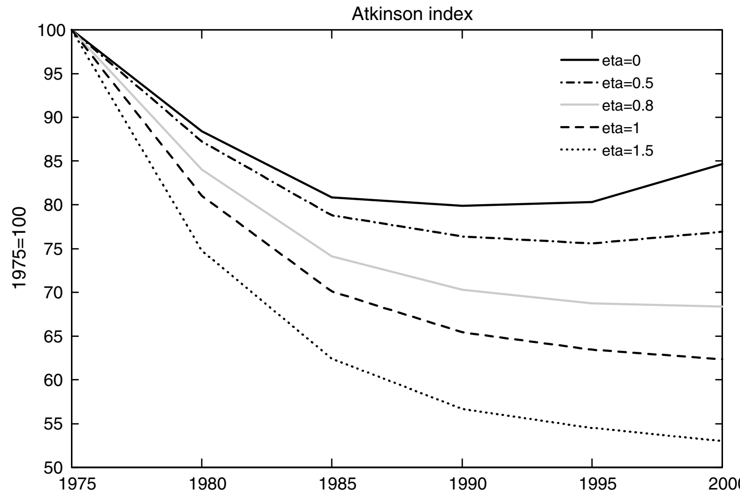


Figure 4. *Evolution of (unweighted) well-being inequality, measured by the multidimensional Atkinson index, for different η-values.*

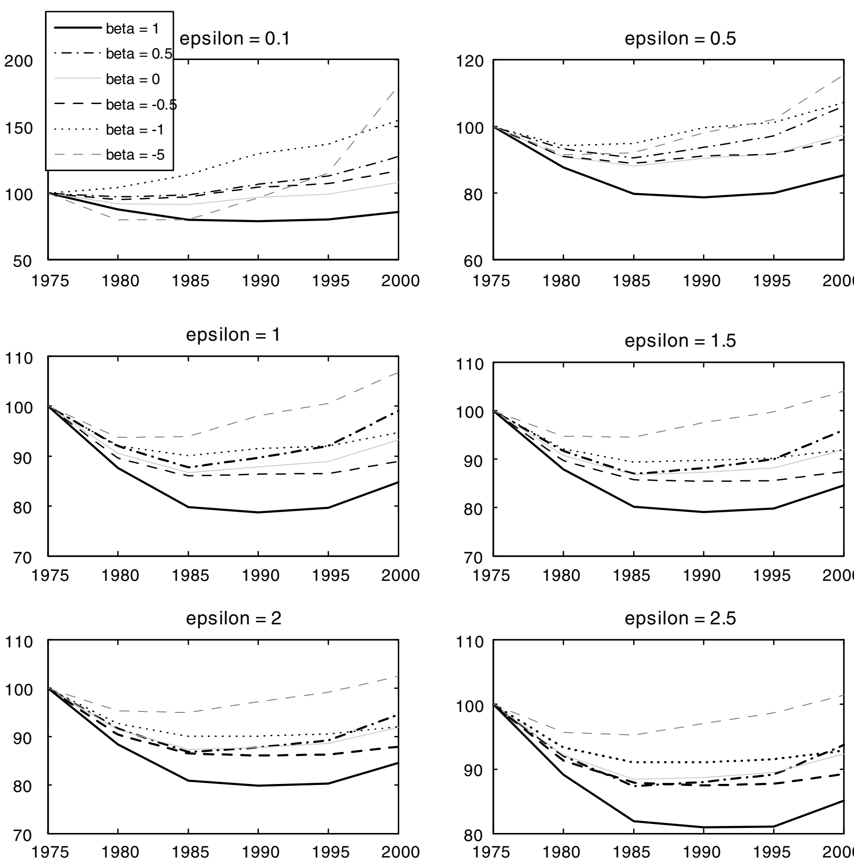


Figure 5. *Evolution of the (unweighted) well-being inequality, measured by the multidimensional Atkinson index, without logarithmic transformation for different ε and β-values.*

ization procedure. By using the standardization procedures described in Table 1, the achievements on the different dimensions of well-being are rescaled to a value between 0 and 1. This rescaling is more or less arbitrary. A first alternative amounts to rescaling the dimensions by the inverse of a measure of central tendency such as the mean (or the median) of the transformed dimensions. It turns out that this kind of rescaling has only a minor effect on the trend of well-being inequality. (In fact, note that the Tsui-index with $\beta = 0$, given in (13), is invariant to all multiplicative transformations.) While rescaling does not matter very much, translations do matter. This is well illustrated by a second alternative standardization procedure, which has been proposed by Hirschberg, Maasoumi, and Slottje (1991) in their paper on measuring quality of life across countries:

$$z_{ij}^{HMS} = \frac{f_j(x_{ij}) - \mu(f_j(x_{ij}))}{\sigma(f_j(x_{ij}))} + 10, \quad i = 1, \ldots, n; \ \ j = 1, \ldots, k. \tag{15}$$

