The Evolution of World Inequality in Well-being

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Abstract

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

Keywords: Multidimensional Inequality Measurement, Index of Well-being, Inter-country Inequality.

JEL Classification: D31, D63, I31, O50

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 (almost) exclusively on income inequality. There is by now virtual 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. Any analysis of

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

the evolution of world inequality should also take other dimensions into account (Bourguignon and Morrisson, 2002). 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. 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 of this approach are Slottje et al. (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 across various dimensions is different. At the other extreme one finds approaches that first construct a composite index of well-being and then measure the inequality in that composite index (for example, Fischer (2003), McGillivray and Pillarisetti (2004), Becker, Philipson and Soares (2005) or Noorbakhsh (2006)). The most popular composite index of well-being is the Human Development Index (HDI), summarizing the performance of the countries on 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, it results at the end 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 will focus

[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).

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 group 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 to look at *un*weighted inequality across countries, so that all countries count equally, small or large. It is obviously debatable that huge countries like China get the same weight as very small countries (see, for example, Sala-i-Martin, 2006). However, this approach can be justified by at least three arguments. 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 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 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 and the use of the Human Development Index and the full income measure of Becker et al. (2005). Section 3 presents our empirical results. 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. Section 4 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_{ij}^t 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 of matrix X describing the achievement of country

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

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, i.e. 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. Broadly speaking, there are two approaches to the aggregation problem. The first approach consists of 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. The second approach is the direct measurement of *multidimensional* inequality. We will present these two approaches in this section, but first we will look more closely at the construction of a composite index of well-being.

2.1 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, e.g. by taking logarithms or through a standardization procedure to make the dimensions comparable. If we define f_j $(j = 1, ..., k)$ to be the dimension-specific transformation functions, we obtain the elements of the transformed distribution matrix Z:

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

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 $S_\beta\left(z_{i.}\right)$. The weights are denoted by w_j.

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

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

[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 Programme 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.

dimension can be compensated by a good performance on another dimension. For β going to $-\infty$, dimensions are treated as perfect complements. This aggregation function will favor an equal development along the dimensions and is comparable to a Rawlsian perspective across the dimensions of well-being. 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 (1) into (2) gives a general composite index of well-being:

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

Different choices for β and for the functions $f_j(.)$ will lead to different composite indices. We will illustrate this with two prominent examples: the Human Development Index and the full income concept suggested by Becker, Philipson and Soares (2005) (BPS in the sequel). The logic behind both approaches is very different: the Human Development Index 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 different consequences concerning the trade-offs between the various dimensions.

2.1.1 Human Development Index

The most prominent example of a composite well-being index is the Human Development Index, published yearly by the UNDP after 1990. As noted before, the Human Development Index 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 to 4 respectively.

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

$$f_j^{HDI}(x_{.j}) = \frac{g_j(x_{.j}) - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \qquad j = 1, ..., 4. \tag{4}$$

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 the logarithmic transformation by pointing out that the

[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.

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 achievement 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 the 1994 version of 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(40000)	0.333
Longevity	$x_{.j}$	25	85	0.333
Literacy rate	$x_{.j}$	0	100	0.222
Enrolment rate	$x_{.j}$	0	100	0.111

Table 1: Transformation, goalposts and weights in the Human Development Index.

The transformed dimensions of the Human Development Index are aggregated by making use of a simple weighted average, with weights w_j. This implies that the parameter β in expression (3) is set equal to 1. As mentioned before, this choice implies that the different (transformed) dimensions are seen as perfect substitutes. It is worth 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 of longevity, which is slightly less than 5 months. Similar results have been obtained by Lind (2004) and Ravallion (1997).

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

Becker, Philipson and Soares (2005) developed a model to incorporate the gains in longevity into an overall assessment of well-being inequality. Contrary to

MRS^{HDI}	GDP per capita	Longevity	Literacy	Enrolment
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

Table 2: Marginal Rates of Substitution between the dimensions of well-being in the HDI.

the HDI, they do not take educational indicators explicitly into account.[6]. The transformation functions of income and longevity used in BPS 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:

$$f_1^{BPS}(x_{.1}) = \frac{(x_{.1})^{1-\eta}}{1-\eta} - \zeta_1 \tag{5}$$

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 $\eta = 0$, there are no diminishing returns. 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 $357 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:

$$f_2^{BPS}(x_{.2}) = \int_0^{x_{.2}} \exp(-rt)dt = \frac{1}{r}\left(1 - \exp\left(-rx_{.2}\right)\right) \tag{6}$$

Due to the concavity of this expression, an increase in well-being obtained by a small prolongation of longevity is much larger for low levels of life expectancy, than it is for high levels. 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 the interest rate 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.

[6] In a recent paper Fleurbaey and Gaulier (2006) 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.

To aggregate the transformed dimensions, the BPS-approach simply multiplies them. 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 (2), which shows the close formal connection between both 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:

$$MRS^{BPS} \approx \frac{1}{(1-\eta)} \frac{x_{.1}}{x_{.2}} \tag{7}$$

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. The BPS- approach allows less substitution than the Human Development Index, especially for countries with low life expectancy

2.2 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) analyzed 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) calculated both Theil's indices and the Wolfson index of the Human Development Index and two other gender-related composite indicators of well-being: the Gender-related Development Index (GDI) and the Gender Empowerment Measure (GEM). Recently, Noorbakhsh (2006) investigated convergence in the Human Development Index by calculating various convergence measures, amongst which the standard deviation of logs, the coefficient of variation and 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 a social welfare function. For the problem of measuring well-being inequality, an additively separable social welfare function is defined over the well-being levels.

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

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 the well-being indices, i.e. *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:

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

The mean composite well-being index across the countries of the world is denoted by $\mu\left(S_\beta\right)$. The scalar $I^U(Z)$ is the fraction of the total well-being that could be destroyed if well-being is equalized across 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:

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

Once one has chosen a specific functional form for $S_\beta(z_{i.})$, calculation of overall inequality with (10) is straightforward. Of course, applying the traditional (relative) inequality measures to the vector of well-being indices $S_\beta(z_{i.})$, is only meaningful if the latter are measured at least at the ratio level. In fact, ordinal transformations of $S_\beta\left(z_{i.}\right)$ 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, i.e. if translations are acceptable, each of these translations will lead to a different value of the traditional (relative) inequality measures. The choice of the transformation functions (1) should therefore be considered carefully.

Less explicit, but analogous 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 $S_\beta\left(z_{i.}\right)$, where the specification of the latter is based on information theoretic considerations. This procedure shares all the advantages and disadvantages of the unidimensional approach.

2.3 Measuring multidimensional inequality in well-being

Although the introduction of an overall index of well-being may at first sight be a natural approach, it sweeps the basic multidimensional nature of the concept of well-being under the carpet. In recent years a growing number of authors have tried to take this multidimensional nature explicitly into account by generalizing the unidimensional Pigou-Dalton transfer principle into a multidimensional setting. Instead of imposing the Pigou-Dalton principle in the space of well-being indices, they directly impose conditions in the space of the distribution matrices Z (or X) themselves. After the seminal article by Kolm (1977) there have been a number of different proposals to generalize the Pigou-Dalton transfer principle for the multidimensional setting (see also Marshall and Olkin (1979, chapter 15)). Two popular generalizations are considered here.

First, 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)*. Kolm shows that the principle of uniform majorization is fulfilled for increasing and strictly concave indicators of well-being. 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. Graphically, the acceptable parameter space is restricted to the (dark and light) colored area of the normative space represented in figure 1.

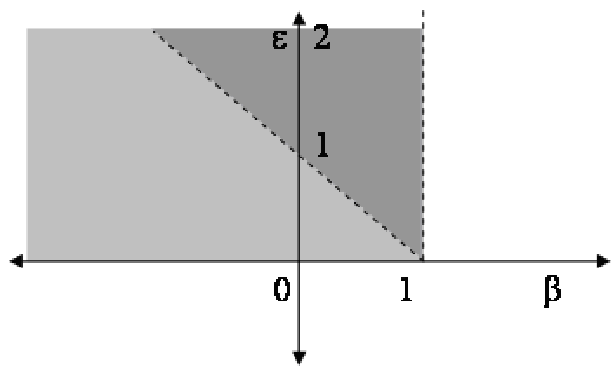

Figure 1: The restrictions on the normative space implied by uniform and correlation increasing majorization.

Second, Atkinson and Bourguignon (1982) build on the compelling idea that for two distribution matrices with the same distributions of 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 of 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 the specification (8) the principle of correlation increasing majorization translates to $\varepsilon + \beta > 1$. In figure 1, this condition limits the normative space further to the dark colored area.

[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.

Both extensions of the unidimensional Pigou-Dalton transfer principle can (*inter alia*) be implemented within the normative approach to multidimensional inequality measurement (For a recent survey of this approach see 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:

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

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. After some algebraic manipulation, applying expression (8) to (11) the following multidimensional inequality index can be derived:

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

where μ is the vector of the column means of Z. When comparing this multidimensional index $I^M_\beta(Z)$ with its unidimensional counterpart $I^U_\beta(Z)$ two remarks can be made. First, the difference between the indices is in their denominator. Whereas the proposed index $I^M_\beta(Z)$ uses the composite indicator of a country with average performance on every indicator as reference point, the indicator obtained by the two step approach $I^U_\beta(Z)$ uses the average value of the composite indicator. Second, given that we work in both 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 approaches are very different. In general, the approach from the previous subsection 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-

[10] Also the multidimensional Dalton index proposed by Bourguignon (1999) is a close relative. If we call $-\varepsilon = \gamma$, then:

$$1 - \left(1 - I^M_\beta(Z)\right)^{1+\gamma} = I^{Bourg}_\beta(Z)$$

Douglas type ($\beta = 0$) and the exponents $w_j(1-\varepsilon) = c_j$ such that $1-\varepsilon = \sum c_j$:

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

3 Results

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? To make our results comparable to previous studies (and for reasons of data availability), we restrict the analysis to 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).