In the above expression, $\sigma(f_j(x_{ij}))$ denotes the standard deviation of the transformed data. This procedure standardizes the data such that the mean equals 10 and the standard deviation 1. The (rather arbitrary) translation to the right is introduced to avoid calculation problems due to negative values. Figure 6 shows that the trend in inequality after applying (15) is remarkably different from the other cases. Moreover, the results obtained are very sensitive to the number of standard deviations by which the distribution is shifted. This is not surprising since we are considering here a translation procedure in the context of scale-invariant (but translation-sensitive) inequality measures. Although this standardization is sometimes used in the design of composite indicators [20], we believe it to be unattractive in this context.

4. SOME RESULTS FOR POPULATION WEIGHTED INEQUALITY

We argued before that, for the purposes of this paper, it seems most relevant to take the countries as the observation units without any population weighting. This implies of course that small countries (e.g., some Sub-Saharan countries performing poorly on the dimensions of well-being used in this paper) get the same weight as large (better-performing) countries such as China and India. To get some idea about the importance of this effect, we also calculated the population weighted inequality measures as a kind of sensitivity analysis. Results for the one-dimensional trends are shown in Table 5. Figures 7 and 8 are directly comparable to the Figures 4 and 5 shown before.

The first row in Table 5 confirms the finding in the literature that the population-weighted income inequality decreases (compare with the first row in Table 3). The increase in the inequality of life expectancy after 1995 remains, however, although it is less outspoken. Population weighting therefore strengthens the negative overall trend in multidimensional inequality (Figure 7). At the same time, it remains true that the concave transformation of income plays a crucial role (Figure 8). Even with population-weighting there is in recent years an increase in multidimensional inequality in well-being for some combinations of parameter values.

5. CONCLUSION

In this paper, we apply some methods from the recent literature on multidimensional inequality measurement to quantify the evolution of well-being inequality across countries. We treat well-being as a multidimensional concept focusing on three important dimensions of life: income, health, and education. Inequality in the three dimensions shows a different trend over the last 25 years. We propose a flexible multidimensional inequality index that allows separating the effect of different normative choices of transformation, standardization, and aggregation procedures. We then perform a detailed sensitivity analysis for the different normative choices. We find out that for many parameter values, international inequality declines being it at a slowing pace. However, extreme weighting schemes can lead to virtually any trend in well-being inequality given the different evolutions on the underlying dimensions. Moreover, the combination of no transformation of the income dimension, a low substitutability of the dimensions, and a mild inequality aversion lead to a sharp increase in well-being inequality over the last years. The most striking finding is the crucial effect of the concave transformation applied to income both in the Human Development Index and in the full income-concept proposed by Becker *et al.* (2005). This observation underlines the need for clarity on the underlying normative choices in empirical work on multidimensional welfare and inequality measurement.

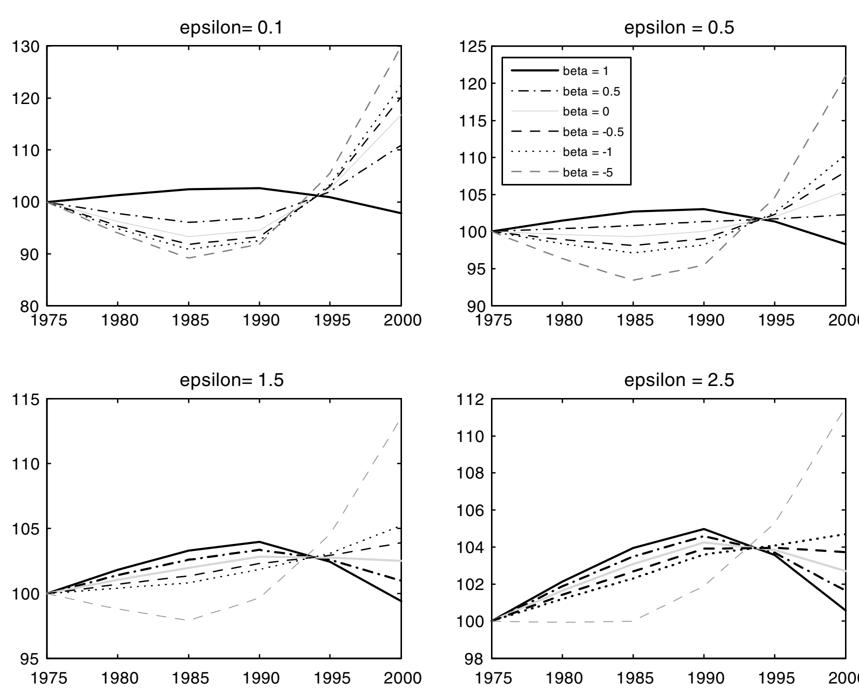


Figure 6. *Evolution of the (unweighted) well-being inequality, measured by the multidimensional Atkinson index, with the Hirschberg et al. standardization, for different ε and β-values.*

Table 5. *Evolution of the (weighted) inequality in different dimensions of well-being, measured by the Atkinson index (ε = 2) (1975 = 100)*

Indicator	1975	1980	1985	1990	1995	2000
GDP/*capita*	100.0	98.0	90.9	86.7	80.3	78.6
log(GDP/*capita*)	100.0	82.3	61.1	50.3	41.1	37.8
Longevity	100.0	86.7	73.2	63.7	59.6	73.7
Literacy ratio	100.0	83.8	70.1	58.4	48.6	44.5
Enrollment ratio	100.0	79.7	65.5	57.3	57.9	48.6

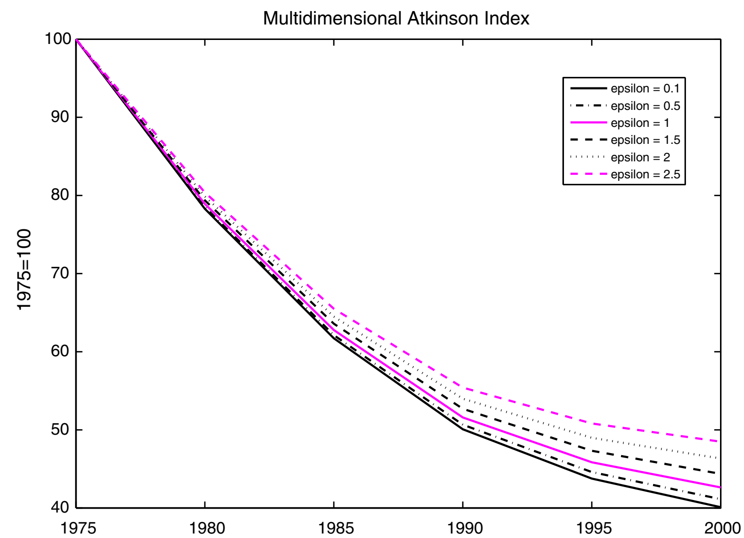


Figure 7. *Evolution of the (weighted) well-being inequality, measured by the multidimensional Atkinson index, for different ε-values.*

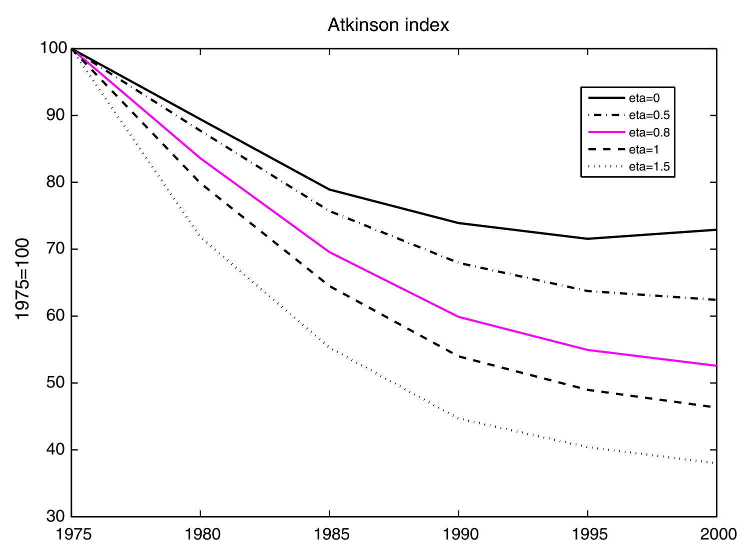


Figure 8. *Evolution of (weighted) well-being inequality, measured by the multidimensional Atkinson index, for different η-values.*

NOTES

1. To give but two examples of the latter: global inequality is the focus of the Human Development Report of the UNDP (2005) and of the World Development Report issued by the World Bank (2006).

2. Our focus is thereby on the evolution of multidimensional inequality indices, rather than on checking multidimensional dominance. Checking multidimensional dominance in this framework is the topic of the papers by Atkinson and Bourguignon (1982) and Muller and Trannoy (2003).