3.1 The data

The data are from the World Development Indicators (2004) and cover the period between 1975 and 2000 with five year intervals. The analysis focuses on the following four indicators. The first indicator is *GDP per capita*, measured in current US$ after correction for purchasing power parity. Dowrick and Akmal (2003) argue that purchasing power parities are not beyond controversy, yet they are easily available and can considered to be the standard in the literature on global income inequality. The second indicator is *life expectancy at birth,* which indicates 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 the age 15 and above who can, with understanding, read and write. Finally, *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

[11] Note that we use secondary enrollment rate in stead 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.

countries, for which 4 indicators in 6 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). Notable absentees in our sample are many Sub-Saharan African countries[13] and virtually all Eastern European Countries, with Latvia and Hungary as exceptions. Detailed information on the countries covered and on the interpolation procedure is given in the appendix.

3.2 Evolution of inequality dimension-by-dimension

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

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

Table 3 summarizes the trends in inequality for the four indicators considered in our dataset. We set $\varepsilon = 2$, which reflects considerable inequality aversion in the different dimensions of well-being. In the following figures we show the development over time for different values of ε. In all the tables and figures inequality is normalized to be 100 in 1975.

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
Enrolment ratio	100.0	83.1	73.0	65.7	62.9	58.9

Table 3: Evolution of the inequality in different dimensions of well-being, measured by the Atkinson Index ($\varepsilon = 2$)

Table 3 and figure 2 both show a clear upward trend in the inequality in GDP per capita. This confirms the general finding in the literature that unweighted income inequality increases (Milanovic, 2005)[15]. For the later interpretation of the HDI, it is useful to consider also the logarithmic transformation of GDP per

[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.

[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.

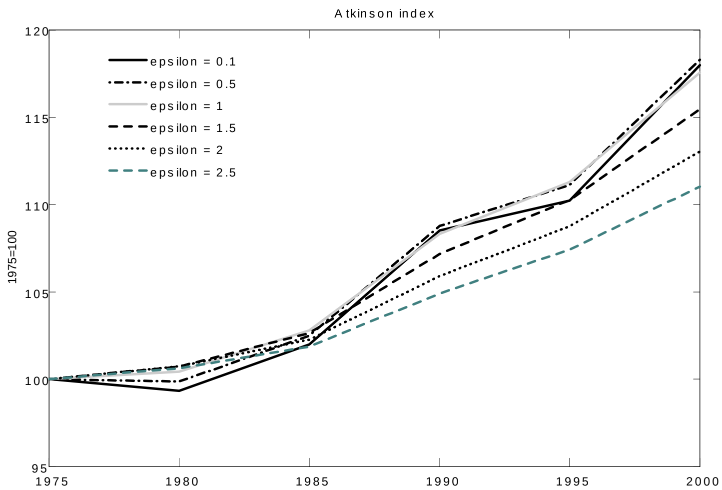

Figure 2: Evolution of the inequality of GDP per capita, measured by the Atkinson index, for different ε-values.

capita instead of GDP per capita itself. As can be seen from the second row of table 3 and from figure 3, this strictly concave transformation alters the trend of income inequality: now inequality decreases in the first decade and increases only mildly in the last decade.

Concerning longevity, Sen (1998) points out that "almost all the poor countries today have higher life expectancy than most of the richer countries had not long ago", and Ram (1998) calls the rapid increase of life expectancy in many poor countries "perhaps the most important single phenomenon to have affected human well-being". Also the Human Development Report (2005) is optimistic on the evolution of life expectancy and its inequality.

> “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 et al., 2004; Moser et al., 2005) suggest a less rosy picture, because of the ongoing AIDS epidemic and the rising infection rates in Asia (see also Becker, Philipson and Soares, 2005). As can be seen in table 3 and figure 4, 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 form the late 1980’s onwards[16].

[16] The influence of AIDS is clear, even with our restricted data set. When we drop all the

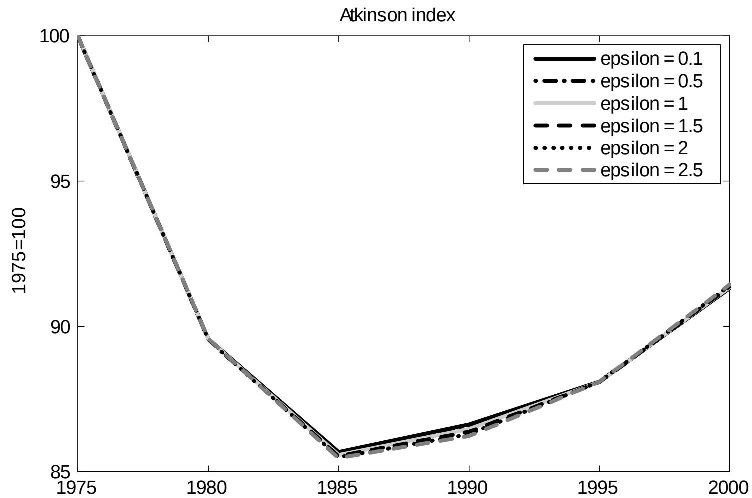

Figure 3: Evolution of the inequality of the logarithm of GDP per capita, measured by the Atkinson index, for different ε-values.