3. This argument is made by Ravallion (2004). A careful overview of the arguments in the discussion on population weighing in the literature on income inequality can be found in Milanovic (2005).

4. A generalized mean of order β has been axiomatized by Blackorby and Donaldson (1982). Maasoumi (1986) obtains a similar individual aggregation function from information theoretical considerations. The United Nations Development Program uses this functional form to aggregate

some components of the Human Poverty Index (HPI), Gender-related Development Index (GDI), and the Gender Empowerment Measure (GEM), all complementary indices to the Human Development Index.

5. In the first human development report this logarithmic transformation was introduced, but from 1991 to 1998 a stepwise Atkinson function was used. This function was criticized by Trabold-Nübler (1991) for its violation of diminishing marginal returns and by Lüchters and Menkhoff (1996) for its indifferentiability. From 1999, the logarithmic transformation was reintroduced.

6. In a recent paper, Fleurbaey and Gaulier (2007) generalize the BPS-model further to incorporate labor, risk, household size and environmental sustainability.

7. Note that these 357 US$ roughly correspond to the poverty line of 1$ a day. Becker *et al.* (2005) show that their calibration implies statistical values of life that are in line with the results from the literature.

8. A *bistochastic* matrix is defined as a nonnegative $n \times n$ matrix with all row and column sums equal to 1.

9. Bourguignon and Chakravarty (2003) criticize the use of correlation increasing majorization, arguing that it implicitly assumes that all dimensions are substitutes.

10. Also the multidimensional Dalton index proposed by Bourguignon (1999) is a close relative. If we call $-\varepsilon = \gamma$, then: $1 - (1 - I_{\beta}^{M}(Z))^{1+\gamma} = I_{\beta}^{Bourg}(Z)$.

11. Note that we use secondary gross enrollment rate instead of combined enrollment rate due to data limitations. The correlation between both enrollment rates is high (0.92 in 2000).

12. For some countries, the index can take values larger than 100%. This will be the case if the total number of enrolled pupils is larger than the population in the relevant age group.

13. Some large Sub-Saharan African countries that are not included in the sample are: Angola, Democratic Republic of Congo, Ethiopia, Gambia, Liberia, Mozambique, Namibia, Sierra Leone, Somalia, South Africa, and Uganda. However, as can be seen from the list of countries in Appendix A, Sub-Sahara Africa remains represented with more than 20 countries.

14. Alternative measures of inequality, such as the Gini index or generalized entropy inequality index give similar results.

15. As mentioned before, there is less consensus on the evolution of population weighted income inequality. Most authors find decreasing inequality, which can be largely attributed to the fast growth of populous countries like China and India.

16. As indicated in Eqn. (4) and in Table 1, the HDI does not take simply a logarithmic transformation of income, but introduces in addition a scaling and a translation operation (subtracting log $GDP_{\min}$). As the Atkinson index is scale invariant, the scaling procedure does not have any effect. The translation operation does have an effect, but it is relatively minor and does not change the overall decreasing pattern shown in Table 3.

17. The influence of AIDS is clear, even with our restricted dataset. When we drop all the Sub-Saharan African countries from our sample, we find a decreasing trend in inequality over the whole period. These results are available from the authors on request. Note, however, that we could not include Russia in our sample: this is another country where mortality increased in the 1990s. The apparently very sharp increase during 1995–2000 should be interpreted in the light of the normalization chosen ($1975 = 100$). The Atkinson-measure for 1975 (with $\varepsilon = 2$) is 0.0352, for 2000 it is 0.0462.

18. We also performed a sensitivity analysis with different values for the parameter r in the transformation function for life expectancy (Eqn. (6)). The use of higher interest rates r diminishes the decrease in inequality somewhat, but the results are not very outspoken.

19. Detailed results are omitted here for the reasons of space. They are available from the authors on request.

20. Morrisson and Murtin (2005) use standard (untranslated) z-scores to standardize the data in their measurement of multidimensional well-being inequality. To avoid computational problems with nonpositive values, Morrisson and Murtin measure inequality by the standard error. Other examples of a standardization based on z-scores can be found in Salzman (2004).

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APPENDIX 1. SAMPLE AND DATA COVERAGE

The table below gives an overview of the 97 countries of the sample and the manipulations that are carried out to solve the problem of missing data. As in the literature on global income inequality we removed from the sample countries with a missing data-point for the indicator GDP *per capita*. For the other dimensions we removed countries with two consecutive missing data-points. (Those countries are not reported in the table.)