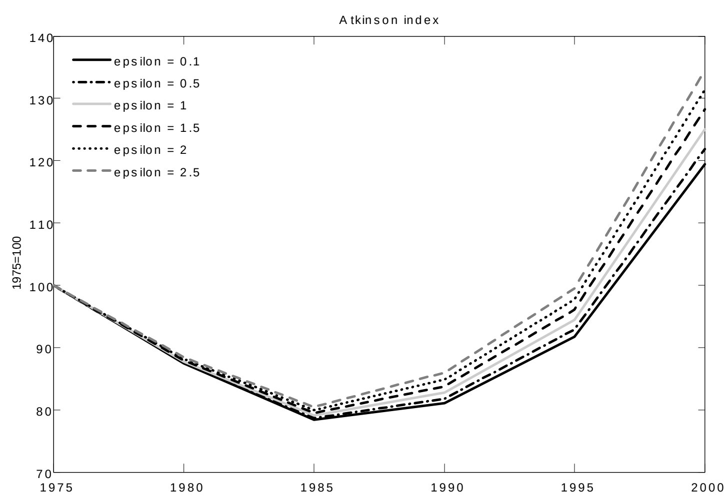

Figure 4: Evolution of the inequality of life expectancy, measured by the Atkinson index, for different ε-values.

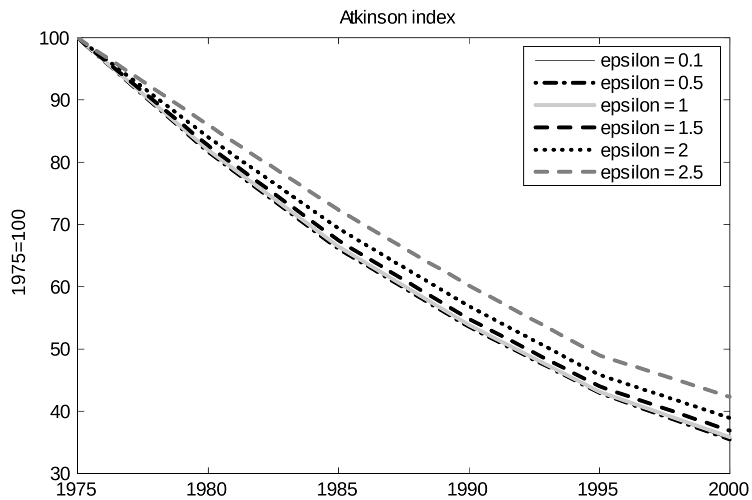

Figure 5: Evolution of the inequality of literacy rate, measured by the Atkinson index, for different ε-values.

Finally, inequality in educational indicators decreased over the entire period (Figures 5 and 6). Authors such as Neumayer (2003) and McGillivray and Pillarisetti (2004) claim that this may be a statistical artefact due to the specific educational indicators used. Literacy rate and enrollment rate are upward bounded and 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 decline in inequality.

We can conclude that unweighted income inequality increases over time, that inequality in the logarithm of income and in life expectancy show 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.

3.3 Evolution of multidimensional inequality

As a starting point and benchmark, figures 7 and 8 show the development over time of the *unidimensional* inequality measure $I^U_\beta(Z)$ (see eq. (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

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.

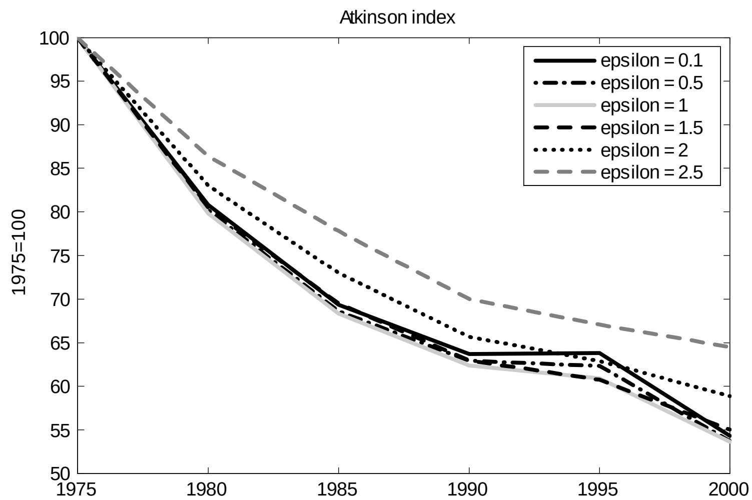

Figure 6: Evolution of the inequality of secondary school enrollment rate, measured by the Atkinson index, for different ε-values.

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 is less pronounced than for the HDI.

Let us now look at the evolution of *multidimensional* inequality, as measured by $I_\beta^M(Z)$ in expression (12). To evaluate the robustness of the results, we calculate $I_\beta^M(Z)$ for a broad range of sensible parameter values. We start from benchmark values which are close to those of the HDI and analyze the sensitivity of the results with respect to ε, the parameter of inequality aversion. Thereafter we relax the assumptions with respect to β, the parameter indicating the substitutability of the different dimensions. We then consider the effect of using different transformation functions, focusing on the weighting scheme, on the choice of a standardization procedure and on the role of the concave transforms as summarized in table (1), or by expressions (5) and (6).

Figure 9 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. We use the transformation functions of the HDI, summarized in table (1) and assume perfect substitutability between the dimension, i.e. $\beta = 1$. In the normative space depicted in figure 1, this analysis amounts to measuring inequality along the dotted line at $\beta = 1$. For all strictly positive ε-values, CIM is satisfied. Comparing figures 7 and 9, it turns out that the shift from $I_\beta^U(Z)$ to the multidimensional measure $I_\beta^M(Z)$ does not

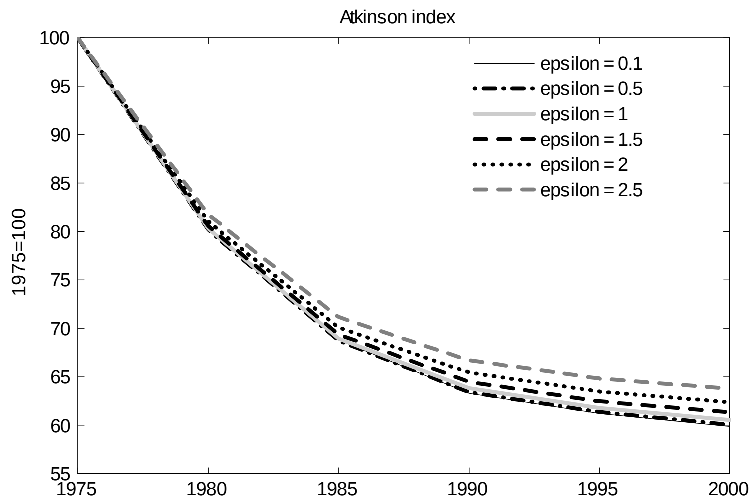

Figure 7: Evolution of the unidimensional inequality of the Human Development Index, measured by the Atkinson index, for different ε-values.

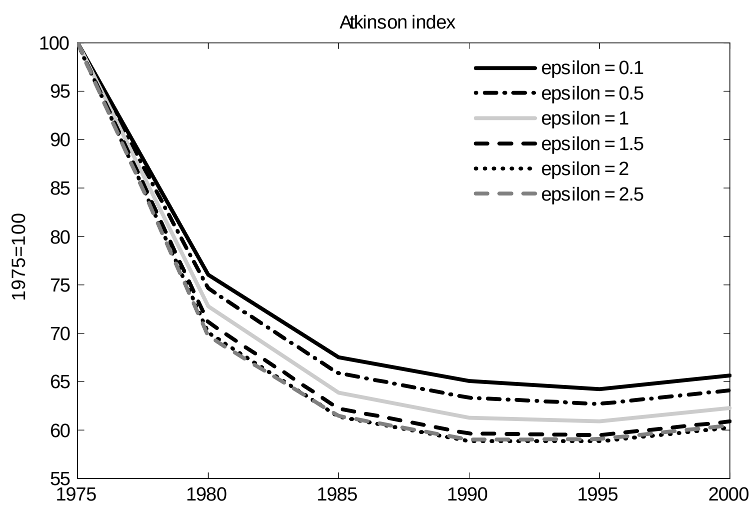

Figure 8: Evolution of the unidimensional inequality of the BPS approach, measured by the Atkinson index, for different ε-values.

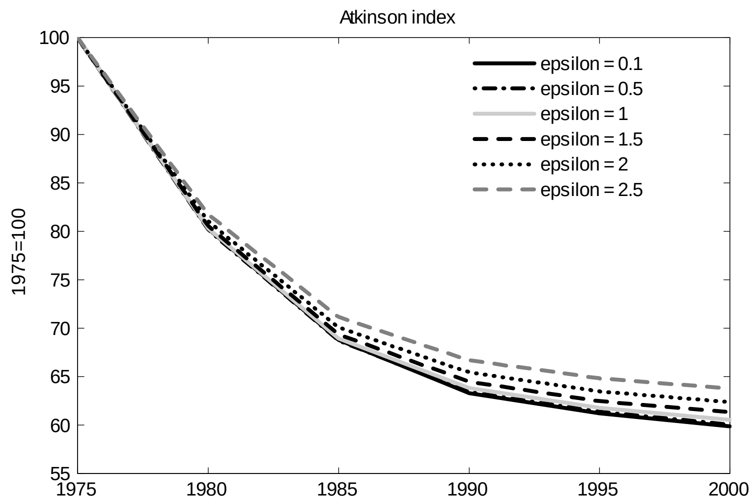

Figure 9: Evolution of well-being inequality, measured by the multidimensional Atkinson index, for different ε-values.

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. Let us therefore now see whether this result is also robust for changes in the other crucial parameters.

We first focus on the role of β, which captures the substitutability between the dimensions. We put $\varepsilon = 2$ and relax β to the range $[-5, 1]$, which amounts to a horizontal movement in the normative space of figure 1. 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 $\beta = 0$. As can be seen from figure 6, the smaller β the larger the relative decrease in inequality. Yet, again, relaxing the linear aggregation procedure of the HDI to a more general one, does not change the trend in well-being inequality dramatically. We indicate in bold the evolutions corresponding to parameter combinations satisfying CIM, i.e. $\varepsilon + \beta > 1$.