For countries with only one data-point missing, we carried out the following manipulations. First, we approximated the missing point by a close data-point, which was not more than two years away. If no such data were available, linear interpolations and extrapolations were carried out, based on the closest available neighboring data. By these manipulations, which do not alter the broad picture of our results, the number of countries in the sample increased from 69 up to 97.

For many highly literate countries, no literacy data are available. We followed the approach used in the Human Development Reports, and set the literacy rate of those countries equal to 99%. Contrary to the common practice in the Human Development Reports, we do not truncate GDP/*capita* to an arbitrary maximum of 40,000 US$ corrected for PPP nor do we truncate the enrollment rate at 100%. Hence, some countries can obtain an indicator higher than 1 for some dimensions.

Country	Manipulation
Algeria	
Argentina	
Australia	Literacy rate = 99%
Austria	Literacy rate = 99%
Bangladesh	
Barbados	Literacy rate = 99%, interpolated data point (enrollment rate 1985)
Belgium	Literacy rate = 99%
Belize	Extrapolated data point (enrollment rate 1975)
Benin	Close data point (enrollment rate 1999 instead of 2000)
Bolivia	
Botswana	
Brazil	

(*Continued on next page*)

Appendix 1—*Continued*

Country	Manipulation
Burkina Faso	Extrapolated data point (literacy rate 2000)
Burundi	
Cameroon	Close data point (enrollment rate 2001 instead of 2000)
Canada	Literacy rate = 99%
Central African Republic	Extrapolated data point (enrollment rate 2000)
Chad	Close data point (enrollment rate 1999 instead of 2000), interpolated data point (enrollment rate 1980)
Chile	
China	
Colombia	
Congo. Rep.	Close data point (enrollment rate 1999 instead of 2000)
Costa Rica	
Cote d'Ivoire	Close data point (enrollment rate 1999 instead of 2000)
Cyprus	
Denmark	Literacy rate = 99%, close data point (enrollment rate 1999 instead of 2000)
Dominican Republic	
Ecuador	
Egypt. Arab Rep.	Extrapolated data point (literacy rate 2000)
El Salvador	Interpolated data point (enrollment rate 1985)
Fiji	Extrapolated data point (literacy rate 2000)
Finland	Literacy rate = 99%
France	Literacy rate = 99%
Georgia	Literacy rate = 99%, extrapolated data point (enrollment rate 1985)
Ghana	
Greece	Literacy rate = 99%
Guatemala	
Haiti	Extrapolated data point (enrollment rate 2000)
Honduras	Extrapolated data point (enrollment rate 2000)
Hungary	Close data point (enrollment rate 1999 instead of 2000)
Iceland	Literacy rate = 99%
India	
Indonesia	
Iran. Islamic Rep.	
Ireland	Literacy rate = 99%
Israel	
Italy	Literacy rate = 99%
Jamaica	
Japan	Literacy rate = 99%
Kenya	
Korea. Rep.	Literacy rate = 99%
Latvia	Extrapolated data point (enrollment rate 1975)
Lesotho	
Luxembourg	Literacy rate = 99%
Malawi	Extrapolated data point (enrollment rate 1975)
Malaysia	
Mali	Close data point (enrollment rate 1998 instead of 2000)
Malta	
Mauritania	
Mexico	
Morocco	
Nepal	
Netherlands	Literacy rate = 99%
New Zealand	Literacy rate = 99%
Nicaragua	
Niger	
Nigeria	Extrapolated data point (enrollment rate 2000)
Norway	Literacy rate = 99%
Oman	
Pakistan	Close data point (literacy rate 1998 instead of 2000), extrapolated data point (enrollment rate 2000)
Panama	
Paraguay	
Peru	Close data point (enrollment rate 1998 instead of 2000)
Philippines	
Portugal	Literacy rate = 99%
Rwanda	
Saudi Arabia	

Appendix 1—*Continued*

Country	Manipulation
Senegal	
Singapore	Extrapolated data point (enrollment rate 2000)
Spain	Literacy rate = 99%
Sri Lanka	Close data point (enrollment rate 2001 instead of 2000)
Sudan	
Swaziland	Close data point (enrollment rate 2001 instead of 2000)
Sweden	Literacy rate = 99%
Switzerland	Literacy rate = 99%
Syrian Arab Republic	
Thailand	
Togo	Close data point (enrollment rate 1999 instead of 2000)
Trinidad and Tobago	
Tunisia	
Turkey	
United Kingdom	Literacy rate = 99%
United States	Literacy rate = 99%
Uruguay	
Venezuela. RB	
Zambia	Extrapolated data point (enrollment rate 2000)
Zimbabwe	