Let us now consider the effect of implementing different transformation functions. The 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. Ram (1982) suggested the use of the first principal component to obtain the weights of the dimensions of the Physical Quality of Life Index. In the setting of the Human Development Index, Noorbakhsh (1998) applies a similar procedure based on the three dimensions of human development: standard of living, health and education. The weights

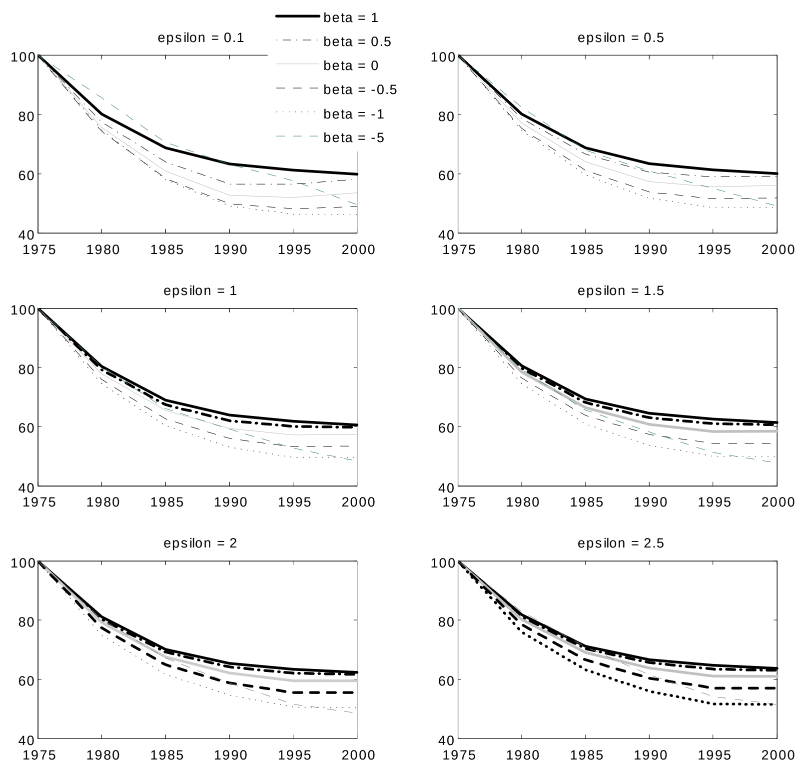

Figure 10: Evolution of well-being inequality, measured by the multidimensional Atkinson index, for different ε and β-values.

implied by a principal components analysis for our data, normalized so as to sum to 1, are reported in table 4. Changes in the trend of well-being inequality due to this alternative weighting scheme are minor (see figure 11). The relative decrease in inequality is a little bit stronger, which is attributable to the larger relative weight on the educational variables. Of course, the use of more extreme weighting schemes allows to obtain 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. In fact, the larger weights given to the educational variables in table 4, are merely a statistical artefact: given that there are two educational variables, it is not surprising that they explain a larger part of the common variance. Weighting schemes are very likely to be controversial and should therefore be stated explicitly, for example, as marginal rates of substitution.

θ_j	1975	1980	1985	1990	1995	2000
log (GDP/capita)	0.1663	0.1772	0.1871	0.1995	0.1986	0.2040
Longevity	0.1952	0.1899	0.1846	0.1894	0.1875	0.2059
Literacy Ratio	0.3204	0.3067	0.2874	0.2659	0.2273	0.2034
Enrolment ratio	0.3181	0.3262	0.3409	0.3452	0.3866	0.3867

Table 4: Weights of the dimensions based on the first principal component, normalized to 1.

Returning to the weighting scheme of the HDI, a second component of the transformation functions is the standardization 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 of the transformed dimension $\mu\left(f_j\left(x_{ij}\right)\right)$:

$$z_{ij}^{alt1} = \frac{f_j\left(x_{ij}\right)}{\mu\left(f_j\left(x_{ij}\right)\right)} \qquad i = 1, ..., n; \quad j = 1, ..., k. \tag{15}$$

This kind of rescaling has a minor effect on the trend of well-being inequality, as can be seen in figure 12 for the mean[17]. Note that the Tsui-index (with $\beta = 0$), given in (13), is invariant to all multiplicative transformations.

A second alternative standardization procedure has been proposed by Hirschberg, Maasoumi and Slottje (1991) in their paper on measuring quality of life across countries. They propose the following standardization procedure:

$$z_{ij}^{alt2} = \frac{f_j\left(x_{ij}\right) - \mu\left(f_j\left(x_{ij}\right)\right)}{\sigma\left(f_j\left(x_{ij}\right)\right)} + 10 \qquad i = 1, ..., n; \quad j = 1, ..., k. \tag{16}$$

[17] The results for other measures of central tendency such as the median or even the maximum are very similar.

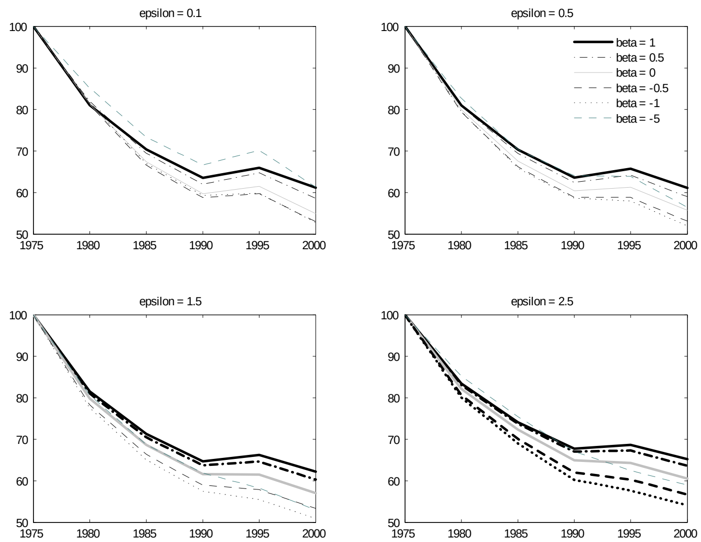

Figure 11: Evolution of well-being inequality, measured by the multidimensional Atkinson index, with principal component weigths, for different ε and β-values. .

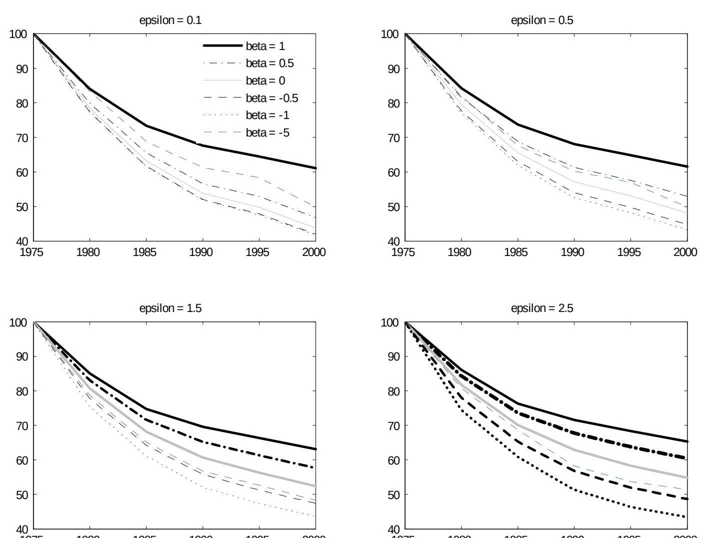

Figure 12: Evolution of well-being inequality, measured by the multidimensional Atkinson index with a simple rescaling standardization, for different ε and β-values.

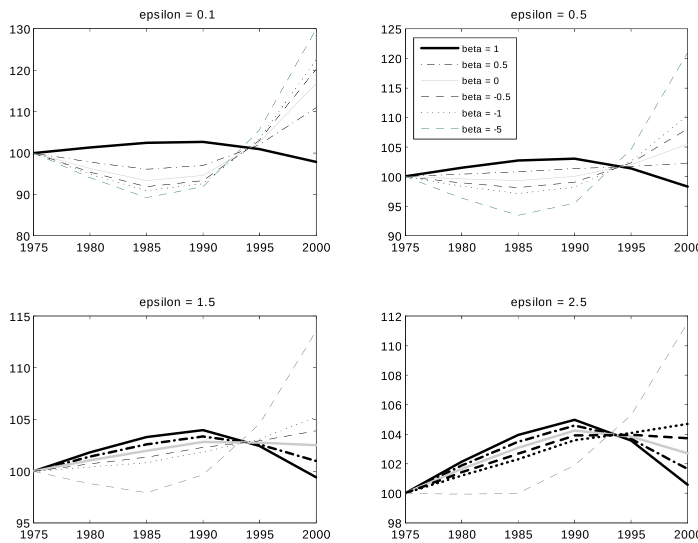

Figure 13: Evolution of well-being inequality, measured by the multidimensional Atkinson index, with the Hirschberg et al. standardization, for different ε and β-values.

$\sigma\left(f_j\left(x_{ij}\right)\right)$ denotes the standard deviation of the transformed data. This procedure standardizes the data such that the mean equals 10 and the standard deviation 1 and is obtained by calculating standard z-scores, which are translated over an arbitrary distance to the right, to make sure that all values are non-negative and calculation problems are avoided. Figure 13 shows that the trend in inequality after applying (16) is remarkably different from the other cases. Moreover, the obtained results 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. Moreover, the choice of 10 standard deviations is fully arbitrary and does not capture any intuitively appealing normative viewpoint. Although this standardization is sometimes used in the design of composite indicators[18], we believe it to be less attractive in this context.

Finally we investigate the effect of the concave transformations on the trend in inequality. Here the results are remarkable. Let us look at income first. The logarithmic transformation embodied in the HDI can be generalized by using the functional form (5) proposed by Becker et al. (2005). Figure 14 summarizes the

[18] Morisson 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).

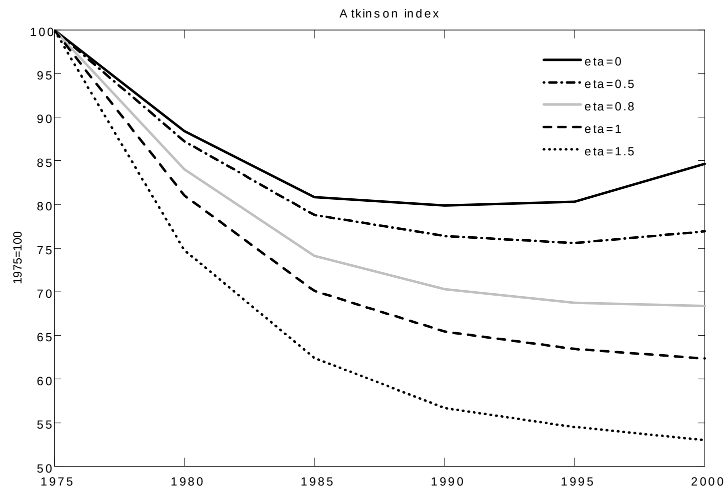

Figure 14: Evolution of well-being inequality, measured by the multidimensional Atkinson index, for different values of η.

sensitivity of the trend in well-being inequality for the η parameter, capturing the concavity of the transformation function of income. The case $\eta = 1$ is the HDI-case 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, a smaller β and ε parameter value further strengthen the trend of increasing well-being inequality (see figure 15). 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 period considered. In the graphical representation of the normative space in figure 1, the area with increasing well-being inequality is situated in the south-west of the colored area.

The argument of diminishing returns can be made for the longevity dimension as well. Different degrees of diminishing returns can be captured by different values for the parameter r in the transformation function (6), introduced by Becker et al. (2005). As can be seen from figure 16, higher interest rates r diminish the decrease in inequality further.

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

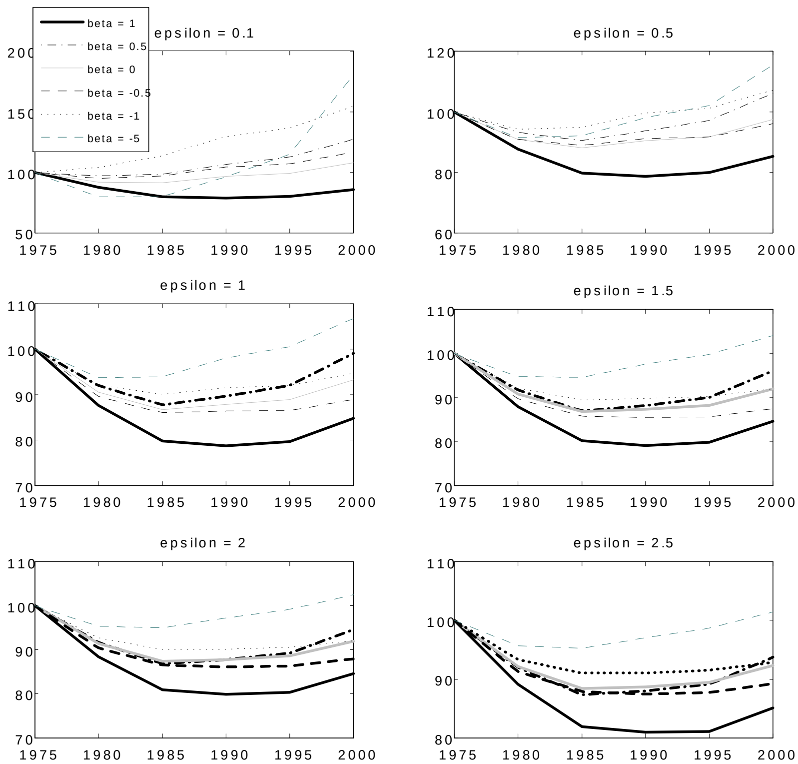

Figure 15: Evolution of well-being inequality, measured by the multidimensional Atkinson index, without logarithmic transformation, for different ε and β-values.

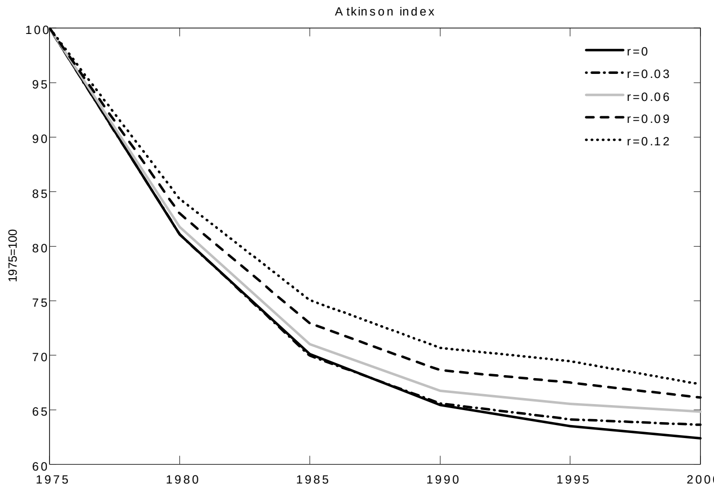

Figure 16: Evolution of well-being inequality, measured by the multidimensional Atkinson index, for different values of r.

tain sense the assumption of decreasing marginal well-being of income, implying that an income increase is worth less to a rich than to 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. It turns out that it is basically this assumption that drives the result (obtained both with the HDI and with the BPS) that well-being inequality shows a decreasing trend in recent decades.

4 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: standard of living, 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, albeit at a declining pace. However, extreme weighting schemes can lead to virtually any trend in well-being inequality given the different evolution of 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, Philipson and Soares (2005). This observation underlines the need for clarity on the underlying normative choices in empirical work on multidimensional welfare and inequality measurement.

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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. Similar to 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 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	
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)

Country	Manipulation
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%

Country	**Manipulation**
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	
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%

Country	**Manipulation**
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	

Table 5: sample and data coverage